European Radiocommunications Committee (ERC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

COMPATIBILITY OF BLUETOOTH WITH OTHER EXISTING AND PROPOSED RADIOCOMMUNICATION SYSTEMS IN THE 2.45 GHZ FREQUENCY BAND

October 2001

EXECUTIVE SUMMARY

This report presents the study of compatibility between Bluetooth and other existing and proposed services operating in the 2.45 GHz frequency band.

I. Assumptions (BT/RFID, RLAN, ENG/OB)

The characteristics of the different systems considered can be found in sections 3 and 4.

II. Methods (Deterministic, Probabilistic, other)

Four methods for interference analysis had been used in this report:

- deterministic method;
- probabilistic method;
- simulation tool;
- SEAMCAT, see ERC Report 68 (modified 2001).

A description of each method is provided in section 5.

In addition to analytical analysis, some laboratory measurements were performed.

III. Results

Deterministic method

Deterministic calculations show that the impact of the 4W RFID with a duty cycle of greater than 15% in any 200 ms period time on the Bluetooth performance is critical. In particular, transmitter-on times exceeding 200 ms will have serious impact. Further studies of the impact of higher application layers are needed.

Blocking has been shown to be the most limiting factor with a separation distance of approximately 10 m or less. This mechanism has a significant impact on the Bluetooth performance in terms of non-acceptable reduction in capacity at high duty-cycles.

Further, the study shows that additional mitigation techniques are required for RFID, such as directional antennas, antenna-dome (to avoid Bluetooth receiver burnout), etc.

Further studies may be required in order to investigate the relationship between Bluetooth levels above the blocking level and acceptable RFID e.i.r.p. and duty cycles.

Probabilistic method (applied to co–channel interference only)

The interference criteria used was I/N=0 dB for all services except for fixed links where the long term criteria was I/N= –10 dB for 20% of the time. The conclusions are that:

- the probability of interference to Bluetooth from existing and planned services, being of the same order of magnitude (plus or minus 1 decade), depends on the unit density;
- the probability of interference from Bluetooth 1 mW to Fixed Wireless Access is severe for a density of 100 units per km^2 and 10 units per km^2 for Bluetooth 100 mW;
- both 1 mW and 100 mW Bluetooth systems will cause harmful interference to ENG/OB or fixed links when operating in close vicinity.

Simulation tool

Simulations for hot-spot areas show significant reduction in throughput for Bluetooth in the case of sufficient high duty cycles or omni-directional antennas, or a large number of RFIDs (>32). For these cases the Bluetooth operating range is limited to a couple of metres in order to maintain acceptable throughput.

For RFID hot spot areas with 8 units in a 35 m radius from the Bluetooth victim, Bluetooth throughput reduces by 15% for a Bluetooth link over distance of up to 1 m. At larger Bluetooth link distances and higher unit densities the throughput is reduced further.

Different RFID densities have been considered. Without the RFID mitigation factor of the antenna beamwidth, the Bluetooth throughput reduction will be severe for high density of RFID devices in combination with high duty-cycles: an RFID reader using a directional antenna mitigates the influence of interference taking into account the protection of existing services.

The simulation shows that reduction of the duty cycle will reduce the impact on the throughput during interference. Intermodulation has a minor contribution to the interference.

SEAMCAT

The Monte–Carlo based SEAMCAT software was used to investigate the interference scenarios and to make comparisons with the results obtained from using the deterministic method.

Due to a number of differences between the two methodologies, a direct comparison could not be made. Nevertheless, assumptions and comparisons were made as described in paragraph 6.4 for half of the interference scenarios. The probability of interference to Bluetooth as a function of the density of the interferer is of the same magnitude for RLAN, RFID3a and 3b, which is about 2 times higher than for 100 mW Bluetooth to Bluetooth.

The probability of interference from 100 mW Bluetooth to RLAN, ENG/OB and fixed links is at least 2 times lower than the interference from RLAN, RFID3a and 3b with the same unit density.

Measurements

It should be noted that the measurement results described in the report are based on a single interferer and a specific Bluetooth equipment, evaluating the tolerable C/I for 10% throughput degradation. However, the absolute power levels of the various systems are significantly different in the C/I evaluation. For the determination of the isolation distances both the C/I and the power level should be considered.

The results show that the tested Bluetooth sample had excellent immunity against narrow band interference, such as FHSS RLAN, Bluetooth, RFID and CW signals.

On the other hand the Bluetooth sample has been found susceptible to wide band interferers, i.e. ENG/OB links (digital & analogue) and DSSS RLAN. This may be due to the higher bandwidth and duty cycle. ENG/OB systems are unlikely to be a major determinant on the long term performance or availability of indoor Bluetooth systems. A more substantive threat to Bluetooth systems is from co-located DSSS RLANs. This threat is likely to be a more common scenario.

The protection ratio required by Bluetooth against interference from 8MHz RFID at all duty cycles is better or comparable to that of a co-located Bluetooth system (60% duty cycle). When the duty cycle of the simulated 8MHz RFID was changed from 10 to 100 %, the protection requirement of Bluetooth increased.

The following duty cycles for 4W RFID (8 MHz) were used in both the interference testing and the calculations in the present report:

- 15 % duty cycle (30 ms on/ 170 ms off);
- 50 % duty cycle (100 ms on /100 ms off);
- 100 % duty cycle.

Any alteration of these parameters could result in significant change to the interference potential to Bluetooth.

It should be noted that due to the limited number of equipment used for the measurements, the results are only indicative.

Summary of conclusions relative to compatibility between Bluetooth and 4W RFID (8 MHz) systems

The study shows that the impact of the 4W RFID (8 MHz) with a duty cycle greater than 15% in any 200 ms period (30 ms on/170 ms off) on the Bluetooth performance is critical.

Further, the study shows that additional mitigation techniques are required from RFID, such as directional antennas, antenna-dome (to avoid Bluetooth receiver burnout) and other appropriate mechanisms in order to ensure that the necessary in–door operation restrictions are met.

INDEX TABLE

1 INTRODUCTION

The spectrum needs of Short Range Devices (SRD) are most often allocated into an ISM band on a frequency-sharing basis (non-interference, non-protection basis) and the industry has the advantage of a general license type approval. Compatibility between all the services sharing a specific spectrum must be maintained to ensure frequency sharing under all reasonable conditions. To meet these constraints, SRD manufacturers are constantly investigating new techniques and technologies offering an improved functionality and sharing capability.

Spread spectrum Bluetooth and RLAN systems operating in the 2.4GHz band demonstrate a high degree of similarity in emissions and interference characteristics. The interference studies described in this report have included operation of spread spectrum Bluetooth both versions (Bluetooth1 mW and Bluetooth 100 mW e.i.r.p.) and RLAN, ENG/OB, and RFID systems.

NOTE: For the purpose of this report Bluetooth 1 mW will be referred as Bluetooth 1 and Bluetooth 100 mW will be referred as Bluetooth 2.

The Special Interest Group (SIG) of Bluetooth decided to develop the equipment based on the ETSI standard ETS 300 328 (RLAN). Both versions have nearly the same design. The difference between Bluetooth 1 and Bluetooth 2 is the mandatory requirement for "power control" for Bluetooth 2. The advantage of this requirement is the possibility to decrease the power level from the maximum to the needed level to realise the defined BER. The result of that is a reduced interference level caused by Bluetooth.

2 MARKET INFORMATION FOR BLUETOOTH

Market information from various sources have been compiled and included in the paragraphs which follow.

2.1 Recent market developments

Since mid 1999 the first Bluetooth equipment have been developed and it is planned to bring the equipment, latest mid 2001, onto the market. But the experiences with the Bluetooth devices are not sufficient enough to make a precise prognosis for the European market penetration.

2.2 Market application for Bluetooth (world wide)

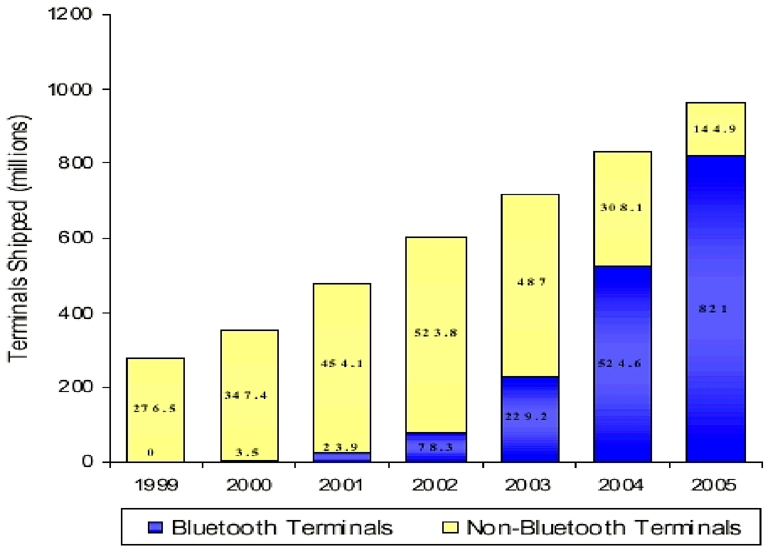
There are numerous applications for the use of Bluetooth eg:

- Mobile phones
- Home cordless telephone
- Walkie Talkie and so on
- Home automation
- Industry automation
- E-commerce
- LAN and Internet access
- A wireless substitution for all the cable connections between PC's an their periferal devices
- Headsets for an handy (outside a car)
- Headsets as an hands free (inside a car)

2.3 Market penetration (world wide)

The figures below are copied from a study of Intex Management Services Ltd. (IMS) by kind permission of IMS. The forecast is given in subsections 2.3.1, 2.3.2, 2.3.3, 2.3.4 and 2.3.5 below:

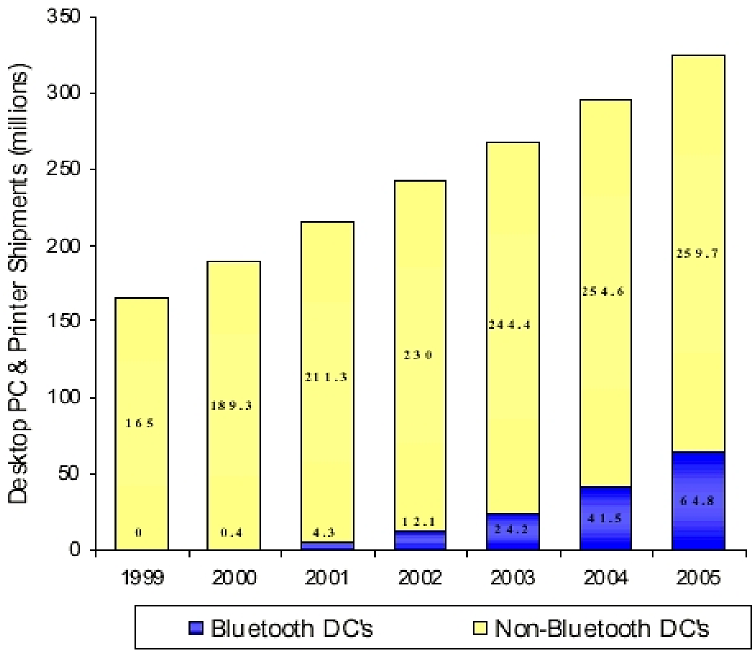
Figure 2.3.1: Forecast for Bluetooth penetration In Cellular Terminals



Source: IMS

0 dBm: 50% low end; headset, vicinity accessories
20 dBm: High end; long range, private access

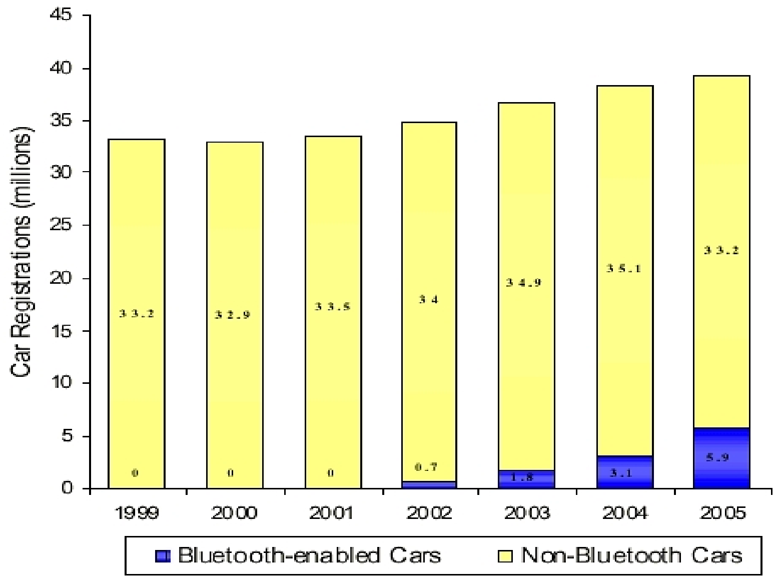
Figure 2.3.2: Forecast Bluetooth penetration in Digital conection Boxes



Source: IMS

0 dBm: 25% low end
20 dBm: 75% high end, long range

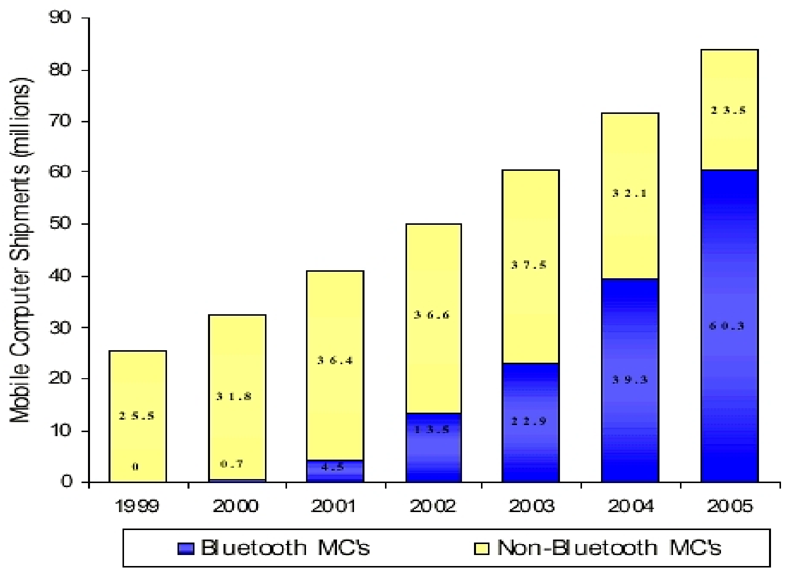
Figure 2.3.3: Forecast for Bluetooth penetration in Automotive Applications



Source: IMS

0 dBm: 75% in car audio, hands free
20 dBm: 25% service access, road toll

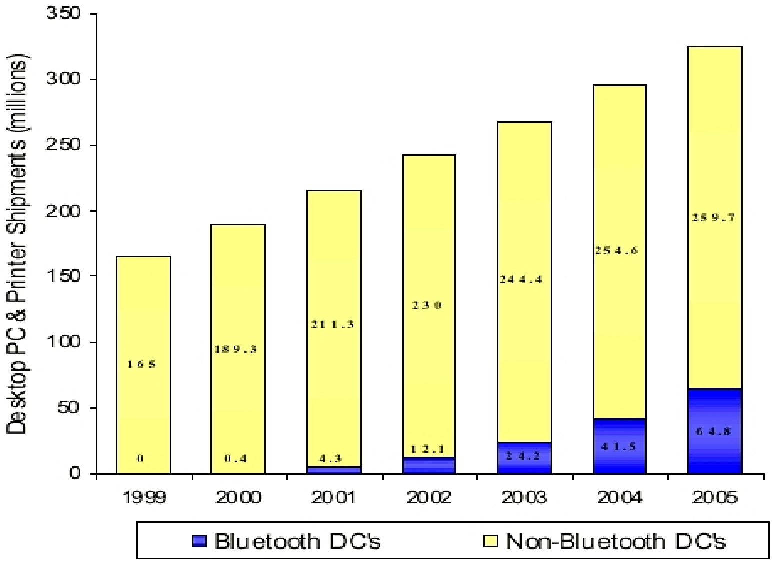
Figure 2.3.4: Forecast for Bluetooth penetration in Mobile Computing



Source: IMS

0 dBm: 40% personal bubble-mouse, keyboard, pstn
20 dBm: 60% access technology, long range

Figure 2.3.5: Forecast for Bluetooth penetration in Desk-top Computing



Source: IMS

0 dBm: 75% communications with accessories
0 dBm: 25% access technology for networks etc.

The market penetration of Bluetooth depends on the size, the possible application and, above all, the price of the equipment. The price itself depends on the number of units, which can be produced and put into the market.

Two types of Bluetooth equipment are specified:

- Bluetooth 1: 1 mW (0 dBm e.i.r.p.) and
- Bluetooth 2: 100 mW (20 dBm e.i.r.p.).

The advantage of the Bluetooth 1 could be perhaps the lower cost because of a lower output level and therefore a lower power consumption, but you have to accept a relative short range of less than 10 metres.

One advantage of Bluetooth 2 is a larger range of up to 100 metres, but on the other hand higher power consumption. The second advantage is the mandatory called “power control” feature, which is only optional for Bluetooth 1. This feature allows decreasing the output power level to a value, which is necessary to obtain the link.

As a result of this assumption the figures above can be interpreted as the sum of Bluetooth 1 and Bluetooth 2, where Bluetooth 1 has more then 75% of the sum because of it’s lower price and the lower power consumption which is needed especially for headsets.

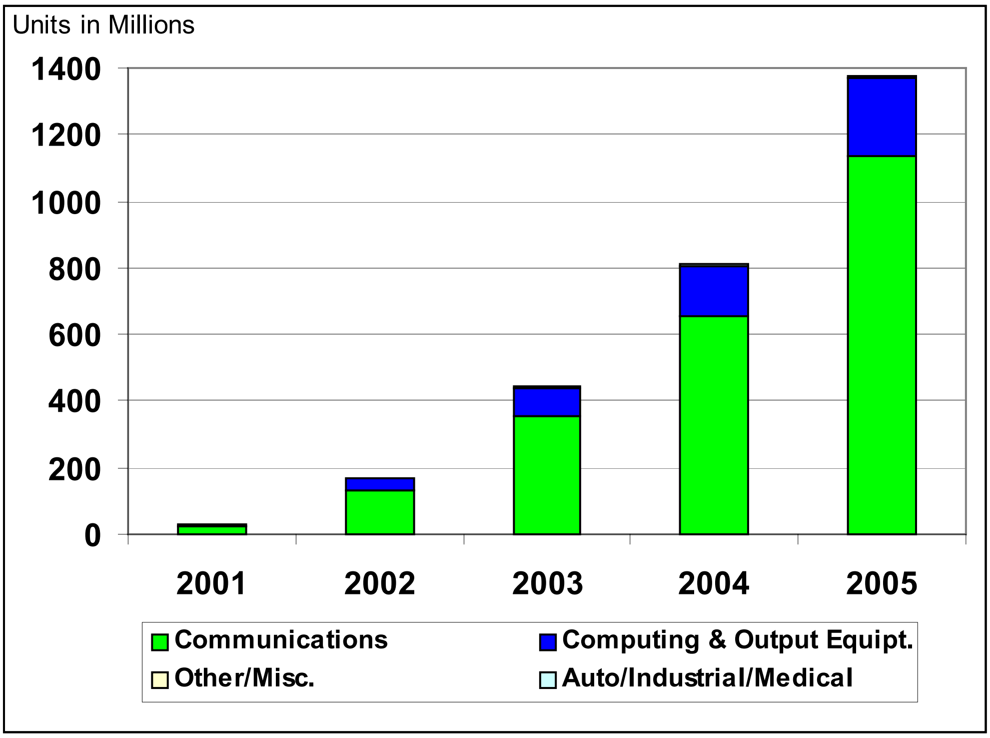
2.4 Forecast for unit density of Bluetooth

The forecast unit density for Bluetooth systems will increase from less than 5 units/km^2 mid of 2001 to more than 1000 units/km^2 end of 2005. For an estimation of the number of active units see paragraph 3.8.2.

2.4.1 Unit forecast

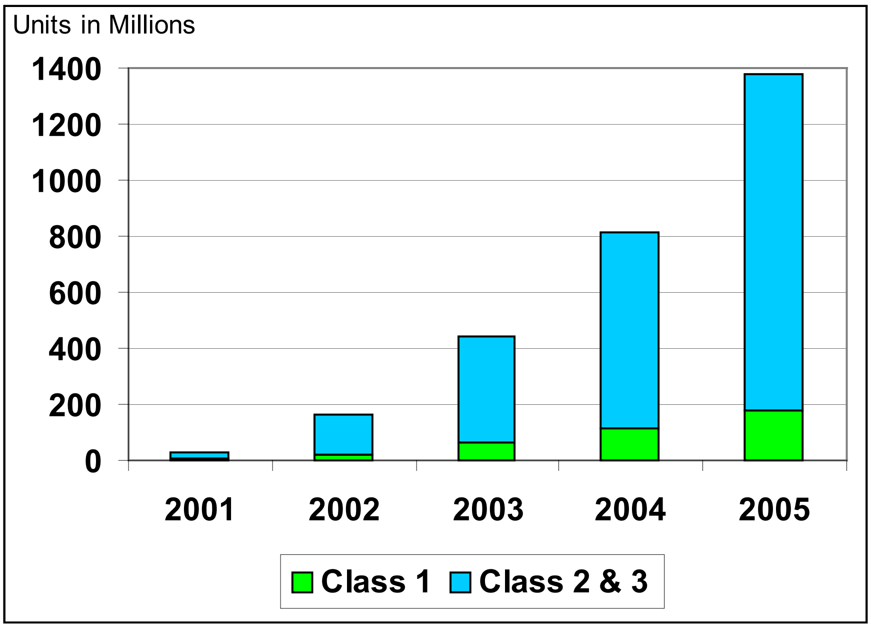
The following market forecast is available:

Figure 2.4.1.a: Market forecast for Bluetooth (in Millions) by application



Source: Cahners In-Stat Group, July 2000

Figure 2.4.1.b: Market forecast for Bluetooth (in Millions) by power class



Source: Cahners In-Stat Group, July 2000

2.5 Summary

The forecasted market penetration of Bluetooth is very difficult today. The forecast numbers mentioned in this document are taken from the IMS and Cahners reports. It may be assumed that these are too optimistic especially for the beginning of the availability of the Bluetooth equipment in 2001. It may be more realistic to assume that the really marketing of Bluetooth will start at the earliest end of 2001 to mid of 2002.

3 TECHNICAL DESCRIPTION FOR BLUETOOTH (As taken from the Bluetooth Specification Version 1.0.B)

Bluetooth is a standard operating in the 2.4 GHz (2400 – 2483.5 MHz) ISM (unlicensed) band, which allows wireless connectivity between various devices, for example between a laptop and a mobile phone. The Bluetooth protocol supports both data and voice communications by utilising two types of link: the SCO (Synchronous Connection Oriented) link and the ACL (Asynchronous Connection-Less) link. The SCO link is a circuit switched link, mainly used for voice, between the master and a single slave. The link uses reserved timeslots. The ACL link is a packet switched connection that uses the remaining timeslots not used by the ACL links and is used for data transmission.

Bluetooth is a fast frequency hopping protocol with a timeslot of 625µs. It hops over 79MHz of the band, and uses GFSK (Gaussian Frequency Shift Keying) modulation. The modulation rate is 1Mbit/s.

Bluetooth units can be connected as a 'master' or a 'slave'. The master can connect to a maximum of seven slaves to form a system known as a piconet. Two or more piconets connected together form a scatternet.

3.1 Frequency band and channel arrangement

The Bluetooth system is operating in the 2.4 GHz ISM (Industrial Scientific Medical) band.

Table 3.1.a: Channel arrangement

Frequency Range	RF Channels
2.4000 - 2.4835 GHz	f = 2402 + k MHz with k = 0,…,78

Channel spacing is 1 MHz. In order to comply with out-of-band regulations in each country, a guard band is used at the lower and upper band edge.

Table 3.1.b: Guard band

Lower Guard Band	Upper Guard Band
2 MHz	3.5 MHz

3.2 Transmitter characteristics

The requirements stated in this section are given as power levels at the antenna connector of the equipment. If the equipment does not have a connector, a reference antenna with 0 dBi gain is assumed.

Due to difficulty in measurement accuracy in radiated measurements, it is preferred that systems with an integral antenna provide a temporary antenna connector during type approval.

If transmitting antennas of directional gain greater than 0 dBi are used, the applicable paragraphs in ETSI ETS 300 328 must be compensated for.

The equipment is classified into three power classes.

A power control is required for the Power Class 1 equipment. The power control is used for limiting the transmitted power over 0 dBm. Power control capability under 0 dBm is optional and could be used for optimising the power consumption and overall interference level. The power steps shall form a monotonic sequence, with a maximum step size of 8 dB and a minimum step size of 2 dB.

A Class 1 equipment with a maximum transmit power of +20 dBm must be able to control its transmit power down to 4 dBm or less.

Equipment with the power control capability optimises the output power in a link with Link Management Protocol commands. It is done by measuring RSSI and reporting back if the power should be increased or decreased.

Table 3.2: Power classes

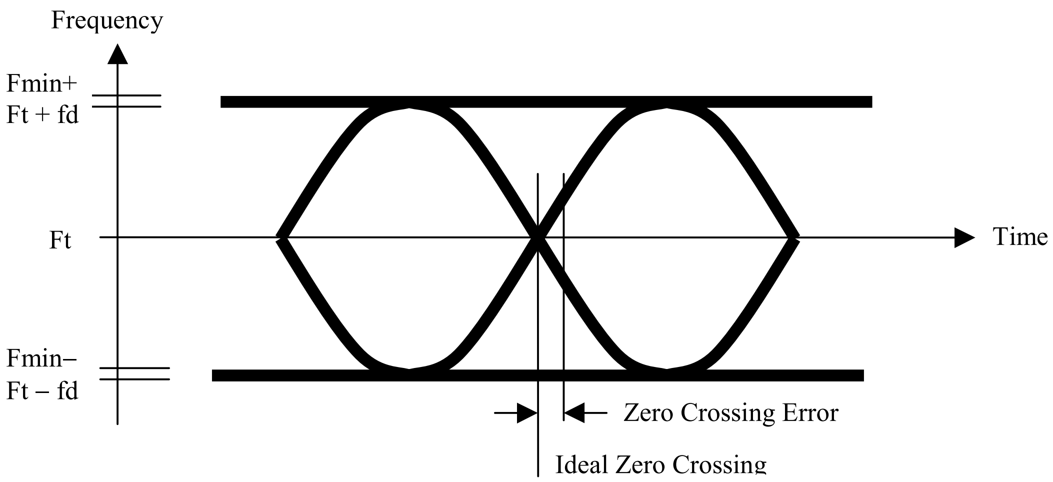
Power Class	Maximum Output Power (Pmax)	Nominal Output Power	Minimum Output Power [1)]	Power Control
1	100 mW (20 dBm)	N/A	1 mW (0 dBm)	Pmin< +4 dBm to Pmax Optional: Pmin[2)] to Pmax
2	2.5 mW (4 dBm)	1 mW (0 dBm)	0.25 mW (–6 dBm)	Optional: Pmin[2)] to Pmax
3	1 mW (0 dBm)	N/A	N/A	Optional: Pmin[2)] to Pmax

Note 1. Minimum output power at maximum power setting.
Note 2. The lower power limit Pmin < –30dBm is suggested but is not mandatory, and may be chosen according to application needs.

3.3 Modulation characteristics

The Modulation is GFSK (Gaussian Frequency Shift Keying) with a BT = 0.5. The Modulation index must be between 0.28 and 0.35. A binary one is represented by a positive frequency deviation, and a binary zero is represented by a negative frequency deviation. The symbol timing shall be better than ± $20*10^{-6}$. Actually transmitted waveform is shown in figure 3.3 below.

Figure 3.3: Actual transmission modulation



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For each transmit channel, the minimum frequency deviation (Fmin = the lesser of {Fmin+, Fmin-}) which corresponds to 1010 sequence shall be no smaller than ± 80% of the frequency deviation (fd) which corresponds to a 00001111 sequence. In addition, the minimum deviation shall never be smaller than 115 kHz.

The zero crossing error is the time difference between the ideal symbol period and the measured crossing time. This shall be less than ±1/8 of a symbol period.

3.4 Spurious emissions

The spurious emission, in-band and out-of-band, is measured with a frequency hopping transmitter hopping on a single frequency; this means that the synthesiser must change frequency between receive slot and transmit slot, but always returns to the same transmit frequency. The limits of EN 300 328 apply.

3.4.1 In-band spurious emissions

Within the ISM band the transmitter shall pass a spectrum mask, given in Table 3.4.1 below. The spectrum must comply with the FCC's 20 dB bandwidth definition stated below, and should be measured accordingly. In addition to the FCC requirement an adjacent channel power on adjacent channels with a difference in channel number of two or greater an adjacent channel power is defined. This adjacent channel power is defined as the sum of the measured power in a 1 MHz channel. The transmitted power shall be measured in a 100 kHz bandwidth using maximum hold. The transmitter is transmitting on channel M and the adjacent channel power is measured on channel number N. The transmitter is sending a pseudo random data pattern throughout the test.

Table 3.4.1: Transmit Spectrum mask

Frequency offset	Transmit Power
± 550 kHz	–20 dBc
|M-N| = 2	–20 dBm
|M-N| ≥ 3	–40 dBm

Note 1: If the output power is less than 0 dBm then, wherever appropriate, the FCC's 20 dB relative requirement overrules the absolute adjacent channel power requirement stated in the above table.

Note 2: In any 100 kHz bandwidth outside the frequency band in which the spread spectrum intentional radiator is operating, the radio frequency power that is produced by the intentional radiator shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power, based on either an RF conducted or a radiated measurement. Attenuation below the general limits specified in § 15.209(a) is not required. In addition, radiated emissions which fall in the restricted bands, as defined in § 15.205(a), must also comply with the radiated emission limits specified in § 15.209(a) (see § 15.205(c)) "of FCC Part 15.247c

Exceptions are allowed in up to three bands of 1 MHz width centred on a frequency which is an integer multiple of 1 MHz. They must, however, comply with an absolute value of –20 dBm.

3.4.2 Out-of-band spurious emission

The measured power should be measured in a 100 kHz bandwidth. The requirements are shown in Table 3.4.2 below.

Table 3.4.2: Out-of-band spurious emission requirement

Frequency Band	Operation mode	Idle mode
30 MHz - 1 GHz	–36 dBm	–57 dBm
1 GHz - 12.75 GHz	–0 dBm	–47 dBm
1.8 GHz - 1.9 GHz	–47 dBm	–47 dBm
5.15 GHz - 5.3 GHz	–47 dBm	–47 dBm

3.5 Radio frequency tolerance

The transmitted initial centre frequency accuracy must be ± 75 kHz from F_c. The initial frequency accuracy is defined as being the frequency accuracy before any information is transmitted. Note that the frequency drift requirement is not included in the ±75 kHz.

The transmitter centre frequency drift in a packet is specified in Table 3.5. The different packets are defined in the base-band specification.

Table 3.5: Frequency drift in a package

Type of Packet	Frequency Drift
One-slot packet	±25 kHz
Three-slot packet	±40 kHz
Five-slot packet	±40 kHz
Maximum drift rate [1)]	400 Hz/µs

Note 1. The maximum drift rate is allowed anywhere in a packet.

3.6 Receiver characteristics

In order to measure the bit error rate performance the equipment must have a "loop back" facility. The equipment sends back the decoded information.

The reference sensitivity level referred to in this chapter equals –70 dBm.

3.6.1 Actual sensitivity level

The actual sensitivity level is defined as the input level for which a raw Bit Error Rate (BER) of 0.1% is met. The requirement for a Bluetooth receiver is an actual sensitivity level of –70 dBm or better. The receiver must achieve the –70 dBm sensitivity level with any Bluetooth transmitter compliant to the transmitter specification specified in Section 1.

3.6.2 Interference performance

The interference performance on Co-channel and adjacent 1 MHz and 2 MHz are measured with the wanted signal 10 dB over the reference sensitivity level. On all other frequencies the wanted signal shall be 3 dB over the reference sensitivity level. Should the frequency of an interfering signal be outside of the band 2400 - 2497 MHz, then the out-of-band blocking specification (see Section 3.6.3) shall apply. The interfering signal shall be Bluetooth-modulated (see section 3.3). The BER shall be ≤0.1%. The carrier-to-interference ratio limits are shown in Table 3.6.2 below.

If two adjacent channel specifications from Table 3.6.2 are applicable to the same channel, the more relaxed specification applies.

Table 3.6.2: Interference performance

Requirement	C/I limit
Co-channel interference, $C/I_{co\text{-}channel}$	11 dB [1)]
Adjacent (1 MHz) interference, $C/I_{@1MHz}$	0 dB [1)]
Adjacent (2 MHz) interference, $C/I_{@2MHz}$	–30 dB
Adjacent (≥ 3 MHz) interference, $C/I_{@\geq 3MHz}$ [4)]	–40 dB
Image frequency interference [2) 3)], C/I_{Image}	–9 dB [1)]
Adjacent (1 MHz) interference to in-band image frequency, $C/I_{Image \pm 1MHz}$	–20 dB [1)]

Note 1. These specifications are tentative and will be fixed within 18 months after the release of the Bluetooth specification version 1.0. Implementations have to fulfil the final specification after a 3-years convergence period starting at the release of the Bluetooth specification version 1.0. During the convergence period, devices need to achieve a co-channel interference resistance of +14 dB, an ACI (at 1 MHz) resistance of +4 dB, Image frequency interference resistance of –6 dB and an ACI to in-band image frequency resistance of –16 dB;

Note 2. In-band image frequency;

Note 3. If the image frequency ≠ n∗1 MHz, then the image reference frequency is defined as the closest n∗1 MHz frequency;

Note 4. Corresponding to blocking level of –27 dBm.

These specifications are only to be tested at nominal temperature conditions with a receiver hopping on one frequency, meaning that the synthesiser must change frequency between receive slot and transmit slot, but always return to the same receive frequency.

Frequencies, where the requirements are not met, are called spurious response frequencies. Five spurious response frequencies are allowed at frequencies with a distance of ≥ 2 MHz from the wanted signal. On these spurious response frequencies a relaxed interference requirement C/I = – 17 dB shall be met.

3.6.3 Out-of-band blocking

The out-of-band blocking is measured with the wanted signal being 3 dB over the reference sensitivity level. The interfering signal shall be a continuous wave signal.

The BER shall be ≤0.1%. The out-of-band blocking shall fulfil the following requirements:

Table 3.6.3. Out-of-band blocking requirements

Interfering frequency	Interfering Signal Power Level
30 MHz - 2000 MHz	–10 dBm
2000 - 2399 MHz	–27 dBm
2498 - 3000 MHz	–27 dBm
3000 MHz - 12.75 GHz	–10 dBm

Some 24 exceptions are permitted which are dependent upon the given receive channel frequency and are centred at a frequency which is an integer multiple of 1 MHz. At 19 of these spurious response frequencies a relaxed power level –50 dBm of the interferer may used to achieve a BER of 0.1%. At the remaining 5 spurious response frequencies the power level is arbitrary.

3.6.4 Intermodulation characteristics

The reference sensitivity performance, BER = 0.1 %, shall be met under the following conditions:

- The wanted signal at frequency f0 with a power level 6 dB over the reference sensitivity level;
- A static sine wave signal at f1 with a power level of –39 dBm, corresponding to a 3rd intercept order point IP3 = -21 dBm;
- A Bluetooth modulated signal (see Section 3.3) at f_2 with a power level of –39 dBm;

Such that $f_0 = 2*f_1 - f_2$ and $|f_2 - f_1| = n*1$ MHz, where n=3, 4 or 5. The system must fulfil one of the three alternatives.

3.6.5 Maximum usable level

The maximum usable input level at which the receiver shall operate shall be better than –20 dBm. The BER shall be less or equal to 0.1% at –20 dBm input power.

3.6.6 Spurious emissions

The spurious emission for a Bluetooth receiver shall be not more than:

Table 3.6.6: Out-of-band spurious emissions

Frequency band	Requirement
30 MHz - 1 GHz	–57 dBm
1 GHz - 12.75 GHz	–47 dBm

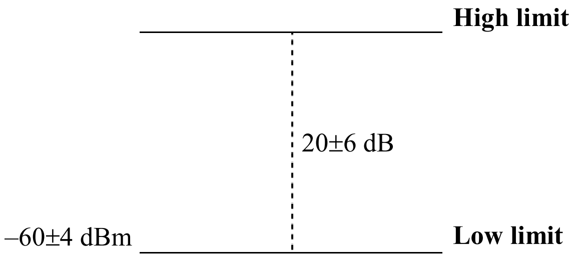
The measured power shall be measured in a 100 kHz bandwidth.

3.6.7 Receiver Signal Strength Indicator (Optional)

A transceiver that wishes to take part in a power-controlled link must be able to measure its received signal strength and determine if the transmitter on the other side of the link should increase or decrease its output power level. A Receiver Signal Strength Indicator (RSSI) makes this possible.

The way the power control is specified is to have a "golden receive power". This "golden receive power" is defined as a range with a low limit and a high limit. The RSSI must have a minimum dynamic range equal to this range. The RSSI must have an absolute accuracy of ± 4dB or better when the received signal power is –60 dBm. In addition, a minimum range of 20±6 dB must be covered, starting from –60 dBm and up (see Figure 3.6.7).

Figure 3.6.7: RSSI dynamic range and accuracy



3.6.8 Reference interfering signal definition

A Bluetooth modulated interfering signal is defined in Table 3.6.8 below.

Table 3.6.8: Definition of interference signal

Modulation	GFSK
Modulation index	0.32±1%
BT	0.5±1%
Bit Rate	1 Mb/s±1*10^{-6}
Modulating Data	PRBS9
Frequency accuracy	better than ±1*10^{-6}

3.7 Bluetooth utilisation factor

Due to the complexity of the envisaged Bluetooth use scenarios, when considering the system specifications of the involved systems (modulation, channel codec schemes, ARQ etc), propagation conditions, positioning of units and their duty cycles and the like, it is necessary to use simplifying models to describe the complex reality in an appropriate, but manageable way, focussing on the most influencing factors. The report must assume that not all devices are active at the same time to simplify the influence of a certain service mix and the related service models.

To refine the used traffic models the present contribution defines some 'macroscopic' traffic models which complement the already roughly modelled 'microscopic' part of the traffic model, which is expressed by the duty cycle, and calculates finally the percentage of active piconets for different scenarios.

3.7.1 Definition of Services relevant for the co-existence study

For simplicity not all announced or envisaged Bluetooth based services can be taken into consideration. A detailed traffic modelling of the various applications, like e.g. mouse, keyboard, printer, etc. for the desktop usage model would increase the complexity of the co-existence study tremendously. Therefore SE24 proposed to define usage model based service mixes for certain scenarios as a compromise between accuracy and complexity of the study.

It might be appropriate to concentrate on those scenarios, which represent most probable situation of daily life on one hand and which are most interesting from co-existence point of view on other hand. So the following scenarios were proposed:

- airport scenario;

- public places (outdoor);
- office scenario;
- home environment.

For those scenarios the service mix has to be defined, which determines the assignment of Bluetooth units to services. To reduce the number of services the following simplification was proposed:

- Desktop service (covers Bluetooth communication with mice, keyboard, joystick);
- Speech services (covers extension of mobile phones, cordless, walkie-talkie and Laptop as speaker phone);
- File transfer (covers the conference usage model);
- Internet communication (covers the Internet Bridge usage model).

3.7.2 Definition of service mix and service models

This section proposes related scenario mixes and the related macroscopic traffic models.

In table 3.7.2.a the macroscopic traffic model for the services above defined are given for each scenario. In this way the service mix for each scenario is given implicitly. In table 3.7.2.b the percentage of active piconets is defined for each scenario.

Table 3.7.2.a: Macroscopic traffic models

	Desktop	Speech	File transfer	Internet
Airport Scenario	0.00 Erl	0.10 Erl	0.10 Erl	0.20 Erl
Public Places	0.00 Erl	0.10 Erl	0.00 Erl	0.20 Erl
Office Scenario	0.50 Erl	0.10 Erl	0.10 Erl	0.10 Erl
Home Environment	0.10 Erl	0.05 Erl	0.05 Erl	0.10 Erl

It shall be noted that the duty cycle of desktop related Bluetooth links (like keyboard or mouse) is significantly lower than duty cycles of other Bluetooth services. To compensate this effect without introducing new complexity to the co-existence study the traffic value of the desktop services is multiplied by factor of 0.5.

Due to the fact that Bluetooth is following the basic rules of TDD, as both directions of one link are sharing the time axis, i.e. two considered communication partners cannot generate interference at the same time. Moreover all units connected to one piconet are well synchronised in frequency and time, i.e. one piconet with up to 8 active units can be seen as one interference source, because only one transmitter can be active at the same time in one piconet. Although up to 8 Bluetooth units can be active in one piconet the most common case for the considered services and scenarios will be one master and one slave. Consequently the number of active units has to be divided by factor of 2 to calculate the number of active piconets.

Table 3.7.2.b presents as final result the percentage of active piconets (utilisation factor) related to the assumed unit density.

Table 3.7.2.b: Bluetooth utilisation factor (percentage of active piconets)

	Utilisation factor
Airport Scenario	0.20
Public Places	0.15
Office Scenario	0.28
Home Environment	0.13

To use the calculated interference in Annex A it is necessary to use the effective unit density. This is defined as the unit density multiplied by the utilisation factor.

3.7.3 Conclusion

The multiplication of the assumed Bluetooth unit density by a utilisation factor given in table 3.7.2.b above is used to model the overall macroscopic traffic behaviour for the most important Bluetooth services.

4 CHARACTERISTICS OF EXISTING AND PROPOSED SYSTEMS IN THE 2.45 GHz BAND

Existing devices operating in the 2.45 GHz band have different characteristics and will have different responses to potential interferers. This chapter details these characteristics that are used as inputs for interference calculations performed in Annex A.

4.1 Electronic News Gathering/Outside Broadcast (ENG/OB) system characteristics

A summary of ENG/OB systems is given in subsections 4.1.1 to 4.1.6 below. For further details see ERC Report 38.

4.1.1 Typical ENG/OB applications

Links used by broadcasters at these frequencies fall, very broadly, into three categories:

- Temporary point-to-point links;
- Short-range links, from a mobile camera to a fixed point;
- Air-to-ground / ground-to-air mobile links.

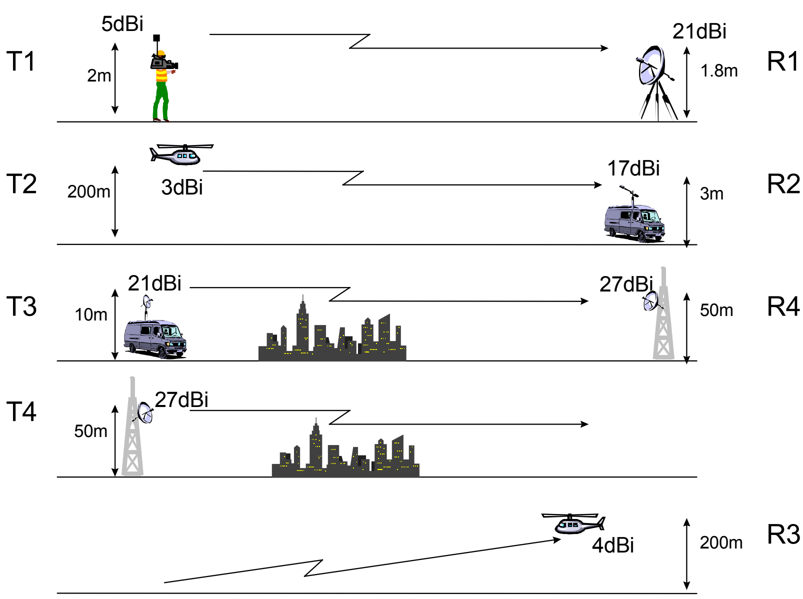
The first of these applications is represented by a link established from a parabolic antenna mounted on the roof of a vehicle at a racecourse to a similar antenna on a 'midpoint' vehicle on a hilltop some 10-20 km distant. The midpoint vehicle might then relay the signal to a permanent OB receiver site at a studio centre or transmitter. The link would be characterised by fairly high-gain antennas at both ends and a line-of-sight path. Such point-to-point links are also established at short notice for ENG purposes and, in this application, paths are often diffracted, with little or no fading margin.

The second application is, typically, that of a handheld camera at a football match, relaying pictures over a distance of a few hundred metres to a fixed receive point. The camera antenna will normally be omni-directional, and may operate to a directional receive antenna which is manually tracked. At longer ranges, the cameraman is accompanied by a second operator who employs a directional transmitter antenna with a modest (~10dBi) gain, manually pointed toward the receiving location.

The airborne link case might be represented either by a helicopter-mounted camera following a motor racing event and relaying the pictures to a ground receiver, or by a camera mounted in a racing car transmitting to a helicopter 'midpoint', which then re-transmits the pictures.

Many other arrangements can be readily imagined, but to reduce the scenarios modelled to a manageable number, the representative system types assumed in the report are illustrated in Figure 4.1.1 below.

Figure 4.1.1: Representative ENG/OB scenarios



4.1.2 FM Receivers for ENG/OB

(R1) Tripod-mounted, medium gain antenna, assumed to be tracking a radio camera at short-range;
(R2) Vehicle roof-mounted, medium-gain antenna (receiving from helicopter);
(R3) Helicopter-mounted, omni-directional antenna coverage (receiving from mobile radio camera);
(R4) High-gain antenna on transmitter mast, 100 m above ground level (agl), assumed to be one end of temporary fixed link.

The different receiver antenna types and estimated communication ranges are shown in Table 4.1.2.a below.

Table 4.1.2.a: Assumed receiver characteristics

Receiver	Antenna type	Gain	Height (agl)	Link
R1	0.6 m dish	21 dBi	1.8 m (tripod)	<500 m, from radio camera
R2	'Golden Rod'	17 dBi	3 m (vehicle roof)	<2 km, tracking helicopter
R3	Franklin	4 dBi	200 m (helicopter)	From radio camera
R4	1.2 m dish	27 dBi	50 m (transmitter mast)	30 km, from roving vehicle

NB: It is assumed that the propagation channel to R1 is characterised by shadowing and multipath effects, R2 and R3 are line-of-sight while R4 is also line-of-sight with multipath fading according to ITU-R P.530.

The same receiver is assumed in all cases: An analogue, FM receiver of 20 MHz bandwidth and 360 K receive system noise temperature. These parameter values are representative of commercially available receivers (data supplied by Continental Microwave Limited, UK). However, the antenna may differ in each case.

For this report the interference probability is calculated for following receiver combinations given in Table 4.1.2.b. below:

Table 4.1.2.b: ENG/OB reference types

Type in this report	Receiver from table 4.1.2.a	Antenna gain	Antenna height
ENG/OB 1	R3	4 dB	200 m
ENG/OB 2	R1	21 dB	1.8 m
ENG/OB 3	R2	17 dB	3 m
ENG/OB 4	R4	27 dB	50 m

4.1.3 FM Transmitters for ENG/OB

Table 4.1.3 below specifies e.i.r.p. levels of +35 dBm to +70 dBm for ENG/OB transmitters, which may give considerable interference to other radio services such as R-LAN, Bluetooth, and SRDs. The communication ranges indicated may be used to estimate the ENG/OB link interference protection.

Transmitter types:

(T1) Handheld camera, low-gain (1.8 m agl);
(T2) Helicopter, lower hemispherical coverage (200 m agl);
(T3) High-gain antenna on pneumatic vehicle mast (10 m agl);
(T4) High-gain antenna on transmitter mast (100 m agl).

Table 4.1.3. Assumed transmitter characteristics

Transmitter	Antenna	Gain	TX	e.i.r.p. (dBW)	Height (agl)	Link
T1	Lindenblad	5 dBi	1 W	5	2 m	<500 m, handheld camera to R1
T2	Wilted dipole	3 dBi	200 W	26	200 m	<2 km, helicopter to R2
T3	0.6 m dish	21 dBi	20 W	34	10m	30 km, roving vehicle to fixed insertion point (R4)
T4	1.2 m dish	27 dBi	20 W	40	50 m	30 km, fixed insertion point to roving vehicle

In all cases an analogue FM transmitter is assumed, with a 20 MHz bandwidth and a spectral mask conforming to that given in Appendix 4 of ERC Report 38.

For the purposes of the modelling undertaken in this study, it is assumed that the power in the ENG/OB transmissions is evenly distributed within a 20 MHz bandwidth.

4.1.4 Digital links

Digital ENG/OB systems are now marketed based on the DVB-T standard used for terrestrial digital TV broadcasting in Europe.

The transmission method used for Digital ENG/OB is Coded Orthogonal Frequency-Division Multiplexing (COFDM). Unlike traditional single-carrier digital transmission methods like QPSK or QAM, COFDM uses hundreds or thousands of individual carriers to transmit the digital signal. The analogue video signal is first sampled and digitised at either a 4:2:0 or 4:2:2 digital sampling rate, and then is encoded using the MPEG-2 video encoding algorithm.

Depending on the video quality desired and the signal-to-noise ratio of the channel, the MPEG-2 packetised transport data stream is transmitted at a bit rate between 5 and 30 Mb/s. The system uses 1704 carriers, each modulated with either QPSK, 16-QAM, or 64-QAM. Forward error-correcting coding is employed at rates 1/2, 2/3, 3/4, 5/6 or 7/8 depending on the modulation used. The receiver noise bandwidth is 7.61 MHz. COFDM is more robust in a multipath environment than are traditional modulation methods.

These COFDM systems can tolerate interfering signal levels approximately 20 dB stronger than can a traditional analogue frequency-modulated ENG/OB transmission. This improvement is valid for interfering signal bandwidths less than approximately 300 kHz. The improvement is gradually reduced to 1-2 dB for interfering signal bandwidths above 2-3 MHz.

4.1.5 Frequency allocations

The exact frequencies employed for these ENG/OB applications vary across Europe, with national usage being summarised in ERC Recommendation 25-10. This Recommendation suggests harmonised bands to be used across the CEPT, and notes the frequency band 2483.5 - 2500 MHz will not be available after the introduction of MSS services. It is further recommended that these applications should migrate to frequencies above 5 GHz.

4.1.6 Criteria for interference to analogue and digital ENG/OB

Section 4.2.3 below discusses the application of the interference criteria contained in ITU-R Recommendation F.758-1 to the interference analysis for frequency sharing between the Fixed Service and RFID operating in the 2.45 GHz band. Unfortunately, a similar recommendation does not exist for ENG/OB video links that also use the 2.45 GHz band. Instead, the broadcasting industry judges the usability of the video link in terms of quality of the received video image.

Because no quantitative performance criteria exist for ENG/OB, the Fixed Service interference criteria contained in the ITU-R Recommendation F.758-1 are not applicable for ENG/OB operations. Furthermore, the fade margins for ENG/OB links range from very large to nearly zero. An example of the first case is a wireless video camera link that operates over a distance of a few metres. An example of the second case is an ENG/OB vehicle that establishes an unscheduled video link back to a studio at short notice over an obstructed path.

Because of the difficulty of establishing quantitative performance criteria for Bluetooth interference to ENG/OB links, a program of laboratory measurements is planned.

ERC Report 38, p. 25 shows that an acceptable value of C/N for an analogue ENG/OB link is +29 dB, which results in a video signal-to-noise ratio of +44 dB. Therefore, the criteria for acceptable interference to an ENG/OB link is given by:

$$I/N(dB) = C/N(dB) - C/I(dB) = 29\text{ dB} - (+30\text{ dB}) = -1\text{ dB } (+/- 3\text{ dB}).$$

The criteria used in the interference analysis of analogue ENG/OB links in this report is that the acceptable level of short-term interference is equal to the receiver noise floor ($I/N = 0$ dB) which is well within the accuracy of the measured results.

For digital ENG/OB using COFDM transmission, the required C/I, as measured in the laboratory of Radiocommunications Agency (UK) is approximately 20 dB larger, hence the acceptable level of short-term interference is 20 dB above the receiver noise floor ($I/N = +20$ dB).

The details of the computation of the short-term interference are described in Section 5 of this report. The numerical computations are performed in the Excel worksheets and are presented in Annex A.

4.2 Fixed Service system characteristics

The system characteristics of Fixed Service (FS) systems are specified in ERC Report 40. The values for two representative systems are selected from ERC Report 40 and used in the interference analysis as given in Table 4.6.1.

4.2.1 The Fixed Service

The FS is defined as a radio communication service between specified fixed points. A typical example of a FS is a line-of-sight radio link employing highly directive antennas transmitting and receiving between two points separated by distances ranging from a few kilometres up to 30 kilometres or more. FS links provide a transmission path for telecommunication services such as voice, data or video.

By their nature, FS links are part of a carefully planned and well-regulated environment that has been developed over many years with internationally harmonised frequency allocations, channel plans and equipment standards. Typical FS links are usually part of a larger telecommunications network with multiple links or relays in point-to-point or point-to-multipoint configurations.

4.2.2 Frequency allocations for Fixed Services.

According to the European Common Allocation Table (ECA) in ERC Report 25, FS have primary status in the 2.45 GHz band. According to the ERO report “Fixed Service Trends Post 1998” only a few CEPT countries have FS in the 2.45 GHz band and in most cases only in a part of the band.

For those countries not using the 2.45 GHz band for FS, there should be no issue with interference from Bluetooth systems. If interference from Bluetooth is a problem it may be solved by restrictions concerning the actual operating frequency to be used in a particular country.

It is noted that FS inside the 2.45 GHz band are not covered by the ITU-R Recommendations 283–5, 382–6 or CEPT Recommendation T/R 13–01.

4.2.3 Criteria for Interference to Fixed Services

The criteria used in this Technical Report to perform the interference analysis for frequency sharing between the FS and Bluetooth operating in the 2.45 GHz band is described in the ITU-R Recommendation F.758-1 (1997). Specifically, in this report the interference to the FS caused by Bluetooth is characterised by the interference power level at the receiver input corresponding to long-term (*i.e.,* 20% of the time) interference.

According to the ITU-R F.758-1, the derivation of the permitted short-term interference levels (*i.e.* <1% of the time) and the associated time percentages is a complex process which would involve additional statistical information that is not currently available for the scenarios of interest in this study.

The long-term interference criteria used for FS in this study is the same as used in the Tables 6 and 7 of the ITU-R F.758-1 (1997). These same tables are presented in the ERC Report 40. These tables present a straightforward, but conservative, approach to specifying the maximum permitted long-term interference. This approach was taken because the detailed characteristics and the spatial distribution of the interference sources are only specified in very general terms, which results from the wide variety of Bluetooth devices and applications.

The problem of interference analysis is greatly simplified by referencing the interference to the receiver’s thermal noise level, since the permitted interference power spectral density thus derived will be dependent solely on receiver noise figure and will be independent of the modulation employed in the victim system. According to ITU-R F.758-1, it can be shown that, independent of the normal received carrier level, the degradation in the fade margin with interference set to a given level relative to receiver thermal noise level is as given in the table 4.2.3 below.

Table 4.2.3: Degradation in Fade Margin vs. Interference Level

Interference level relative to receiver thermal noise (dB)	Resultant degradation in fade margin (dB)
–6	1
–10	0.5

Within the tables listing the characteristics of typical FS systems, the choice of an interference-to-thermal-noise (*I/N*) ratio of –6 dB or –10 dB is selected to match the typical requirements for the individual systems. The details of the computation of the short-term interference are described in Section 5 of this report. The numerical computations were performed in the Excel worksheets and are presented in Annex A. The appropriate value of the *I/N* ratio (in dB) is entered into Line 20 of the worksheets in the sub-section A.2.1 of Annex A of this report.

In order to perform more detailed frequency sharing analyses than are performed in the present report, specific interference criteria must be derived in accordance with Annex 1 of the ITU-R Recommendation to match the individual, specific sharing scenario under consideration. These criteria will need to be agreed between the parties concerned (Interferer and Victim).

The interference criterion used in the analysis of FS in this report is that the acceptable level of interference is 10 dB below the receiver noise floor. The details of the computation of the interference are described in Section 5 of this Technical Report. The numerical computations were performed in the Excel worksheets and are presented in Annex A.

4.3 R-LAN characteristics

Radio Local Area Networks (R-LANs) provide access and mobility for the commercial workforce, government and educational institutions, as well as for computers in home and office environments. Current R-LAN systems operate at a power level of 100mW e.i.r.p. in the 2.45 GHz band, using spread spectrum technologies. R-LANs work predominantly in point-to-multipoint configurations with mobile or fixed devices communicating with fixed access points.

4.3.1 Interference to R-LAN

The interference analysis covers power levels of up to 100 mW e.i.r.p. for Bluetooth (Bluetooth 2) and the impact on R-LAN systems. R-LAN and Bluetooth systems may be co-located, so co-existence between the systems is desirable.

Interference test results from Bluetooth into R-LAN are described in Section 6.4

4.3.2 R-LAN Receiver characteristics

Frequency Hopping (FHSS) and Direct Sequence (DSSS) Spread Spectrum technologies are applied in R-LAN systems, and their receiver characteristics are:

FHSS:	Receiver sensitivity	–90 dBm or better
	Noise bandwidth	1 MHz
	Number of channels	79
DSSS:	Receiver sensitivity	–90 dBm or better
	Noise bandwidth	15 MHz
	Number of overlapping channels	13, every 5 MHz, user selectable

Common to FHSS/DSSS is that majority of applications use omni-directional antennas with a typical gain of max 2 dBi.

4.3.3 R-LAN transmitter characteristics

R-LAN transmitter characteristics are as follows:

FHSS/ DSSS:	e.i.r.p. (omni-directional):	20 dBm
	Duty cycle	Can be anything between 1% and 99%, regulation does not impose any limit
FHSS:	3dB signal bandwidth	< 0.35 MHz
	Number of channels	79
	Hop increment	1 MHz
DSSS:	3 dB Channel bandwidth	15 MHz
	Null to null bandwidth	22 MHz
	Number of overlapping channels	13, every 5 MHz, user selectable

In order to assess the current interference potential of R-LANs, this report uses the maximum permissible duty cycle of 100% for all units inside the interference zone.

4.3.4 Criteria for interference to R-LAN

Section 4.1.6 above discussed the interference criteria developed for the ENG/OB video links that also share the 2.45 GHz band.

Section 4.2.3 above discussed the application of the interference criteria contained in the ITU-R Recommendation F.758-1 to the interference analysis for frequency sharing between the FS and other services operating in the 2.45 GHz band.

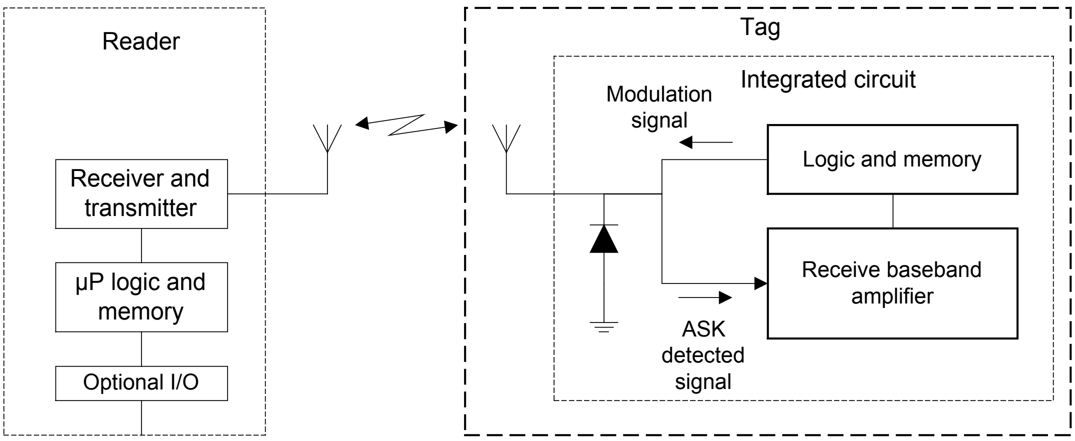
These interference criteria are not applicable for the analysis of interference from Bluetooth to R-LAN and other short range devices that operate on an intermittent basis. This is because the spread-spectrum packetised data transmission of such victim devices provides additional interference protection that is not available to ENG/OB and FS.

For the interference analysis in this report, it has been assumed that interference to an R-LAN receiver occurs whenever the interfering signal equals the receiver's front-end noise floor (*i.e.,* the interference equals the *kTB* noise). The details of the computation of the short-term interference are described in Section 5 of this report. The numerical computations were performed in the Excel worksheets and are presented in Annex A.

4.4 RFID characteristics

A typical RFID system consists of a reader and a number of tags as shown at figure 4.4 below.

Figure 4.4: Typical RFID system



Unlike other communication systems an RFID system has a single mixing receiver, in the reader only. The tag is positioned in the other end of the communication link and the majority of tag designs consist of two parts, a printed wire board, which contains an antenna, and an integrated circuit (IC). Consequently, the tag is a simple, low cost, device without any internal RF generation. Its functionality is dependent on the received field from the reader since the tag reflects the received RF back to the reader, as an RF mirror. Sometimes RFID systems are referred to as "modulation back-scatter systems" since it scatters a reflected signal and modulates this reflected, scattered signal to convey information. For battery less tags dc power is supplied by the received RF field thus requiring the high transmit power.

The reader transmits data to the tag using amplitude shift keying (ASK) modulation. The tag transmits data to the reader by receiving an unmodulated RF carrier from the reader, modulating the signal with phase shift keying (PSK) and then reflecting this signal back to the reader.

The diode in the tag IC performs three functions:

- ASK detector for the forward link communication from the reader;
- Phase modulation of the unmodulated carrier from the reader to send a signal to the reader;
- RF rectification of received RF carrier to provide the dc power supply for the battery-less tag IC.

As a summary, the following RFID parameters were used for interference analysis in this report:

Common parameters:

- e.i.r.p. +36 dBm (for indoor use);
- e.i.r.p. +27 dBm (for indoor/outdoor use);

- Antenna gain: > +6dBi;
- Antenna beam width: < 90 degrees;
- Duty cycle: < 15%.

FHSS systems:
- Tx 3 dB Signal bandwidth: < 0.35 MHz;
- Number of channels: 20 (or 79 for FCC part 15);
- Hop increment: 0.35 MHz (or 1 MHz for FCC part 15).

NB (Narrow Band) systems:
- Number of channels: 3 (The 3 channels can be set anywhere inside the band);
- 3 dB signal bandwidth: <0.01 MHz;
- Channel spacing: 0.6 MHz.

4.5 Typical SRD characteristics

For other types of SRD used in interference analysis in this report, the following parameters were assumed:
- e.i.r.p.: +10 dBm;
- Antenna gain: 0 dBi;
- Antenna beam width: 360 degrees;
- 3 dB Channel Bandwidth: 1 MHz
- Frequency (for narrow band BW<1 MHz): anywhere in the 2.45 GHz band.

4.6 Victim and Interferer characteristics

4.6.1 Summary victim receiver characteristics

The characteristics of the victim receivers are summarised in table 4.6.1 below.

Table 4.6.1. Characteristics of victim receivers

	Noise Level at receiver input	Noise Equiv. Bandwidth (NEB)	Antenna gain	Antenna beam-width degrees	Antenna height
General SRD	–104 dBm	1 MHz	1.6 dBi	360	3 m
Bluetooth [1)]	–90 dBm	1 MHz	0 dBi	360	1.5 m
R-LAN FHSS	–104 dBm	1 MHz	2 dBi	360	2.5 m
R-LAN DSSS	–92 dBm	15 MHz	2 dBi	360	2.5 m
RFID	–72 dBm	350 kHz	6 dBi	87	1.5
ENG/OB 1	–94 dBm	20 MHz	4 dBi	360	200 m
ENG/OB 2	–94 dBm	20 MHz	21 dBi	15	1.8 m
ENG/OB 3	–94 dBm	20 MHz	17 dBi	24	3 m
ENG/OB 4	–94 dBm	20 MHz	27 dBi	8	50 m
Digital ENG/OB	Same as analogue systems above, but with NEB = 7.6 MHz				
Fixed 1	–105 dBm	3 MHz	25 dBi	10	50 m
Fixed 2	–97dBm	20 MHz	35 dBi	3	50 m

Note 1: The reference receive noise level used for Bluetooth is –90 dBm based on a –70 dBm sensitivity as given in the Bluetooth specification and in an (in-channel) SNR required (20 dB). Receiver noise level of –90 dBm is different from the optimum utilisation of a 1 MHz channel.

4.6.2 Summary of interfering transmitter characteristics

The interfering characteristics of existing and potential new services are summarised in Table 4.6.2 below. The values in Table 4.6.2 are reflective of values used in the worksheets presented in Annex A.

Table 4.6.2: Characteristics of systems for interference analysis

	Maximum Radiated Power (e.i.r.p.)	Modulation Bandwidth (3dB)	Total Band-width	Max. Duty Cycle	Antenna Beam-width (degrees)	Antenna Height
Reference systems:						
SRD, Narrow band	+10 dBm	1 MHz	1 MHz	100 %	360	3.0 m
R-LAN, FHSS	+20 dBm	1 MHz	79 MHz	100 %	360	2.5 m
R-LAN, DSSS	+20 dBm	15 MHz	15 MHz	100 %	360	2.5 m
Proposed systems:						
Bluetooth 1	0 dBm	1 MHz	79 MHz	60 %	360	1.5 m
Bluetooth 2	+20 dBm	1 MHz	79 MHz	60 %	360	1.5 m
RFID 3a, FHSS	+36 dBm	0.35 MHz	8 MHz	100 % 1)	87	1.5 m
RFID 3b, FHSS	+27 dBm	0.35 MHz	8 MHz	100 %	87	1.5 m
RFID 3a, FHSS	+36 dBm	0.35 MHz	8 MHz	15 % 2)	87	1.5 m
RFID 5a, narrow band	+27 dBm	10 kHz	2 MHz	100 %	69	3.0 m
RFID 5b, narrow band	+20 dBm	10 kHz	2 MHz	100 %	69	3.0 m
R-LAN, FHSS	+27 dBm	1 MHz	79 MHz	100 %	77	2.5 m
R-LAN, DSSS	+27 dBm	15 MHz	15 MHz	100 %	77	2.5 m

Note 1: Original proposal;
Note 2: Max ton 30 ms in any 200 ms period.

5 SHARING WITH OTHER RADIO COMMUNICATION SYSTEMS

In any communication system, transmitters could be considered as interferers and receivers as victims. Sometimes, one type of device could fall into both categories. For example, an SRD could be a victim by receiving interference from another system. On the other hand, this same SRD could also be an interferer to another system. In this report, "victim" and "interferer" are terms that represent devices to evaluate interference. The terms "victim" and "interferer" therefore represent their roles in this interference analysis, not their operational characteristics.

Sharing of the 2.45 GHz band is feasible if the probability of interference is sufficiently low. Interference occurs if the interferer and victim operate:

a) on overlapping frequencies;
b) in proximity to each other;
c) at the same time;
d) with overlapping antenna patterns.

The probability of interference depends on the factors above and the conditions under which devices are deployed:

a) Urban or rural environment;
b) Indoor or outdoor environment;
c) Density of interferers.

Interference analysis for either existing or proposed systems did not include effects due to adjacent channel operation. These effects would greatly increase the complexity of the analysis, and if it were included, the probabilities for existing and proposed systems would increase. Since both probabilities would increase, the comparison of proposed systems and existing systems would likely remain unchanged. Analysis of adjacent channels was excluded to reduce the analysis complexity while at the same time maintain similar results.

The following sections describe the probabilistic and deterministic methods of calculating the potential of interference.

5.1 Deterministic method

5.1.1 General

The deterministic method focuses on one interferer, or possibly two or more interferers when intermodulation is studied, and a Bluetooth link with varying distances. Performance in terms of throughput is then studied. This differs from the statistical model in the sense that fixed scenarios are studied instead of a statistical ones which entails a clearer understanding of the interference mechanisms of the specific interference scenario.

For analysis under the deterministic approach, the simulation model described in annex D has been used. Bluetooth is a low cost and medium performance product. To achieve an aggressive low cost goal several compromises were made particularly on fundamental receiver parameters, which normally are considered vital for an operation in the shared band 2400-2483.5 MHz. This document calculates Bluetooth blocking and co-channel and adjacent channel interference by the Minimum Coupling Loss (MCL) method. The accumulative effects are considered under the probabilistic method, described in section 5.2.5. The calculated data are compared with the C/I values, measured by RA/UK. An appropriate indoor propagation model was used, as described in section 5.1.3.

5.1.2 Nominal received signal

For relaxed receiver specifications a stronger wanted signal is necessary. In agreement with this statement Bluetooth manufacturers have argued that the minimum wanted receive signal must be equal to the Maximum Usable Sensitivity (MUS)+10 dB. After discussion it was agreed to base all interference scenarios on received signal level of MUS+3 dB. As the Bluetooth specification establishes that MUS is -70 dBm, the minimum receive signal, P_{RX_MIN} is:

$$P_{RX\_MIN} = MUS + 3 = -70 + 3 = -67\ dBm$$

For Bluetooth calculations in the following sub-sections therefore a minimum received input signal of –67 dBm is used.

5.1.3 Propagation model used for deterministic method

The discussion of this section only applies to calculations performed using the deterministic method. Propagation models for the probabilistic method are discussed in section 5.2.2.

At 2.45 GHz, the Path Loss (PL) is:

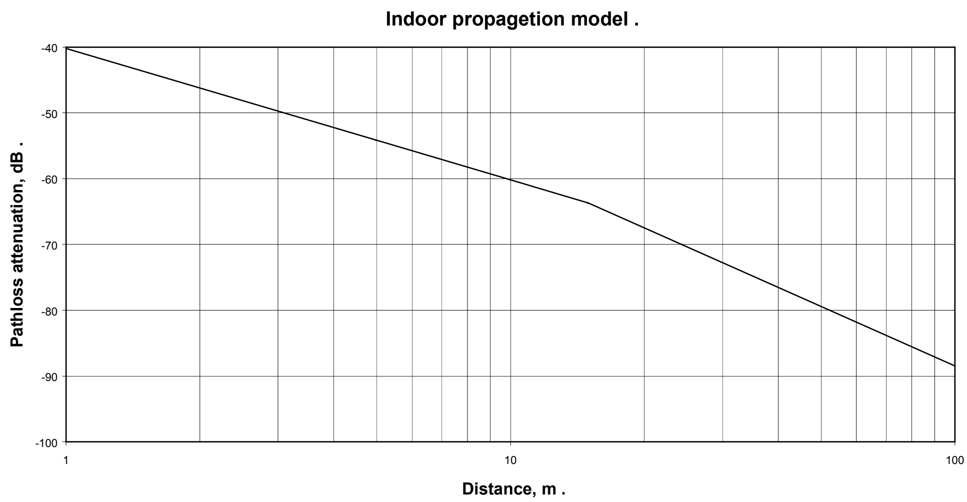
a) for distances below 15m (free-space propagation applies): $PL = 40.2 + 20\log d$ (dB) (5.1.3.a);

b) for distances above 15 m: $PL = 63.7 + 30\log\frac{d}{15}$ (dB) (5.1.3.b);

where d is distance in metres.

The graphical representation for the model is shown in figure 5.1.3 below.

Figure 5.1.3. Worst case indoor propagation model for deterministic calculations



5.1.4 *Minimum Coupling Loss and protection distance*

The protection distance, d_P , for any interference is determined by means of the Minimum Coupling Loss (MCL) calculations. A generic formula for MCL is given in section 5.2.1. In cases where the received threshold power and C/I are given, MCL can be calculated by:

$$MCL = P_{RAD} - P_{RX} + C/I \qquad (5.1.4)$$

where:

MCL - Minimum Coupling Loss, dB;
P_{RAD} - Radiated power (eirp) for interfering transmitter, dBm;
P_{RX} - Bluetooth received power, dBm;
C/I - Carrier to interference ratio specified for the Bluetooth receiver, dB.

The calculated MCL can be obtained through evaluation of path loss (PL) over a certain protection distance d_P. This can be derived from an appropriate propagation model:

$$d = 10^{(PL-40.2)/20}$$, for PL<63.7 dB, and

$$d = 15 * \left(10^{(PL-63.7)/30}\right)$$, for PL ≥ 63.7 dB.

5.1.4.1 *Co-channel*

The following two cases for co-channel interference are investigated:

a) Constant envelope: C/I = 11 dB;
b) Noise like: C/I = 18 dB.

5.1.4.2 *Adjacent channel*

The following Bluetooth specifications were used for calculations:

- 1st adjacent channel: C/I = 0 dB;
- 2nd adjacent channel: C/I = -30 dB;
- 3rd and higher adj. channel: C/I = -40 dB.

5.1.4.3 *Blocking*

The following Bluetooth specification was used for calculations:

- for 3rd adjacent channel and higher, C/I = -40 dB, corresponding to blocking of –27 dBm at (MUS+3) dB.

Blocking and co-channel interference mechanisms are given in the Table 5.1.4.3 below.

Table 5.1.4.3: Interference mechanisms to Bluetooth for different types of interferer

Interferer type	Power dBm (eirp)	Duty cycle (%)	ChanBW MHz	Primary mechanism of interference
SRD narrow band	+10	100	1	Blocking
SRD, CATV	+10	100	20	Co-channel
RLAN, DSSS	+20	100	15	Co-channel
RLAN, FHSS	+20	100	1	Blocking
RFID, FHSS	+36	10/15/50/100	0.3	Blocking
ENG/OB, video cam. Analogue	+35	100	20	Co-channel
ENG/OB, helicopter. Analogue	+56	100	20	Co-channel
ENG/OB, video cam. Digital	+35	100	7.4	Co-channel
ENG/OB, helicopter. Digital	+56	100	7.4	Co-channel

5.1.4.4 3rd order Intermodulation

5.1.4.4.1 Introduction

Third order intermodulation (3rd order IM) products are generated whenever two signal with frequencies f_1 and f_2 are injected into a non-linear device that produces spurious signals at frequencies $f_{3im1} = 2f_1\text{-}f_2$ and $f_{3im2} = 2f_2\text{-}f_1$. The strength of these IM products depends on the nature of the non-linearity and the strength of the two signals. If the two signals are separated by $\Delta f = f_2 - f_1$, then the 3rd order products will fall at frequencies Δf above and Δf below the two desired signals.

The distribution of 3rd order intermodulation components, which would result from RFID transmitter operation on 7 of the 1 MHz Bluetooth hopping channels located in the centre of the 2.400-2.4835 GHz band is shown in table 1 below. This table assumes transmission on seven frequencies, denoted f1, f2,… f7 which coincide with Bluetooth hopping channels numbered 45 through 51. This would be representative of the situation in which RFID operation is restricted to an 8MHz sub-band. The additional 1 MHz (0.5 MHz at each end) represents a guard band.

Table 5.1.4.4.1: 3rd order intermodulation components for N=7 transmitting channels

Bluetooth RX hopping channel no.	Interferer no. inside RX channel	Frequency Combinations giving 3rd order IM							No. of 3rd order products	Prob. of falling into an RX chan
1									0	0,000
2									0	0,000
3									0	0,000
.									.	.
.									.	.
37									0	0,000
38									0	0,000
39		f1,f7							1	0,024
40		f1,f6							1	0,024
41		f1,f5	f2,f7						2	0,048
42		f1,f4	f2,f6						2	0,048
43		f1,f3	f2,f5	f3,f7					3	0,071
44		f1,f2	f2,f4	f3,f6					3	0,071
45	f1		f2,f3	f3,f5	f4,f7				3	0,071
46	f2			f3,f4	f4,f6				2	0,048
47	f3		f2,f1		f4,f5	f5,f7			3	0,071
48	f4			f3,f2		f5,f6			2	0,048
49	f5			f3,f1	f4,f3		f6,f7		3	0,071
50	f6				f4,f2	f5,f4			2	0,048
51	f7				f4,f1	f5,f3	f6,f5		3	0,071
52						f5,f2	f6,f4	f7,f6	3	0,071
53						f5,f1	f6,f3	f7,f5	3	0,071
54							f6,f2	f7,f4	2	0,048
55							f6,f1	f7,f3	2	0,048
56								f7,f2	1	0,024
57								f7,f1	1	0,024
58									0	0,000
59									0	0,000
.									.	.
.									.	.
77									0	0,000
78									0	0,000
79									0	0,000
	N = 7 units	Total 3rd order IM combinations, X: X = N*(N-1) = 7*(7-1) = 42						TOTAL	42	1,000

In general, the number of combinations for interfering signals that cause 3rd order IM is given by:

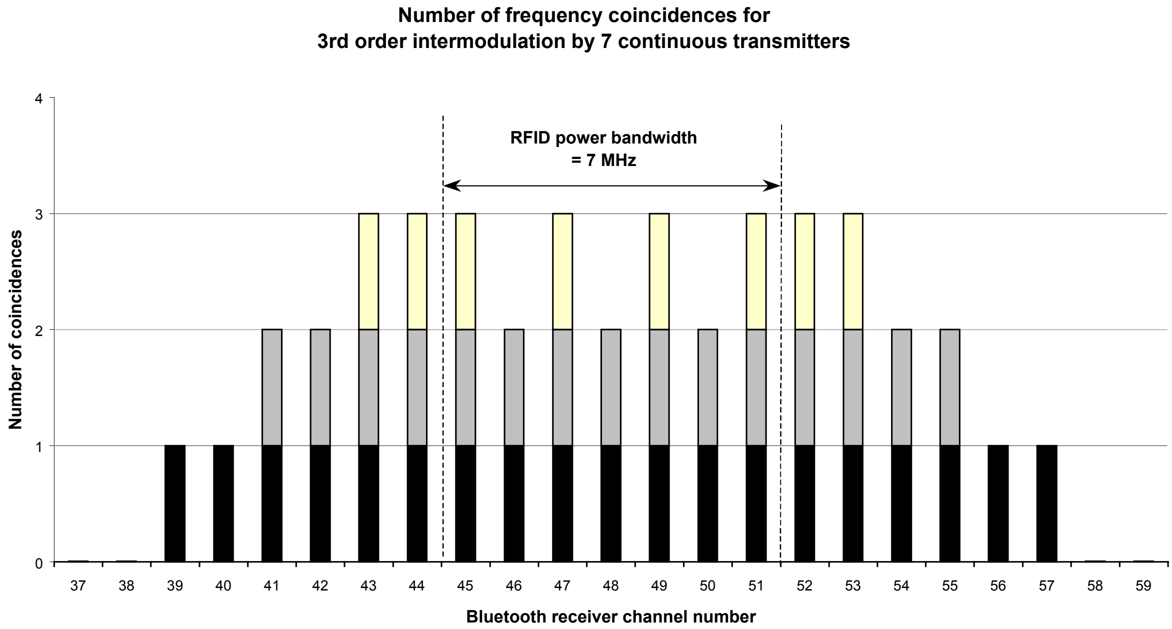
$$q = n \cdot (n-1),$$

where: n - number of interfering transmitters.

In the example given in figure 5.1.4.4.1 below, $q=42$.

It should be noted that the 3rd order IM products are restricted to 19 channels roughly centred on and around the Bluetooth hopping channels. Figure 5.1.4.4.1 below is a plot that shows graphically these channels and the total number of interfering signals per receiver channel for the example given in Table 5.1.4.4.1. Observe that the majority of the 3rd order products are clustered in the centre of the band, and they occur with decreasing rate at frequencies removed from the RFID transmit band. At a distance greater than +/-7 MHz from the central band, there is no 3rd order IM interference and 60 of the Bluetooth hopping channels are not affected by 3rd order IM.

Figure 5.1.4.4.1: Number of interference products for N=7 simultaneous transmitters



From figure 5.1.4.4.1 it can be seen that 19 consecutive channels are interfered if all 7 transmitters are transmitting simultaneously at different frequencies.
In this case the probability of interference to Bluetooth will be:

$$P = \frac{\text{Number of interfering channels}}{\text{Total number of victim channels}} = \frac{19}{79} = 0.24 \text{ .}$$

The individual components of interference are results of both co-channel and 3rd order IM interference. Co-channel components will result from units positioned at greater distances and can therefore easily interfere over the whole 7 MHz power bandwidth used by RFID. The 3rd order IM will fill approximately 19 MHz as shown in figure 5.1.4.4.1.

If all interfering units are outside the protection range for IM, then interference will only occur inside the 7 MHz of power bandwidth for RFID. In this case the interfering probability to Bluetooth is at the most is:

$$P = \frac{\text{No of interfering channels}}{\text{Total number of victim channels}} = \frac{7}{79} = 0.089 \text{ .}$$

This low interference probability is accomplished by the effective use of mitigation techniques such as reduced duty cycle and increased antenna directivity.

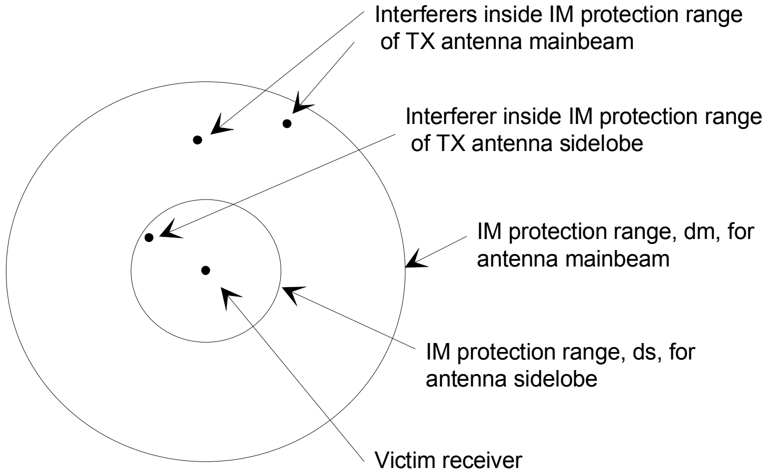
5.1.4.4.2 Interference mitigation

RFID uses the following interference mitigation techniques:

a) Transmitter duty cycle: 15% average;
b) Antenna beam width for the main beam: 87 degrees maximum;
c) Antenna beam width for side lobe approximately: 90 degrees (typical of a patch antenna which has very low backwards radiation)

The interference scenarios are illustrated in figure 5.1.4.4.2:

Figure 5.1.4.4.2: Protection ranges inside and outside antenna main beam



The RFID antenna has 15 dB side lobe attenuation. This results in a reduction of the intermodulation protection range when the interference is outside the main beam of the antenna. The Bluetooth receiver has a 3rd order IM specification, P_{INTMOD} = -39 dBm. The protection range can be determined by:

$$P_{INTMOD} = P_{RFID} - PL \ , \qquad (5.1.4.4.2)$$

where:

PL	- Path loss in dB;
P_{RFID}	- RFID radiated power = +36 dBm.

Re-arranging equation (5.1.4.4.2.):

$$PL = P_{RFID} - P_{INTMOD} = 36\ dBm - (-39\ dBm) = 75\ dB\ .$$

Using SE24 indoor propagation model of free-space propagation until 15 metre and 30dB/decade roll-off above yields the following protection distances for 3rd order intermodulation:

- Protection distance for main beam, d_M = 35 m;
- Protection distance for side lobe , d_S = 9.8 m.

For a uniform distribution of the interfering RFID units within the protection ranges, the ratio between units in areas inside the protection ranges for side lobe and main beam respectively is:

$$Ratio = \left(\frac{d_S}{d_M}\right)^2 = \left(\frac{9{,}8}{35}\right)^2 = 7.84 * 10^{-2}$$

5.1.4.4.3 Hot-spot unit densities

To investigate the worst case intermodulation scenarios, assuming large "hot-spot" unit densities, it is proposed to calculate the effect of N=8, 16 and 32 RFID units inside the intermodulation protection range:

Table 5.1.4.4.3. Hot-spot unit densities for intermodulation calculations

Scenario	**No of units inside main beam protection area**	**No of units inside side lobe protection area**
1 (common case)	8	1
2 (very high density case)	16	1
3 (extreme but very seldom case)	32	3

5.1.4.4.4 Probability of occurrence

Since the two events are statistically independent, the probability that a single RFID unit is interfering to a victim receiver with an omni-directional antenna is:

$$p = P_{MAINBEAM\_COLL} * P_{TIME\_COLL}$$

where:

$P_{MAINBEAM\_COLL}$ - probability of victim being inside of the interferer antenna's main beam;
P_{TIME_COLL} - probability of transmitter being "on" at a given time (= duty cycle).

To determine the number of IM frequencies it is necessary to calculate the probability of how many of the above *N* units are transmitting at the same time. This can be done by calculating the probability *P(n)*, which is the probability that *n* units out of *N* are transmitting simultaneously. This is given by the following binomial probability formula:

$$P_{(n)} = \frac{N!}{n!*(N-n)!} * p^n * (1-p)^{N-n}$$

Using the data in table 5.1.4.4.4 the results of the calculations of *P(n)* are shown in figure 5.1.4.4.4 below:

Figure 5.1.4.4.4. Probability of simultaneous transmissions generating intermodulation

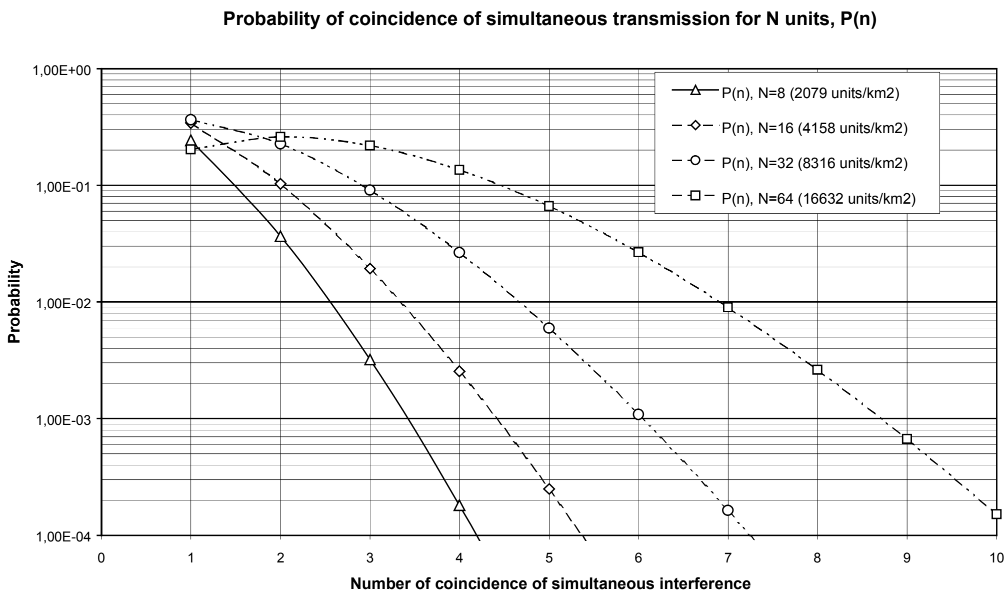


Table 5.1.4.4.4 below shows the relevant 3rd order IM combinations and their probabilities for interfering to Bluetooth.

Table 5.1.4.4.4 Probability for intermodulation to Bluetooth by 4W RFID for different population densities

	"n" = number of transmitters "on" at the same time					
	2	**3**	**4**	**5**	**6**	**7**
Max No of IM components in a victim channel (19 maximum)	2	9	16	25 (in 19 ch. max.)	36 (in 19 ch. max.)	49 (in 19 ch max.)
Percentage of all Bluetooth channels affected	2/79 = 2.5%	9/79 = 11.4%	16/79 = 20.3%	19/79 = 24.1%	19/79 = 24.1%	19/79 = 24.1%
No of units inside the IM protection range (hot-spot density, N)	Below is given probability for occurrence of above effected channels					
Scenario 1, N=8	3.5 E-02	3.2 E-03	1.8 E-04	< 1 E-04	< 1 E-04	< 1 E-04
Scenario 2, N=16	1.0 E-01	1.9 E-02	2.7 E-02	2.5 E-04	< 1 E-04	< 1 E-04
Scenario 3, N=32	2.2 E-01	9.0 E-02	2.8 E-02	6.0 E-03	1.1 E-03	1.8 E-04

Table 5.1.4.4.4 shows that intermodulation will happen occasionally, but the probability is low due to the mitigation applied for RFID.

Another way of looking at IM products is to assess the required isolation distances d_1 and d_2 between the interfering transmitters and the victim receiver. Given the propagation model from section 5.1.3 these distances can be obtained from the minimum received interference power levels I_1 and I_2 at which degradation might occur. The Bluetooth IM specification assumes $I_1 = I_2$ corresponding to $d_1 = d_2$. In practice, however, the interferers have different distances in general. I.e. if one transmitter is closer to the victim, the distance to the other one must increase in order to guarantee that the limit of intermodulation products does not exceed a given threshold. The general relation is given by

$$IM = 2I_1 + I_2 - 2IP_3$$

where:

I_1 - the received power of interferer 1 with carrier frequency f_1 in dBm;
I_2 - the received power of interferer 2 with carrier frequency f_2 in dBm;
IP_3 - the 3rd order intercept point in dBm (Bluetooth specification requires $IP_3 \geq -21$ dBm);
IM - the power of the intermodulation product at frequency $2f_1$-f_2, measured in dBm.

Assuming one interferer at a distance d_1 , the required distance d_2 for a second transmitter on another frequency for a maximum tolerable IM can be determined with the following procedure:

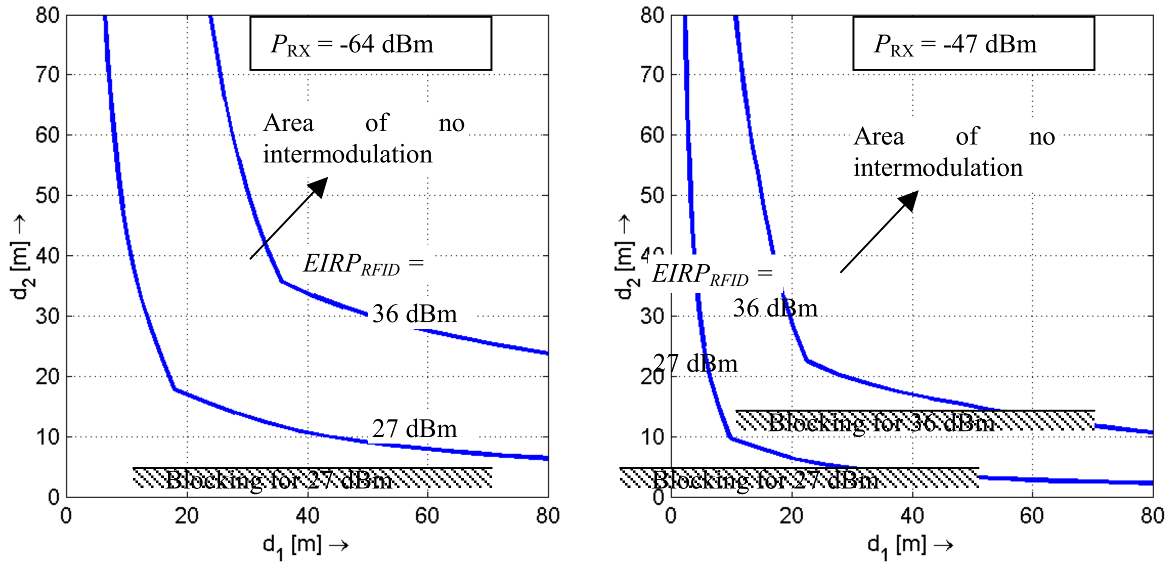
a) Determine I_1 from d_1 using the channel model from section 5.3.1;
b) Determine I_2 from the formula above: $I_2 = IM + 2IP_3 - 2I_1$;
c) Determine d_2 from I_2 using the inverse relations of the channel model from section 5.1.4.

Note: For $d_1 \leq d_2$ this is a worst case consideration, because the determined power at $2f_1$-f_2 is greater than the power at $2f_2$-f_1. To obtain the IM-product with maximum power, I_1 and I_2 must be exchanged in the above formula for $d_1 > d_2$.

Figure 5.1.4.4.4.1 shows the required isolation distances for intermodulation interference to a Bluetooth receiver as a victim caused by two RFID interferers, having distances d_1 and d_2, respectively, from the victim. The first figure is for a Bluetooth device operating at the receive level of –64 dBm, which is the level for the IM-specification. In this case the detectable level of intermodulation is IM= –75 dBm. For the second figure a receive level of –47 dBm is used, corresponding to a Bluetooth link over 2 m distance. This represents also a link from a headset at the human ear to a mobile phone in the pocket (1 m distance +6 dB body loss), which can be considered as a typical application in the vicinity of RFID devices. Both figures contain two curves with EIRP of 36 dBm and 27 dBm, respectively, for the RFID transmitters. 36 dBm represents the worst case, where the main beam of RFID antenna is pointing towards the Bluetooth receiver.

Each curve divides the d_1-d_2 plane into two regions. For all distance pairs [d_1, d_2] above this curve it is guaranteed that the intermodulation product in any receive channel is below the given limit.

Figure 5.1.4.4.4.1: Isolation distances d_1 and d_2 of two RFID readers interfering to a Bluetooth victim



For 4W RFID devices and a Bluetooth device operating at (MUS+6) dB, quite large isolation distances can be obtained. Even for 500 mW RFID and a Bluetooth receiver operating at a higher level, the required distances is in the order of 10 m, which appears unacceptably high. However, this must be compared with the isolation distances required for blocking which are around 14 m for 36 dBm and 5 m for 27 dBm. For a 2 m Bluetooth link IM products become only significant, if at least one interferer is close to the blocking level. For low receive level and a 4W RFID intermodulation products may be more significant. Compared to co-channel and adjacent channel interference the effect of IM products is assessed as being low.

It should be noted that these deterministic limits do not necessarily mean actual interference. In a realistic environment, only a few frequencies are interfered by IM products and through frequency hopping only a fraction of all hops are affected. The overall link quality might therefore be still acceptable although the IM-limit is exceeded on a few channels. The effect is further reduced by a low duty cycle of RFID transmitters, which results in a low probability that two or more transmitters within the isolation range are active at the same time. This is in alignment with the conclusions given in Table 5.1.4.4.4.

5.1.5 Mechanisms of interference

By applying the methods described in section 5.1.4 above, the protection distance can be calculated for various interferer types if the interferers are continuously transmitting.

It shall be noted that different types of interferers will have different interference mechanisms depending of their bandwidth. The relevant computations for protection distances were calculated in Excel spreadsheet, as given in Annex B of this report. A summary of these calculations for different interference mechanisms is shown in Table 5.1.5 below.

Table 5.1.5: Interference mechanisms and protection distances to Bluetooth for different types of interferer

Interferer type	Power (e.i.r.p) dBm	Duty cycle (%)	Channel BW MHz	Primary mechanism of interference	Calculated protection distance, metre [2)]	Protection distance using UK/RA measured C/I, m [3)]
SRD narrow band	+10	100	1	Blocking	0.7	1.5
SRD, CATV	+10	100	20	Co-channel	36	35.7
RLAN, DSSS	+20	100	15	Co-channel	85	40
RLAN, FHSS	+20	100	1	Blocking	2	4.9
RFID, FHSS	+36	10/15/50/100	0.3	Blocking	-/-/-/14.2	4.9/ 5.5/ 19.3/24
ENG/OB video cam. - Analogue	+35	100	20	Co-channel	243	142
ENG/OB helicopter - Analogue	+56	100	20	Co-channel	1948 [1)]	869 [1)]
ENG/OB video cam. - Digital	+35	100	7.61	Co-channel	339	145
ENG/OB helicopter - Digital	+56	100	7.61	Co-channel	3202 [1)]	716 [1)]

Note1: Calculated with free space model and 15 dB wall attenuation;
Note 2: Worst case protection distances based on Bluetooth specified C/I values of 11 dB (co-channel) and –40 dB (blocking), and unobstructed indoor propagation model (see section 5.1.3);
Note 3: Worst-case protection distances based on measured C/I values (see section 6.5) for an unobstructed indoor propagation path (see model in section 5.1.3).

In order to assess the effect of co-channel and adjacent channel interference on a Bluetooth link, C/I values must be mapped to a quality measure. In this study, the packet throughput of a data connection is taken as measure for the link quality. The study of throughput in dependence on C/I reveals some insight into the interference mechanism to Bluetooth. For simplicity, study considers the normalised throughput, which is 1 in case of no interference. Because of the ARQ-mechanism in Bluetooth, a packet is not only lost if the forward link is erroneous, but also if the acknowledgement on the backward channel is erroneous. Since a packet and its acknowledgement is transmitted on different frequencies, which are selected independent from each other, the relative throughput of a Bluetooth data link is given by $(1-P_{err})^2$, where P_{err} is the average packet error rate.

The packet error rate P_{err} depends on the actual Carrier to Interference ratio C/I. In order to concentrate on the main effects, a packet is considered as error-free, if C/I exceeds a given threshold, it is considered as erroneous, if C/I is below that threshold.

The frequency hopping mechanism in Bluetooth ensures that each of the 79 channels are used with the same probability. I.e. even if the C/I is constantly below a given threshold on one channel, the average packet error rate is 1/79 as long as the

C/I is sufficiently high on all other channels. This principle can be applied if the interferer dwell time on a channel is much higher than the dwell time of the Bluetooth link. This condition holds for all considered scenarios, except one: Interference from Bluetooth operating in HV1-mode to Bluetooth operating in DM5- mode. In this case there are 5 interferer hops per victim hop. This degrades throughput significantly.

The interferer duty cycle has also impact on throughput. Note that packet errors can only occur during the on-time of the interfering transmitter. The total throughput of a data link is therefore given by

$$R = P_{on} \cdot (1 - P_{err})^2$$

where:

P_{err} - the average packet error rate during on-time;
P_{on} - the probability that the interferer is active (duty cycle).

For the analysis two types of interferers need to be distinguished:

a) narrowband, if the interferer bandwidth is not greater than the Bluetooth receive bandwidth such as Bluetooth, RFIDs and RLAN with frequency hopping,
b) wideband, if the interferer bandwidth is much greater than the Bluetooth receive bandwidth such as DSSS RLAN, ENG/OB systems (analogue and digital).

Narrowband interferers

All narrowband interferers in the ISM band are characterised by constant envelope transmit signals. From the interference point of view they have the same effect as a Bluetooth interferer with same power. Therefore, the C/I-limits can be taken from the Bluetooth specification.

The method for determining the throughput degradation versus C/I is explained for a narrowband interferer with 100% duty cycle:

- At high C/I the packet error rate is 0, the throughput is 1;
- If C/I falls below the threshold for co-channel interference (11 dB), one of 79 hopping channels is erroneous, i.e. the packet error rate is 1/79 and the throughput reduces to R = 0.975;
- If C/I falls below the threshold for the 1st adjacent channel interference (0 dB), the co-channel and both adjacent channels are affected. The packet error rate is 3/79 and the throughput reduces to R = 0.926;
- For C/I < -40 dB the blocking level is reached, i.e. all channel are affected and the throughput breaks down.

Figure 5.1.5 shows R versus C/I for various conditions, curve 1A is the one for a narrowband interferer like RFID with 100% duty cycle. Curve 1C is the same for 15% duty cycle. Curve 1B and 1D shows the effect of a fast hopping interferer.

Wideband interferers

In contrast to narrowband interferers, wideband interferers produce into a narrowband receiver a noise-like signal, which has a highly time-varying envelope. For noise-like interference, the co-channel C/I requirement cannot be taken from the specification. Experiments have shown that for Bluetooth a limit of $C/I_N \approx 18$ dB must be used instead, where I_N is the interference power after channel filtering. I_N is related to the total interference power I as follows:

$$I_N = I - 10\log_{10}(B_I/B_{Blue}),$$

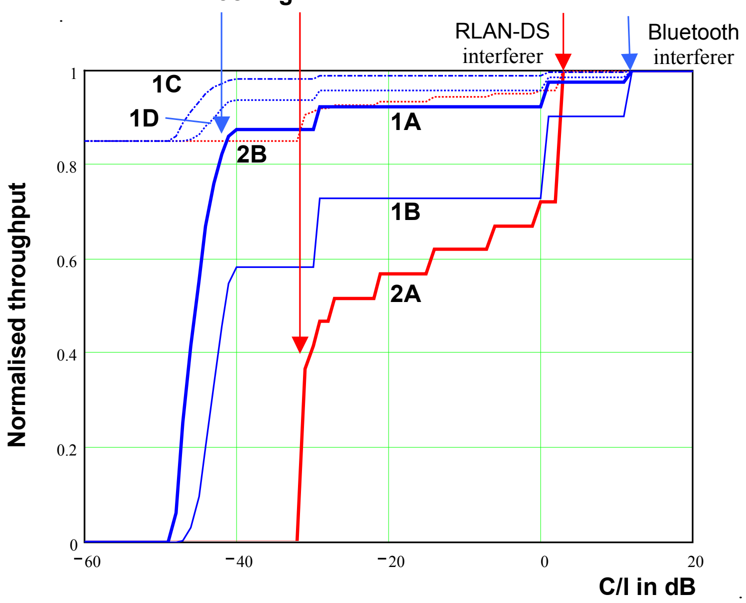
where:

B_{Blue} - the noise equivalent bandwidth of the Bluetooth receiver (≈ 1 MHz);
B_I - the noise equivalent bandwidth of the interfering signal.

Additionally, the adjacent channel C/I requirements cannot be used, because this assumes that only one receive channel is interfered. For wideband interferers, the Bluetooth performance in channels which are adjacent to the interferer core spectrum is normally dominated by spectral components from the interferer which fall into the receive band.

In order to give an impression of the principal characteristic of throughput versus C/I, a DS-RLAN system is taken as an example. Using a realistic spectral shape of the transmit signal the throughput is calculated and shown as curve 2A in figure 5.1.5. The first and largest step in throughput reduction corresponds to P_{err} = 13/79. At 3 dB below two additional channels are interfered, giving P_{err}=15/79. (DSSS RLAN has 3 dB bandwidth of 15 MHz, corresponding to 15 Bluetooth channels). Each further step in throughput reduction corresponds to an increase of 2/79 in the packet error rate. If the diagram would be turned by 90° to the left, the curve has approximately the shape of the right side of the DSSS RLAN transmit spectrum. The throughput breaks nearly down to 0 for C/I < -30 dBm although the blocking level of –27 dBm is not yet reached. This is due to the fact that the spectrum has side shoulders stemming from 3rd order non-linearity. This widening of the spectrum effectively blocks nearly the whole band for C/I < –32 dB.

Fig. 5.1.5: Bluetooth throughput behaviour vs. C/I



Legend:

1A – 1D for constant envelope narrowband interferers;

1A	*interferer: 100% duty cycle;*	*victim:*	*DM1-mode;*
1B	*interferer: Bluetooth DM1, 100% duty cycle;*	*victim:*	*DM5-mode;*
1C	*interferer: 15% duty cycle;*	*victim:*	*DM1-mode;*
1D	*interferer: Bluetooth DM1, 15% duty cycle;*	*victim:*	*DM5-mode;*

2A, 2B for DS-RLAN interferer (valid for both DM1 and DM5 mode of Bluetooth victim):

2A interferer: 100% duty cycle

2B interferer: 15% duty cycle.

The following important conclusion from these considerations can be drawn: tolerable C/I limits heavily depend on the quality criteria (throughput threshold) and on the type of interference. If the tolerable threshold is set to e.g. 90%, the C/I limit for a narrowband interferer would be –30 dB. If the threshold would be set to 95%, the C/I requirement would be 0 dB. For a wideband interferer it would be around 3 dB in both cases. It is therefore important to base a final evaluation of interference effects not only on one quality threshold.

5.1.6 Bluetooth receiver burnout

The possibility for RF burnout of a Bluetooth receiver front-end by the impact from a +36 dBm (e.i.r.p.) RFID transmitter was discussed. The conclusion was that RF burnout is not possible if RFID manufacturers provide a dome over the antenna.

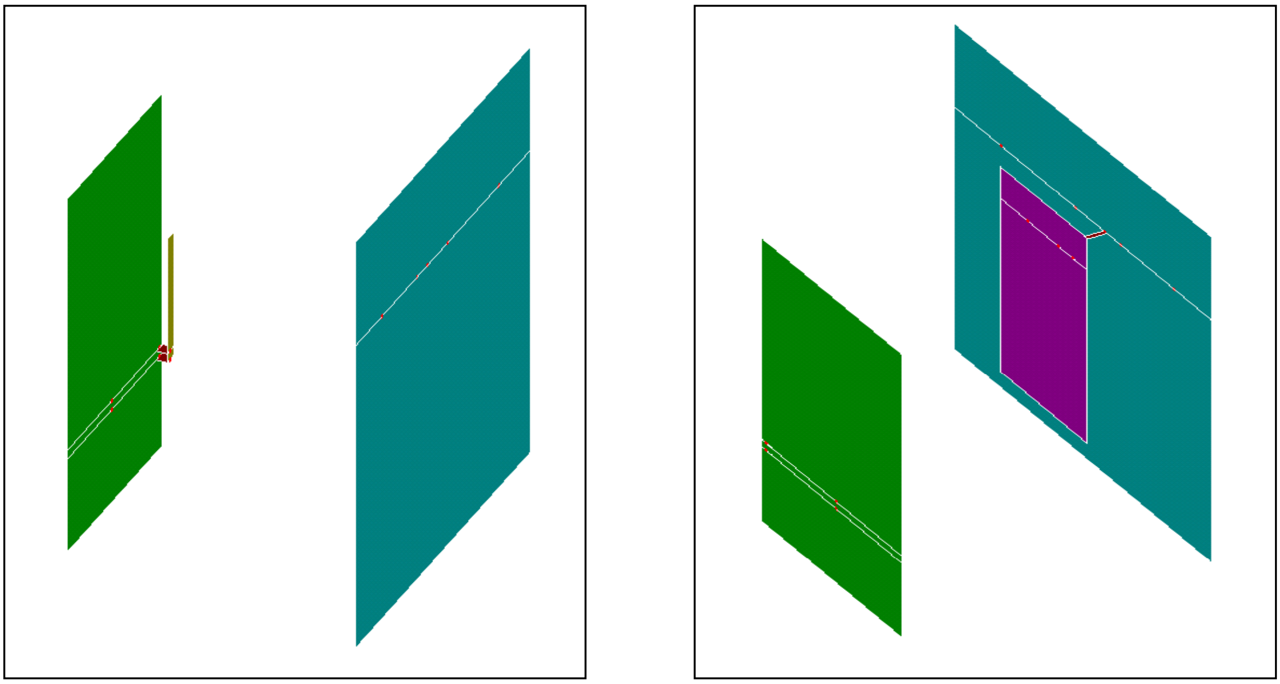
5.1.6.1 Simulations

Simulation Model

At the distances when the burnout problem potentially occurs, the victim device is in the near field of the RF ID antenna. In this situation normal propagation equations are not valid. However, this problem can be overcome by simulation methods for which there are a number of tools available on the market. This study used the IED3 tool, developed in New Zealand. This tool allows to perform 2.5D simulations.

The simulation model consisted of the RFID antenna, modelled as a patch on a small ground plane. The gain of the patch was 8 dBi (no resistive losses were considered), which is 2 dB more than the minimum gain, stated in the draft EN 300 440. For the victim antenna the study used a PIFA (Planar Inverted F Antenna). This antenna is typical for portable devices used in this frequency band and has a maximum gain of +1 dBi in free field. The set-up of simulation model is shown on Fig. 5.1.6.1 below.

Fig. 5.1.6.1: Simulation model (left: PIFA visible, right: patch is visible)



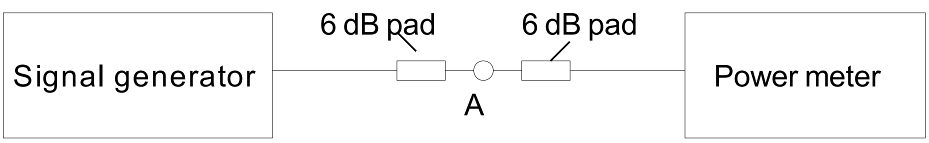
Results
The simulation was performed at 2450 MHz with distance between the antennas ranging from 1 cm to 50 cm. Simulation tool was used to calculate the isolation between the two antennas (S21) for each distance, as shown below:

Distance, cm	S21, dB
11	-3
2	-5
5	-9.5
10	-14
20	-19
30	-22
40	-25
50	-26.5

In the proposed high power RFID system the antenna is fed with 1W (30 dBm), when the antenna gain is 6 dBi. Considering that the gain of the patch was 8 dBi instead of 6 dBi the feeding power should be reduced to 28 dBm. This means that when the distance between the interferer and the victim is 1 cm (3 dB isolation), the victim receiver has to withstand +25 dBm power and so on.

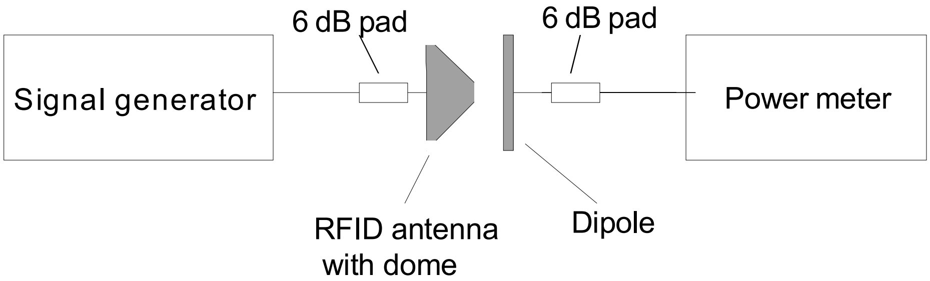
5.1.6.2 Measurements

To determine the possibility for RF burnout the following test set-up was used:



a) The signal generator level was increased to establish a reference level at the power meter. The power meter reading was noted as the reference level, P_{ref}.

b) The cable connection was disconnected in point A. RFID antenna and dipole antenna were connected as shown below:



The two antennas were moved physically to obtain maximum power transfer and the power reading P_n, at the power meter was noted. The power transmission loss through the two antennas was measured as:

$$P_{Loss} = P_{ref} - P_n = 12.8 \text{ dB}.$$

For a 4 W e.i.r.p. RFID system, with 1 W conducted power into a 6 dBi gain antenna, the maximum power at the receiver input is therefore:

$$P = 30 \text{ dBm} - 12.8 \text{ dB} = 17.2 \text{ dBm}.$$

This power level is too low to burnout the receiver.

5.1.6.3 Conclusions

The simulation performed show that a victim at a distance of 10 cm from the high power RFID system would need to withstand +14 dBm and +9 dBm at distance of 20 cm.

Today's state-of-the-art semiconductor processes for portable receiver front-end circuits use thin oxide, 0.18 um transistors for 1.8 V supply. In the near future these sizes will shrink further to allow 1.2 and 0.8 V transistors. The smaller sizes will mean that the ability to cope with high input levels decrease. For designers the maximum input level is an important parameter to consider, when trying to get the best performance out of the receiver. A maximum level of +15 dBm is a realistic goal, which will not degrade other performance parameters significantly. As the simulations described in this report show there is a risk that this level is exceeded. It should be noted that the burnout problem is valid also with 15% duty cycle on the RFID transmitter and that it can cause long-term effects that will degrade the performance of the victim receiver and finally cause permanent damage and failure.

5.2 Probabilistic method

Interference probability analysis is a four-step process, leading to an interference assessment for different scenarios. Those steps are:

Step 1) Determine the Minimum Coupling Loss (MCL) between the interferer and the victim, see section 5.2.1;
Step 2) Translate the MCL into a minimum interference range for a single interferer by means of an appropriate propagation model, see section 5.2.2;
Step 3) Calculate the number of potential interferers inside the interference area, see section 5.2.3;
Step 4) Evaluate the cumulative probability of interference using equation 5.2.5.b, see section 5.2.5.

5.2.1 Minimum Coupling Loss

MCL between the interfering transmitter and victim receiver determines the interference cell size. This cell size (radius) R_{INT} has to be calculated by means of an applicable propagation model (see sub-section 5.2.2) and minimum coupling loss. The MCL is the minimum path loss required for non-detectable interference from interferer to victim, which is given by:

$$MCL = P_{srd} + G_t - L_b - Lf_t + G_r - Lf_r + 10 \log(B_r \cap B_t / B_t) - I \qquad (5.2.1)$$

where:

I	- maximum permissible interference level at victim receiver;
P_{srd}	- interfering transmitter conducted power;
G_t	- interfering transmitter antenna gain;
G_r	- victim receiver antenna gain;
Lf_t	- interfering transmitter feeder loss;
Lf_r	- victim receiver feeder loss;
B_t	- interfering transmitter 3 dB bandwidth;
B_r	- victim receiver 3 dB bandwidth;
L_b	- building loss as appropriate.

Expression $B_r \cap B_t$ in the above formula means overlapping part of the transmitter and receiver frequency band. In this analysis, it is assumed that the device having the smaller bandwidth always is included within the bandwidth of the other system. Thus the overlapping part is equal to the smaller bandwidth $B_r \cap B_t = \min\{B_t, B_r\}$.

5.2.2 Propagation models

A different propagation model is used for each of the following three environments: indoor, urban and rural. Most of the Bluetooth, RFID and RLAN systems are operated indoors, and in this case an additional 15 dB building attenuation is assumed in case of interference to outdoor victims, which is typical of a 22 cm masonry wall. All of the propagation models below predict the median value of path loss.

5.2.2.1 Indoor propagation

The indoor model uses free space propagation for distances less than 10 m (a path loss exponent of 2). Beyond 10 m the exponent is 3.5. The following indoor model is assumed valid for distances from 10 m to 500 m:

$$Pl(r)(dB) = 60.2 + 35\log\left(\frac{r}{10}\right) + M_{WALL} \qquad (5.2.2)$$

Beyond 500 m, this model is not applicable, since most indoor building areas are smaller than 500 m. The indoor propagation model is supported by numerous measurements described in literature, e.g. “Wireless Communications” by T. S. Rappaport, ISBN 0-13-375536-3, Chapter 3.

5.2.2.2 Indoor downwards directed antenna

The propagation of RF energy in the 2.45 GHz band inside a building differs from that in the outdoor environment because propagation within buildings is strongly influenced by many variable factors. These include the layout of the building, the construction materials used, the building type, and the furniture and other fixtures within the building. Because the wavelength in the 2.45 GHz band is approximately 12 cm, there will be a very large number of objects and surfaces within the building having dimensions on the order of one half wavelength (6 cm) or more which are capable of interacting with the radio energy in the 2.45 GHz band. Each one of these objects is potential source of reflection, diffraction, or scattering of the radio frequency energy.

In the case of a downward-looking low-gain antenna, the dominant mechanism for propagation of energy to a potential victim receiver will not be via the line-of-sight. Instead the interfering signal will be reflected from the multiplicity of surfaces in the area illuminated by the antenna. Because of the low gain interferer antenna (typically 0 to +6dBi), its beam width will be large, illuminating many reflecting surfaces. These surfaces will not be uniform, but will in fact be oriented in many directions and will be of a variety of sizes and shapes. The net result of this collection of incidental reflectors is to re-radiate the incident energy in all directions. If we consider the reflecting surfaces to be uniformly distributed in their orientation and perfectly reflecting, the total incident energy will be re-radiated uniformly in all directions. Thus the reflecting surfaces have the effect of totally “defocusing” the pattern of the downward-looking interferer antenna. What we effectively have in this idealised scenario is an isotropic radiator, in so far as the propagation of an interfering signal to a distant receiver is concerned.

But few of the reflecting objects within the main beam of the interferer antenna will be perfect reflectors of energy in the 2.45 GHz band, and furthermore diffraction effects will arise because of obstructions in the various signal paths. Therefore we can expect that the “effective gain” of the downward-looking antenna will be somewhat less than 0 dBi. This has been the experience of vendors of equipment.

5.2.2.3 Urban propagation

The urban model used in this report is the CEPT SE21 urban model. This model is described by ITU-R Report 567-4 and is valid for frequencies between 150 MHz and 1500 MHz. The CEPT/SE21 model further extends the frequency range to 3000 MHz:

$$L(urban, dB) = 45.144 + 33.9 \log 2000 + 10 \log (f/2000) - 13.82 \log h_{tx} - a(h_{rx}) - a(h_{tx}) + (44.9 - 6.55 \log h_{tx}) \log d =$$

$$= 124.04 + 10 \log f - 13.82 \log h_{tx} - a(h_{rx}) - a(h_{tx}) + (44.9 - 6.55 \log h_{tx}) \log d.$$

The CEPT/SE21 model is restricted to the same range of parameters as are the other CEPT models:

f =2000-3000 MHz;
h_{tx} = 30-200 m;
h_{rx} = 1-10 m;
d = 1-20 km.

The CEPT/SE21 urban propagation model makes further modifications to the Hata model, as follows:

$$L_{CEPT}(urban, dB) = 124.04 + 10 \log f - 13.82 \log h_{tx} - a(h_{rx}) - a(h_{tx}) + (44.9 - 6.55 \log h_{tx}) \log d;$$

where: $a(h_{tx})$ $= Min [0, 20 \log (h_{tx}/30)]$;
$a(h_{rx})$ $= (1.1 \log f - 0.7) Min(10, h_{rx}) - (1.56 \log f - 0.8) + Max [0, 20 \log (h_{rx}/10)]$,
are "antenna height gain factors" for the transmitter and receiver antennas, respectively.

The equations given above predict large negative values (*e.g.,* negative18 dB) for the transmitter's antenna height gain for low antennas. This arises because the CEPT/SE21 model assumes that the transmitter antenna is mounted high (above 30 m) and in the clear. But in the situations of interest in this report, typically both transmit and receiver antennas are below 10 m, so those nearby ground clutter and reflections are no longer negligible.

For the purposes of this report, the SE21 propagation model was extended with the "height gain" equation:

$$a(h_{tx}) = (1.1 \log f - 0.7) Min(10, h_{tx}) - (1.56 \log f - 0.8) dB + Max [0, 20 \log (ht_{rx}/10)]$$

when both antenna heights are less than 10m.

5.2.2.4 Rural propagation

5.2.2.4.1 Propagation within radio line-of -sight

The rural propagation model used within the radio line-of-sight in this report is the CEPT SE21 rural model, also referred to as the "modified free space loss" model. The rural model assumes free space propagation until a certain break point distance, r_{BREAK} depending on the antenna heights for the interferer and victim:

$$Pl(r)(dB) = 20 \log(4\pi r/\pi) + M_{WALL}, \qquad \text{for } r < r_{BREAK} = 4\pi * h_t * h_r/\lambda;$$

$$Pl(r)(dB) = 20 \log(r^2/(h_t * h_r)) + M_{WALL}, \qquad \text{for } r > r_{BREAK} = 4\pi * h_t * h_r/\lambda.$$

5.2.2.4.2 Propagation outside radio line-of -sight

In cases where the victim is either a Fixed Station or ENG/OB receiver with high gain elevated antennas, the SE21 rural propagation model described above may predict protection distances exceeding the radio line-of-sight distances. In these cases the rural propagation model is based upon the ITU-R Recommendation P.452-8 (1997) "Prediction Procedure for the Evaluation of Microwave Interference Between Stations on the Surface of the Earth at Frequencies above about 0.7 GHz".

The ITU-R P.452 considers six interference propagation mechanisms:

- Line-of-sight;

- Diffraction;
- Tropospheric scatter;
- Surface ducting;
- Elevated layer reflection and refraction;
- Hydrometer scatter.

The approach described in the procedure of the ITU-R P.452 is to keep separate the prediction of interference signal levels from the different propagation mechanisms up to the point where they are combined into an overall prediction for the path. This approach is well suited to the purposes of this report for it facilitates the elimination of the propagation mechanisms, which are not pertinent to this report.

The basic input parameters required for the procedure of the ITU-R P.452 are:

- Frequency;
- Required time percentage for which the calculated basic transmission loss is not exceeded;
- Longitude of station (for the transmitter and receiver);
- Latitude of station (for the transmitter and receiver);
- Antenna centre height above ground level (for the transmitter and receiver);
- Antenna centre height above mean sea level (for the transmitter and receiver);
- Antenna gain in the direction of the horizon along the great-circle interference path (for the transmitter and receiver).

The ITU-R P.452 procedure assumes that the locations of both stations are precisely known and fixed (recall that it was developed for analysing interference in the Fixed Service), and therefore it is not possible in this report to specify some of the input parameters required to utilise the full procedure. See following sub-section "Path profile analysis" for details.

For the purposes of this report, the propagation model predicts the particular values of basic transmission loss which are not exceeded 50% of the time, *i.e.,* the median path loss. This report also uses median values of the radio meteorological parameters which are representative of temperate climates. Therefore the average value for the ratio of effective Earth's radius to the actual Earth's radius is K=1.33. Assuming an average Earth's radius of 6371 km, an effective Earth's radius was considered equal: $A_e = K \times 6371$ km = 8473 km ≈ 8500 km. This value was used throughout the calculations.

5.2.2.4.3 Interference Path Classifications and Propagation Model Requirements

The following table lists the three classifications of the interference paths and the corresponding propagation models.

Table 5.2.2.4a: Classification for interference path and propagation model

Classification	Propagation Models Required
Line-of-sight with 1st Fresnel zone clearance	Line-of-sight Clutter loss
Line-of-sight with diffraction, i.e., Terrain intrusion into the 1st Fresnel zone	Line-of-sight Diffraction Clutter loss
Trans-horizon	Diffraction Ducting/layer refraction Tropometric scatter Clutter loss

Because of the low radiated power levels and low antenna heights utilised by Bluetooth and similar short-range devices, trans-horizon propagation is not a significant factor for the interference analysis of this report and will not be used.

The following parts of this sub-section discuss each of the pertinent propagation models listed in the right-hand column of the above table.

5.2.2.4.4 Line-of-sight

The basic path loss $L_{b0}(p)$, not exceeded for time percentage p% due to line of sight propagation, is given by:

$$L_{b0}(p) = 92.5 + 20 \log f + 20 \log d + E_s(p) + Ag \quad \text{dB}$$

where:

f - frequency in GHz;
d - path length in km;
$E_s(p)$ - correction for multipath and focusing effects;
$E_s(p) = 2.6\ [1 - exp(-d/10)]\ log\ (p/50)$, $E_s(p) = 0$ for p = 50%;
Ag - the total gaseous absorption, which is negligible at 2.4 GHz.

Therefore the basic free space path loss formula in the 2.45 GHz band simplifies to:

$L_{b0}(p) = 100.3 + 20\ log\ d$, (dB);

where:

d is the path length in km.

5.2.2.4.5 Clutter Loss

Considerable benefit, in terms of protection from interference, can be derived from the additional diffraction losses experienced by antennas that are imbedded in local ground clutter (*i.e.*, buildings, vegetation).

In lieu of parameters specific to a particular antenna location, the ITU-R Recommendation P.526 defines seven nominal values to be used for clutter heights and distances in particular environments:

Table 5.2.2.4b: Nominal clutter heights and distances

Category	Nominal height, m	Nominal distance, km
Open	0	--
Rural	4	0.1
Coniferous trees	20	0.05
Deciduous trees	15	0.05
Suburban	9	0.25
Urban	20	0.02
Dense Urban	25	0.02

The additional path loss due to interference protection arising from local clutter is given by:

$$A_h = 10.25 \times exp(-d_k) \times \{1 - tanh\ [6\ (h/h_a - 0.625)]\} - 0.33 \quad \text{dB}$$

where:

d_k - distance (km) from nominal clutter point to the antenna;
h - antenna height (m) above local ground level;
h_a - nominal clutter height (m) above local ground level.

For the antenna heights assumed in this report, the additional losses arising from clutter in the rural environment are given in the following table:

Table 5.2.2.4c: Additional clutter losses, dB, for rural environment

Antenna height, m	Rural	Coniferous trees	Deciduous trees
1.5	17.3	19.1	19.1
2.5	8.9	19.1	19.1
3.0	3.1	19.1	19.1
10	0	15.6	7.0
50	0	0	0
200	0	0	0

5.2.2.4.6 Diffraction Loss

For the purposes of this report, the excess diffraction loss is computed by the method described in the ITU-R Recommendation P.526, assuming that $p = 50\%$. This method is used for the calculation of the diffraction loss over both line-of-sight paths having sub-path obstruction and trans-horizon paths. Therefore, the inclusion of diffraction loss into the propagation model accounts for the effects of the curvature of the Earth on the path loss at distances both less than and greater than the radio line of sight.

The basic transmission loss $L_{bd}(p)$ not exceeded for p% of the time for a diffraction path is given by:

$$L_{bd}(p) = 92.5 + 20 \log f + 20 \log d + L_d(p) + E_{sd}(p) + Ag + Ah \qquad \text{dB}$$

where:

$L_d(p)$ - additional transmission loss due to diffraction over a spherical Earth calculated by the procedure described in ITU-R P.526-5;
$E_{sd}(p)$ - correction for multipath and focusing effects,
Ag - total gaseous absorption, which is negligible at 2.4 GHz;
Ah - additional clutter loss used in calculations.

At short distances, the diffraction loss will be zero and therefore the transmission loss given above is simplifies to free space path loss, decreasing as 20**log(d)*.

5.2.2.4.7 Diffraction over the Smooth Earth

Diffraction of the radio signal is produced by the surface of the ground and other obstacles in the radio path between the transmitter and receiver. A family of ellipsoids (ellipses of revolution) subdivides the intervening space between the transmitter and receiver; all having their foci located at the transmitter and receiver antenna locations. The ellipses are defined by the location of points having path lengths of $n\lambda/2$ greater than the free-space line of sight path, where n is a positive integer and λ is the wavelength. The n-th ellipse is called the n-th Fresnel ellipsoid. As a practical matter, the propagation is considered to be line-of-sight (*i.e.*, to occur with negligible diffraction, if there is no obstacle within the first Fresnel ellipsoid.)

The radius of the Fresnel ellipsoid is given by the following formula:

$$R_n = \quad [n \lambda d_1 d_2 / (d_1 + d_2)]^{1/2}$$

Where d_1 and d_2 are the distances from the transmitter and receiver to the point where the ellipsoid radius is calculated.

The additional transmission loss due to diffraction over a spherical earth is computed from the formula:

$$L_d(p) = -[F(X) + G(Y_1) + G(Y_2)],$$

where:

$F(X) = 11 + 10 \log(X) - 17.6\,X.$ - *the distance factor;*
$X = 2.2\, \beta f^{1/3} a_e^{-2/3} d;$
d the path length, km;
a_e - equivalent Earth radius, 8500 km;
f - frequency, MHz.

The antenna "height gain" factor is given by:

$G(Y) \approx 17.6\,(Y - 1.1)^{1/2} - 5 \log(Y-1.1) - 8$ for $Y>2$, and
$G(Y) \approx 20 \log(Y + 0.1\,Y^3)$ for $Y < 2$,

where:

$Y = 9.6 \times 10^{-3} \beta f^{2/3} a_e^{-1/3} h,$
h - antenna height, m.

The above equations were used to compute the total path loss for the rural propagation cases analysed in this report.

5.2.2.4.8 Path profile analysis

In order to perform a more precise estimate of the propagation path loss over a particular radio path, a path profile of terrain heights above mean sea level is normally required. Based upon the geographical co-ordinates of the transmitter and receiver stations, the terrain heights above mean sea level along the great-circle path are derived from a topographic database or from appropriate large-scale contour maps. Typically, data are required for every 0.25 km along the great-circle path. This profile should include the ground heights at the transmitter and receiver station locations at the start and end points. The height of the Earth's curvature, based on the effective Earth's radius, is added to the profile heights along the path.

Appendix 2 to Annex 1 of ITU-R P.452-8 specifies a step-by step procedure for performing this analysis. Computer programs are available which facilitate the numerous calculations required in this procedure. However, this more precise approach is not appropriate for this report because of the lack of a well-defined specific path between the transmitters and receivers of interest. Additionally, the large number of potential interfering transmitters would result in a substantial computational burden. Consequently, for the purposes of this report a smooth earth having “average” characteristics in the analysis were assumed.

5.2.2.4.9 Total path loss determination for diffraction and clutter

The ITU procedure was used to determine the total path loss as a function of distance for different antenna heights as required by the interference scenarios in this report. This information was used to determine the protection distance by matching the path loss with the required Minimum Coupling Loss (MCL).

5.2.3 Number of interfering units

The radius of the interference cell, R_{INT}, is the path length, *d*, corresponding to the Minimum Coupling Loss (MCL), as determined in section 5.2.1 above. The total number of interfering transmitters within that cell, N_{INT}, is computed from the radius of the interfering cell and the spatial distribution of the interfering transmitters.

In this report two different distribution models have been used to derive the cumulative probability of interference: a uniform distribution and an exponential distribution. The uniform distribution is used to assess the interference into ENG/OB and Fixed Services, where the victim’s higher antenna and greater sensitivity result in large interference cells.

The exponential distribution of interfering transmitters is used to assess the interference to SRD that have significantly smaller interference cells than ENG/OB and Fixed Services. Consequently, the interference will mostly arise from clusters of interferers located nearby the victim receiver. This clustering is modelled by the exponential distribution given in equation 5.2.3.a below.

For larger interference area, e.g. for interference to ENG/OB or Fixed Services, a uniform distribution is used. For further information of the related unit density numbers used, see Annex A. In the exponential distribution, the density of interferer decays as the distance from the victim increases. This is best described by the following formula:

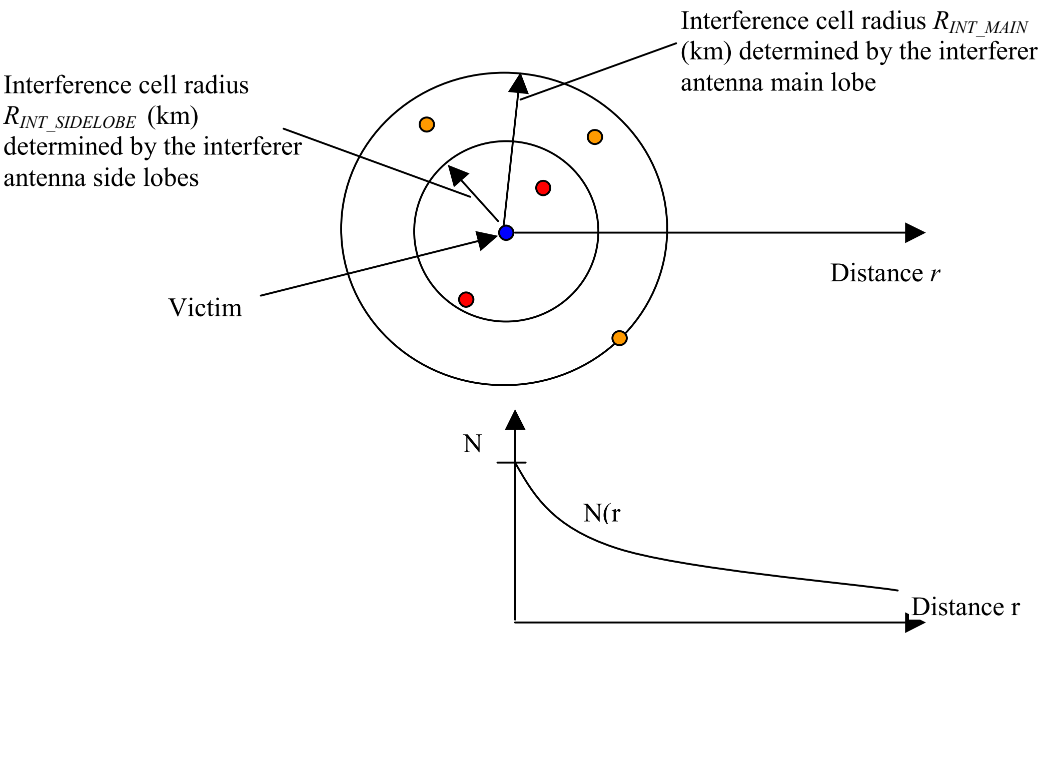
$$N(r) = No \cdot \exp(-k \cdot r) \qquad (5.2.3.a)$$

where:

No - represents the interferer density (units/km square) in the centre of the interference cell;
r - distance toward the periphery of the interference cell;
k - decay constant that is set to *k*= 2 to represent expected distribution of interferers.

The following figure 5.2.3 illustrates exponential density of interferers.

Figure. 5.2.3: Interference cell size(s) and the interferers’ density



In Figure 5.2.3 above, the larger interference cell is determined using the gain of the interferer antenna in the direction of the main beam. The smaller cell is determined using the gain of the antenna in other directions (side lobes).

The total number of interferers in any of the interference cells is calculated:

$$N_{INT}(R_{INT}) = \iint_{r\beta} N(r) \cdot r \cdot dr \cdot d\beta \qquad (5.2.3.b)$$

Integration over $r = (0\ ,\ R_{INT})$ and the angle beta, β over β = (0 , 2 π) yields:

$$N_{INT}(R_{INT}) = \frac{2\pi\ No}{k^2} \cdot [1 - (k\ R_{INT} + 1) \cdot \exp(-k\ R_{INT})] \qquad (5.2.3.c)$$

Equation (5.2.3.c) is used to calculate the number of interferers within interference cell boundaries.

5.2.4 Probability of antenna pattern, time, and frequency collision

5.2.4.1 Probability of alignment of antenna main beams

In the simplest case both interferer and victim have omni-directional antennas resulting in a pattern collision probability of 100%. However, many of the systems of interest in this report use directional antennas to reduce interference potential.

If the victim is in the main beam of the interferer antenna and seeing him through his antenna's main lobe, then the interference probability for antenna beam angle β, for interferer and victim is given by:

$$P_{PAT\_COL} = \frac{\beta_{VIC\_MAINBEAM}}{360} * \frac{\beta_{INT\_MAINBEAM}}{360} \qquad (5.2.4.1)$$

5.2.4.2 Added probability for antenna sidelobes

For interfering devices that use directional antennas, the interference arising from sidelobes may be significant. If the victim is in the side lobes of the Interferer antenna and seeing him through his antenna's main lobe, then the additional interference probability is:

$$P_{PAT\_COL} = \frac{360 - \beta_{INF\_MAINBEAM}}{360} * \frac{\beta_{VIC\_MAINBEAM}}{360} \qquad (5.2.4.2.a)$$

Equation (5.2.4.2.a) must be used with caution if the side lobe radiation pattern is $\leq(360 - \beta_{INT\_MAIN})$.

RFID readers and other SRD frequently use "patch" type antennas, which are mounted on a large ground plane. The presence of the ground plane minimises radiation in the hemisphere to the rear of the antenna. In this case the overall equation is:

$$P_{PAT\_COL} = \frac{180 - \beta_{INF\_MAINBEAM}}{360} * \frac{\beta_{VIC\_MAINBEAM}}{360} \qquad (5.2.4.2.b)$$

Equation (5.2.4.2.b) must be used with caution if the side lobe radiation pattern is $\leq(180 - \beta_{INT\_main})$.

The cumulative probability of interference from both main beam and sidelobes is given in Section 5.2.5. Interference through the sidelobes of the antenna in both ends has not been considered in this report for the sake of simplicity. It should be noted that Bluetooth normally uses omni-directional antennas without sidelobes.

5.2.4.3 Probability for frequency overlap

5.2.4.3.1 Phenomena modeled by a universal P_{FREQ_COL} formula

The phenomena that the universal P_{FREQ_COL} formula models are described below:

- For the case of DSSS and NB (fixed channel) systems it is the randomness of the frequency channel assignment that causes uncertainty of the "frequency collision event". Narrower channel bandwidths (either Tx or Rx) will contribute to a lower P_{FREQ_COL}. This occurs because narrowing either (or both) of these bandwidths results in a larger number of non-overlapping frequency windows available in the 2.45 GHz band and thus a larger number of non-overlapping BW_{TX} -BW_{RX} pairs

- For the case of FHSS systems it is the randomness of the instantaneous frequency hop within the total set of hopping channels used (some of which may cause interference while others may not) that causes uncertainty of the frequency collision event.
- The most complex case is a FHSS system hopping over only a portion of the 2.45 GHz band. Such a system benefits from both the randomness of the "frequency hopping span" position within the 2.45 GHz band as well as from the randomness of instantaneous frequency hop.

5.2.4.3.2 Definition of the frequency collision event

The main reason for the difficulty in the calculation of the P_{FREQ_COL} is the lack of a clear definition of precisely what constitutes the "frequency collision event".

The difficulty of clearly defining the frequency collision event arises because it must properly describe a complex mix of interfering systems, having various signal bandwidths (relatively narrow or wide with respect to each other) and various frequency spectrum shapes. Also the spectrum overlap of the interfering systems (being analogue in nature) can be full or partial, resulting in different effects on the interference.

In the interest of consistency the following basic assumptions and definitions have been adopted in this report:

- The interfering transmitter and victim receiver channel bandwidths used in all P_{FREQ_COL} calculations are 3 dB bandwidths. Thus, in terms of the transmitter, this is the *uniform-power-density-equivalent* of the null-to-null bandwidth originally used in the spreadsheets. In case of the receiver, the uniform power density equivalent is the *system-noise-bandwidth*. Annex A spreadsheets have appropriate input "cells" for these parameters (*Tx 3-dB bandwidth* and *Rx system-noise-bandwidth*).
- For DSSS and NB, "channel bandwidths" is the bandwidth of a single channel. It can be user selectable, but not necessarily so. (This is not relevant to the "probability of interference" calculation since we assume a random choice of the channel in this probabilistic interference model.)
- For FHSS, "channel bandwidths" is the bandwidth of a single hopping channel.

In consideration of the discussion above, the P_{FREQ_COL} is determined only by the "instantaneous bandwidth" occupied by both the interferer and the victim, normalised to the total available bandwidth (for example, the entire 83.5 MHz in the 2.45 GHz band).

The narrower this "instantaneous bandwidth" of either the victim receiver or the interfering transmitter, the likelihood that they will overlap within in the spectrum window of the full ISM band is smaller. If the interferer or the victim is a FHSS system, the relevant "instantaneous BW" is the bandwidth of a single hop, while in case of DSSS or NB then it is the DSSS or NB single channel bandwidth.

The universal formula for P_{FREQ_COL} immediately follows from the following definition of the frequency collision event:

The frequency collision event involving two interfering systems with system noise bandwidths BW_{INT} and BW_{VICT} occurs if at least half of the spectrum of the narrower bandwidth system overlaps with the spectrum of the other (wider bandwidth) system.

Notice that there is really no difference, which of the two systems is the victim or interferer here. It is only their instantaneous bandwidths that determine the probability of overlap.

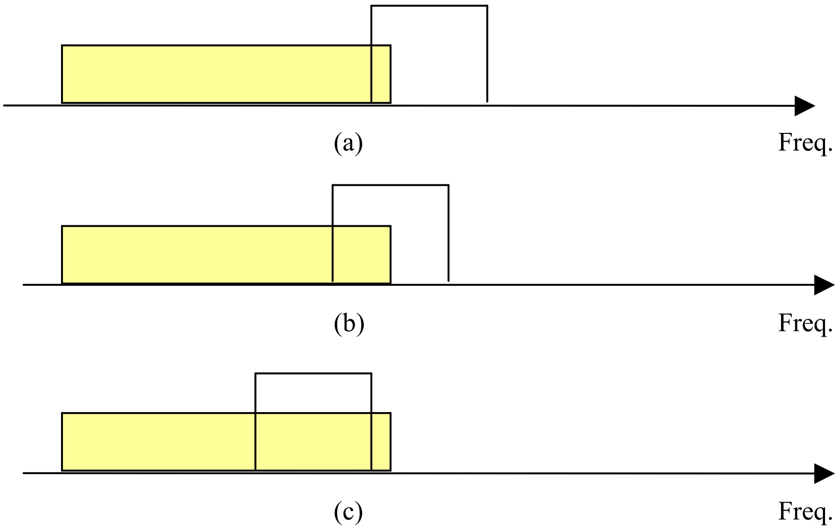
The figure 5.2.4.3 below illustrates the essence of this definition of the "frequency collision event". The shaded area in the drawing represents the wider bandwidth (uniform spectral density equivalent) system spectrum. The shaded spectrum can be either interferer or victim.

Case (a) in Fig. 5.2.4.3 represents the situation with a marginal frequency overlap. In this case only a small fraction (and thus below the interference threshold) of the interferer power falls within the victim receiver. Although the spectra overlap somewhat, this still is not considered to be harmful interference.

Case (c) represents a total frequency overlap that definitely would cause harmful interference, if the interfering signal were sufficiently strong.

Somewhere in between Cases (a) and Case (c) is the case when the frequency overlap is such that any further increase would lead to a harmful level of interference. Case (b) represents the case when half of the spectrum of the narrower BW system overlaps with the wider bandwidth one. In this case, approximately half of the narrower system bandwidth is corrupted by interference (in case the narrower bandwidth system is victim) or penetrate the wider bandwidth victim (in case the narrower bandwidth system is interferer). This would constitute a –3 dB overlap. This "half-power" (-3dB) case was used as the criteria for defining the "frequency collision event", as discussed above.

Figure 5.2.4.3: Definition of frequency collision event



The benefits of frequency hopping in terms of reduction of the probability of frequency collision are realised if just one of the interference elements (the victim or interferer) is of FHSS type. The interference situation generally does not improve by having both the transmitter and receiver frequency hopping.

Additional interference mitigation measures such as optimised channel selection (frequency use planning) are not taken into account in analysis, although they can be used to reduce or sometimes even completely eliminate the interference. These techniques are applicable to all systems that feature a channel selection utility *e.g.* DSSS R-LANs conformant to the IEEE 802.11 R-LAN standard or frequency hopped systems, which adaptively select their hopping channels.

5.2.4.3.3 Universal formula for frequency collision, P_{FREQ_COL}

Following the definition of the P_{FREQ_COL} given in the preceding sub-sections, a universal formula is given by:

$$P_{FREQ\_COL} = P_{FREQ\_COL\_1} \cdot P_{FREQ\_COL\_2}, \qquad (5.2.4.3a)$$

$$P_{FREQ\_COL\_1} = \min\left(1, \frac{\max(BW_{VICT}, SPAN_{INT}) + \frac{1}{2} \cdot \min(BW_{VICT}, SPAN_{INT})}{BW_{AVAIL}}\right), \qquad (5.2.4.3b)$$

$$P_{FREQ\_COL\_2} = \min\left(1, \frac{\max(BW_{VICT}, BW_{INT}) + \frac{1}{2} \cdot \min(BW_{VICT}, BW_{INT})}{BW_{AVAIL}}\right), \qquad (5.2.4.3c)$$

where:

BW_{VICT} , MHz - channel bandwidth of victim receiver (for FHSS - a single hop BW);

$SPAN_{INT}$, MHz - for FHSS it is the frequency span in which the FHSS hops, for DSSS and Narrow Band systems - it is just the ISM bandwidth of 80 MHz;

BW_{INT} , MHz – channel bandwidth of interfering transmitter (for FHSS - a single hop BW);

BW_{AVAIL} , MHz - the available bandwidth.

For all systems except FHSS, which uses a portion of the 2.45 GHz band, equation (5.2.4.3b) produces 1 and thus:

$$P_{FREQ\_COL} = P_{FREQ\_COL\_2}\ .$$

It should be noted that analysis by the universal formula above assumes random frequency overlap. However, RFID systems can be programmed to avoid frequency overlap, which would further reduce the probability of frequency collision for example for interference to Fixed Services or ENG/OB.

5.2.4.4 Probability for time collision

The probability for time collision, P_{time_col}, is given by:

$$P_{time\_col} = \frac{\min[T_{AVG};(T_{INT\_ON} + T_{VICTIM\_ON})]}{T_{AVG}} \qquad (5.2.4.4a)$$

where: T_{AVG} - repetition period of the interferer;
T_{INT_ON} - time during T_{AVG} that the transmitter is on;
T_{VICTIM_ON} - time during T_{AVG} that the receiver is on;
provided: that both T_{INT_ON} and T_{VICTIM_ON} are non-zero.

In the case where either T_{INT_ON} *or* T_{VICTIM_ON} is zero, there will be no interference, *i.e.*, $P_{time\_col} = 0$.

In the case of connection-oriented services, specifically ENG/OB and Fixed Services, Equation (5.2.4.4.a) becomes $P_{time\_col} = 1.0$, because the victim-on time can be arbitrarily long.

On the other hand, for packet-oriented services, where the packet length is much shorter than T_{ON} this equation reduces to the duty cycle of the transmitter:

$$P_{time\_col} = \text{transmitter duty cycle.} \qquad (5.2.4.4b)$$

Formula (5.2.4.4b) is used in the calculations for packet-oriented services to take account of the wide variation of transmitted data. Some systems operate at 100% duty cycle and others operate with less.

5.2.5 Cumulative probability of interference

Once the interference cell size is determined (minimum coupling loss translated into distance), a cumulative probability of interference by a single unit, P_{UNIT}, can be calculated as combined probability of the following non-correlated events:

- probability of antenna beams (interferer and victim) crossing each other, $P_{PAT\_COL,}$ pattern collision probability;
- probability of frequency collision, P_{FREQ_COL};
- probability of interferer and victim colliding with each other in time domain, $P_{TIME\_COL.}$

Also, one must assume a practical spatial density and calculate the corresponding total number of interferers in the area N_{INT_TOT}, as was described in Section 5.2.3 above.

The probability of becoming a victim of any one of the potential interferers in the area can be calculated as:

$$P_{INTF\_TOT} = 1 - \prod_{N_{INTF\_TOT\,(PAT\_COL)}} (1 - P_{TIME\_COL} \cdot P_{FREQ\_COL} \cdot P_{PAT\_COL}) \quad (5.2.5a)$$

The multiplication operator in the equation (5.2.5a) will have two parts when the interferers antenna is directional, which results in two interfering distances caused by the main beam and sidelobes respectively. Hence, the resulting formula for the total interference probability is:

$$P_{INTF\_TOT} = 1 - \Big[\ ((1 - P_{TIME\_COL} \cdot P_{FREQ\_COL} \cdot P_{PAT\_COL\_MAIN})^{N_{INT\_MAIN}})\ * \\ * ((1 - P_{TIME\_COL} \cdot P_{FREQ\_COL} \cdot P_{PAT\_COL\_SIDELOBE})^{N_{INT\_SIDELOBE}})\ \Big] \qquad (5.2.5b)$$

5.2.6 Calculations of interference probability

The probabilities of interference to and from Bluetooth are calculated in the Excel worksheets given in Annex A and presented in Section 6.

Multiple columns in worksheets are related to various existing and proposed systems individually either as a victim or an interferer. The combined interference effect of co-located systems of different categories is not analysed. Most of formulas used in each worksheet are presented in the chapter 6 and are consistent across the worksheets. Input data for each sheet is organised in the similar manner, resulting in the set of sheets that are easy to compare, modify or expand by adding new sheets for other systems operating in the 2.45 GHz band.

Section 6.2 presents the most relevant subset of Interference Probability calculations from the Annex A. But before looking into the numerical results, it is important to note that the calculations in Annex A deliver absolute values of “instantaneous interference probability”. Therefore calculation and subsequent interpretation of the results must be preceded by the precise definition of the interference criteria. This is done in Section 6.1.

It is obvious that an increase of e.i.r.p. of any radio communication system increases its interference potential. However, the application of appropriate interference mitigation techniques compensates for negative effects of increased e.i.r.p. and by this the compatibility between various systems in the 2.45 GHz band may be maintained.

Calculations in Annex A quantify the trade-off between negative impact of increase of interferer e.i.r.p. and positive impact of implementation of multiple interference mitigation techniques. Interference mitigation techniques to be implemented on the proposed systems are summarised in Section 6.2.

Finally, protocol aspects of the proposed services, such as maximum transmit-on time and transmit-repetition rate were not considered in the calculations given in Annex A. Protocol aspects of proposed systems are particularly relevant when analysing compatibility with the existing packet-oriented systems such as IEEE 802.11 R-LANs or Bluetooth. However, as the more susceptible users in the 2.45 GHz band are connection-oriented services (ENG/OB and possible Fixed Services) that do not benefit from reduced interference duty cycle or spread spectrum, the detailed analyses of interfering protocols are omitted.

5.2.6.1 Interference criteria as applied in the calculations in Annex A

Whenever the actual interference level in the victim receiver rises above the interference threshold, the model used in this report recognizes that an event called “unacceptably high interference” has occurred. For the purpose of this study, it is considered for nearly all victims that the interference threshold (threshold between acceptable and unacceptable interference level) is the same as the victim’s own receiver noise:

$$I = N \quad \Rightarrow \quad I/N = 0 \text{ dB},$$

resulting in the interference criteria being:

$$I/N \geq 0 \text{ dB}.$$

Fixed services are an exception as the ITU-R Recommendation F.758-1 specifies the interference threshold I/N= -10 dB. Therefore, the interference model delivers the Instantaneous Interference Probabilities of I/N exceeding 0 dB for all but Fixed Services where –10 dB is used.

The worksheets in Annex A are dedicated to Bluetooth as either victim or interferer. Based on the victim receiver characteristics (noise bandwidth and noise figure) and typical environmental noise level, each worksheet calculates the victim receiver’s own noise as the interference threshold except for Fixed Services, see below.

For some victim systems (e.g. Fixed Services), the interference criterion is defined as a tolerable I/N that may be exceeded, but only over the limited portion of time. How this “time” component is linked to the Instantaneous Interference Probability is explained below.

Strictly speaking, one should know the statistical information about the interferer activity over time in order to calculate the time behaviour of the cumulative interference of the whole interfering population. However, the situation simplifies in case of a large number of non-correlated interferers (in terms of timing, frequency, etc.) producing short bursts of interference. In such a case, that is largely applicable to this study, each Instantaneous Interference Probability calculated in Annex A may be also interpreted as the “percentage of time during which the specified I/N ≥ 0 dB (or I/N ≥ -10 dB for Fixed Services) criteria is met”.

For example, this means that a calculation result such as:

"Instantaneous Interference Probability = 20%",

can also be interpreted as:

"I/N ≥ 0 dB during 20% of time"

Similarly, one could define any other I/N (dB) interference criteria, calculate the associated Instantaneous Interference Probability and interpret it as a percentage of time over which the defined interference threshold may be exceeded.

6 PRESENTATION OF CALCULATION RESULTS

6.1 Deterministic Method

Overall results of applying deterministic method are given in Table 5.1.5 for different interference mechanisms.

6.1.1 Simulation results

The results for three duty cycles 0.25, 0.5 and 1.0 and using omni-directional antennas are shown in the following figures where *d* is the distance from the RFID to the victim.

Fig. 6.1.1.1 : Duty cycle=1

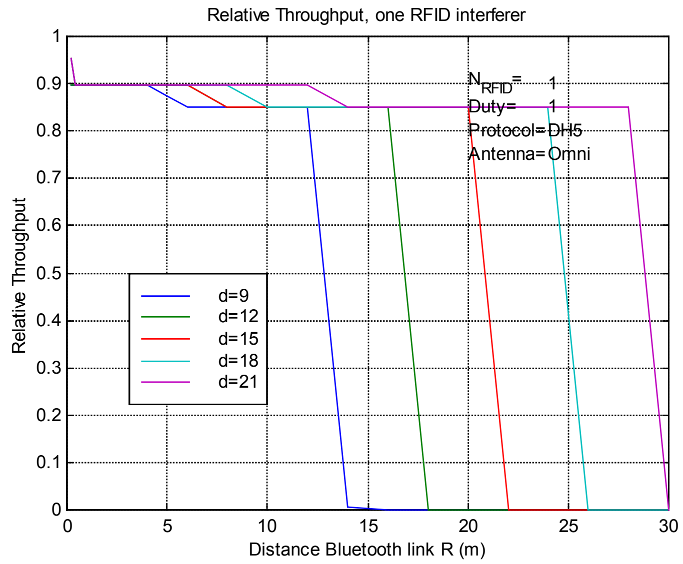


Fig. 6.1.1.2 : Duty cycle =0.5

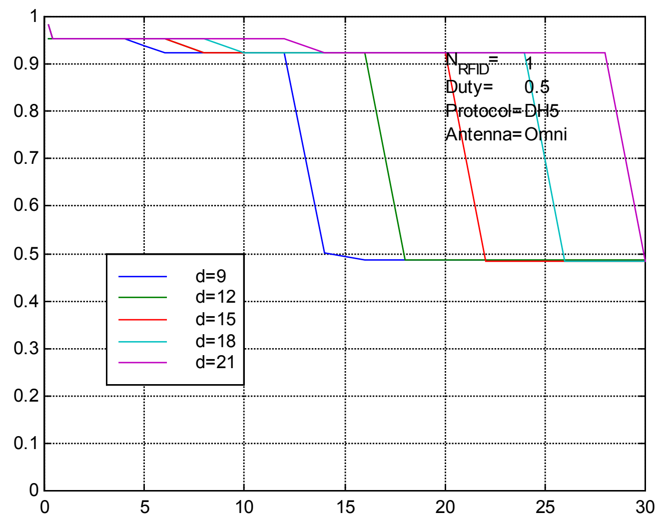
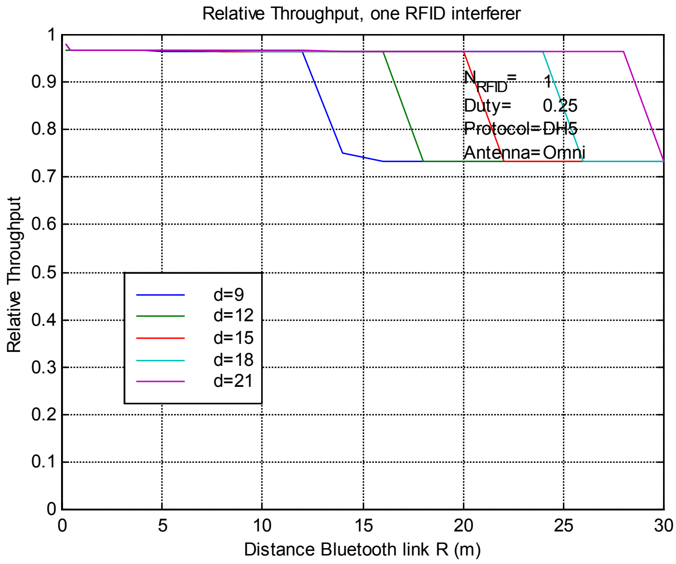


Fig. 6.1.1.3 : Duty cycle=0.25



6.1.2 Discussion

The results in the figures in the previous sub-section 6.1.1 can easily be interpreted in terms of a number of thresholds when certain interference mechanisms become active.

- 1st threshold: co-channels interference with probability $\frac{1}{79}$ and relative throughput:

$$\eta_1 = (1 - \frac{1}{79})^2 ;$$

- 2nd threshold: 1st adjacent channel interference with probability $\frac{3}{79}$ and relative throughput:

$$\eta_2 = (1 - \frac{3}{79})^2 = 0.922;$$

- 3rd threshold: 2nd adjacent channel interference with probability $\frac{5}{79}$ and relative throughput

$$\eta_3 = (1 - \frac{5}{79})^2 = 0.877.$$

These results are in reasonable accordance with simulation results when compared with figures in section 6.1.1. The simulation results however predict somewhat lower throughput than the theory predicts. This however is within the accuracy of the simulator due to limited number of generated Bluetooth packets. When duty v is lower than 1, there is the timing factor and the throughput will asymptotically approach close to (1- v) for large R.

Theory predicts (1- v_{eff}) where v_{eff} is the effective duty cycle, which is somewhat larger than the nominal duty cycle v due to the fact that a Bluetooth packet is already lost, if only a fraction overlaps with the on-time of the interferer.
The effective duty-cycle is given approximately by

$$v_{eff} = \frac{2Length\_of\_DH5\_protocol + on\_time}{RFID\_\text{interval}} =$$

$$= \frac{10T_{BT\_frame} + vT_{RFID}}{T_{RFID}} = \frac{6.25 + v \cdot 200}{200} = v + 0.031$$

6.2 Probabilistic Method

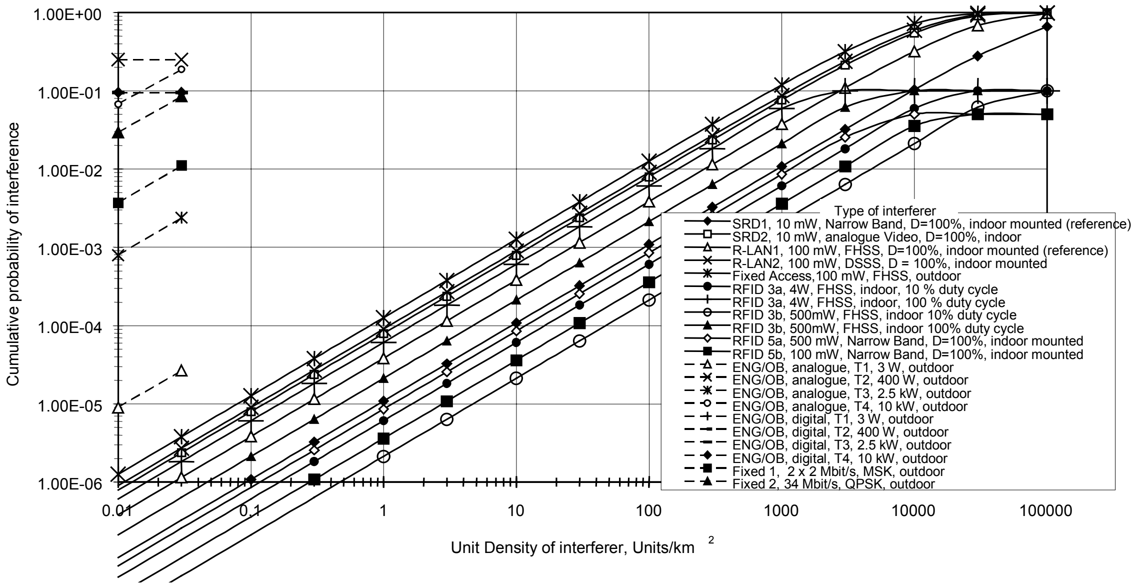
Interference calculations were performed for the relevant operating environments. Resulting interference probabilities were calculated for each victim. In order to display the results of the study in a more informative manner, all results are presented in separate graphs:

- Interference probabilities from the existing services into Bluetooth as a victim;
- Interference probabilities into the existing services from Bluetooth 1as an interferer;
- Interference probabilities into the existing services from Bluetooth 2 as an interferer.

The appropriate way of assessing the interference in the 2.45 GHz band is to calculate the absolute interference probabilities for realistically deployed existing and proposed systems. Besides showing absolute values, this graphical presentation also allows easy comparison of the interference probabilities of proposed systems to existing SRD systems, as recommended by the WGFM SRD Maintenance Group.

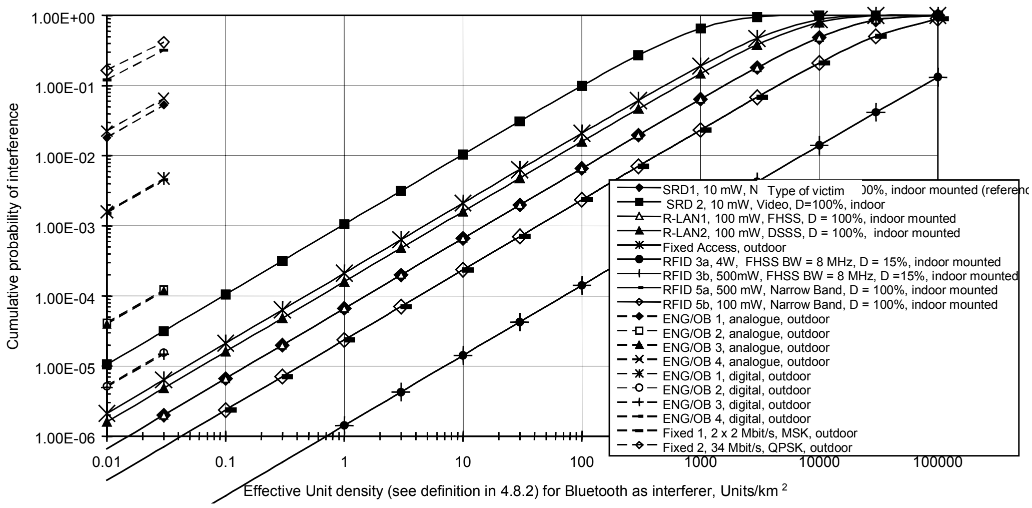
The cumulative probabilities of interference to Bluetooth from existing and planned services are shown in Figure 6.2a.

Figure 6.2.a. Cumulative probability of interference to Bluetooth from existing and planned 2.45 GHz services.



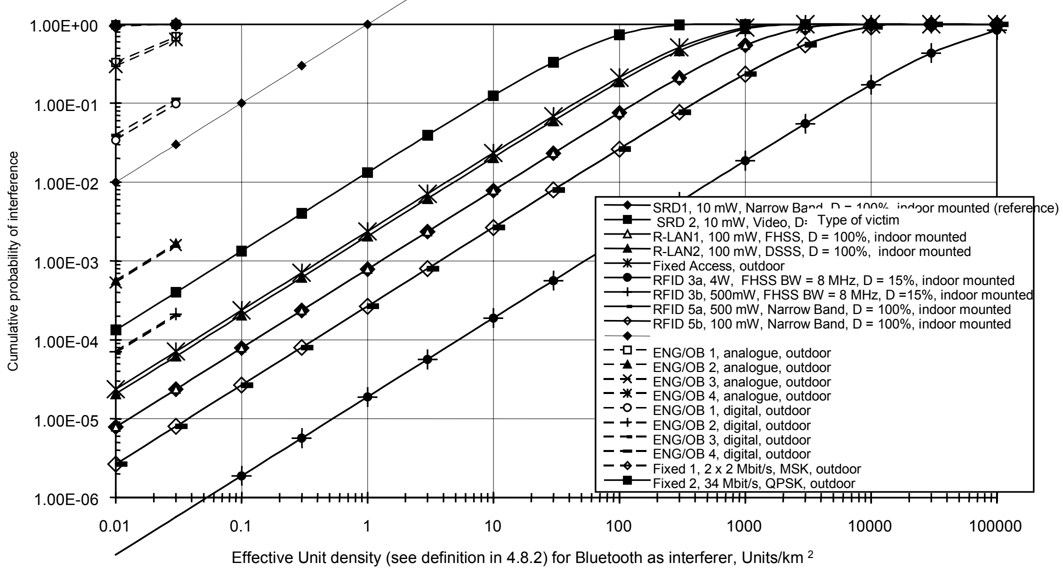
Cumulative probabilities of interference from 1 mW Bluetooth into existing and planned services are shown in Fig.6.2b.

Figure 6.2.b Cumulative probability of interference by Bluetooth to existing & planned services in the 2.45 GHz Band (Bluetooth power = 1 mW eirp)



Cumulative probabilities of interference from Bluetooth 2 (100 mW) into existing/planned services are shown in Fig. 6.2.c.

Figure 6.2.c Cumulative probability of interference by Bluetooth to existing & planned services in the 2.45 GHz Band (Bluetooth power = 100 mW eirp)



6.3 Simulation results

6.3.1 General

This chapter reports the results from applying the Monte-Carlo model to analyse Bluetooth victim receiver performance in hot-spot scenarios in which there are a large number of RFID transmitters present in a given area.

Throughput performance of three non-coded data protocol DH1, DH3 and DH5 have been simulated. Voice links on the other hand have not been considered due to difficulties in mapping simulation results into voice quality.

6.3.2 Simulation

6.3.2.1 Model

For a detailed description see Annex D of this report.

6.3.2.2 RFID parameters

6.3.2.2.1 General

The EIRP of each RFID reader is 4W with duty cycles ranging between 3.5% and 100%. The average RFID duty cycle is 15%. RFID units are not time-synchronised and they are assumed to be independent of each other. Frequency hopping is used for both RFID systems and Bluetooth. The hopping sequence for RFID is assumed to be approximately 320 times slower than in Bluetooth. The channel bandwidth for RFID is assumed to be 0.35 MHz and this system defines 20 different hops for the carrier frequency in a 7 MHz sub band positioned in the middle of the ISM band. The channel bandwidth for Bluetooth is assumed to be 1.00 MHz and this system uses 79 non-overlapping hopping frequencies.

RFID parameters are summarised in Table 6.3.2.2.1 below.

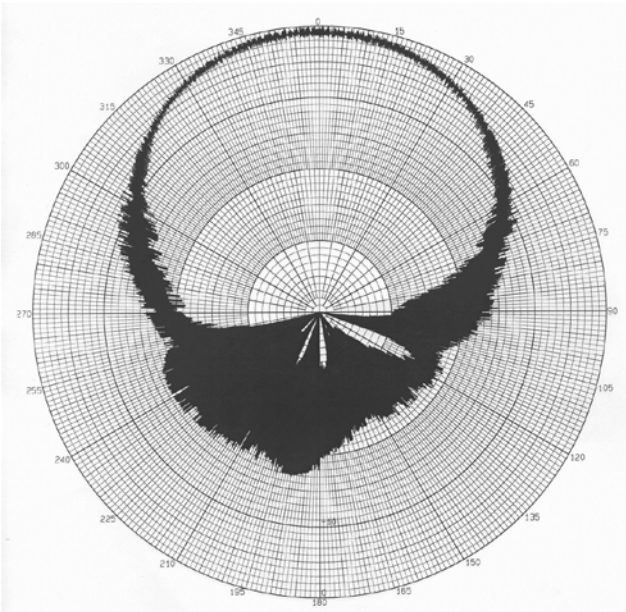
Table 6.3.2.2.1. RFID parameters

EIRP	4W
Duty Cycle	3.5-100%
Channel Bandwidth	0.35 MHz
Number of hop frequencies	20
Frequency Band	2.446-2.454 GHz

6.3.2.2.2 Antenna model

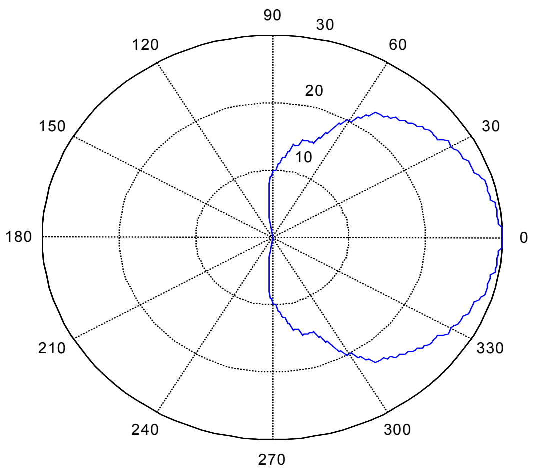
From measured antenna pattern of a typical RFID reader a simplified mathematical model has been extracted. The radiation pattern of a typical 2.45 GHz RFID antenna is shown in figure 6.3.2.2.2.a below.

Fig 6.3.2.2.a: Measured antenna radiation pattern (H-plane)



From measurement the following simplified symmetric model has been extracted, as shown on Fig. 6.3.2.2b.

Figure 6.3.2.2.b: Extracted and simplified model of antenna radiation pattern (H-plane)



6.3.2.3 Bluetooth parameters

The used packet type was DH5 (data high-rate five slots) and its maximal bit rate is assumed to be 432.6 kbit/s (symmetrical traffic). Comparison with DH1 and DH3 packets, with lower throughput, are given but the focus is on DH5 protocol since it is the most vulnerable data protocol. Maximum data loading was assumed.

The C/I interference performance from Bluetooth specification is given by:

- *C/I=11* dB, co-channel;
- *C/I=0* dB, at $\Delta f=1$MHz, 1st adjacent channel;
- *C/I=-30* dB, at $\Delta f=2$MHz, 2nd adjacent channel;

C/I=-40 dB, at $\Delta f \geq 3$MHz, 3rd adjacent channel;
where Δf is the frequency offset between RFID and Bluetooth.

The lower C/I values than those specified in the list above, would result in lost packets for receivers meeting the specification with no margin. The conditions are related to the receiver sensitivity at bit error rate of 0.1%. The DH5-packet has a size of approximately 3000 bits.

Some important Bluetooth parameters used in the simulations are defined in table 6.3.2.3 below.

Table 6.3.2.3: Main Bluetooth parameters

EIRP	1mW
Packet type	DH1, DH3 and DH5
Channel Bandwidth	1 MHz
Number of hops	79

Two other Bluetooth protocols, DH1 and DH3 have been studied in one case. Higher power classes in Bluetooth (+6 and +20 dBm) have not been studied since 0 dBm is expected be the predominant case.

6.3.2.4 Propagation model

The assumed propagation model is given by:

$$L = \begin{cases} 40.2 + 20\log_{10} R \;, & \text{for} \quad R < 15\,m; \\ 63.7 + 30\log_{10}\left(\dfrac{R}{15}\right), & \text{for} \quad R > 15\,m. \end{cases}$$

It gives the path loss of 40.2 dB for distance of 1 m and 63.7 dB for 15 m.

6.3.2.5 Hot spot scenario

6.3.2.5.1 Scenario 1

In this scenario, which may be called "Statistical Hot-Spot Scenario", all RFID units are placed randomly within a circle of 35 m radius. The cases with 8, 16 and 32 RFID units have been studied.

The hot-spot densities are described in table 6.3.2.5.1 below:

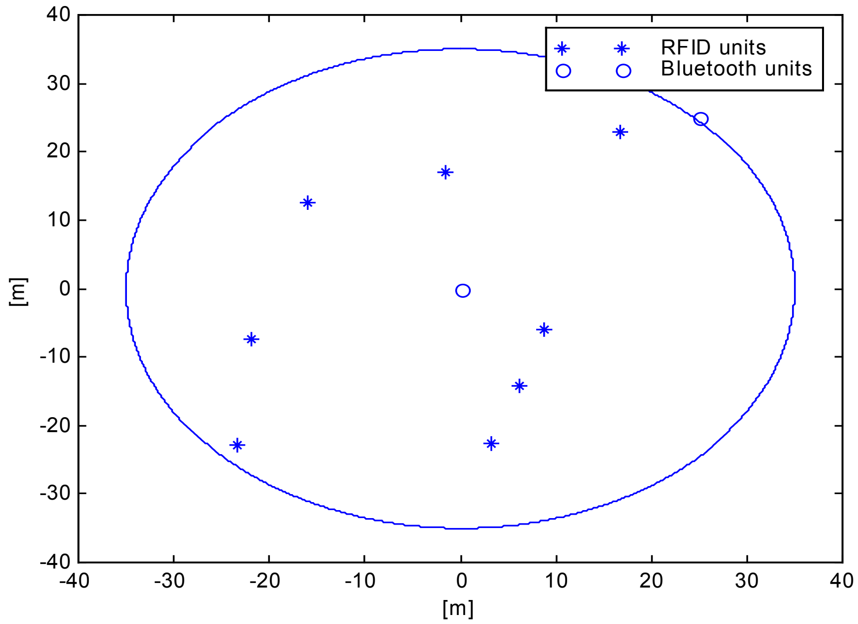
Table 6.3.2.5.1: RFID "hot-spot" unit density categorisation

Hot-spot density	Public areas	Non-public areas
≤ 2	Small size shops Private parking access	
2 – 4	Medium size shops Public parking access	Small stockrooms
4 – 8	Large size shops Local small super markets	Small size factories Small ware houses
8 – 16	Large super markets Department stores	Medium size factories Warehouses
16 – 32	Hyper Markets Building material markets Airport check-in area	Large factories Large warehouses Airport baggage handling Central container handling

The randomness, or statistical distribution, can be defined in many different ways. In this study an equal distribution in the XY-plane was assumed. A large number of scenarios have been simulated in order to approximate an ensemble average with high confidence. Other much more severe distributions, which would be more concentrated around the Bluetooth victim, could be applied. The assumptions in this report can therefore be considered to be conservative.

The Bluetooth receiver is placed in the centre, while the transmitter is placed at the varying distance from the receiver as shown in figure 6.3.2.5.1.

Figure 6.3.2.5.1: Positions of RFID and Bluetooth units in 1st scenario realisation

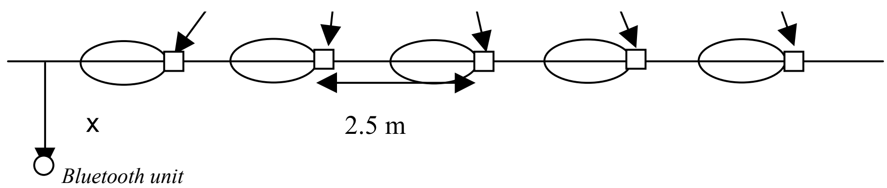


6.3.2.5.2 Scenario 2

This scenario may be called "Cashier counter scenario" and is illustrated in the Fig. 6.3.2.5.2 below. RFID power in this case is 27 dBm e.i.r.p.

Figure 6.3.2.5.2: Positions of RFID and Bluetooth units in 2nd scenario realisation

A number of RFID interrogator units placed in an array with 6 dBi directional antennas pointing in the same direction



6.3.2.5.3 Scenario 3

Scenario 3 uses a realistic hot-spot implementation where the duty cycle varies depending of the actual number of transponders to be interrogated. The scenario is selected to more closely represent the operation of RFID readers in an operational environment:

- 8 units with standby duty cycle of 3.5 %;
- 7 units for interrogation of single tags with a duty cycle of 10%;
- 1 unit with high duty cycle for continuous interrogation of multiple tags with a duty cycle of 95% with an on-time of 5 sec and off-time of 200 ms.

The average duty cycle for this system of 16 readers is 12%.

6.3.3 Simulation Results

6.3.3.1 Scenario 1

Fig. 6.3.3.1: Throughput performance comparing non-coded data protocols DH1, DH3 and DH5

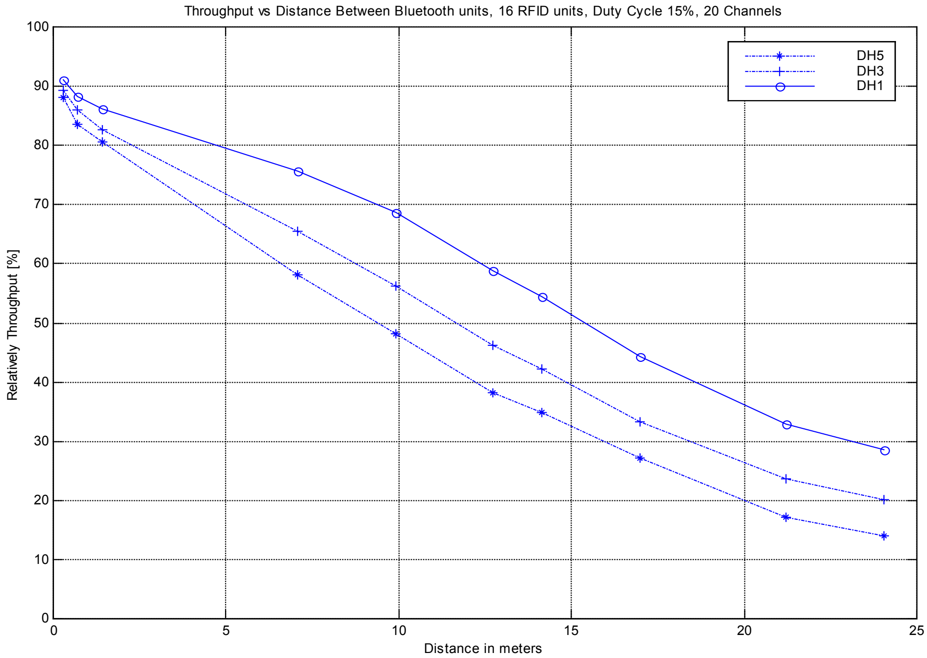


Fig 6.3.3.2: Throughput performance comparing directional and omni-directional antennas

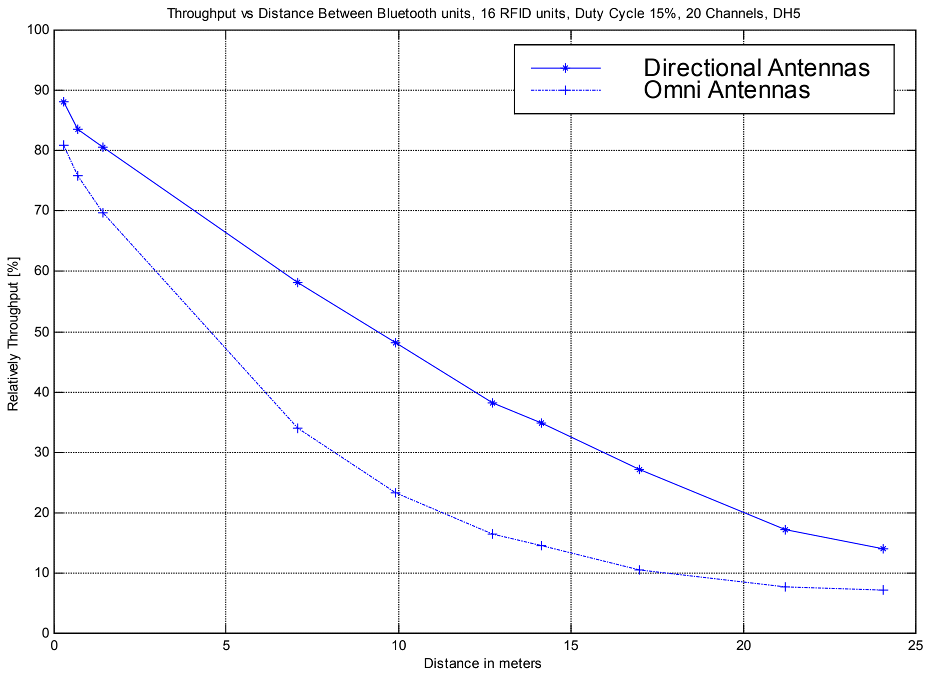


Fig. 6.3.3.3: Throughput performance comparing duty cycles

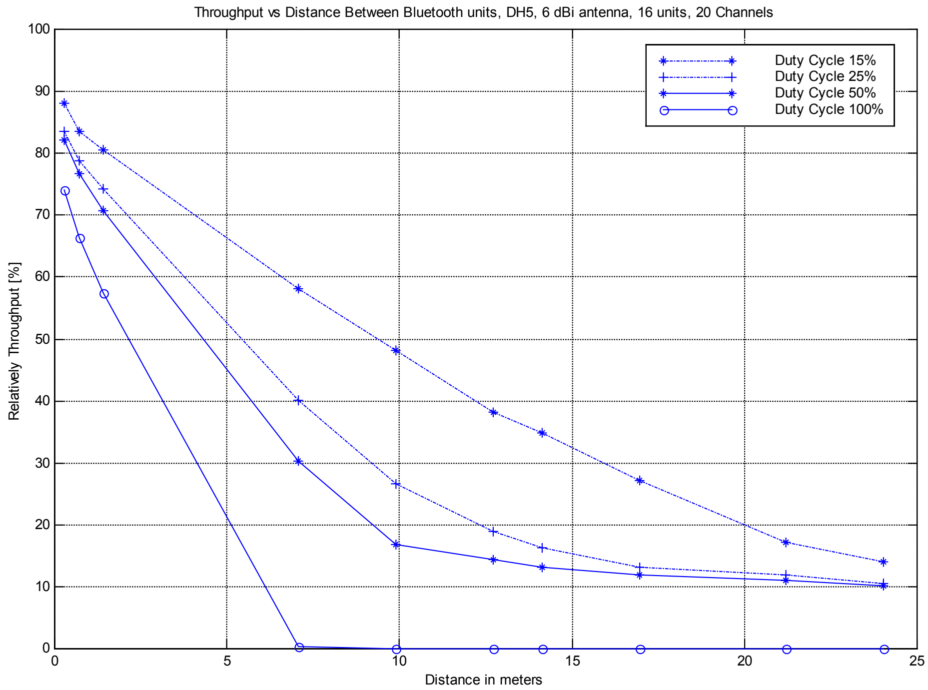


Fig. 6.3.3.4: Throughput performance comparing different "hot-spot" densities of RFID

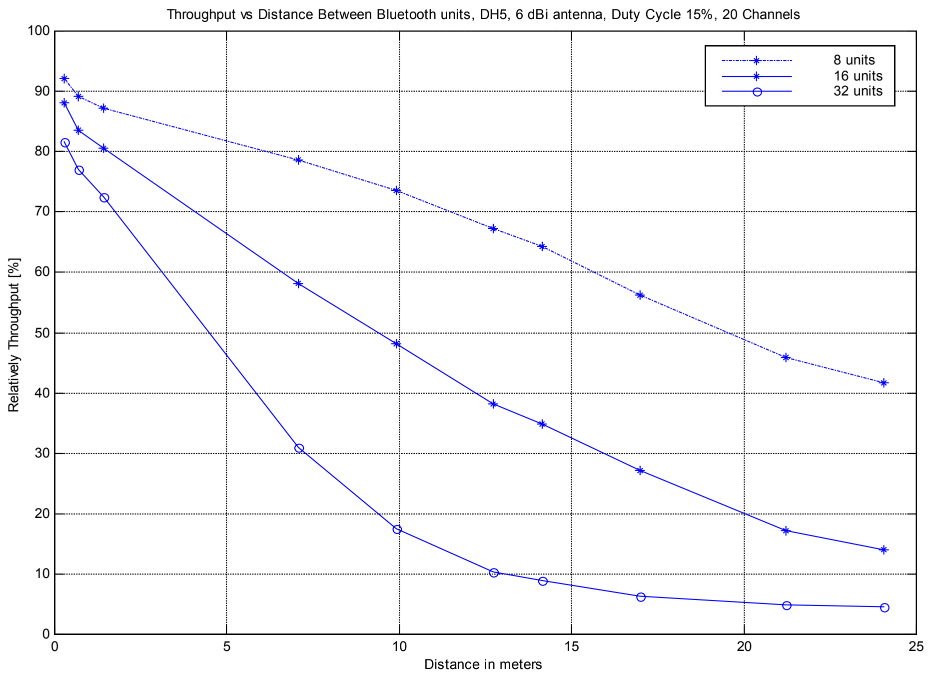
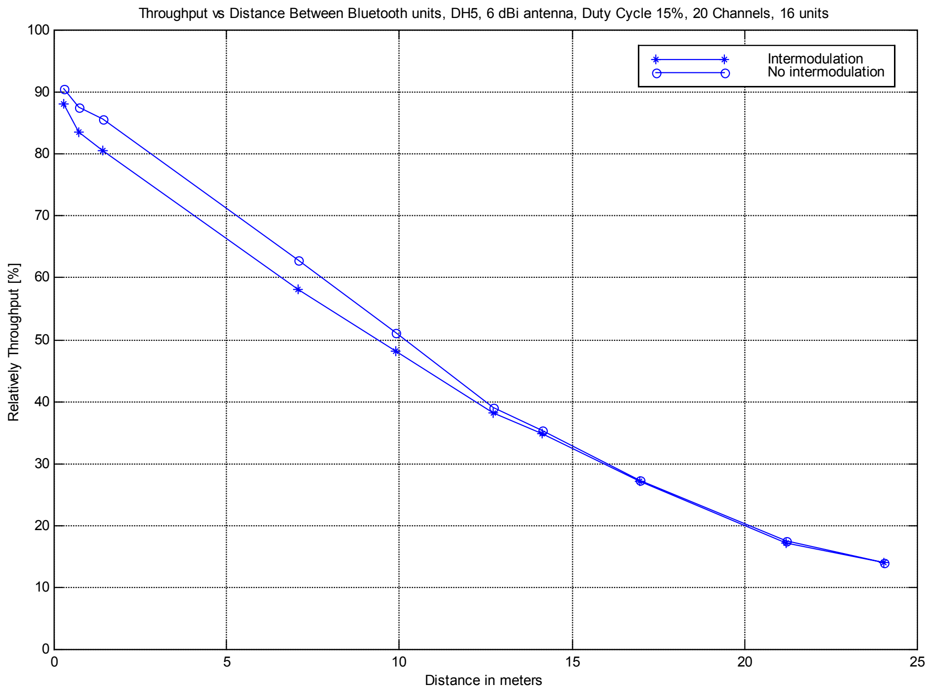
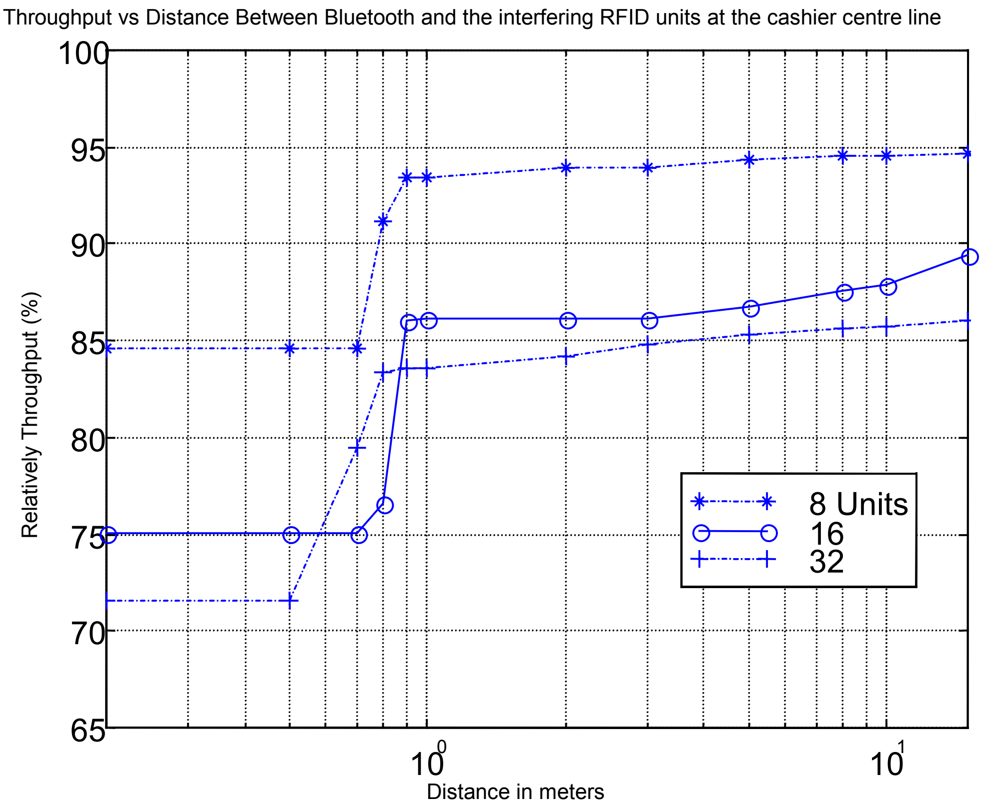


Figure 6.3.3.5: Throughput performance evaluating influence from 3rd order intermodulation



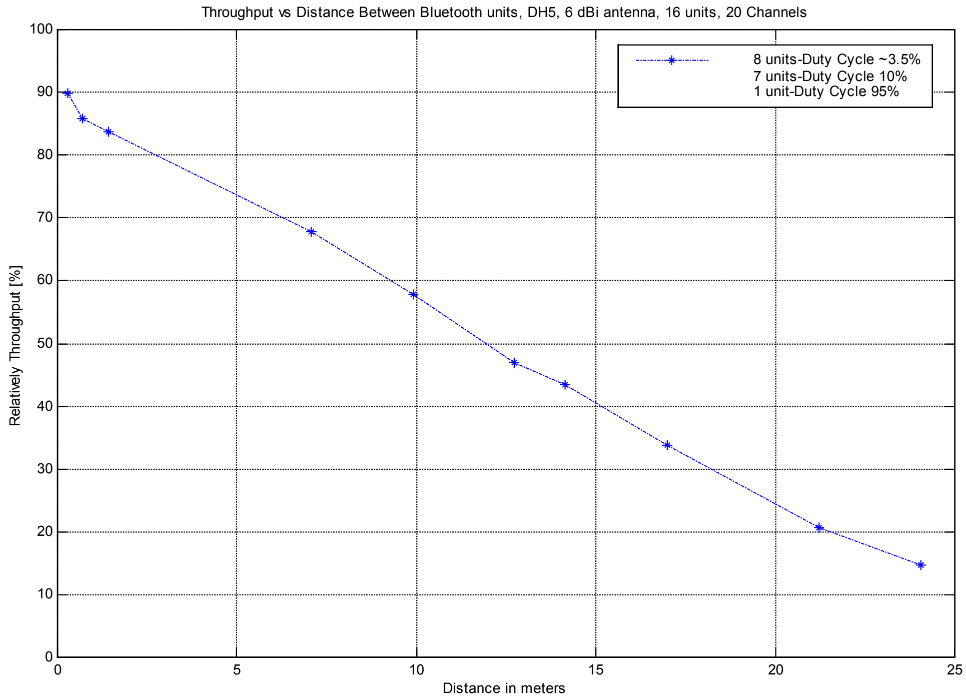
6.3.3.2 Scenario 2

Fig. 6.3.3.6: Throughput performance using 8, 16 and 32 units, d=15%



6.3.3.3 Scenario 3

Fig. 6.3.3.7: Throughput performance using 16 units, mixed duty cycle 3,5%, 10 % and 95%



6.3.4 Conclusion of simulation

An RFID hot-spot scenario within a circle of 35 meters has been simulated, this is called scenario 1 or “Statistical Hot-Spot scenario”.

The maximum Bluetooth throughput 432.6 kb/s of the DH5 protocol is reduced as the number of interferers increase. For an RFID hot-sport density of 8, a Bluetooth victim looses 15% of the maximal throughput within a close distance up to one meter. At larger distances and unit densities the throughput is reduced further. Different RFID densities have been considered. Without the RFID mitigation factor of the antenna beamwidth the Bluetooth throughput reduction will be severe for high density of RFID devices in combination with high duty-cycles.

The difference between the three studied protocols, see figure 6.3.3.1, shows that DH5 is more vulnerable compared to DH1 and DH3 as expected. An RFID reader using a directional antenna mitigates the influence of interference. This effect improves the throughput with up to 50%, see figure 6.3.3.2.

The influence of duty cycle upon interference is very important according to what is shown in fig. 6.3.3.3. The higher RFID unit density is, the higher becomes the interference. This in turn results in lower throughput (figure 6.3.3.4). At a distance of 5 m, the throughput is degraded by 20%, 32% and 50% in the 8, 16 and 32 unit density cases respectively. Even in these more severe cases, the Bluetooth link is not prevented from operating.

As expected, the intermodulation adds to the interference but the contribution to the throughput reduction is minor, see fig 6.3.3.5.

Scenario 2, “cashier counter scenario”, has been simulated using DH5 protocol, see fig 6.3.3.6. No drastic throughput reduction occurs, but some reduction down to between 70-85% throughput can be expected when approaching the cashier desk closer than one meter.

Finally, Scenario 3 shows that the individual duty cycle is not as important as the total averaged duty cycle of the collection of all the RFID readers for the hot spot scenario considered. The throughput reduces to 58% at 10m separation between the two Bluetooth link units.

6.4 Comparison of MCL and SEAMCAT simulations

Due to a number of differences between the two methodologies a simple comparison of results could not be undertaken. In order to make a general comparison of the SEAMCAT analysis tool to the MCL-derived calculation results, two comparable methodologies would have to be used. This was done by using the MCL-based methodology to emulate the scenarios used in SEAMCAT. The original SEAMCAT scenarios using an (N + I)/I = 3 interference criterion had been performed.

In section 6.4.1 it is shown how the SEAMCAT tool was used to evaluate the level of probability of interference when the density of interfering devices increases within a defined fixed radius. In section 6.4.2 the study presents the simulation of similar scenarios using the MCL-based calculations. Finally, section 6.4.3 compares the results obtained in sections 6.4.1 and 6.4.2.

6.4.1 SEAMCAT Study

The SEAMCAT analysis tool uses the Monte-Carlo methodology, which can be used for all radio-interference scenarios. From different parameters, such as antenna pattern, radiated power, frequency distribution and the C/I (major parameter), the tool calculates the statistical distribution function of the system. The tool can consider band emission, intermodulation and receiver blocking. Results are presented as a probability of interference, so a careful interpretation of the results is required.

Fixed simulation radius of 564.3 m had been chosen in this study, as this corresponds to a simulation area of 1km². The simulation radius R_{simu} was calculated by using equation (6.4.1a), which is given in the SEAMCAT user documentation (annex 13, page 70):

$$R_{simu} = \sqrt{\frac{n^{active}}{\pi * dens_{it}^{active}}} \quad (6.4.1a)$$

where : - $dens_{it}^{active} = dens_{it} * P_{it}^{tx} * activity_{it}(time)$;

- n^{active} - number of active interferers in the simulation (n^{active} should be sufficiently large so that the (n+1)-th interferer would bring a negligible additional interfering power);
- $dens_{it}^{active}$ - density of active transmitters;
- P_{it} - probability of transmission;
- $activity_{it}(time)$ - temporal activity variation as a function of the *time* - time of the day (hh/mm/ss).

By setting the activity to 1 (or constant) and a probability of transmission of 1, the equation becomes:

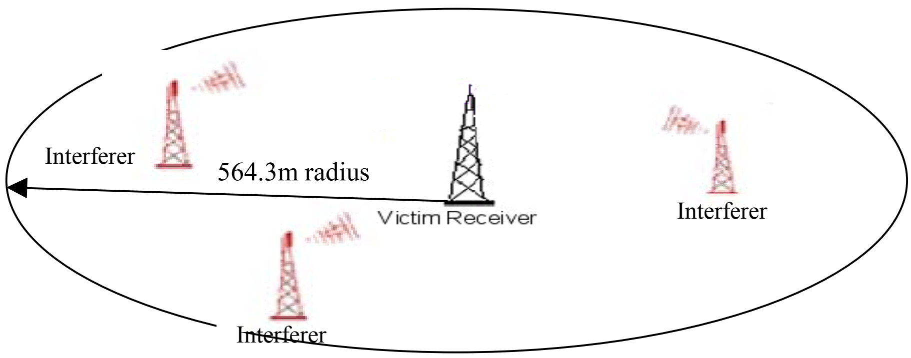
$$R_{simu} = \sqrt{\frac{n^{active}}{\pi * dens_{it}}} \quad (6.4.1b)$$

When choosing a density of x interferer/km^2=No of active transmitter, equation (6.4.1b) can be solved and a simulation radius of 564.3m is defined:

$$R_{simu} = \sqrt{\frac{1\,km^2}{\pi}} = 0.5643 \text{ km}$$

The first suggested simulation is to evaluate the probability of interference of a variable number of transmitters within a defined 564.3 m radius. The idea is presented fig 6.4.1.

Figure 6.4.1: Number 'X' of interfering devices within 564.3 m radius from the victim



A number of different interference scenarios were simulated. The input parameters used for each device are given in Annex C.1 in a form of SEAMCAT input file. Interference scenarios were simulated using the agreed values of C/I, see Annex C.2 for summary of results.

In order to be able to compare results with the MCL-based calculations, the interference scenarios were re-simulated using (N+I)/N = 3dB. Results of these calculations are summarised in Annex C.3.

6.4.2 MCL STUDY

It was decided to obtain simulations of realistic scenarios and to complete the SEAMCAT study with a comparison with the MCL-based method. In this section, the MCL-calculated interference probabilities for the scenarios defined in Annex C.1 are presented.

In order to compare to certain extent the results obtained by MCL methodology with the SEAMCAT results, an analysis is proposed for setting the distance range, where a comparison of both methods is possible since the distributions defined in SEAMCAT and MCL methodology differ.

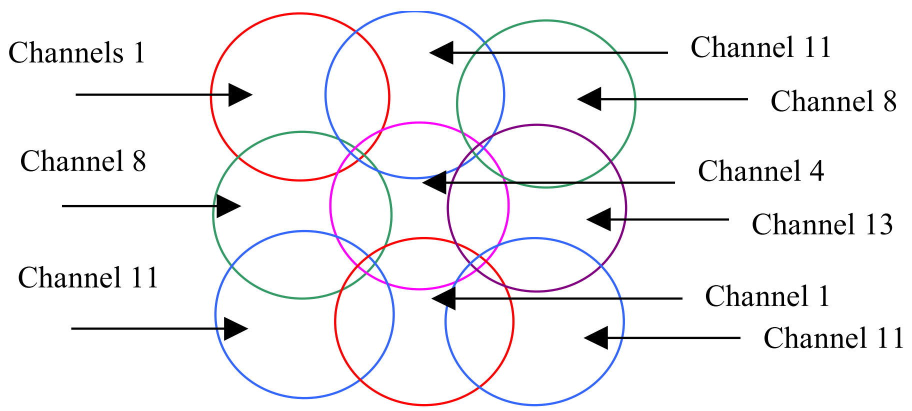
Note on RFID antenna directivity
RFID3a and RFID3b interferers radiate more power in the main beam direction of the antenna (±43 deg). At the rear side of the antenna (remaining 274 out of 360 deg) the power is 15 dB lower. Although the attenuation in the rear is 15 dB, the surface covered by this component is not negligible and was therefore considered in the analysis.

Note on RLAN coordinated cell and frequency planning
With RLAN2 to RLAN2 interference the IEEE 802.11b clear channel behavior and channel assignments made by configuring the Access Protocols (APs) is taken into account. The clear channel assignment is part of the 802.11 CSMA/CA protocol. This protocol includes a listen-before-talk scheme: before starting a transmission the medium is sensed to be idle. Furthermore, the channel selection for the APs, which is currently done by a network administrator from a controller PC, will be done in the future through self-configuration. The channel selection will manage the 5 independent channels (5 in Europe, 4 in the US)[1] as illustrated in Fig. 6.4.2.

In that way the cells around the AP use channels in a planned way. With large cells, the stations at the edge of the cell might operate near the sensitivity limits. With smaller cells and nearby the AP, the receive levels are higher. In principle, RLAN2 on RLAN2 interference analysis has to be analysed by a statistical method because the cell/frequency planning is coordinated. Therefore the corresponding MCL-based analysis reflecting self-interference probability is misleading. These assume a random activity by RLAN2 devices in terms of channel usage and positioning. However, the usage of channel is done in a harmonized manner.

Bluetooth systems are based on assumption of no co-ordination between individual piconets. Thus, the MCL-based analysis is fully correct for Bluetooth.

Fig. 6.4.2: Channel frequency reuse pattern



[1] Europe 2412, 2417, .. 2472 MHz; with 15 MHz in between the adjacent channel rejection allows partial cell overlap, for full cell overlap a 25 MHz spacing is required.

The following describes the scenarios used in the calculations. Corresponding results in graphical form are shown in Annex C.4 of the report.

1) Interference into RLAN Type 2 (RLAN2)

a) RFID3a into RLAN2, urban, indoor-indoor
MCL_{main} = 121, interference range R = 546 m,
Number of interferers Nint = 0.47•density
$P_{ant\_main} = 0.24$ (86/360), $P_{freq} = 0.2375$, $P_{time} = 1$, $P_{main} = 1 - (0.943)^{0.47 \bullet density}$
MCL_{rear} = 106, interference range R = 204 m,
Number of interferers Nint = 0.1•density
$P_{ant\_rear} = 0.76$ (274/360), $P_{freq} = 0.2375$, $P_{time} = 1$, $P_{rear} = 1 - (0.820)^{0.1 \bullet density}$
$P_{tot} = 1-((0.943)^{0.47 \bullet density} \bullet (0.820)^{0.1 \bullet density})$

b) RFID3b into RLAN2, urban, outdoor-indoor
MCL_{main} = 112, interference range R = 190 m,
Number of interferers Nint = 0.088•density
$P_{ant\_main} = 0.24$ (86/360), $P_{freq} = 0.2375$, $P_{time} = 1$, $P_{main} = 1 - (0.943)^{0.088 \bullet density}$
MCL_{rear} = 97, interference range R = 71 m,
Number of interferers Nint = 0.014•density
$P_{ant\_rear} = 0.76$ (274/360), $P_{freq} = 0.2375$, $P_{time} = 1$, $P_{rear} = 1 - (0.820)^{0.014 \bullet density}$
$P_{tot} = 1-((0.943)^{0.088 \bullet density} \bullet (0.820)^{0.014 \bullet density})$

c) RLAN2 into RLAN2, urban, indoor-indoor
MCL = 105, interference range R = 190.6 m,
Number of interferers Nint = 0.088•density
$P_{ant} = 1$, $P_{freq} = 0.2848$, $P_{time} = 1$, Ptot $= 1 - (0.715)^{0.088 \bullet density}$

d) BT100mW into RLAN2, urban, indoor-indoor
MCL = 105, interference range R = 190.6 m,
Number of interferers Nint = 0.088•density
$P_{ant} = 1$, $P_{freq} = 0.1987$, $P_{time} = 1$, Ptot $= 1 - (0.801)^{0.088 \bullet density}$

2) Interference into Bluetooth 1 mW (BT1 mW)

a) RFID3a into BT1 mW, urban, indoor-indoor
MCL_{main} = 121, interference range R = 546 m,
Number of interferers Nint = 0.47•density
$P_{ant\_main} = 0.24$ (86/360), $P_{freq} = 0.0156$, $P_{time} = 1$, $P_{main} = 1 - (0.996)^{0.47 \bullet density}$
MCL_{rear} = 106, interference range R = 204 m,
Number of interferers Nint = 0.1•density
$P_{ant\_rear} = 0.76$ (274/360), $P_{freq} = 0.0156$, $P_{time} = 1$, $P_{rear} = 1 - (0.988)^{0.1 \bullet density}$
$P_{tot} = 1-((0.996)^{0.47 \bullet density} \bullet (0.988)^{0.1 \bullet density})$

b) RFID3b into BT1 mW, urban outdoor-indoor
MCL_{main} = 112, interference range R = 190 m,
Number of interferers Nint = 0.088•density
$P_{ant\_main} = 0.24$ (86/360), $P_{freq} = 0.0156$, $P_{time} = 1$, $P_{main} = 1 - (0.996)^{0.088 \bullet density}$
MCL_{rear} = 97, interference range R = 71 m,
Number of interferers Nint = 0.014•density
$P_{ant\_rear} = 0.76$ (274/360), $P_{freq} = 0.0156$, $P_{time} = 1$, $P_{rear} = 1 - (0.988)^{0.014 \bullet density}$
$P_{tot} = 1-((0.996)^{0.088 \bullet density} \bullet (0.988)^{0.014 \bullet density})$

c) RLAN2 into BT1 mW, urban, indoor-indoor
MCL = 93.24, interference range R = 88 m,
Number of interferers Nint = 0.022•density
$P_{ant} = 1$, $P_{freq} = 0.195$, $P_{time} = 1$, Ptot $= 1 - (0.805)^{0.022 \bullet density}$

d) BT100mW into BT1 mW, urban, indoor-indoor
MCL = 105, interference range R = 191 m,
Number of interferers Nint = 0.089•density

$P_{ant} = 1$, $P_{freq} = 0.0189$, $P_{time} = 1$, Ptot = 1 - $(0.981)^{0.089•density}$

3) Interference into ENG/OB Type 3 (ENG/OB3)

a) RFID3a into ENG/OB3, urban, indoor-outdoor
MCL_{main} = 143, interference range R = 1940 m,
Number of interferers Nint = 11.82•density
P_{ant_main} = 0.008 (86/360 • 12/360), P_{freq} = 1, P_{time} = 1, P_{main} = 1 - $(0.992)^{11.82•density}$
MCL_{rear} = 128, interference range R = 728 m,
Number of interferers Nint = 1.67•density
P_{ant_rear} = 0.025 (274/360 • 12/360), P_{freq} = 1, P_{time} = 1, P_{rear} = 1 - $(0.975)^{1.67•density}$
P_{tot} = 1-($(0.992)^{11.82•density}$ • $(0.975)^{1.67•density}$)

b) RFID3b into ENG/OB3, urban, outdoor-outdoor
MCL_{main} = 149, interference range R = 2870 m,
Number of interferers Nint = 25.9•density
P_{ant_main} = 0.008 (86/360 • 12/360), P_{freq} = 1, P_{time} = 1, P_{main} = 1 - $(0.992)^{25.9•density}$
MCL_{rear} = 134, interference range R = 1077 m,
Number of interferers Nint = 3.64•density
P_{ant_rear} = 0.025 (274/360 • 12/360), P_{freq} = 1, P_{time} = 1, P_{rear} = 1 - $(0.975)^{3.64•density}$
P_{tot} = 1-($(0.992)^{25.9•density}$ • $(0.975)^{3.64•density}$)

c) RLAN2 into ENG/OB3, urban, indoor-outdoor
MCL = 127, interference range R = 831 m,
Number of interferers Nint = 2.17•density
P_{ant} = 0.033, P_{freq} = 0.238, P_{time} = 1, Ptot = 1 - $(0.992)^{2.17•density}$

d) BT100mW into ENG/OB3, urban, indoor-outdoor
MCL = 127, interference range R = 682 m,
Number of interferers Nint = 1.46•density
P_{ant} = 0.033, P_{freq} = 1, P_{time} = 1, Ptot = 1 - $(0.967)^{1.46•density}$

4) Interference into Fixed Link Type 1 (Fixed1)

a) RFID3a into Fixed1, urban, indoor-outdoor
MCL_{main} = 151.1, interference range R = 2440 m,
Number of interferers Nint = 18.7•density
P_{ant_main} = 0.0064 (9.7*86/360*360), P_{freq} = 1, P_{time} = 1, Ptot = 1 - $(0.994)^{18.7•density}$
MCL_{rear} = 136.1, interference range R = 915 m,
Number of interferers Nint = 2.63•density
P_{ant_rear} = 0.021 (9.7*274/360 *360), P_{freq} = 1, P_{time} = 1, P_{rear} = 1 - $(0.979)^{2.63•density}$
P_{tot} = 1-($(0.994)^{18.7•density}$ • $(0.979)^{2.63•density}$)

b) RFID3b into Fixed1, urban, outdoor-outdoor
MCL_{main} = 157.1, interference range R = 3610 m,
Number of interferers Nint = 40.94•density
P_{ant_main} = 0.0064 (9.7*86/360*360), P_{freq} = 1, P_{time} = 1, Ptot = 1 - $(0.994)^{40.94•density}$
MCL_{rear} = 142.1, interference range R = 1354 m,
Number of interferers Nint = 5.76•density
P_{ant_rear} = 0.021 (9.7*274/360 *360), P_{freq} = 1, P_{time} = 1, P_{rear} = 1 - $(0.979)^{5.76•density}$
P_{tot} = 1-($(0.994)^{40.94•density}$ • $(0.979)^{5.76•density}$)

c) RLAN2 into Fixed1, urban, indoor-outdoor
MCL = 128.1, interference range R = 660 m,
Number of interferers Nint = 1.37•density
P_{ant} = 0.027, P_{freq} = 0.2089, P_{time} = 1, Ptot = 1 - $(0.994)^{1.37•density}$

d) BT100mW into Fixed1, urban, indoor-outdoor
MCL = 135.1, interference range R = 857 m,
Number of interferers Nint = 2.3•density
P_{ant} = 0.027, P_{freq} = 0.0446, P_{time} = 1, Ptot = 1 - $(0.999)^{2.3•density}$

6.4.3 Comparing MCL results with SEAMCAT results

First it must be noted that in the above-presented results of MCL-based calculations, the maximum permissible interference level at victim receiver corresponds to the noise floor. Therefore, the interference criterion for SEAMCAT was chosen equal (N + I)/I = 3 dB.

One of the most important divergences between both methods is the distribution of the interferers. In SEAMCAT this distribution is uniform and the simulation radius is given by:

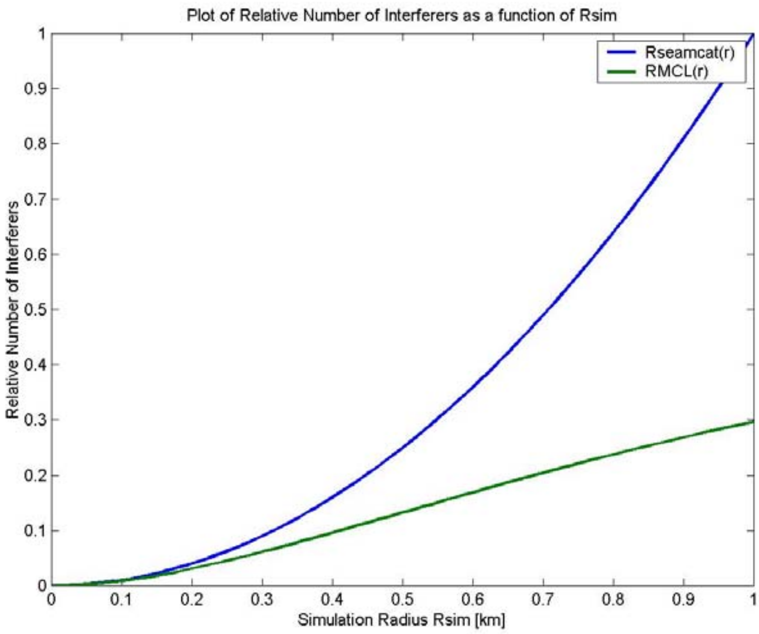
$$R_{simu} = \sqrt{\frac{n^{active}}{\pi * dens_{it}}} \Rightarrow n^{active} = \pi * dens_{it} * R_{simu}{}^{2}.$$

With the MCL-based methodology used in this report for evaluating the interference to RLAN2 and Bluetooth, the interferer distribution is exponential and is given by:

$$N_{\text{int}} = \frac{\pi}{2} * dens_{it} * [1 - (2R + 1) * \exp(-2R)].$$

In order to compare these two equations, the simplification by $\pi * dens_{it}$ gives:

$$\hat{N}_{SEAMCAT}(R) = R^2$$
$$\hat{N}_{MCL}(R) = \frac{1}{2} - \left(R + \frac{1}{2}\right) * \exp(-2R).$$



As can be seen from the above plot, it is assumable that for radius of up to 200 m, the defined distributions are in some extent comparable. Therefore, the MCL calculated curves obtained for 1a) and 2a) cases (see section 6.4.2) where the radius of the interference cell is larger than 200 m can not be compared with SEAMCAT simulations.

Another important point should be noted. Due to the way the simulation radius is determined in SEAMCAT (6.4.1a), the densities used in the SEAMCAT simulations for comparison with MCL-derived results have to be adapted in order to match the number of active transmitters considered in the MCL calculations. The probabilities showing the comparison of both methods are therefore plotted as a function of the active number of interferers, see Annex C.5.

6.5 Results of measurements made by RA/UK

This section describes the laboratory measurements, which were conducted at the Radio Technology & Compatibility Group (RTCG) of the Radiocommunications Agency in the UK, as part of their support to CEPT Working Group SE. They were designed to assess the mutual compatibility between Bluetooth and other services operating in the ISM band, in particular analogue and digital ENG OB links, Radio Frequency Access (RFA), 8 MHz FHSS RFID and RLAN (FHSS&DSSS).

Test set-up and combination of conducted tests are described below.

Figure 6.5.a: Test set-up for Bluetooth interference into ENG/OB and RLAN

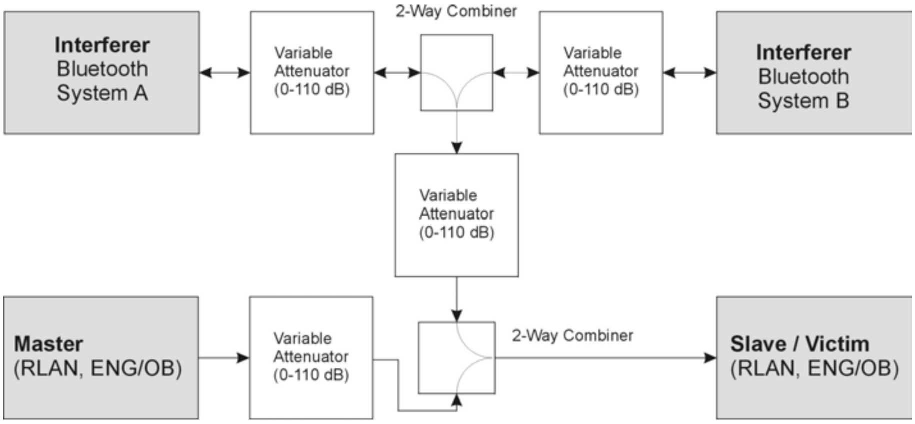
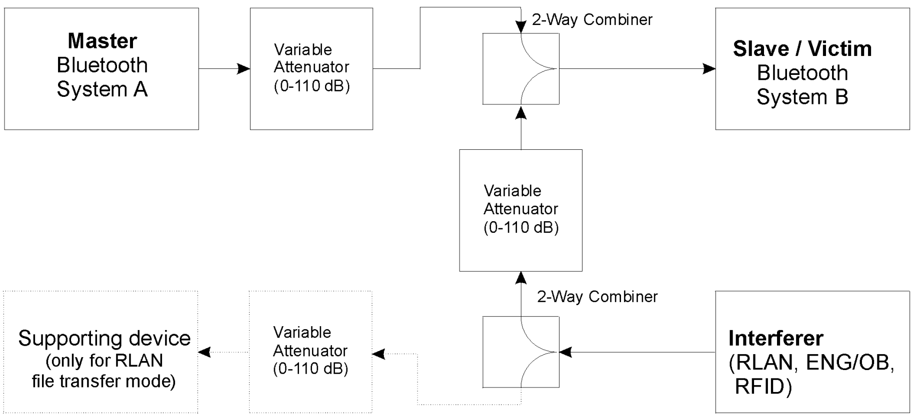


Figure 6.5.b: Test set-up for interference to Bluetooth



Information on test combinations is available in tables 6.5.3 and 6.5.4. The tests were made using DM1 packet for file transmission. The details are shown in the table 6.5a below.

Table 6.5.a: DM1 packet details

Packet Type	Payload Header (Bytes)	User Payload (Bytes)	FEC	CRC	Symmetric max rate	Asymmetric max forward rate (kb/s)	Asymmetric max reverse rate (kb/s)
DM1	1	0-17	2/3	yes	108.8	108.8	108.8

'D' relates to data, 'M' to medium (rate) and 'H' to high (rate). The numbers refer to the number of timeslots that a packet can occupy. For example, a DM1 packet will occupy only one timeslot, but a DM3 packet can occupy up to three timeslots, and a DM5 packet can occupy up to five timeslots.

The voice tests were conducted using HV1 packet and details of this are shown in 6.5b below.

Table 6.5.b: HV1 details

Type	Payload header (bytes)	User Payload (bytes)	FEC	CRC	Symmetric max rate (kbit/s)
HV1	N/A	10	1/3	No	64.0

HV1 packets are the most heavily protected with the FEC=1/3. All data packets have also their header protected by 1/3 FEC (known as HEC – Header Error Correction).

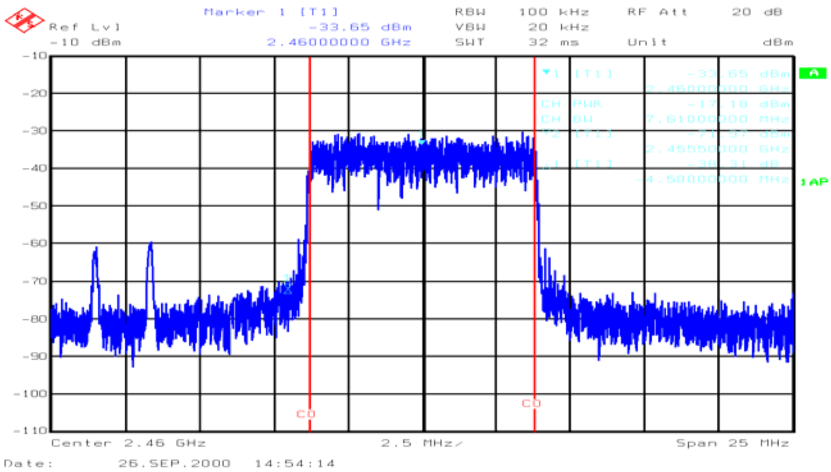
The following systems were tested both as an interferer as well as a victim.

6.5.1 ENG/OB Links

TV ENG/OB links can be used for temporary point to point links and for short-range links from a mobile camera to a fixed point. They are used for applications such as coverage of sporting events. It is foreseen that analogue links will gradually be replaced by digital links. There is also likely to be a greater use of ENG/OB TV links in the future due to the increasing numbers of television channels and hence the capability to provide greater coverage of sporting events, news items and so forth. For further details see section 4.1.

6.5.1.1 Digital ENG/OB equipment

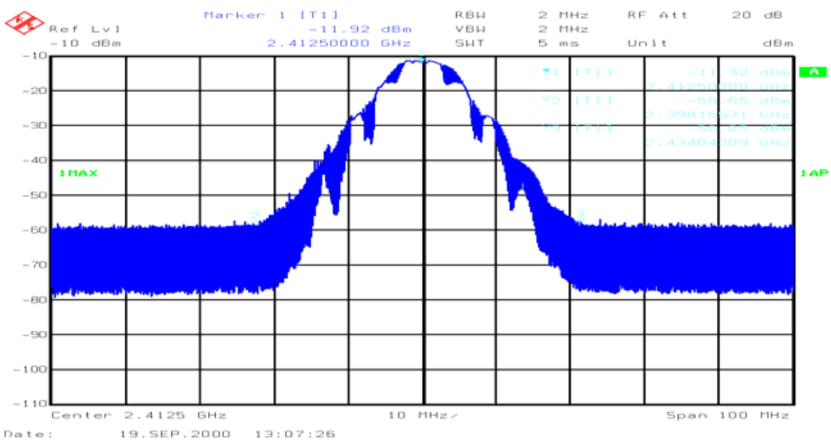
The digital ENG/OB equipment used was COFDM, and it was possible to select three different types of modulation: QPSK (1/2 error correction), 16-QAM (1/2 error correction) and 64-QAM (1/2 and 2/3 error correction). The spectrum plot is shown below.



For further information on digital ENG/OB, see section 4.1.4.

6.5.1.2 Analogue ENG/OB equipment

Four channels were available with the following centre frequencies: 2412.5MHz (channel 1), 2432.5MHz (channel 2), 2452.5MHz (channel 3), and 2472.5MHz (channel 4). The equipment operated using FM modulation, and the output power was found to be ~0dBm. The RF spectrum plot of this analogue ENG/OB equipment is shown below.



For further details on ENG/OB systems, see section 4.1.

6.5.2 RFID system

The RFID operating in the 8 MHz sub-band was simulated on RTCG's FASS (Frequency Agile Signal Simulator) system and following technical parameters were used:

- Spread spectrum : FHSS
- No of frequency hops: 20
- Carrier Spacing : 350 kHz
- Modulation : Two Level ASK
- Symbol Rate : 76 kB/s
- Baseband Filter : Nyquist 0.35 Alpha factor
- Duty cycle : 10/15/50/100 %
- Repetion period: 200 mS.

For further details, see section 4.4.

6.5.3 Test Results for Bluetooth as victim receiver

The tests for interference to a Bluetooth receiver was made for the following transmitters:

- RLAN (FHSS & DSSS);
- FHSS RFID;
- Radio Frequency Access (RFA);
- digital & analogue TV ENG/OB links.

The results of these tests are given in Table 6.5.3 below.

Table 6.5.3: Interference test results for Bluetooth as a victim receiver[1)]

Interferer	Victim	Bluetooth mode	C/I ratio (dB) (90% throughput)	Interference mechanism
Bluetooth (FASS Simulated, 59% duty cycle)	Bluetooth (development kit)	(DM1 data)	- 35	Co-channel
RLAN (DSSS)	„	(DM1 data)	2.5 [2)]	Co-channel
RLAN (FHSS)	„	(DM1 data)	-33 [2)]	Blocking
Digital (COFDM) ENG/OB link	„	(DM1 data)	+4 [2)]	Co-channel
Analogue (FM) ENG/OB link	„	(DM1 data)	-2 [2)]	Co-channel
Simulated 8 MHz RFID (10% duty cycle: 20ms on/180ms off)	„	(DM1 data)	-49 [2)]	Blocking
Simulated 8MHz RFID (15 % duty cycle: 30ms on/170ms off)	„	(voice HV1)	-54	Blocking
Simulated 8MHz RFID (15 % duty cycle: 30ms on/170ms off)	„	(DM1 data)	-48 [2)]	Blocking
Simulated 8MHz RFID (50 % duty cycle: 100ms on/100ms off)	„	(DM1 data)	-36 [2)]	Blocking
Simulated 8MHz RFID (100 % duty cycle)	„	(DM1 data)	-33 [2)]	Blocking
RFA	„		Measurements start Jan/Feb 2001	Blocking
Non-modulated carrier	„	(DM1 data)	-30 <=> -33	Blocking

Notes:

(1) 90 % data throughput was used as failure criteria. All measurements were conducted with the victim receiver level set at (MUS+10 dB);
(2) No degradation to voice link at this C/I value.

6.5.4 Test results for Bluetooth as interferer

The tests for interference from Bluetooth were made for the following victim receivers:

- RLAN (FHSS & DSSS);
- FHSS RFID;
- Radio Frequency Access (RFA);

- Digital & analogue TV ENG/OB links.

The results of these tests are given in Table 6.5.4 below:

Table 6.5.4: Interference test results for Bluetooth as an interferer[1)]

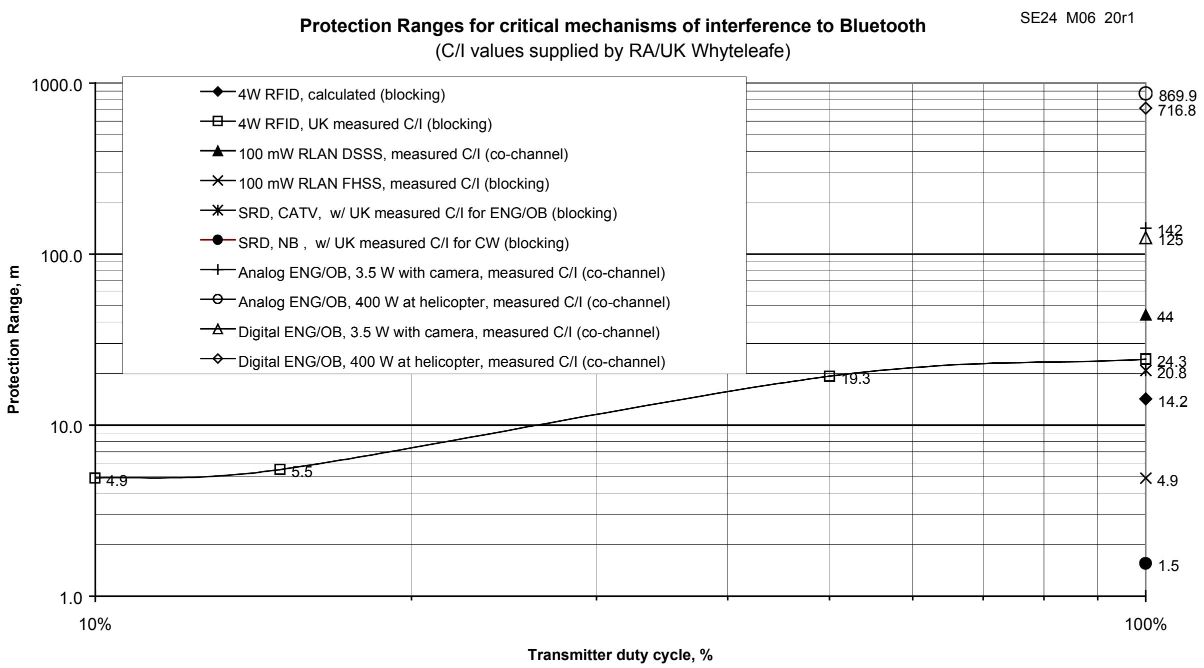
Interferer	Victim	C/I ratio (dB) (90% throughput)	Interference mechanism
Bluetooth development kit (Voice HV1)	RLAN (DSSS – 11Mb/s)	8.5	Co-channel
,,	RLAN (DSSS – 5.5Mb/s)	4.5	Co-channel
	RLAN (DSSS – 2 Mb/s)	3.5	Co-channel
,,	RLAN (DSSS – 1 Mb/s)	1.5	Co-channel
,,	RLAN (FHSS – 1Mb/s)	7.5	Co-channel
,,	Digital (COFDM) ENG/OB link (QPSK - FEC ½)	-5	Co-channel
,,	Digital (COFDM) ENG/OB link (16QAM – FEC ½)	2	Co-channel
,,	Digital (COFDM) ENG/OB link (64QAM - FEC ½)	8	Co-channel
,,	Digital (COFDM) ENG/OB link (64QAM – FEC 2/3)	19	Co-channel
,,	RFA	Measurements start Jan/Feb 2001	Co-channel
,,	Analogue (FM) ENG/OB link	18	Co-channel

Notes:
(1) All measurements were conducted with the victim receiver level were set at (MUS+10 dB);
(2) Subjective viewing method was used to assess interference into TV ENG/OB links;
(3) 90 % data throughput was used as failure criteria for RLAN.

If transmitters are duty cycle controlled, there is an additionally mitigation factor depending of the duty cycle, D. Measurements by RA/UK has justified this dependence.

Figure 6.5.4 below shows the most important results based on Annex B calculations and C/I values measured by RA/UK laboratory.

Figure 6.5.4



6.5.5 Summary of laboratory tests

The information contained within this report provides protection requirements for Bluetooth and various classes of equipment operating co-frequency.

The majority of interference measurements contained within this report have used a 90% data throughput as the system failure criteria for Bluetooth. However, a small number of measurements were performed to assess the impact on the Bluetooth (HV1) voice link of an interferer, and these indicated that interference levels of approximately 2 dB above those for data could be tolerated without serious degradation to the voice link.

The results show that Bluetooth, under a 90% throughput criterion, has a reasonable immunity against narrow band interference such as FHSS RLAN, Bluetooth, FHSS RFID and CW. But it was found to be susceptible to wide band interferers i.e. TV ENG/OB links (digital & analogue) and DSSS RLAN due to higher bandwidth and the 90% throughput criteria.

It should be noted that the measurements results described in the tables 6.5.3 and 6.5.4 are based on a single interferer.

6.5.5.1 ENG/OB

TV ENG/OB systems could potentially be viewed as an interference threat to Bluetooth. However, the nature of newsgathering is such that virtually all links operate only temporarily and for very short duration, usually only a matter of a few hours in a single location. Taken on a broader level, the sporadic nature of ENG/OB transmissions mean they are unlikely to be a major determinant on the long term performance or availability of indoor Bluetooth systems.

6.5.5.2 DSSS RLAN

Perhaps a more substantive threat to a Bluetooth system is a co-located DSSS RLAN access point, as this is likely to be a more common scenario. The protection requirement (C/I) of Bluetooth from these devices is 2.5dB.

It should also be noted that the reverse assessment, that of the impact of Bluetooth on RLANs (both DSSS and FHSS), indicated the protection requirements (C/I) for these devices are 8.5 dB and 7.5 dB respectively. Again, this may indicate the potential for interference to these systems if they are co-located with Bluetooth.

6.5.5.3 FHSS RLAN/Bluetooth

The two similar frequency-hopping systems (FHSS RLAN & Bluetooth) produced very different interference rejection performance results. The Bluetooth protection against FHSS RLAN interference was requiring C/I= –33 dB, whereas FHSS RLAN required +7.5 dB protection against Bluetooth interference. This may be due to difference in hopping speed (dwell time) and packet structure of the two systems.

6.5.5.4 RFID

The protection required by Bluetooth against interference from 8MHz RFID (at all duty cycles) is better or comparable to that of a co-located Bluetooth system. For RFID with a 100% duty cycle the C/I= -33 dB, as compared to -35 dB for co-located Bluetooth devices. When the duty cycle of the simulated 8MHz RFID was changed from 100 to 10 %, the protection of Bluetooth improved by 16 dB to a C/I= –49dB. This significant improvement in protection ratio, at a lower RFID duty cycle, may be due to the resulting lower average power from the interferer.

It should be noted that the results of simulated 8MHz RFID interference into Bluetooth given in the report are only valid for RFID technical parameters shown in the report and duty cycle values given below:

- 10 % duty cycles (20 ms on /180ms off);
- 15 % duty cycle (30ms on/ 170 ms off);
- 50 % duty cycle (100ms on /100ms off).

Any alteration of these parameters could result in significant change to the interference potential to Bluetooth.

7 CONCLUSIONS

This report presents the study of compatibility between Bluetooth and other existing and proposed services operating in the 2.45 GHz frequency band.

7.1 Assumptions (BT/RFID, RLAN, ENG/OB)

The characteristics of the different systems considered can be found in sections 3 and 4.

7.2 Methods (Deterministic, Probabilistic, other)

Four methods for interference analysis had been used in this report:

- deterministic method;
- probabilistic method;
- simulation tool;
- SEAMCAT, see ERC Report 68 (modified 2001).

A description of each method is provided in section 5.

In addition to analytical analysis, some laboratory measurements were performed.

7.3 Results

Deterministic method

Deterministic calculations show that the impact of the 4W RFID with a duty cycle of greater than 15% in any 200 ms period time on the Bluetooth performance is critical. In particular, transmitter-on times exceeding 200 ms will have serious impact. Further studies of the impact of higher application layers are needed.

Blocking has been shown to be the most limiting factor with a separation distance of approximately 10 m or less. This mechanism has a significant impact on the Bluetooth performance in terms of non-acceptable reduction in capacity at high duty-cycles.

Further, the study shows that additional mitigation techniques are required for RFID, such as directional antennas, antenna-dome (to avoid Bluetooth receiver burnout), etc.

Further studies may be required in order to investigate the relationship between Bluetooth levels above the blocking level and acceptable RFID e.i.r.p. and duty cycles.

Probabilistic method (applied to co–channel interference only)

The interference criteria used was I/N=0 dB for all services except for fixed links where the long term criteria was I/N= –10 dB for 20% of the time. The conclusions are that:

- the probability of interference to Bluetooth from existing and planned services, being of the same order of magnitude (plus or minus 1 decade), depends on the unit density;
- the probability of interference from Bluetooth 1 mW to Fixed Wireless Access is severe for a density of 100 units per km^2 and 10 units per km^2 for Bluetooth 100 mW;
- both 1 mW and 100 mW Bluetooth systems will cause harmful interference to ENG/OB or fixed links when operating in close vicinity.

Simulation tool

Simulations for hot-spot areas show significant reduction in throughput for Bluetooth in the case of sufficient high duty cycles or omni-directional antennas, or a large number of RFIDs (>32). For these cases the Bluetooth operating range is limited to a couple of metres in order to maintain acceptable throughput.

For RFID hot spot areas with 8 units in a 35 m radius from the Bluetooth victim, Bluetooth throughput reduces by 15% for a Bluetooth link over distance of up to 1 m. At larger Bluetooth link distances and higher unit densities the throughput is reduced further.

Different RFID densities have been considered. Without the RFID mitigation factor of the antenna beamwidth, the Bluetooth throughput reduction will be severe for high density of RFID devices in combination with high duty-cycles: an

RFID reader using a directional antenna mitigates the influence of interference taking into account the protection of existing services.

The simulation shows that reduction of the duty cycle will reduce the impact on the throughput during interference. Intermodulation has a minor contribution to the interference.

SEAMCAT

The Monte–Carlo based SEAMCAT software was used to investigate the interference scenarios and to make comparisons with the results obtained from using the deterministic method.

Due to a number of differences between the two methodologies, a direct comparison could not be made. Nevertheless, assumptions and comparisons were made as described in paragraph 6.4 for half of the interference scenarios. The probability of interference to Bluetooth as a function of the density of the interferer is of the same magnitude for RLAN, RFID3a and 3b, which is about 2 times higher than for 100 mW Bluetooth to Bluetooth.

The probability of interference from 100 mW Bluetooth to RLAN, ENG/OB and fixed links is at least 2 times lower than the interference from RLAN, RFID3a and 3b with the same unit density.

Measurements

It should be noted that the measurement results described in the report are based on a single interferer and a specific Bluetooth equipment, evaluating the tolerable C/I for 10% throughput degradation. However, the absolute power levels of the various systems are significantly different in the C/I evaluation. For the determination of the isolation distances both the C/I and the power level should be considered.

The results show that the tested Bluetooth sample had excellent immunity against narrow band interference, such as FHSS RLAN, Bluetooth, RFID and CW signals.

On the other hand the Bluetooth sample has been found susceptible to wide band interferers, i.e. ENG/OB links (digital & analogue) and DSSS RLAN. This may be due to the higher bandwidth and duty cycle. ENG/OB systems are unlikely to be a major determinant on the long term performance or availability of indoor Bluetooth systems. A more substantive threat to Bluetooth systems is from co-located DSSS RLANs. This threat is likely to be a more common scenario.

The protection ratio required by Bluetooth against interference from 8MHz RFID at all duty cycles is better or comparable to that of a co-located Bluetooth system (60% duty cycle). When the duty cycle of the simulated 8MHz RFID was changed from 10 to 100 %, the protection requirement of Bluetooth increased.

The following duty cycles for 4W RFID (8 MHz) were used in both the interference testing and the calculations in the present report:

- 15 % duty cycle (30 ms on/ 170 ms off);
- 50 % duty cycle (100 ms on /100 ms off);
- 100 % duty cycle.

Any alteration of these parameters could result in significant change to the interference potential to Bluetooth.

It should be noted that due to the limited number of equipment used for the measurements, the results are only indicative.

Summary of conclusions relative to compatibility between Bluetooth and 4W RFID (8 MHz) systems

The study shows that the impact of the 4W RFID (8 MHz) with a duty cycle greater than 15% in any 200 ms period (30 ms on/170 ms off) on the Bluetooth performance is critical.

Further, the study shows that additional mitigation techniques are required from RFID, such as directional antennas, antenna-dome (to avoid Bluetooth receiver burnout) and other appropriate mechanisms in order to ensure that the necessary in–door operation restrictions are met.

ANNEX A.1. Interference to Bluetooth from existing and planned services in the 2.400 - 2.4835 GHz Band

Interfering transmitters =>	**SRD 1 NB**	**SRD 2 video**	**RLAN 1**	**RLAN 2**	**Fixed Access**	**4W RFID 3a**	**4W RFID 3a**	**0.5W RFID 3b**	**0.5W RFID 3b**	**0.5 W RFID 5a**	**0.1 W RFID 5b**	**ENG/ OB 1**	**ENG/ OB 2**	**ENG/ OB 3**	**ENG/ OB 4**	**ENG/ OB 1**	**ENG/ OB 2**	**ENG/ OB 3**	**ENG/ OB 4**	**Fixed Servic e 1**	**Fixed Servic e 2**
	NB	NB	FHSS	DSSS	FHSS	FHSS	FHSS	FHSS	FHSS	NB	NB	Analo gue R3	Analo gue R1	Analo gue R2	Analo gue R4	Digital R3	Digital R1	Digital R2	Digital R4	2x2M bit/s MSK	34 Mbit/s QPSK
INPUT DATA below																					
TX output power conducted, Pt (dBW)	-22	-26	-12	-12	-12	0	0	-9	-9	-11	-18	0	23	13	13	0	23	13	13	1	1
TX duty cycle	0.10	1.00	0.10	0.10	1.00	0.10	1.00	0.10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Input Building attenuation, (dB)	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Input Frequency, (MHz)	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450
TX ant. gain minus feeder loss, Gt - Lft (dB)	2	6	2	2	2	6	6	6	6	8	8	5	3	21	27	5	3	21	27	25	35.7
TX antenna horizontal coupling loss factor, (dB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tx Ant Main Lobe 3-dB beamwidth at 0 deg elevation, (deg)	360	87	360	360	360	87	87	87	87	69	69	360	360	15	8	360	360	15	8	10	3
Tx Antenna Sidelobe 3-dB beamwidth at 0 deg elevation, (deg)	0	93	0	0	0	93	93	93	93	111	111	0	0	345	352	0	0	345	352	350	357
TX Antenna sidelobe attenuation at 0 deg elevation, (dB)	0	15	0	0	0	15	15	15	15	15	15	0	0	25	25	0	0	25	25	26	25
Input RX ant. gain - feeder loss, Gr - Lfr (dB)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Rx antenna 3-dB beamwidth, (degrees)	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360
Auto calc. of Victim RX noise (10*log kTB)+NF (dBW)	-123.8	-123.8	-123.8	-123.8	-123.8	-123.8	-123.8	-123.8	-123.8	-123.8	-123.8	-123.8	-123.8	-123.8	-123.8	-123.8	-123.8	-123.8	-123.8	-123.8	-123.8
Input Victim RX Noise figure, NF (dB)	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Background noise in ISM band (dB above system noise)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Relative interference level, I/N,(dB)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Input TX mod. Equivalent noise BW, BWt (kHz)	1000	20000	1000	15000	350	350	350	350	350	100	100	20000	20000	20000	20000	7600	7600	7600	7600	3000	20000
Input Victim RX noise bandwidth, BWr (kHz)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Input the shorter antenna height, Hm (m)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Input the taller antenna height, Hb (m)	3	3	2.5	2.5	1.5	1.5	1.5	1.5	1.5	3	3	1.8	200	10	100	1.8	200	10	100	50	50
Radio line of sight, (km)	12.1	12.1	11.5	11.5	10.0	10.0	10.0	10.0	10.0	12.1	12.1	10.5	63.0	18.0	46.0	10.5	63.0	18.0	46.0	34.0	34.0
Off-channel coupling loss, dB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Clutter loss for low antenna height in rural areas, dB	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3
RFID radiated power, (dBm) EIRP																					
RFID - Main Beam EIRP (dBm)	10	10	20	20	20	36	36	27	27	27	20	35	56	64	70	35	56	64	70	56	66.7
Required Path Loss for main beam (Minimum Coupling Loss, MCL)																					
Path loss, in-door to in-door, PL (dB)	82.8	69.8	92.8	81.1	n/a	108.8	108.8	99.8	99.8	99.8	92.8	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Path loss, in-door to out-door units, PL (dB)	82.8	69.8	92.8	81.1	92.8	108.8	108.8	99.8	99.8	99.8	92.8	94.8	115.8	123.8	129.8	99.0	120.0	128.0	134.0	124.1	126.5
Dfree_space (km) in-door to out-door	0.135	0.030	0.427	0.110	0.427	2.694	2.694	0.956	0.956	0.956	0.427	0.537	6.023	15.129	30.187	0.871	9.771	24.543	48.970	15.552	20.645
Path loss, out-door to out-door units, PL (dB)	97.8	84.8	107.8	96.1	107.8	123.8	123.8	114.8	114.8	114.8	107.8	109.8	130.8	138.8	144.8	114.0	135.0	143.0	149.0	139.1	141.5
Dfree_space (km) out-door to out-door	0.759	0.170	2.401	0.620	2.401	15.14	15.14	5.374	5.374	5.374	2.401	3.019	33.87	85.07	169.7	4.897	54.94	138.0	275.3	87.45	116.1

Interfering transmitters =>	**SRD 1 NB**	**SRD 2 Video**	**RLAN 1**	**RLAN 2**	**Fixed Access**	**4W RFID 3a**	**4W RFID 3a**	**0.5W RFID 3b**	**0.5W RFID 3b**	**0.5 W RFID 5a**	**0.1 W RFID 5b**	**ENG/ OB 1**	**ENG/ OB 2**	**ENG/ OB 3**	**ENG/ OB 4**	**ENG/ OB 1**	**ENG/ OB 2**	**ENG/ OB 3**	**ENG/ OB 4**	**Fixed Service 1**	**Fixed Service 2**
INPUT DATA below	NB	NB	FHSS	DSSS	FHSS	FHSS	FHSS	FHSS	FHSS	NB	NB	Analogue R3	Analogue R1	Analogue R2	Analogue R4	Digital R3	Digital R1	Digital R2	Digital R4	2x2Mbit/s MSK	34 Mbit/s QPSK
Required path loss for sidelobes (Minimum Coupling Loss, MCL)																					
Path loss, in-door to in-door, PL (dB)	82.8	54.8	92.8	81.1	n/a	93.8	93.8	84.8	84.8	84.8	77.8	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Path loss, in-door to out-door units, PL (dB)	82.8	54.8	92.8	81.1	92.8	93.8	93.8	84.8	84.8	84.8	77.8	94.8	115.8	98.8	104.8	99.0	120.0	103.0	109.0	98.1	101.5
Dfree_space (km) in-door to out-door	0.135	0.005	0.427	0.110	0.427	0.479	0.479	0.170	0.170	0.170	0.076	0.537	6.023	0.851	1.698	0.871	9.771	1.380	2.754	0.779	1.161
Path loss, out-door to out-door units, PL (dB)	97.8	69.8	107.8	96.1	107.8	108.8	108.8	99.8	99.8	99.8	92.8	109.8	130.8	113.8	119.8	114.0	135.0	118.0	124.0	113.1	116.5
Dfree_space (km) out-door to out-door	0.759	0.030	2.401	0.620	2.401	2.694	2.694	0.956	0.956	0.956	0.427	3.019	33.87	4.784	9.546	4.897	54.94	7.761	15.48	4.383	6.529
Protection Distances for co-channel interference from main beam																					
Indoor model, in-door to in-door, (km)	0.044	0.019	0.086	0.039	n/a	0.245	0.245	0.136	0.136	0.136	0.086	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Urban model, in-door to out-door, (km)	0.038	0.016	0.066	0.031	0.054	0.154	0.154	0.086	0.086	0.115	0.073	0.066	24.73	2.213	26.72	0.086	34.21	2.913	36.23	7.441	8.800
Urban model, out-door to out-door, (km)	0.101	0.043	0.176	0.082	0.145	n/a	n/a	0.229	0.229	0.308	0.195	0.175	78.73	5.900	79.19	0.230	108.9	7.765	107.3	20.69	24.47
Rural, in-door to out-door, (km)	0.135	0.030	0.149	0.110	0.116	0.291	0.291	0.173	0.173	0.245	0.427	0.142	6.023	1.778	7.944	0.181	9.771	2.265	10.11	4.032	4.646
Rural, out-door to out-door, (km)	0.218	0.170	0.354	0.180	0.274	n/a	n/a	0.411	0.411	0.581	0.388	0.337	11.90	4.217	18.83	0.429	15.15	5.372	23.99	9.561	11.01
h^2*h^2/r^4, (m)	250	118	405	206	314	789	789	470	470	664	444	386	13616	4825	21555	491	17342	6146	27453	10940	12604
a (Hm)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
a (Hb)	4.60	4.60	3.08	3.08	0.06	0.06	0.06	0.06	0.06	4.60	4.60	0.96	51.81	25.79	45.79	0.96	51.81	25.79	45.79	39.77	39.77
Protection Distances for co-channel interference from sidelobe																					
Indoor model, in-door to in-door, (km)	0.044	0.007	0.086	0.039	0.086	0.091	0.091	0.051	0.051	0.051	0.032	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Urban model, in-door to out-door, (km)	0.038	0.006	0.066	0.031	0.054	0.058	0.058	0.032	0.032	0.043	0.027	0.066	24.73	0.432	4.373	0.086	34.21	0.568	5.929	1.264	1.600
Urban model, out-door to out-door, (km)	0.101	0.016	0.176	0.082	n/a	n/a	n/a	0.086	0.086	0.115	0.073	0.175	78.73	1.151	12.95	0.230	108.9	1.515	17.56	3.515	4.450
Rural, in-door to out-door, (km)	0.135	0.005	0.149	0.110	0.116	0.123	0.123	0.170	0.170	0.170	0.076	0.142	6.023	0.851	1.698	0.181	9.771	1.380	2.754	0.779	1.161
Rural, out-door to out-door, (km)	0.218	0.030	0.354	0.180	n/a	n/a	n/a	0.173	0.173	0.245	0.427	0.337	11.90	1.000	9.546	0.429	15.15	1.274	5.690	4.383	6.529
h^2*h^2/r^4, (m)	250	50	405	206	314	333	333	198	198	280	187	386	13616	1144	5111	491	17342	1457	6510	2449	2989
a (Hm)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
a (Hb)	4.60	4.60	3.08	3.08	0.06	0.06	0.06	0.06	0.06	4.60	4.60	0.96	51.81	25.79	45.79	0.96	51.81	25.79	45.79	39.77	39.77

Interfering transmitters =>	**SRD 1**	**SRD 2**	**RLAN 1**	**RLAN 2**	**Fixed Access**	**4W RFID 3a**	**4W RFID 3a**	**0.5W RFID 3b**	**0.5W RFID 3b**	**0.5 W RFID 5a**	**0.1 W RFID 5b**	**ENG/ OB T1**	**ENG/ OB T2**	**ENG/ OB T3**	**ENG/ OB T4**
	NB	video	FHSS	DSSS	FHSS	FHSS	FHSS	FHSS	FHSS	NB	NB	Analog	Analo	Analo	Analo
Exponent k	2	2	2	2	2	2	2	2	2	2	2				
Intermediate Results for New Formula															
TX Single Channel BW (MHz)	1.00	20.00	1.00	15.00	0.35	0.35	0.35	0.35	0.35	0.10	0.10	20.00	20.00	20.00	20.00
TX Hopping Span (MHz)	79.00	79.00	79.00	79.00	79.00	8.00	8.00	8.00	8.00	4.00	4.00	20.00	20.00	20.00	20.00
RX Single Channel BW (MHz)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Unit collision probability elements															
Probability for frequency collision inside interferer band, PFREQ_COL	0.018	0.257	0.018	0.195	0.014	0.015	0.015	0.015	0.015	0.014	0.014	0.256	0.256	0.256	0.256
Probability for time collision, PTIME_COL	0.100	1.000	0.100	0.100	1.000	0.100	1.000	0.100	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Prob. for main beam pattern collision, PPAT_COL	1.000	0.241	1.000	1.000	1.000	0.241	0.241	0.241	0.241	0.191	0.191	1.000	1.000	0.042	0.021
Prob. for side-lobe pattern collision, PPAT_COL	0.000	0.258	0.000	0.000	0.000	0.258	0.258	0.258	0.258	0.308	0.308	0.000	0.000	0.957	0.978
Maximum probability of interference for part band interference	0.987	0.987	0.987	0.987	0.987	0.100	0.100	0.100	0.100	0.050	0.050	0.250	0.250	0.250	0.250
Total Main beam Mitigation Factor	1.89 E -03	6.22 E -02	1.89 E -03	1.95 E -02	1.48 E -02	3.76 E -04	3.76 E -03	3.76 E -04	3.76 E -03	2.83 E -03	2.83 E -03	2.56 E -01	2.56 E -01	1.10 E -02	5.51 E -03

	Number of interfering units inside a circular protection area of interferer's main beam (exponential distribution for SRD, linear for ENG/OB and Fixed) **Unit density (units/km2)**														
	0.01	0.03	0.1	0.3	1	3	10	30	100	300	1 k	3 k	10 k	30 k	100 k
SRD1 NB, indoor	5.82 E -05	1.75 E -04	5.82 E -04	1.75 E –03	5.82 E -03	1.75 E -02	5.82 E -02	1.75 E -01	5.82 E -01	1.75 E -00	5.82 E -00	1.75 E +01	5.82 E +01	1.75 E +02	5.82 E +02
SRD2 analogue Video, indoor	1.09 E -05	3.26 E -05	1.09 E -04	3.26 E -04	1.09 E -03	3.26 E -03	1.09 E -02	3.26 E -02	1.09 E -01	3.26 E -01	1.09 E -00	3.26 E -00	1.09 E +01	3.26 E +01	1.09 E +02
R-LAN1 FHSS, indoor	2.05 E -04	6.16 E -04	2.05 E -03	6.16 E -03	2.05 E -02	6.16 E -02	2.05 E -01	6.16 E -01	2.05 E -00	6.16 E -00	2.05 E +01	6.16 E +01	2.05 E +02	6.16 E +02	2.05 E +03
R-LAN2 DSSS, indoor	4.64 E -05	1.39 E -04	4.64 E -04	1.39 E -03	4.64 E -03	1.39 E -02	4.64 E -02	1.39 E -01	4.64 E -01	1.39 E -00	4.64 E -00	1.39 E +01	4.64 E +01	1.39 E +02	4.64 E +02
Fixed Access,100 mW, FHSS, outdoor	8.61 E -05	2.58 E -04	8.61 E -04	2.58 E -03	8.61 E -03	2.58 E -02	8.61 E -02	2.58 E -01	8.61 E -01	2.58 E -00	8.61 E -00	2.58 E +01	8.61 E +01	2.58 E +02	8.61 E +02
RFID 3a, 4W, FHSS, indoor, 10 % duty cycle	1.37 E -03	4.11 E -03	1.37 E -02	4.11 E -02	1.37 E -01	4.11 E -01	1.37 E -00	4.11 E -00	1.37 E +01	4.11 E +01	1.37 E +02	4.11 E +02	1.37 E +03	4.11 E +03	1.37 E +04
RFID 3a, 4W, FHSS, indoor, 100 % duty cycle	1.37 E -03	4.11 E -03	1.37 E -02	4.11 E -02	1.37 E -01	4.11 E -01	1.37 E -00	4.11 E -00	1.37 E +01	4.11 E +01	1.37 E +02	4.11 E +02	1.37 E +03	4.11 E +03	1.37 E +04
RFID 3b, 500mW, FHSS, indoor 10% duty cycle	4.83 E -04	1.45 E -03	4.83 E -03	1.45 E -02	4.83 E -02	1.45 E -01	4.83 E -01	1.45 E -00	4.83 E -00	1.45 E +01	4.83 E +01	1.45 E +02	4.83 E +02	1.45 E +03	4.83 E +03
RFID 3b, 500mW, FHSS, indoor 100% duty cycle	4.83 E -04	1.45 E -03	4.83 E -03	1.45 E -02	4.83 E -02	1.45 E -01	4.83 E -01	1.45 E -00	4.83 E -00	1.45 E +01	4.83 E +01	1.45 E +02	4.83 E +02	1.45 E +03	4.83 E +03
RFID 5a, 500 mW, NB, indoor	4.83 E -04	1.45 E -03	4.83 E -03	1.45 E -02	4.83 E -02	1.45 E -01	4.83 E -01	1.45 E -00	4.83 E -00	1.45 E +01	4.83 E +01	1.45 E +02	4.83 E +02	1.45 E +03	4.83 E +03
RFID 5b, 100 mW, NB, indoor	2.05 E -04	6.16 E -04	2.05 E -03	6.16 E -03	2.05 E -02	6.16 E -02	2.05 E -01	6.16 E -01	2.05 E -00	6.16 E -00	2.05 E +01	6.16 E +01	2.05 E +02	6.16 E +02	2.05 E +03
ENG/OB, analogue, T1, 3 W	1.35 E -04	4.05 E -04	1.35 E -03	4.05 E -03	1.35 E -02	4.05 E -02	1.35 E -01	4.05 E -01	1.35 E -00	4.05 E -00	1.35 E +01	4.05 E +01	1.35 E +02	4.05 E +02	1.35 E +03
ENG/OB, analogue, T2, 400 W	1.92 E +01	5.77 E +01	1.92 E +02	5.77 E +02	1.92 E +03	5.77 E +03	1.92 E +04	5.77 E +04	1.92 E +05	5.77 E +05	1.92 E +06	5.77 E +06	1.92 E +07	5.77 E +07	1.92 E +08
ENG/OB, analogue, T3, 2.5 kW	1.54 E -01	4.62 E -01	1.54 E -00	4.62 E -00	1.54 E +01	4.62 E +01	1.54 E +02	4.62 E +02	1.54 E +03	4.62 E +03	1.54 E +04	4.62 E +04	1.54 E +05	4.62 E +05	1.54 E +06
ENG/OB, analogue, T4, 10 kW	2.24 E +01	6.73 E +01	2.24 E +02	6.73 E +02	2.24 E +03	6.73 E +03	2.24 E +04	6.73 E +04	2.24 E +05	6.73 E +05	2.24 E +06	6.73 E +06	2.24 E +07	6.73 E +07	2.24 E +08
ENG/OB 1, digital, outdoor	2.34 E -04	7.02 E -04	2.34 E -03	7.02 E -03	2.34 E -02	7.02 E -02	2.34 E -01	7.02 E -01	2.34 E -00	7.02 E -00	2.34 E +01	7.02 E +01	2.34 E +02	7.02 E +02	2.34 E +03
ENG/OB 2, digital, outdoor	3.68 E +01	1.10 E +02	3.68 E +02	1.10 E +03	3.68 E +03	1.10 E +04	3.68 E +04	1.10 E +05	3.68 E +05	1.10 E +06	3.68 E +06	1.10 E +07	3.68 E +07	1.10 E +08	3.68 E +08
ENG/OB 3, digital, outdoor	2.67 E -01	8.00 E -01	2.67 E -00	8.00 E -00	2.67 E +01	8.00 E +01	2.67 E +02	8.00 E +02	2.67 E +03	8.00 E +03	2.67 E +04	8.00 E +04	2.67 E +05	8.00 E +05	2.67 E +06
ENG/OB 4, digital, outdoor	4.12 E +01	1.24 E +02	4.12 E +02	1.24 E +03	4.12 E +03	1.24 E +04	4.12 E +04	1.24 E +05	4.12 E +05	1.24 E +06	4.12 E +06	1.24 E +07	4.12 E +07	1.24 E +08	4.12 E +08
Fixed 1, 2 x 2 Mbit/s, MSK	1.74 E -00	5.22 E -00	1.74 E +01	5.22 E +01	1.74 E +02	5.22 E +02	1.74 E +03	5.22 E +03	1.74 E +04	5.22 E +04	1.74 E +05	5.22 E +05	1.74 E +06	5.22 E +06	1.74 E +07
Fixed 2, 34 Mbit/s, QPSK	2.43 E -00	7.30 E -00	2.43 E +01	7.30 E +01	2.43 E +02	7.30 E +02	2.43 E +03	7.30 E +03	2.43 E +04	7.30 E +04	2.43 E +05	7.30 E +05	2.43 E +06	7.30 E +06	2.43 E +07

Number of interfering units inside a circular protection area for interferer's side lobes (exponential distribution for SRD, linear for ENG/OB and Fixed)
Unit density (units/km2)

	0.01	0.03	0.1	0.3	1	3	10	30	100	300	1 k	3 k	10 k	30 k	100 k
SRD1 NB	5.82 E-05	1.75 E-04	5.82 E-04	1.75 E-03	5.82 E-03	1.75 E-02	5.82 E-02	1.75 E-01	5.82 E-01	1.75 E-00	5.82 E-00	1.75 E+01	5.82 E+01	1.75 E+02	5.82 E+02
SRD2 analogue Video, indoor	1.53 E-06	4.60 E-06	1.53 E-05	4.60 E-05	1.53 E-04	4.60 E-04	1.53 E-03	4.60 E-03	1.53 E-02	4.60 E-02	1.53 E-01	4.60 E-01	1.53 E-00	4.60 E-00	1.53 E+01
R-LAN1 FHSS, indoor	2.05 E-04	6.16 E-04	2.05 E-03	6.16 E-03	2.05 E-02	6.16 E-02	2.05 E-01	6.16 E-01	2.05 E-00	6.16 E-00	2.05 E+01	6.16 E+01	2.05 E+02	6.16 E+02	2.05 E+03
R-LAN2 DSSS, indoor	4.64 E-05	1.39 E-04	4.64 E-04	1.39 E-03	4.64 E-03	1.39 E-02	4.64 E-02	1.39 E-01	4.64 E-01	1.39 E-00	4.64 E-00	1.39 E+01	4.64 E+01	1.39 E+02	4.64 E+02
Fixed Access,100 mW, FHSS, outdoor	8.61 E-05	2.58 E-04	8.61 E-04	2.58 E-03	8.61 E-03	2.58 E-02	8.61 E-02	2.58 E-01	8.61 E-01	2.58 E-00	8.61 E-00	2.58 E+01	8.61 E+01	2.58 E+02	8.61 E+02
RFID 3a, 4W, FHSS, indoor, 10 % duty cycle	2.32 E-04	6.97 E-04	2.32 E-03	6.97 E-03	2.32 E-02	6.97 E-02	2.32 E-01	6.97 E-01	2.32 E-00	6.97 E-00	2.32 E+01	6.97 E+01	2.32 E+02	6.97 E+02	2.32 E+03
RFID 3a, 4W, FHSS, indoor, 100 % duty cycle	2.32 E-04	6.97 E-04	2.32 E-03	6.97 E-03	2.32 E-02	6.97 E-02	2.32 E-01	6.97 E-01	2.32 E-00	6.97 E-00	2.32 E+01	6.97 E+01	2.32 E+02	6.97 E+02	2.32 E+03
RFID 3b, 500mW, FHSS, indoor 10% duty cycle	7.51 E-05	2.25 E-04	7.51 E-04	2.25 E-03	7.51 E-03	2.25 E-02	7.51 E-02	2.25 E-01	7.51 E-01	2.25 E-00	7.51 E-00	2.25 E+01	7.51 E+01	2.25 E+02	7.51 E+02
RFID 3b, 500mW, FHSS, indoor 100% duty cycle	7.51 E-05	2.25 E-04	7.51 E-04	2.25 E-03	7.51 E-03	2.25 E-02	7.51 E-02	2.25 E-01	7.51 E-01	2.25 E-00	7.51 E-00	2.25 E+01	7.51 E+01	2.25 E+02	7.51 E+02
RFID 5a, 500 mW, NB, indoor	7.51 E-05	2.25 E-04	7.51 E-04	2.25 E-03	7.51 E-03	2.25 E-02	7.51 E-02	2.25 E-01	7.51 E-01	2.25 E-00	7.51 E-00	2.25 E+01	7.51 E+01	2.25 E+02	7.51 E+02
RFID 5b, 100 mW, NB, indoor	3.06 E-05	9.19 E-05	3.06 E-04	9.19 E-04	3.06 E-03	9.19 E-03	3.06 E-02	9.19 E-02	3.06 E-01	9.19 E-01	3.06 E-00	9.19 E-00	3.06 E+01	9.19 E+01	3.06 E+02
ENG/OB, analogue, T1, 3 W	1.35 E-04	4.05 E-04	1.35 E-03	4.05 E-03	1.35 E-02	4.05 E-02	1.35 E-01	4.05 E-01	1.35 E-00	4.05 E-00	1.35 E+01	4.05 E+01	1.35 E+02	4.05 E+02	1.35 E+03
ENG/OB, analogue, T2, 400 W	1.92 E+01	5.77 E+01	1.92 E+02	5.77 E+02	1.92 E+03	5.77 E+03	1.92 E+04	5.77 E+04	1.92 E+05	5.77 E+05	1.92 E+06	5.77 E+06	1.92 E+07	5.77 E+07	1.92 E+08
ENG/OB, analogue, T3, 2.5 kW	5.86 E-03	1.76 E-02	5.86 E-02	1.76 E-01	5.86 E-01	1.76 E-00	5.86 E-00	1.76 E+01	5.86 E+01	1.76 E+02	5.86 E+02	1.76 E+03	5.86 E+03	1.76 E+04	5.86 E+04
ENG/OB, analogue, T4, 10 kW	6.01 E-01	1.80 E-00	6.01 E-00	1.80 E+01	6.01 E+01	1.80 E+02	6.01 E+02	1.80 E+03	6.01 E+03	1.80 E+04	6.01 E+04	1.80 E+05	6.01 E+05	1.80 E+06	6.01 E+06
ENG/OB 1, digital, outdoor	2.34 E-04	7.02 E-04	2.34 E-03	7.02 E-03	2.34 E-02	7.02 E-02	2.34 E-01	7.02 E-01	2.34 E-00	7.02 E-00	2.34 E+01	7.02 E+01	2.34 E+02	7.02 E+02	2.34 E+03
ENG/OB 2, digital, outdoor	3.68 E+01	1.10 E+02	3.68 E+02	1.10 E+03	3.68 E+03	1.10 E+04	3.68 E+04	1.10 E+05	3.68 E+05	1.10 E+06	3.68 E+06	1.10 E+07	3.68 E+07	1.10 E+08	3.68 E+08
ENG/OB 3, digital, outdoor	1.01 E-02	3.04 E-02	1.01 E-01	3.04 E-01	1.01 E-00	3.04 E-00	1.01 E+01	3.04 E+01	1.01 E+02	3.04 E+02	1.01 E+03	3.04 E+03	1.01 E+04	3.04 E+04	1.01 E+05
ENG/OB 4, digital, outdoor	1.10 E-00	3.31 E-00	1.10 E+01	3.31 E+01	1.10 E+02	3.31 E+02	1.10 E+03	3.31 E+03	1.10 E+04	3.31 E+04	1.10 E+05	3.31 E+05	1.10 E+06	3.31 E+06	1.10 E+07
Fixed 1, 2 x 2 Mbit/s, MSK	5.02 E-02	1.51 E-01	5.02 E-01	1.51 E-00	5.02 E-00	1.51 E+01	5.02 E+01	1.51 E+02	5.02 E+02	1.51 E+03	5.02 E+03	1.51 E+04	5.02 E+04	1.51 E+05	5.02 E+05
Fixed 2, 34 Mbit/s, QPSK	8.05 E-02	2.41 E-01	8.05 E-01	2.41 E-00	8.05 E-00	2.41 E+01	8.05 E+01	2.41 E+02	8.05 E+02	2.41 E+03	8.05 E+03	2.41 E+04	8.05 E+04	2.41 E+05	8.05 E+05

Total cumulative probability of interference to indoor Bluetooth as a function of interferer unit density

	Unit density of interferer (units/km2)														
Type of interferers below .	0.01	0.03	0.1	0.3	1	3	10	30	100	300	1 k	3 k	10 k	30 k	100 k
SRD1, 10 mW, Narrow Band, D=100%, indoor mounted (reference)	1.08 E -07	3.25 E -07	1.08 E -06	3.25 E -06	1.08 E -05	3.25 E -05	1.08 E -04	3.25 E -04	1.08 E -03	3.25 E -03	1.08 E -02	3.20 E -02	1.03 E -01	2.78 E -01	6.62 E -01
SRD2, 10 mW, analogue Video, D=100%, indoor	7.93 E -07	2.38 E -06	7.93 E -06	2.38 E -05	7.93 E -05	2.38 E -04	7.93 E -04	2.38 E -03	7.90 E -03	2.35 E -02	7.62 E -02	2.12 E -01	5.48 E -01	9.07 E -01	9.88 E -01
R-LAN1, 100 mW, FHSS, D=100%, indoor mounted (reference)	3.83 E -07	1.15 E -06	3.83 E -06	1.15 E -05	3.83 E -05	1.15 E -04	3.83 E -04	1.15 E -03	3.82 E -03	1.14 E -02	3.76 E -02	1.09 E -01	3.18 E -01	6.83 E -01	9.78 E -01
R-LAN2, 100 mW, DSSS, D = 100%, indoor mounted	9.03 E -07	2.71 E -06	9.03 E -06	2.71 E -05	9.03 E -05	2.71 E -04	9.02 E -04	2.70 E -03	8.99 E -03	2.67 E -02	8.63 E -02	2.37 E -01	5.95 E -01	9.33 E -01	9.88 E -01
Fixed Access,100 mW, FHSS, outdoor	1.27 E -06	3.80 E -06	1.27 E -05	3.80 E -05	1.27 E -04	3.80 E -04	1.26 E -03	3.79 E -03	1.26 E -02	3.73 E -02	1.19 E -01	3.16 E -01	7.18 E -01	9.78 E -01	9.88 E -01
RFID 3a, 4W, FHSS, indoor, 10 % duty cycle	6.10 E -08	1.83 E -07	6.10 E -07	1.83 E -06	6.10 E -06	1.83 E -05	6.10 E -05	1.83 E -04	6.10 E -04	1.83 E -03	6.08 E -03	1.81 E -02	5.92 E -02	1.00 E -01	1.00 E -01
RFID 3a, 4W, FHSS, indoor, 100 % duty cycle	6.10 E -07	1.83 E -06	6.10 E -06	1.83 E -05	6.10 E -05	1.83 E -04	6.10 E -04	1.83 E -03	6.08 E -03	1.81 E -02	5.92 E -02	1.00 E -01	1.00 E -01	1.00 E -01	1.00 E -01
RFID 3b, 500mW, FHSS, indoor 10% duty cycle	2.12 E -08	6.36 E -08	2.12 E -07	6.36 E -07	2.12 E -06	6.36 E -06	2.12 E -05	6.36 E -05	2.12 E -04	6.36 E -04	2.12 E -03	6.34 E -03	2.10 E -02	6.17 E -02	1.00 E -01
RFID 3b, 500mW, FHSS, indoor 100% duty cycle	2.12 E -07	6.37 E -07	2.12 E -06	6.37 E -06	2.12 E -05	6.37 E -05	2.12 E -04	6.36 E -04	2.12 E -03	6.35 E -03	2.10 E -02	6.17 E -02	1.00 E -01	1.00 E -01	1.00 E -01
RFID 5a, 500 mW, Narrow Band, D=100%, indoor mounted	8.54 E -08	2.56 E -07	8.54 E -07	2.56 E -06	8.54 E -06	2.56 E -05	8.54 E -05	2.56 E -04	8.54 E -04	2.56 E -03	8.51 E -03	2.53 E -02	5.00 E -02	5.00 E -02	5.00 E -02
RFID 5b, 100 mW, Narrow Band, D=100%, indoor mounted	3.60 E -08	1.08 E -07	3.60 E -07	1.08 E -06	3.60 E -06	1.08 E -05	3.60 E -05	1.08 E -04	3.60 E -04	1.08 E -03	3.60 E -03	1.07 E -02	3.54 E -02	5.00 E -02	5.00 E -02
ENG/OB, analogue, T1, 3 W, outdoor	8.95 E -06	2.68 E -05													
ENG/OB, analogue, T2, 400 W, outdoor	2.50 E -01	2.50 E -01													
ENG/OB, analogue, T3, 2.5 kW, outdoor	7.94 E -04	2.38 E -03													
ENG/OB, analogue, T4, 10 kW, outdoor	6.74 E -02	1.89 E -01													
ENG/OB, digital, T1, 3 W, outdoor	9.50 E -02	9.50 E -02													
ENG/OB, digital, T2, 400 W, outdoor	9.50 E -02	9.50 E -02													
ENG/OB, digital, T3, 2.5 kW, outdoor	9.50 E -02	9.50 E -02													
ENG/OB, digital, T4, 10 kW, outdoor	9.50 E -02	9.50 E -02													
Fixed 1, 2 x 2 Mbit/s, MSK, outdoor	3.69 E -03	1.10 E -02													
Fixed 2, 34 Mbit/s, QPSK, outdoor	2.92 E -02	8.50 E -02													

ANNEX A.2. Interference from 1 mW Bluetooth to existing and planned services in the 2.400 - 2.4835 GHz band

Victims =>	SRD 1	SRD 2	RLAN 1	RLAN 2	Fixed Access	4W RFID 3a	0.5 W RFID 3b	0.5 W RFID 5a	0.1 W RFID 5b	ENG/ OB 1	ENG/ OB 2	ENG/ OB 3	ENG/ OB 4	ENG/ OB 1	ENG/ OB 2
	NB	Video	FHSS	DSSS	FHSS	FHSS	FHSS	NB	NB	Analo	Analo	Analo	Analo	Digital	Digital
INPUT DATA below										R3	R1	R2	R4	R3	R1
TX output power conducted, Pt (dBW)	-32	-32	-32	-32	-32	-32	-32	-32	-32	-32	-32	-32	-32	-32	-32
TX duty cycle	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Input Building attenuation, (dB)	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Input Frequency, (MHz)	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450
TX ant. gain minus feeder loss, Gt - Lft (dB)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Antenna horizontal coupling loss factor, (dB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tx Ant Main Lobe 3-dB beamwidth at 0 deg elevation, (deg)	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360
Rx Antenna Sidelobe 3-dB beamwidth at 0 deg elevation, (deg)	0	93	0	0	0	93	93	111	111	0	345	336	352	0	345
RX Antenna sidelobe attenuation at 0 deg elevation, (dB)	0	0	0	0	0	15	15	15	15	0	25	25	25	0	25
Input RX ant. gain - feeder loss, Gr - Lfr (dB)	2	6	2	2	2	6	6	8	8	4	21	17	27	4	21
Rx antenna 3-dB beamwidth, (degrees)	360	87	360	360	360	87	87	69	69	360	15	24	8	360	15
Auto calc. of Victim RX noise = (10*log kTB)+NF (dBW)	-140.8	-127.8	-140.8	-129.1	-140.8	-123.4	-123.4	-150.8	-150.8	-127.8	-127.8	-127.8	-127.8	-132.0	-132.0
Input Victim RX Noise figure, NF (dB)	3.0	3.0	3.0	3.0	3.0	25.0	25.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Background noise in ISM band (dB above system noise)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Relative interference level, I/N,(dB)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	0.0	0.0	0.0	0.0	20.0	20.0
Input TX mod. Equivalent noise BW, BWt (kHz)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Input Victim RX noise bandwidth, BWr (kHz)	1000	20000	1000	15000	1000	350	350	100	100	20000	20000	20000	20000	7600	7600
Input the shorter antenna height, Hm (m)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Input the taller antenna height, Hb (m)	3	3	3	3	5	1.5	1.5	2.5	2.5	200	1.8	3	50	200	1.8
Radio line of sight, (km)	12.1	12.1	12.1	12.1	14.2	10.0	10.0	11.5	11.5	63.0	10.5	12.1	34.0	63.0	10.5
Off-channel coupling loss, dB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Clutter loss for low antenna height in rural areas, dB	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3
Bluetooth radiated power, (dBm) EIRP															
RFID - Main Beam EIRP (dBm)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Required Path Loss for main beam (Minimum Coupling Loss, MCL)															
Path loss, in-door to in-door, PL (dB)	82.8	73.8	82.8	71.1	n/a	64.8	64.8	88.8	88.8	n/a	n/a	n/a	n/a	n/a	n/a
Path loss, in-door to out-door units, PL (dB)	82.8	73.8	82.8	71.1	82.8	64.8	64.8	88.8	88.8	81.8	98.8	94.8	104.8	66.0	83.0
Dfree_space (km) in-door to out-door	0.135	0.048	0.135	0.035	0.135	0.017	0.017	0.269	0.269	0.120	0.851	0.537	1.698	0.019	0.138
Path loss, out-door to out-door units, PL (dB)	97.8	88.8	97.8	86.1	97.8	n/a	79.8	103.8	103.8	96.8	113.8	109.8	119.8	81.0	98.0
Dfree_space (km) out-door to out-door	0.759	0.269	0.759	0.196	0.759	0.096	0.096	1.515	1.515	0.676	4.784	3.019	9.546	0.110	0.776

Victims =>	**SRD 1** NB	**SRD 2** Video	**RLAN 1** FHSS	**RLAN 2** DSSS	**Fixed Access** FHSS	**4W RFID 3a** FHSS	**0.5 W RFID 3b** FHSS	**0.5 W RFID 5a** NB	**0.1 W RFID 5b** NB	**ENG/ OB 1** Analo R3	**ENG/ OB 2** Analo R1	**ENG/ OB 3** Analo R2	**ENG/ OB 4** Analo R4	**ENG/ OB 1** Digital R3	**ENG/ OB 2** Digital R1
INPUT DATA below															
Required path loss for sidelobes (Minimum Coupling Loss, MCL)															
Path loss, in-door to in-door, PL (dB)	82.8	73.8	82.8	71.1	n/a	49.8	49.8	73.8	73.8	n/a	n/a	n/a	n/a	n/a	n/a
Path loss, in-door to out-door units, PL (dB)	82.8	73.8	82.8	71.1	82.8	49.8	49.8	73.8	73.8	81.8	73.8	69.8	79.8	66.0	58.0
Dfree_space (km) in-door to out-door	0.135	0.048	0.135	0.035	0.135	0.003	0.003	0.048	0.048	0.120	0.048	0.030	0.095	0.019	0.008
Path loss, out-door to out-door units, PL (dB)	97.8	88.8	97.8	86.1	97.8	n/a	64.8	88.8	88.8	96.8	88.8	84.8	94.8	81.0	73.0
Dfree_space (km) out-door to out-door	0.759	0.269	0.759	0.196	0.759	0.017	0.017	0.269	0.269	0.676	0.269	0.170	0.537	0.110	0.044
Protection Distances for co-channel interference to main beam															
Indoor model, in-door to in-door, (km)	0.044	0.024	0.044	0.020	n/a	0.014	0.014	0.066	0.066	n/a	n/a	n/a	n/a	n/a	n/a
Urban model, in-door to out-door, (km)	0.038	0.021	0.038	0.018	0.056	0.009	0.009	0.051	0.051	1.792	0.085	0.083	2.004	0.529	0.030
Urban model, out-door to out-door, (km)	0.101	0.056	0.101	0.047	0.150	n/a	0.023	0.136	0.136	5.706	0.227	0.222	5.573	1.685	0.081
Rural, in-door to out-door, (km)	0.135	0.048	0.135	0.035	0.135	0.017	0.017	0.269	0.269	n/a	n/a	n/a	n/a	n/a	n/a
Rural, out-door to out-door, (km)	0.218	0.269	0.218	0.196	0.759	n/a	0.096	0.281	0.281	0.676	0.424	0.435	3.159	0.110	0.171
h^2*h^2/r^4, (m)	250	149	250	127	322	63	63	322	322	1923	485	498	3614	775	196
a (Hm)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
a (Hb)	4.60	4.60	4.60	4.60	10.65	0.06	0.06	3.08	3.08	51.81	0.96	4.60	39.77	51.81	0.96
Protection Distances for co-channel interference to sidelobe															
Indoor model, in-door to in-door, (km)	0.044	0.024	0.044	0.020	n/a	0.005	0.005	0.025	0.025	n/a	n/a	n/a	n/a	n/a	n/a
Urban model, in-door to out-door, (km)	0.038	0.021	0.038	0.018	0.056	0.003	0.003	0.019	0.019	1.792	0.017	0.016	0.364	0.529	0.006
Urban model, out-door to out-door, (km)	0.101	0.056	0.101	0.047	0.150	n/a	0.009	0.051	0.051	5.706	0.044	0.043	1.014	1.685	0.016
Rural, in-door to out-door, (km)	0.135	0.048	0.135	0.035	0.135	0.003	0.003	0.048	0.048	n/a	n/a	n/a	n/a	n/a	n/a
Rural, out-door to out-door, (km)	0.218	0.269	0.218	0.196	0.759	n/a	0.017	0.269	0.269	0.676	0.269	0.170	0.537	0.110	0.044
h^2*h^2/r^4, (m)	250	149	250	127	322	26	26	136	136	1923	115	118	857	775	46
a (Hm)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
a (Hb)	4.60	4.60	4.60	4.60	10.65	0.06	0.06	3.08	3.08	51.81	0.96	4.60	39.77	51.81	0.96
Exponent k	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Intermediate Results for New Formula															
TX Single Channel BW (MHz)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
TX Hopping Span (MHz)	79.00	79.00	79.00	79.00	79.00	8.00	8.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
RX Single Channel BW (MHz)	1.00	20.00	1.00	15.00	1.00	0.35	0.35	0.10	0.10	20.00	20.00	20.00	20.00	7.60	7.60
Unit collision probability elements															
Probability for frequency collision, PFREQ_COL	0.018	1.000	0.018	0.196	0.018	0.015	0.015	0.013	0.013	0.275	0.275	0.275	0.275	0.120	0.120
Probability. for time collision, PTIME_COL	0.600	1.000	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600
Prob. for main beam pattern collision, PPAT_COL	1.000	0.241	1.000	1.000	1.000	0.241	0.241	0.191	0.191	1.000	0.042	0.068	0.021	1.000	0.042
Prob. for side-lobe pattern collision, PPAT_COL	0.000	0.258	0.000	0.000	0.000	0.258	0.258	0.308	0.308	0.000	0.957	0.932	0.978	0.000	0.957
Probability for coincidence of channel assignment	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Total Main beam Mitigation Factor	1.13 E -02	2.41 E -01	1.13 E -02	1.18 E -01	1.13 E -02	2.17 E -03	2.17 E -03	1.53 E -03	1.53 E -03	1.65 E -01	7.08 E -03	1.12 E -02	3.55 E -03	7.20 E -02	3.09 E -03

Number of interfering units inside a circular protection area of Interferer's main beam (exponential distribution for SRD, linear for ENG/OB and Fixed)

Unit density (units/km2)	0.01	0.03	0.1	0.3	1	3	10	30	100	300	1 k	3 k	10 k	30 k	100 k
SRD1, 10 mW, Narrow Band, D = 100%, indoor mounted (reference)	5.82 E -05	1.75 E -04	5.82 E -04	1.75 E -03	5.82 E -03	1.75 E -02	5.82 E -02	1.75 E -01	5.82 E -01	1.75 E -00	5.82 E -00	1.75 E +01	5.82 E +01	1.75 E +02	5.82 E +02
SRD 2, 10 mW, Video, D=100%, indoor mounted	1.82 E -05	5.47 E -05	1.82 E -04	5.47 E -04	1.82 E -03	5.47 E -03	1.82 E -02	5.47 E -02	1.82 E -01	5.47 E -01	1.82 E -00	5.47 E -00	1.82 E +01	5.47 E +01	1.82 E +02
R-LAN1 FHSS, indoor	5.82 E -05	1.75 E -04	5.82 E -04	1.75 E -03	5.82 E -03	1.75 E -02	5.82 E -02	1.75 E -01	5.82 E -01	1.75 E -00	5.82 E -00	1.75 E +01	5.82 E +01	1.75 E +02	5.82 E +02
R-LAN2 DSSS, indoor	1.28 E -05	3.83 E -05	1.28 E -04	3.83 E -04	1.28 E -03	3.83 E -03	1.28 E -02	3.83 E -02	1.28 E -01	3.83 E -01	1.28 E -00	3.83 E -00	1.28 E +01	3.83 E +01	1.28 E +02
Fixed Access, outdoor	9.28 E -05	2.78 E -04	9.28 E -04	2.78 E -03	9.28 E -03	2.78 E -02	9.28 E -02	2.78 E -01	9.28 E -01	2.78 E -00	9.28 E -00	2.78 E +01	9.28 E +01	2.78 E +02	9.28 E +02
RFID 3a, 4W, FHSS, indoor	5.67 E -06	1.70 E -05	5.67 E -05	1.70 E -04	5.67 E -04	1.70 E -03	5.67 E -03	1.70 E -02	5.67 E -02	1.70 E -01	5.67 E -01	1.70 E -00	5.67 E -00	1.70 E +01	5.67 E +01
RFID 3b, 500mW, FHSS, indoor	5.67 E -06	1.70 E -05	5.67 E -05	1.70 E -04	5.67 E -04	1.70 E -03	5.67 E -03	1.70 E -02	5.67 E -02	1.70 E -01	5.67 E -01	1.70 E -00	5.67 E -00	1.70 E +01	5.67 E +01
RFID 5a, 500 mW, NB, indoor	1.25 E -04	3.74 E -04	1.25 E -03	3.74 E -03	1.25 E -02	3.74 E -02	1.25 E -01	3.74 E -01	1.25 E -00	3.74 E -00	1.25 E +01	3.74 E +01	1.25 E +02	3.74 E +02	1.25 E +03
RFID 5b, 100 mW, NB, indoor	1.25 E -04	3.74 E -04	1.25 E -03	3.74 E -03	1.25 E -02	3.74 E -02	1.25 E -01	3.74 E -01	1.25 E -00	3.74 E -00	1.25 E +01	3.74 E +01	1.25 E +02	3.74 E +02	1.25 E +03
ENG/OB 1, analogue, outdoor	1.01 E -01	3.03 E -01	1.01 E -00	3.03 E -00	1.01 E +01	3.03 E +01	1.01 E +02	3.03 E +02	1.01 E +03	3.03 E +03	1.01 E +04	3.03 E +04	1.01 E +05	3.03 E +05	1.01 E +06
ENG/OB 2, analogue, outdoor	2.28 E -04	6.84 E -04	2.28 E -03	6.84 E -03	2.28 E -02	6.84 E -02	2.28 E -01	6.84 E -01	2.28 E -00	6.84 E -00	2.28 E +01	6.84 E +01	2.28 E +02	6.84 E +02	2.28 E +03
ENG/OB 3, analogue, outdoor	2.17 E -04	6.52 E -04	2.17 E -03	6.52 E -03	2.17 E -02	6.52 E -02	2.17 E -01	6.52 E -01	2.17 E -00	6.52 E -00	2.17 E +01	6.52 E +01	2.17 E +02	6.52 E +02	2.17 E +03
ENG/OB 4, analogue, outdoor	1.26 E -01	3.79 E -01	1.26 E -00	3.79 E -00	1.26 E +01	3.79 E +01	1.26 E +02	3.79 E +02	1.26 E +03	3.79 E +03	1.26 E +04	3.79 E +04	1.26 E +05	3.79 E +05	1.26 E +06
ENG/OB 1, digital, outdoor	8.81 E -03	2.64 E -02	8.81 E -02	2.64 E -01	8.81 E -01	2.64 E -00	8.81 E -00	2.64 E +01	8.81 E +01	2.64 E +02	8.81 E +02	2.64 E +03	8.81 E +03	2.64 E +04	8.81 E +04
ENG/OB 2, digital, outdoor	2.89 E -05	8.67 E -05	2.89 E -04	8.67 E -04	2.89 E -03	8.67 E -03	2.89 E -02	8.67 E -02	2.89 E -01	8.67 E -01	2.89 E -00	8.67 E -00	2.89 E +01	8.67 E +01	2.89 E +02
ENG/OB 3, digital, outdoor	2.75 E -05	8.26 E -05	2.75 E -04	8.26 E -04	2.75 E -03	8.26 E -03	2.75 E -02	8.26 E -02	2.75 E -01	8.26 E -01	2.75 E -00	8.26 E -00	2.75 E +01	8.26 E +01	2.75 E +02
ENG/OB 4, digital, outdoor	8.48 E -03	2.55 E -02	8.48 E -02	2.55 E -01	8.48 E -01	2.55 E -00	8.48 E -00	2.55 E +01	8.48 E +01	2.55 E +02	8.48 E +02	2.55 E +03	8.48 E +03	2.55 E +04	8.48 E +04
Fixed 1, 2 x 2 Mbit/s, MSK, outdoor	7.17 E -01	2.15 E -00	7.17 E -00	2.15 E +01	7.17 E +01	2.15 E +02	7.17 E +02	2.15 E +03	7.17 E +03	2.15 E +04	7.17 E +04	2.15 E +05	7.17 E +05	2.15 E +06	7.17 E +06
Fixed 2, 34 Mbit/s, QPSK, outdoor	1.00 E -00	3.01 E -00	1.00 E +01	3.01 E +01	1.00 E +02	3.01 E +02	1.00 E +03	3.01 E +03	1.00 E +04	3.01 E +04	1.00 E +05	3.01 E +05	1.00 E +06	3.01 E +06	1.00 E +07

Number of interfering units inside a circular protection area for interferer's side lobes (exponential distribution for SRD, linear for ENG/OB and Fixed)

Unit density (units/km2)	0.01	0.03	0.1	0.3	1	3	10	30	100	300	1 k	3 k	10 k	30 k	100 k
SRD1, 10 mW, Narrow Band, D = 100%, indoor mounted (reference)	5.82 E -05	1.75 E -04	5.82 E -04	1.75 E -03	5.82 E -03	1.75 E -02	5.82 E -02	1.75 E -01	5.82 E -01	1.75 E -00	5.82 E -00	1.75 E +01	5.82 E +01	1.75 E +02	5.82 E +02
SRD 2, 10 mW, Video, D=100%, indoor	1.82 E -05	5.47 E -05	1.82 E -04	5.47 E -04	1.82 E -03	5.47 E -03	1.82 E -02	5.47 E -02	1.82 E -01	5.47 E -01	1.82 E -00	5.47 E -00	1.82 E +01	5.47 E +01	1.82 E +02
R-LAN1 FHSS, indoor	5.82 E -05	1.75 E -04	5.82 E -04	1.75 E -03	5.82 E -03	1.75 E -02	5.82 E -02	1.75 E -01	5.82 E -01	1.75 E -00	5.82 E -00	1.75 E +01	5.82 E +01	1.75 E +02	5.82 E +02
R-LAN2 DSSS, indoor	1.28 E -05	3.83 E -05	1.28 E -04	3.83 E -04	1.28 E -03	3.83 E -03	1.28 E -02	3.83 E -02	1.28 E -01	3.83 E -01	1.28 E -00	3.83 E -00	1.28 E +01	3.83 E +01	1.28 E +02
Fixed Access, outdoor	9.28 E -05	2.78 E -04	9.28 E -04	2.78 E -03	9.28 E -03	2.78 E -02	9.28 E -02	2.78 E -01	9.28 E -01	2.78 E -00	9.28 E -00	2.78 E +01	9.28 E +01	2.78 E +02	9.28 E +02
RFID 3a, 4W, FHSS, indoor	7.97 E -07	2.39 E -06	7.97 E -06	2.39 E -05	7.97 E -05	2.39 E -04	7.97 E -04	2.39 E -03	7.97 E -03	2.39 E -02	7.97 E -02	2.39 E -01	7.97 E -01	2.39 E -00	7.97 E -00
RFID 3b, 500mW, FHSS, indoor	7.97 E -07	2.39 E -06	7.97 E -06	2.39 E -05	7.97 E -05	2.39 E -04	7.97 E -04	2.39 E -03	7.97 E -03	2.39 E -02	7.97 E -02	2.39 E -01	7.97 E -01	2.39 E -00	7.97 E -00
RFID 5a, 500 mW, NB, indoor	1.83 E -05	5.48 E -05	1.83 E -04	5.48 E -04	1.83 E -03	5.48 E -03	1.83 E -02	5.48 E -02	1.83 E -01	5.48 E -01	1.83 E -00	5.48 E -00	1.83 E +01	5.48 E +01	1.83 E +02
RFID 5b, 100 mW, NB, indoor	1.83 E -05	5.48 E -05	1.83 E -04	5.48 E -04	1.83 E -03	5.48 E -03	1.83 E -02	5.48 E -02	1.83 E -01	5.48 E -01	1.83 E -00	5.48 E -00	1.83 E +01	5.48 E +01	1.83 E +02
ENG/OB 1, analogue, outdoor	1.01 E -01	3.03 E -01	1.01 E -00	3.03 E -00	1.01 E +01	3.03 E +01	1.01 E +02	3.03 E +02	1.01 E +03	3.03 E +03	1.01 E +04	3.03 E +04	1.01 E +05	3.03 E +05	1.01 E +06
ENG/OB 2, analogue, outdoor	8.68 E -06	2.60 E -05	8.68 E -05	2.60 E -04	8.68 E -04	2.60 E -03	8.68 E -03	2.60 E -02	8.68 E -02	2.60 E -01	8.68 E -01	2.60 E -00	8.68 E -00	2.60 E +01	8.68 E +01
ENG/OB 3, analogue, outdoor	8.27 E -06	2.48 E -05	8.27 E -05	2.48 E -04	8.27 E -04	2.48 E -03	8.27 E -03	2.48 E -02	8.27 E -02	2.48 E -01	8.27 E -01	2.48 E -00	8.27 E -00	2.48 E +01	8.27 E +01
ENG/OB 4, analogue, outdoor	4.17 E -03	1.25 E -02	4.17 E -02	1.25 E -01	4.17 E -01	1.25 E -00	4.17 E -00	1.25 E +01	4.17 E +01	1.25 E +02	4.17 E +02	1.25 E +03	4.17 E +03	1.25 E +04	4.17 E +04
ENG/OB 1, digital, outdoor	8.81 E -03	2.64 E -02	8.81 E -02	2.64 E -01	8.81 E -01	2.64 E -00	8.81 E -00	2.64 E +01	8.81 E +01	2.64 E +02	8.81 E +02	2.64 E +03	8.81 E +03	2.64 E +04	8.81 E +04
ENG/OB 2, digital, outdoor	1.10 E -06	3.30 E -06	1.10 E -05	3.30 E -05	1.10 E -04	3.30 E -04	1.10 E -03	3.30 E -03	1.10 E -02	3.30 E -02	1.10 E -01	3.30 E -01	1.10 E -00	3.30 E -00	1.10 E +01
ENG/OB 3, digital, outdoor	1.05 E -06	3.15 E -06	1.05 E -05	3.15 E -05	1.05 E -04	3.15 E -04	1.05 E -03	3.15 E -03	1.05 E -02	3.15 E -02	1.05 E -01	3.15 E -01	1.05 E -00	3.15 E -00	1.05 E +01
ENG/OB 4, digital, outdoor	2.81 E -04	8.42 E -04	2.81 E -03	8.42 E -03	2.81 E -02	8.42 E -02	2.81 E -01	8.42 E -01	2.81 E -00	8.42 E -00	2.81 E +01	8.42 E +01	2.81 E +02	8.42 E +02	2.81 E +03
Fixed 1, 2 x 2 Mbit/s, MSK, outdoor	2.37 E -02	7.11 E -02	2.37 E -01	7.11 E -01	2.37 E -00	7.11 E -00	2.37 E +01	7.11 E +01	2.37 E +02	7.11 E +02	2.37 E +03	7.11 E +03	2.37 E +04	7.11 E +04	2.37 E +05
Fixed 2, 34 Mbit/s, QPSK, outdoor	3.32 E -02	9.95 E -02	3.32 E -01	9.95 E -01	3.32 E -00	9.95 E -00	3.32 E +01	9.95 E +01	3.32 E +02	9.95 E +02	3.32 E +03	9.95 E +03	3.32 E +04	9.95 E +04	3.32 E +05

Cumulative probability of interference as a function of Bluetooth unit density

	Unit density of Bluetooth (units/km2)														
Type of victims below	0.01	0.03	0.1	0.3	1	3	10	30	100	300	1 k	3 k	10 k	30 k	100 k
SRD1, 10 mW, Narrow Band, D = 100%, indoor mounted (reference)	6.62 E -07	1.99 E -06	6.62 E -06	1.99 E -05	6.62 E -05	1.99 E -04	6.62 E -04	1.99 E -03	6.60 E -03	1.97 E -02	6.41 E -02	1.80 E -01	4.84 E -01	8.63 E -01	9.99 E -01
SRD 2, 10 mW, Video, D=100%, indoor	1.05 E -05	3.15 E -05	1.05 E -04	3.15 E -04	1.05 E -03	3.15 E -03	1.04 E -02	3.10 E -02	9.97 E -02	2.70 E -01	6.50 E -01	9.57 E -01	10.00 E -01	10.00 E -01	1.00 E -00
R-LAN1, 100 mW, FHSS, D = 100%, indoor mounted	6.62 E -07	1.99 E -06	6.62 E -06	1.99 E -05	6.62 E -05	1.99 E -04	6.62 E -04	1.99 E -03	6.60 E -03	1.97 E -02	6.41 E -02	1.80 E -01	4.84 E -01	8.63 E -01	9.99 E -01
R-LAN2, 100 mW, DSSS, D = 100%, indoor mounted	1.60 E -06	4.80 E -06	1.60 E -05	4.80 E -05	1.60 E -04	4.80 E -04	1.60 E -03	4.79 E -03	1.59 E -02	4.69 E -02	1.48 E -01	3.81 E -01	7.98 E -01	9.92 E -01	10.00 E -01
Fixed Access, outdoor	2.11 E -06	6.34 E -06	2.11 E -05	6.34 E -05	2.11 E -04	6.34 E -04	2.11 E -03	6.32 E -03	2.09 E -02	6.14 E -02	1.91 E -01	4.70 E -01	8.79 E -01	9.98 E -01	10.00 E -01
RFID 3a, 4W, FHSS BW = 8 MHz, D = 15%, indoor mounted	1.42 E -08	4.26 E -08	1.42 E -07	4.26 E -07	1.42 E -06	4.26 E -06	1.42 E -05	4.26 E -05	1.42 E -04	4.26 E -04	1.42 E -03	4.25 E -03	1.41 E -02	4.17 E -02	1.32 E -01
RFID 3b, 500mW, FHSS BW = 8 MHz, D =15%, indoor mounted	1.42 E -08	4.26 E -08	1.42 E -07	4.26 E -07	1.42 E -06	4.26 E -06	1.42 E -05	4.26 E -05	1.42 E -04	4.26 E -04	1.42 E -03	4.25 E -03	1.41 E -02	4.17 E -02	1.32 E -01
RFID 5a, 500 mW, Narrow Band, D = 100%, indoor mounted	2.35 E -07	7.06 E -07	2.35 E -06	7.06 E -06	2.35 E -05	7.06 E -05	2.35 E -04	7.06 E -04	2.35 E -03	7.04 E -03	2.33 E -02	6.82 E -02	2.10 E -01	5.06 E -01	9.05 E -01
RFID 5b, 100 mW, Narrow Band, D = 100%, indoor mounted	2.35 E -07	7.06 E -07	2.35 E -06	7.06 E -06	2.35 E -05	7.06 E -05	2.35 E -04	7.06 E -04	2.35 E -03	7.04 E -03	2.33 E -02	6.82 E -02	2.10 E -01	5.06 E -01	9.05 E -01
ENG/OB 1, analogue, outdoor	1.80 E -02	5.31 E -02													
ENG/OB 2, analogue, outdoor	4.11 E -05	1.23 E -04													
ENG/OB 3, analogue, outdoor	3.92 E -05	1.18 E -04													
ENG/OB 4, analogue, outdoor	2.25 E -02	6.60 E -02													
ENG/OB 1, digital, outdoor	1.59 E -03	4.75 E -03													
ENG/OB 2, digital, outdoor	5.21 E -06	1.56 E -05													
ENG/OB 3, digital, outdoor	4.97 E -06	1.49 E -05													
ENG/OB 4, digital, outdoor	1.53 E -03	4.58 E -03													
Fixed 1, 2 x 2 Mbit/s, MSK, outdoor	1.21 E -01	3.21 E -01													
Fixed 2, 34 Mbit/s, QPSK, outdoor	1.65 E -01	4.19 E -01													

ANNEX A.3. Interference from 100 mW Bluetooth to existing and planned services in the 2.400 - 2.4835 GHz band

Victims =>	**SRD 1** NB	**SRD 2** Video	**RLAN 1** FHSS	**RLAN 2** DSSS	**Fixed Access** FHSS	**4W RFID 3a** FHSS	**0.5 W RFID 3b** FHSS	**0.5 W RFID 5a** NB	**0.1 W RFID 5b** NB	**ENG/ OB 1** Analo R3	**ENG/ OB 2** Analo R1	**ENG/ OB 3** Analo R2	**ENG/ OB 4** Analo R4	**ENG/ OB 1** Digital R3	**ENG/ OB 2** Digital R1	**ENG/ OB 3** Digital R2	**ENG/ OB 4** Digital R4	**Fixed Service 1** 2x2Mbit/s MSK	**Fixed Service 2** 34 Mbit/s QPSK
INPUT DATA below																			
TX output power conducted, Pt (dBW)	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12
TX duty cycle	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Input Building attenuation, (dB)	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Input Frequency, (MHz)	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450
TX ant. gain minus feeder loss, Gt - Lft (dB)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Antenna horizontal coupling loss factor, (dB)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tx Ant Main Lobe 3-dB beamwidth at 0 deg elevation, (deg)	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360	360
Rx Antenna Sidelobe 3-dB beamwidth at 0 deg elevation, (deg)	0	93	0	0	0	93	93	111	111	0	345	336	352	0	345	336	352	350	0
RX Antenna sidelobe attenuation at 0 deg elevation, (dB)	0	0	0	0	0	15	15	15	15	0	25	25	25	0	25	25	25	25	25
Input RX ant. gain - feeder loss, Gr - Lfr (dB)	2	6	2	2	2	6	6	8	8	4	21	17	27	4	21	17	27	25	35.7
Rx antenna 3-dB beamwidth, (degrees)	360	87	360	360	360	87	87	69	69	360	15	24	8	360	15	24	8	10	3
Auto calc. of Victim RX noise = (10*log kTB)+NF (dBW)	-140.8	-127.8	-140.8	-129.1	-140.8	-123.4	-123.4	-150.8	-150.8	-127.8	-127.8	-127.8	-127.8	-132.0	-132.0	-132.0	-132.0	-136.1	-127.8
Input Victim RX Noise figure, NF (dB)	3.0	3.0	3.0	3.0	3.0	25.0	25.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Background noise in ISM band (dB above system noise)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Relative interference level, I/N,(dB)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	20.0	-10.0	-10.0
Input TX mod. Equivalent noise BW, BWt (kHz)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Input Victim RX noise bandwidth, BWr (kHz)	1000	20000	1000	15000	1000	350	350	100	100	20000	20000	20000	20000	7600	7600	7600	7600	3000	20000
Input the shorter antenna height, Hm (m)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Input the taller antenna height, Hb (m)	3	3	3	3	5	1.5	1.5	2.5	2.5	200	1.8	3	50	200	1.8	3	50	50	50
Radio line of sight, (km)	12.1	12.1	12.1	12.1	14.2	10.0	10.0	11.5	11.5	63.0	10.5	12.1	34.0	63.0	10.5	12.1	34.0	34.0	34.0
Off-channel coupling loss, dB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Clutter loss for low antenna height in rural areas, dB	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3
Bluetooth radiated power, (dBm) EIRP																			
RFID - Main Beam EIRP (dBm)	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Required path loss for main beam (Minimum Coupling Loss, MCL)																			
Path loss, in-door to in-door, PL (dB)	102.8	93.8	102.8	91.1	n/a	84.8	84.8	108.8	108.8	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Path loss, in-door to out-door units, PL (dB)	102.8	93.8	102.8	91.1	102.8	84.8	84.8	108.8	108.8	101.8	118.8	114.8	124.8	86.0	103.0	99.0	109.0	141.1	143.5
Dfree_space (km) in-door to out-door	1.350	0.478	1.350	0.349	1.350	0.170	0.170	2.694	2.694	1.202	8.508	5.368	16.975	0.195	1.380	0.871	2.754	110.096	146.157
Path loss, out-door to out-door units, PL (dB)	117.8	108.8	117.8	106.1	117.8	n/a	99.8	123.8	123.8	116.8	133.8	129.8	139.8	101.0	118.0	114.0	124.0	156.1	158.5
Dfree_space (km) out-door to out-door	7.592	2.690	7.592	1.960	7.592	0.956	0.956	15.147	15.147	6.758	47.843	30.187	95.459	1.096	7.761	4.897	15.486	619.118	821.900
Required path loss for side lobes (Minimum Coupling Loss, MCL)																			
Path loss, in-door to in-door, PL (dB)	102.8	93.8	102.8	91.1	n/a	69.8	69.8	93.8	93.8	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Path loss, in-door to out-door units, PL (dB)	102.8	93.8	102.8	91.1	102.8	69.8	69.8	93.8	93.8	101.8	93.8	89.8	99.8	86.0	78.0	74.0	84.0	116.1	118.5
Dfree_space (km) in-door to out-door	1.350	0.478	1.350	0.349	1.350	0.030	0.030	0.479	0.479	1.202	0.478	0.302	0.955	0.195	0.078	0.049	0.155	6.191	8.219
Path loss, out-door to out-door units, PL (dB)	117.8	108.8	117.8	106.1	117.8	n/a	84.8	108.8	108.8	116.8	108.8	104.8	114.8	101.0	93.0	89.0	99.0	131.1	133.5
Dfree_space (km) out-door to out-door	7.592	2.690	7.592	1.960	7.592	0.170	0.170	2.694	2.694	6.758	2.690	1.698	5.368	1.096	0.436	0.275	0.871	34.81	46.21

ANNEX A.3 (Cont.). Interference from 100 mW Bluetooth to existing and planned services in the 2.400 - 2.4835 GHz band

Victims => **INPUT DATA below**	**SRD 1** NB	**SRD 2** Video	**RLAN 1** FHSS	**RLAN 2** DSSS	**Fixed Access** FHSS	**4W RFID 3a** FHSS	**0.5 W RFID 3b** FHSS	**0.5 W RFID 5a** NB	**0.1 W RFID 5b** NB	**ENG/ OB 1** Analo R3	**ENG/ OB 2** Analo R1	**ENG/ OB 3** Analo R2	**ENG/ OB 4** Analo R4	**ENG/ OB 1** Digital R3	**ENG/ OB 2** Digital R1	**ENG/ OB 3** Digital R2	**ENG/ OB 4** Digital R4	**Fixed Servic e 1** 2x2M bit/s MSK	**Fixed Servic e 2** 34 Mbit/s QPSK
Protection distances for co-channel interference to main beam																			
Indoor model, in-door to in-door, (km)	0.165	0.091	0.165	0.076	n/a	0.051	0.051	0.245	0.245	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Urban model, in-door to out-door, (km)	0.140	0.078	0.140	0.065	0.209	0.032	0.032	0.188	0.188	8.393	0.315	0.307	7.837	2.479	0.112	0.109	2.669	23.714	28.046
Urban model, out-door to out-door, (km)	0.374	0.208	0.374	0.174	0.556	n/a	0.086	0.502	0.502	26.718	0.839	0.820	21.793	7.892	0.299	0.292	7.422	65.943	77.989
Rural, in-door to out-door, (km)	0.291	0.173	0.291	0.349	0.376	0.170	0.170	0.375	0.375	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Rural, out-door to out-door, (km)	0.690	0.411	0.690	0.351	0.891	n/a	0.173	0.890	0.890	6.758	1.342	1.376	9.989	1.096	0.540	0.554	4.023	25.440	29.311
h^2*h^2/r^4, (m)	790	470	790	401	1019	198	198	1018	1018	6082	1535	1574	11429	2450	618	634	4603	29107	33537
a (Hm)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
a (Hb)	4.60	4.60	4.60	4.60	10.65	0.06	0.06	3.08	3.08	51.81	0.96	4.60	39.77	51.81	0.96	4.60	39.77	39.77	39.77
Protection distances for co-channel interference to side lobes																			
Indoor model, in-door to in-door, (km)	0.165	0.091	0.165	0.076	n/a	0.019	0.019	0.091	0.091	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Urban model, in-door to out-door, (km)	0.140	0.078	0.140	0.065	0.209	0.012	0.012	0.071	0.071	8.393	0.061	0.060	1.425	2.479	0.022	0.021	0.485	4.313	5.101
Urban model, out-door to out-door, (km)	0.374	0.208	0.374	0.174	0.556	n/a	0.032	0.188	0.188	26.718	0.164	0.160	3.963	7.892	0.058	0.057	1.350	11.992	14.183
Rural, in-door to out-door, (km)	0.291	0.173	0.291	0.349	0.376	0.030	0.030	0.158	0.158	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Rural, out-door to out-door, (km)	0.690	0.411	0.690	0.351	0.891	n/a	0.170	0.375	0.375	6.758	0.318	0.326	5.368	1.096	0.128	0.275	0.871	6.033	6.951
h^2*h^2/r^4, (m)	790	470	790	401	1019	84	84	429	429	6082	364	373	2710	2450	147	150	1092	6902	7953
a (Hm)	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
a (Hb)	4.60	4.60	4.60	4.60	10.65	0.06	0.06	3.08	3.08	51.81	0.96	4.60	39.77	51.81	0.96	4.60	39.77	39.77	39.77
Exponent k	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2				
Intermediate results for new formula																			
TX Single Channel BW (MHz)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00				
TX Hopping Span (MHz)	79.00	79.00	79.00	79.00	79.00	8.00	8.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00				
RX Single Channel BW (MHz)	1.00	20.00	1.00	15.00	1.00	0.35	0.35	0.10	0.10	20.00	20.00	20.00	20.00	7.60	7.60				
Unit collision probability elements																			
Probability for frequency collision, PFREQ_COL	0.018	1.000	0.018	0.196	0.018	0.015	0.015	0.013	0.013	0.275	0.275	0.275	0.275	0.120	0.120				
Probability for time collision, PTIME_COL	0.600	1.000	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600				
Prob. for main beam pattern collision, PPAT_COL	1.000	0.241	1.000	1.000	1.000	0.241	0.241	0.191	0.191	1.000	0.042	0.068	0.021	1.000	0.042				
Prob. for side-lobe pattern collision, PPAT_COL	0.000	0.258	0.000	0.000	0.000	0.258	0.258	0.308	0.308	0.000	0.957	0.932	0.978	0.000	0.957				
Prob. for coincidence of channel assignment	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
Total Main beam Mitigation Factor	1.13 E -02	2.41 E -01	1.13 E -02	1.18 E -01	1.13 E -02	2.17 E -03	2.17 E -03	1.53 E -03	1.53 E -03	1.65 E -01	7.08 E -03	1.12 E -02	3.55 E -03	7.20 E -02	3.09 E -03				

Number of interfering units inside a circular protection area of interferer's main beam (exponential distribution for SRD, linear for ENG/OB and Fixed)

Unit density (units/km2)	0.01	0.03	0.1	0.3	1	3	10	30	100	300	1 k	3 k	10 k	30 k	100 k
SRD1, 10 mW, Narrow Band, D = 100%, indoor mounted (reference)	6.90 E -04	2.07 E -03	6.90 E -03	2.07 E -02	6.90 E -02	2.07 E -01	6.90 E -01	2.07 E -00	6.90 E -00	2.07 E +01	6.90 E +01	2.07 E +02	6.90 E +02	2.07 E +03	6.90 E +03
SRD 2, 10 mW, Video, D=100%, indoor mounted	2.32 E -04	6.97 E -04	2.32 E -03	6.97 E -03	2.32 E -02	6.97 E -02	2.32 E -01	6.97 E -01	2.32 E -00	6.97 E -00	2.32 E +01	6.97 E +01	2.32 E +02	6.97 E +02	2.32 E +03
R-LAN1 FHSS, indoor	6.90 E -04	2.07 E -03	6.90 E -03	2.07 E -02	6.90 E -02	2.07 E -01	6.90 E -01	2.07 E -00	6.90 E -00	2.07 E +01	6.90 E +01	2.07 E +02	6.90 E +02	2.07 E +03	6.90 E +03
R-LAN2 DSSS, indoor	1.65 E -04	4.95 E -04	1.65 E -03	4.95 E -03	1.65 E -02	4.95 E -02	1.65 E -01	4.95 E -01	1.65 E -00	4.95 E -00	1.65 E +01	4.95 E +01	1.65 E +02	4.95 E +02	1.65 E +03
Fixed Access, outdoor	1.04 E -03	3.12 E -03	1.04 E -02	3.12 E -02	1.04 E -01	3.12 E -01	1.04 E -00	3.12 E -00	1.04 E +01	3.12 E +01	1.04 E +02	3.12 E +02	1.04 E +03	3.12 E +03	1.04 E +04
RFID 3a, 4W, FHSS, indoor	7.51 E -05	2.25 E -04	7.51 E -04	2.25 E -03	7.51 E -03	2.25 E -02	7.51 E -02	2.25 E -01	7.51 E -01	2.25 E -00	7.51 E -00	2.25 E +01	7.51 E +01	2.25 E +02	7.51 E +02
RFID 3b, 500mW, FHSS, indoor	7.51 E -05	2.25 E -04	7.51 E -04	2.25 E -03	7.51 E -03	2.25 E -02	7.51 E -02	2.25 E -01	7.51 E -01	2.25 E -00	7.51 E -00	2.25 E +01	7.51 E +01	2.25 E +02	7.51 E +02
RFID 5a, 500 mW, NB, indoor	1.37 E -03	4.11 E -03	1.37 E -02	4.11 E -02	1.37 E -01	4.11 E -01	1.37 E -00	4.11 E -00	1.37 E +01	4.11 E +01	1.37 E +02	4.11 E +02	1.37 E +03	4.11 E +03	1.37 E +04
RFID 5b, 100 mW, NB, indoor	1.37 E -03	4.11 E -03	1.37 E -02	4.11 E -02	1.37 E -01	4.11 E -01	1.37 E -00	4.11 E -00	1.37 E +01	4.11 E +01	1.37 E +02	4.11 E +02	1.37 E +03	4.11 E +03	1.37 E +04
ENG/OB 1, analogue, outdoor	2.21 E -00	6.64 E -00	2.21 E +01	6.64 E +01	2.21 E +02	6.64 E +02	2.21 E +03	6.64 E +03	2.21 E +04	6.64 E +04	2.21 E +05	6.64 E +05	2.21 E +06	6.64 E +06	2.21 E +07
ENG/OB 2, analogue, outdoor	3.11 E -03	9.34 E -03	3.11 E -02	9.34 E -02	3.11 E -01	9.34 E -01	3.11 E -00	9.34 E -00	3.11 E +01	9.34 E +01	3.11 E +02	9.34 E +02	3.11 E +03	9.34 E +03	3.11 E +04
ENG/OB 3, analogue, outdoor	2.97 E -03	8.91 E -03	2.97 E -02	8.91 E -02	2.97 E -01	8.91 E -01	2.97 E -00	8.91 E -00	2.97 E +01	8.91 E +01	2.97 E +02	8.91 E +02	2.97 E +03	8.91 E +03	2.97 E +04
ENG/OB 4, analogue, outdoor	1.93 E -00	5.79 E -00	1.93 E +01	5.79 E +01	1.93 E +02	5.79 E +02	1.93 E +03	5.79 E +03	1.93 E +04	5.79 E +04	1.93 E +05	5.79 E +05	1.93 E +06	5.79 E +06	1.93 E +07
ENG/OB 1, digital, outdoor	1.93 E -01	5.79 E -01	1.93 E -00	5.79 E -00	1.93 E +01	5.79 E +01	1.93 E +02	5.79 E +02	1.93 E +03	5.79 E +03	1.93 E +04	5.79 E +04	1.93 E +05	5.79 E +05	1.93 E +06
ENG/OB 2, digital, outdoor	3.95 E -04	1.18 E -03	3.95 E -03	1.18 E -02	3.95 E -02	1.18 E -01	3.95 E -01	1.18 E -00	3.95 E -00	1.18 E +01	3.95 E +01	1.18 E +02	3.95 E +02	1.18 E +03	3.95 E +03
ENG/OB 3, digital, outdoor	3.76 E -04	1.13 E -03	3.76 E -03	1.13 E -02	3.76 E -02	1.13 E -01	3.76 E -01	1.13 E -00	3.76 E -00	1.13 E +01	3.76 E +01	1.13 E +02	3.76 E +02	1.13 E +03	3.76 E +03
ENG/OB 4, digital, outdoor	2.24 E -01	6.71 E -01	2.24 E -00	6.71 E -00	2.24 E +01	6.71 E +01	2.24 E +02	6.71 E +02	2.24 E +03	6.71 E +03	2.24 E +04	6.71 E +04	2.24 E +05	6.71 E +05	2.24 E +06
Fixed 1, 2 x 2 Mbit/s, MSK, outdoor	1.77 E +01	5.30 E +01	1.77 E +02	5.30 E +02	1.77 E +03	5.30 E +03	1.77 E +04	5.30 E +04	1.77 E +05	5.30 E +05	1.77 E +06	5.30 E +06	1.77 E +07	5.30 E +07	1.77 E +08
Fixed 2, 34 Mbit/s, QPSK, outdoor	2.47 E +01	7.41 E +01	2.47 E +02	7.41 E +02	2.47 E +03	7.41 E +03	2.47 E +04	7.41 E +04	2.47 E +05	7.41 E +05	2.47 E +06	7.41 E +06	2.47 E +07	7.41 E +07	2.47 E +08

Number of interfering units inside a circular protection area for interferer's side lobes (exponential distribution for SRD, linear for ENG/OB and Fixed)

Unit density (units/km2)	0.01	0.03	0.1	0.3	1	3	10	30	100	300	1 k	3 k	10 k	30 k	100 k
SRD1, 10 mW, Narrow Band, D = 100%, indoor mounted (reference)	6.90 E -04	2.07 E -03	6.90 E -03	2.07 E -02	6.90 E -02	2.07 E -01	6.90 E -01	2.07 E -00	6.90 E -00	2.07 E +01	6.90 E +01	2.07 E +02	6.90 E +02	2.07 E +03	6.90 E +03
SRD 2, 10 mW, Video, D=100%, indoor	2.32 E -04	6.97 E -04	2.32 E -03	6.97 E -03	2.32 E -02	6.97 E -02	2.32 E -01	6.97 E -01	2.32 E -00	6.97 E -00	2.32 E +01	6.97 E +01	2.32 E +02	6.97 E +02	2.32 E +03
R-LAN1 FHSS, indoor	6.90 E -04	2.07 E -03	6.90 E -03	2.07 E -02	6.90 E -02	2.07 E -01	6.90 E -01	2.07 E -00	6.90 E -00	2.07 E +01	6.90 E +01	2.07 E +02	6.90 E +02	2.07 E +03	6.90 E +03
R-LAN2 DSSS, indoor	1.65 E -04	4.95 E -04	1.65 E -03	4.95 E -03	1.65 E -02	4.95 E -02	1.65 E -01	4.95 E -01	1.65 E -00	4.95 E -00	1.65 E +01	4.95 E +01	1.65 E +02	4.95 E +02	1.65 E +03
Fixed Access, outdoor	1.04 E -03	3.12 E -03	1.04 E -02	3.12 E -02	1.04 E -01	3.12 E -01	1.04 E -00	3.12 E -00	1.04 E +01	3.12 E +01	1.04 E +02	3.12 E +02	1.04 E +03	3.12 E +03	1.04 E +04
RFID 3a, 4W, FHSS, indoor	1.09 E -05	3.26 E -05	1.09 E -04	3.26 E -04	1.09 E -03	3.26 E -03	1.09 E -02	3.26 E -02	1.09 E -01	3.26 E -01	1.09 E -00	3.26 E -00	1.09 E +01	3.26 E +01	1.09 E +02
RFID 3b, 500mW, FHSS, indoor	1.09 E -05	3.26 E -05	1.09 E -04	3.26 E -04	1.09 E -03	3.26 E -03	1.09 E -02	3.26 E -02	1.09 E -01	3.26 E -01	1.09 E -00	3.26 E -00	1.09 E +01	3.26 E +01	1.09 E +02
RFID 5a, 500 mW, NB, indoor	2.32 E -04	6.97 E -04	2.32 E -03	6.97 E -03	2.32 E -02	6.97 E -02	2.32 E -01	6.97 E -01	2.32 E -00	6.97 E -00	2.32 E +01	6.97 E +01	2.32 E +02	6.97 E +02	2.32 E +03
RFID 5b, 100 mW, NB, indoor	2.32 E -04	6.97 E -04	2.32 E -03	6.97 E -03	2.32 E -02	6.97 E -02	2.32 E -01	6.97 E -01	2.32 E -00	6.97 E -00	2.32 E +01	6.97 E +01	2.32 E +02	6.97 E +02	2.32 E +03
ENG/OB 1, analogue, outdoor	2.21 E -00	6.64 E -00	2.21 E +01	6.64 E +01	2.21 E +02	6.64 E +02	2.21 E +03	6.64 E +03	2.21 E +04	6.64 E +04	2.21 E +05	6.64 E +05	2.21 E +06	6.64 E +06	2.21 E +07
ENG/OB 2, analogue, outdoor	1.19 E -04	3.56 E -04	1.19 E -03	3.56 E -03	1.19 E -02	3.56 E -02	1.19 E -01	3.56 E -01	1.19 E -00	3.56 E -00	1.19 E +01	3.56 E +01	1.19 E +02	3.56 E +02	1.19 E +03
ENG/OB 3, analogue, outdoor	1.13 E -04	3.39 E -04	1.13 E -03	3.39 E -03	1.13 E -02	3.39 E -02	1.13 E -01	3.39 E -01	1.13 E -00	3.39 E -00	1.13 E +01	3.39 E +01	1.13 E +02	3.39 E +02	1.13 E +03
ENG/OB 4, analogue, outdoor	6.38 E -02	1.91 E -01	6.38 E -01	1.91 E -00	6.38 E -00	1.91 E +01	6.38 E +01	1.91 E +02	6.38 E +02	1.91 E +03	6.38 E +03	1.91 E +04	6.38 E +04	1.91 E +05	6.38 E +05
ENG/OB 1, digital, outdoor	1.93 E -01	5.79 E -01	1.93 E -00	5.79 E -00	1.93 E +01	5.79 E +01	1.93 E +02	5.79 E +02	1.93 E +03	5.79 E +03	1.93 E +04	5.79 E +04	1.93 E +05	5.79 E +05	1.93 E +06
ENG/OB 2, digital, outdoor	1.50 E -05	4.51 E -05	1.50 E -04	4.51 E -04	1.50 E -03	4.51 E -03	1.50 E -02	4.51 E -02	1.50 E -01	4.51 E -01	1.50 E -00	4.51 E -00	1.50 E +01	4.51 E +01	1.50 E +02
ENG/OB 3, digital, outdoor	1.43 E -05	4.30 E -05	1.43 E -04	4.30 E -04	1.43 E -03	4.30 E -03	1.43 E -02	4.30 E -02	1.43 E -01	4.30 E -01	1.43 E -00	4.30 E -00	1.43 E +01	4.30 E +01	1.43 E +02
ENG/OB 4, digital, outdoor	7.40 E -03	2.22 E -02	7.40 E -02	2.22 E -01	7.40 E -01	2.22 E -00	7.40 E -00	2.22 E +01	7.40 E +01	2.22 E +02	7.40 E +02	2.22 E +03	7.40 E +03	2.22 E +04	7.40 E +04
Fixed 1, 2 x 2 Mbit/s, MSK, outdoor	5.84 E -01	1.75 E -00	5.84 E -00	1.75 E +01	5.84 E +01	1.75 E +02	5.84 E +02	1.75 E +03	5.84 E +03	1.75 E +04	5.84 E +04	1.75 E +05	5.84 E +05	1.75 E +06	5.84 E +06
Fixed 2, 34 Mbit/s, QPSK, outdoor	8.17 E -01	2.45 E -00	8.17 E -00	2.45 E +01	8.17 E +01	2.45 E +02	8.17 E +02	2.45 E +03	8.17 E +03	2.45 E +04	8.17 E +04	2.45 E +05	8.17 E +05	2.45 E +06	8.17 E +06

Cumulative probability of interference as a function of Bluetooth unit density

Type of victims below	Unit density of Bluetooth (units/km2)														
	0.01	0.03	0.1	0.3	1	3	10	30	100	300	1 k	3 k	10 k	30 k	100 k
SRD1, 10 mW, Narrow Band, D = 100%, indoor mounted (reference)	7.86 E -06	2.36 E -05	7.86 E -05	2.36 E -04	7.85 E -04	2.35 E -03	7.83 E -03	2.33 E -02	7.56 E -02	2.10 E -01	5.44 E -01	9.05 E -01	10.00 E -01	10.00 E -01	1.00 E -00
SRD 2, 10 mW, Video, D=100%, indoor	1.34 E -04	4.01 E -04	1.34 E -03	4.00 E -03	1.33 E -02	3.93 E -02	1.25 E -01	3.30 E -01	7.37 E -01	9.82 E -01	10.00 E -01	1.00 E -00	1.00 E -00	1.00 E -00	1.00 E -00
R-LAN1, 100 mW, FHSS, D = 100%, indoor mounted	7.86 E -06	2.36 E -05	7.86 E -05	2.36 E -04	7.85 E -04	2.35 E -03	7.83 E -03	2.33 E -02	7.56 E -02	2.10 E -01	5.44 E -01	9.05 E -01	10.00 E -01	10.00 E -01	1.00 E -00
R-LAN2, 100 mW, DSSS, D = 100%, indoor mounted	2.07 E -05	6.20 E -05	2.07 E -04	6.19 E -04	2.06 E -03	6.18 E -03	2.04 E -02	6.01 E -02	1.87 E -01	4.62 E -01	8.73 E -01	9.98 E -01	10.00 E -01	1.00 E -00	1.00 E -00
Fixed Access, outdoor	2.37 E -05	7.11 E -05	2.37 E -04	7.10 E -04	2.37 E -03	7.08 E -03	2.34 E -02	6.86 E -02	2.11 E -01	5.09 E -01	9.06 E -01	9.99 E -01	10.00 E -01	1.00 E -00	1.00 E -00
RFID 3a, 4W, FHSS BW = 8 MHz, D = 15%, indoor mounted	1.89 E -07	5.66 E -07	1.89 E -06	5.66 E -06	1.89 E -05	5.66 E -05	1.89 E -04	5.66 E -04	1.88 E -03	5.64 E -03	1.87 E -02	5.50 E -02	1.72 E -01	4.32 E -01	8.48 E -01
RFID 3b, 500mW, FHSS BW = 8 MHz, D =15%, indoor mounted	1.89 E -07	5.66 E -07	1.89 E -06	5.66 E -06	1.89 E -05	5.66 E -05	1.89 E -04	5.66 E -04	1.88 E -03	5.64 E -03	1.87 E -02	5.50 E -02	1.72 E -01	4.32 E -01	8.48 E -01
RFID 5a, 500 mW, Narrow Band, D = 100%, indoor mounted	2.67 E -06	8.00 E -06	2.67 E -05	8.00 E -05	2.67 E -04	8.00 E -04	2.66 E -03	7.97 E -03	2.63 E -02	7.69 E -02	2.34 E -01	5.51 E -01	9.31 E -01	10.00 E -01	10.00 E -01
RFID 5b, 100 mW, Narrow Band, D = 100%, indoor mounted	2.67 E -06	8.00 E -06	2.67 E -05	8.00 E -05	2.67 E -04	8.00 E -04	2.66 E -03	7.97 E -03	2.63 E -02	7.69 E -02	2.34 E -01	5.51 E -01	9.31 E -01	10.00 E -01	10.00 E -01
ENG/OB 1, analogue, outdoor	3.29 E -01	6.98 E -01													
ENG/OB 2, analogue, outdoor	5.61 E -04	1.68 E -03													
ENG/OB 3, analogue, outdoor	5.35 E -04	1.60 E -03													
ENG/OB 4, analogue, outdoor	2.94 E -01	6.48 E -01													
ENG/OB 1, digital, outdoor	3.42 E -02	9.92 E -02													
ENG/OB 2, digital, outdoor	7.12 E -05	2.14 E -04													
ENG/OB 3, digital, outdoor	6.79 E -05	2.04 E -04													
ENG/OB 4, digital, outdoor	3.96 E -02	1.14 E -01													
Fixed 1, 2 x 2 Mbit/s, MSK, outdoor	9.59 E -01	10.00 E -01													
Fixed 2, 34 Mbit/s, QPSK, outdoor	9.88 E -01	10.00 E -01													

Annex B. Protection distances for critical blocking and co-channel interferences, obtained with the MCL method

	SRD NB	**SRD CATV** Analogue	**RLAN DSSS**	**RLAN FHSS**	**RFID FHSS**	**RFID FHSS**	**RFID FHSS**	**RFID FHSS**	**ENG/OB Camera** Analogue	**ENG/OB Helicopt** Analogue	**ENG/OB Camera** Digital	**ENG/OB Helicopt** Digital
A. Data:												
Radiated power, eirp , P_{RAD} , dBm	10	10	20	20	36	36	36	36	35	56	35	56
Transmitter bandwidth, MHz	1	20	15	1	0.35	0.35	0.35	0.35	20	20	7.4	7.4
Transmitted duty cycle, %	100%	100%	100%	100%	10%	15%	50%	100%	100%	100%	100%	100%
BT Co-channel interference, C/I, dB	11	11	11	11	11	11	11	11	11	11	11	11
BT Out of channel interference, C/I, dB	-40	-40	-40	-40	-40	-40	-40	-40	-40	-40	-40	-40
BT RX on-channel power for MUS+3dB	-67	-67	-67	-67	-67	-67	-67	-67	-67	-67	-67	-67
Wall attenuation to outdoor helicopter, dB	0	0	0	0	0	0	0	0	0	15	0	15
B. Calculations w/o TX duty cycle												
MCL, co-channel, dB, see note 1	88.0	75.0	86.2	98.0	114.0	114.0	114.0	114.0	100.0	106.0	104.3	110.3
Protection dist for d_P > 15m	97	36	85	209	712	712	712	712	243	n/a	339	n/a
Protection dist for d_P < 15m (or free space)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1948	n/a	3202
MCL, out-of-channel, dB	37.0	24.0	35.2	47.0	63.0	63.0	63.0	63.0	49.0	55.0	53.3	59.3
Protection dist for d_P < 15m	0.69	0.15	0.56	2.19	13.80	13.80	13.80	13.80	2.75	5.49	4.52	9.02
Protection dist for d_P > 15m	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
C. Calculation w/ TX duty cycle												
Mitigation, duty cycle, dB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MCL, co- or out of chan as appropriate, dB	37.0	75.0	86.2	47.0	63.0	63.0	63.0	63.0	100.0	106.0	104.3	110.3
Protection dist for d_P < 15m (or free space)	0.69	n/a	n/a	2.19	13.80	13.80	13.80	n/a	n/a	1948	n/a	3202
Protection dist for d_P > 15m	n/a	36	85	4	n/a	n/a	n/a	n/a	243	n/a	339	n/a
D. Equipment measurements, operating												
RA/UK Whyteleafe C/I measurements	-33	4	2.5	-33	-49	-48	-36	-33	4	4	-2	-2
MCL with measured C/I, dB	44.0	68.0	77.7	54.0	54.0	55.0	67.0	70.0	93.0	99.0	91.3	97.3
Protection dist for d_P < 15m (or free space)	1.5	n/a	n/a	4.9	4.9	5.5	n/a	n/a	n/a	869.9	n/a	716.8
Protection dist for d_P > 15m	n/a	21	44	n/a	n/a	n/a	19	24	142	n/a	125	n/a
	SRD NB	**SRD CATV** Analogue	**RLAN DSSS**	**RLAN FHSS**	**RFID FHSS**	**RFID FHSS**	**RFID FHSS**	**RFID FHSS**	**ENG/OB Camera** Analogue	**ENG/OB Helicopt** Analogue	**ENG/OB Camera** Digital	**ENG/OB Helicopt** Digital

Protection distances, data for chart.
Use preliminary data for UK measurements

	Duty Cycle %			
	10%	15%	50%	100%
4W RFID, calculated (blocking)				14.2
4W RFID, UK measured C/I (blocking)	4.9	5.5	19.3	24.3
100 mW RLAN DSSS, measured C/I (co-channel)				44
				4.9
100 mW RLAN FHSS, measured C/I (blocking)				
SRD, CATV, w/ UK measured C/I for ENG/OB (blocking)				35.7
SRD, NB , w/ UK measured C/I for CW (blocking)				1.5
Analog ENG/OB, 3.5 W with camera, measured C/I (co-channel)				142
Analog ENG/OB, 400 W at helicopter, measured C/I (co-channel)				869.9
Digital ENG/OB, 3.5 W with camera, measured C/I (co-channel)				125
Digital ENG/OB, 400 W at helicopter, measured C/I (co-channel)				716.8

Annex C.1
SEAMCAT input file describing interference scenario

Victim Link	Victim values	Interferer Link	Values I1	Values I2	Values I3	Values I4
General		**General**				
VLK_REFERENCE	RLAN (DS)	ILK_REFERENCE	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
VLK_DESCRIPTION	RLAN (DS)	ILK_DESCRIPTION	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
VLK_FREQUENCY	2450	ILK_FREQUENCY	2446-2454	2446-2454	2450	2402 - 2480
VLK_CHECK_TX	N					
VLK_DRSS	-90	**Transmitter**				
		ILK_TX_REFERENCE	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
Receiver		ILK_TX_DESCRIPTION	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
VLK_RX_REFERENCE	RLAN (DS)	ILK_TX_POWER_SUPPLIED	30	21	20	20
VLK_RX_DESCRIPTION	RLAN (DS)	ILK_TX_UNWNTED(F)	Mask	Mask	Mask	Mask
VLK_RX_CI	10	ILK_CHECK_NOISE FLOOR	N	N	N	N
VLK_RX_CNI	0	ILK_TX_UNWANTED0(F)				
VLK_RX_NIN	3	ILK_TX_BANDWIDTH	8000	8000	15000	78000
VLK_RX_NOISE_FLOOR	-100	ILK_TX_REF_BANDWIDTH	350	350	15000	1000
VLK_RX_BLOCKING	60	ILK_TX_CHECK_POWER_CENTRO	N	N	N	N
VLK_RX_ATTENUATION_SELECTION	user-defined	ILK_TX_ANT_HEIGTH	1.5 m	1.5 m	2.5 m	1.5 m
VLK_RX_SENSITIVITY	-91	ILK_TX_AZIMUTH	0.360	0.360	0	0
VLK_RX_BANDWIDTH	15000	ILK_TX_ELEVATION	0	0	0	0
VLK_RX_INTERMOD	0					
VLK_RX_CHECK_PC_MAX	N	ILK_TX_PC_STEP_SIZE				
VLK_RX_PC_MAX_INCREASE		ILK_TX_PC_MIN				
VLK_RX_ANT_HEIGTH	1.5 m	ILK_TX_PC_MAX				
VLK_RX_AZIMUTH	0					
VLK_RX_ELEVATION	0	**Coverage radius parameters**				
		ILK_COVERAGE_RADIUS_MODE	user-defined	user-defined	user-defined	user-defined
Antenna Rx		ILK_COVERAGE_RADIUS	0.01 km	0.01 km	0.1 km	0.1 km
VLK_RX_ANT_REFERENCE	RLAN (DS)					
VLK_RX_ANT_DESCRIPTION	RLAN (DS)	ILK_TX_REF_ANT_HEIGTH				
VLK_RX_ANT_PEAK_GAIN	0	ILK_RX_REF_ANT_HEIGTH				
VLK_RX_ANT_CHECK_HPATTERN	N	ILK_REF_POWER				
VLK_RX_ANT_HOR_PATTERN		ILK_REF_FREQUENCY				
VLK_RX_ANT_CHECK_VPATTERN	N					
VLK_RX_ANT_VER_PATTERN						

Transmitter	
Wanted transmitter	
VLK_TX_REFERENCE	RLAN (DS)
VLK_TX_DESCRIPTION	RLAN (DS)
VLK_TX_POWER_SUPPLIED	20
VLK_TX_ANT_HEIGTH	2.5 m
VLK_TX_AZIMUTH	0
VLK_TX_ELEVATION	0
Coverage radius parameters	
VLK_COVERAGE_RADIUS_MODE	user-defined
VLK_COVERAGE_RADIUS	0.1 km
VLK_TX_REF_ANT_HEIGTH	
VLK_RX_REF_ANT_HEIGTH	
VLK_REF_POWER	
VLK_REF_FREQUENCY	
VLK_MIN_DIST	
VLK_MAX_DIST	
VLK_TX_AVAILABILITY	
VLK_TX_FADING	
VLK_TX_TRAFFIC_DENSITY	
VLK_TX_TRAFFIC_NBR_CHANNE	
VLK_TX_TRAFFIC_USERES	
VLK_TX_TRAFFIC_FRRQ_CLUST	

cont. Coverage radius parameters				
ILK_MIN_DIST				
ILK_MX_DEST				
ILK_TX_AVAILABILITY				
ILK_TX_FADING				
Simulation radius parameters				
ILK_TX_NBR_ACTIVE	Variable	Variable	Variable	Variable
ILK_TX_DENS_ACTIVE	Variable	Variable	Variable	Variable
ILK_TX_PROB_TRANS	1	1	1	1
ILK_TX_ACTIVITY	1	1	1	1
ILK_TX_TIME	5	5	5	5
ILK_TX_TRAFFIC_DENSITY				
ILK_TX_TRAFFIC_NBR_CHANNE				
ILK_TX_TRAFFIC_NBR_USERS				
ILK_TX_TRAFFIC_FREQ_CLUST				
Antenna Tx				
ILK_TX_ANT_REFERENCE	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
ILK_TX_ANT_DESCRIPTION	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
ILK_TX_ANT_PEAK_GAIN	6 dBi	6 dBi	0 dBi	0 dBi
ILK_TX_ANT_CHECK_HPATTERN	Y	Y	N	N
ILK_TX_ANT_HOR_PATTERN	43° (15 dB)	43° (15 dB)		
ILK_TX_ANT_CHECK_VPATTERN	N	N	N	N
ILK_TX_ANT_VER_PATTERN				

Antenna Tx	
VLK_TX_ANT_REFERENCE	RLAN (DS)
VLK_TX_ANT_DESCRIPTION	RLAN (DS)
VLK_TX_ANT_PEAK_GAIN	0
VLK_TX_ANT_CHECK_HPATTERN	N
VLK_TX_ANT_HOR_PATTERN	
VLK_TX_ANT_CHECK_VPATTERN	N
VLK_TX_ANT_VER_PATTERN	

WTx VRx path

Relative location	
VLK_CHECK_DISTANCE	N
VLK_LOC_DISTANCE	
VLK_LOC_ANGLE	
VLK_DELTAX	
VLK_DELTAY	

Propagation model	
VLK_PROPAGATION_SELECTION	HATA
VLK_CHECK_MEDIAN_LOSS	Y
VLK_CHECK_VARIATION	Y
VLK_GEN_ENV	URBAN
VLK_TX_LOCAL_ENV	INDOOR
VLK_RX_LOCAL_ENV	INDOOR
VLK_PROPAG_ENV	BELOW ROOF
VLK_LF	0
VLK_B	1
VLK_DROOM	20
VLK_HFLOOR	3
VLK_WL_II	0
VLK_WL_IO	15
VLK_WL_STD_DEV_II	0
VLK_WL_STD_DEV_IO	0

VLK_SPH_WATER	
VLK_SPH_EARTH	
VLK_SPH_GRAD	
VLK_SPH_REFRAC	

Wanted receiver				
ILK_RX_REFERNCE	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
ILK_RX_DESCRIPTION	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
ILK_RX_ANT_HEIGTH	1.5 m	1.5 m	2.5 m	1.5 m
ILK_RX_AZIMUTH	0.360	0.360	0	0
ILK_RX_ELEVATION	0	0	0	0

Antenna Rx				
ILK_RX_ANT_REFERENCE	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
ILK_RX_ANT_DESCRIPTION	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
ILK_RX_ANT_PEAK_GAIN	6 dBi	6 dBi	0 dBi	0 dBi
ILK_RX_ANT_CHECK_HPATTERN	Y	Y	N	N
ILK_RX_ANT_HOR_PATTERN	43° (15 dB)	43° (15 dB)		
ILK_RX_ANT_CHECK_VPATTERN	N	N	N	N
ILK_RX_ANT_VER_PATTERN				

Itx VRx path				
Relative location				
ILK_CORRELATION_MODE	N	N	N	N
ILK_VR_LOCATION_DISTANCE				
ILK_VR_LOC_ANGLE				
ILK_VR_DELTAX				
ILK_VR_DELTAY				

Propagation model				
ILK_VR_PROPAGATION	Hata	Hata	Hata	Hata
ILK_VR_MEMO_PROPAG				
ILK_VR_CHECK_MEDIAN_LOSS	Y	Y	Y	Y
ILK_VR_CHECK_VARIATION	Y	Y	Y	Y
ILK_VR_GEN_ENV	URBAN	URBAN	URBAN	URBAN
ILK_VR_TX_LOCAL_ENV	INDOOR	OUTDOOR	INDOOR	INDOOR
ILK_VR_RX_LOC_ENV	INDOOR	INDOOR	INDOOR	INDOOR
ILK_VR_PROPAG_ENV	BELOW ROOF	BELOW ROOF	BELOW ROOF	BELOW ROOF
ILK_VR_LF	0	0	0	0
ILK_VR_B	1	1	1	1

cont. Propagation model				
ILK_VR_DROOM	4	4	4	4
ILK_VR_HFLOOR	3	3	3	3
ILK_VR_WL_II	0	0	0	0
ILK_VR_WL_IO	15	15	15	15
ILK_VR_WL_STD_DEV_II	0	0	0	0
ILK_VR_WL_STD_DEV_IO	0	0	0	0

ITX WRx path				
Relative location				
ILK_CHECK_DISTANCE	N	N	N	N
ILK_WR_LOC_DISTANCE				
ILK_WR_LOCAL_ANGLE				

Propagation model				
ILK_WR_PROPAGATION	Hata	Hata	Hata	Hata
ILK_VR_MEMO_PROPAG				
ILK_WR_CHECK_MEDIAN_LOSS	Y	Y	Y	Y
ILK_WR_CHECK_VARIATION	Y	Y	Y	Y
ILK_GEN_ENV	URBAN	URBAN	URBAN	URBAN
ILK_WR_TX_LOCAL_ENV	INDOOR	OUTDOOR	INDOOR	INDOOR
ILK_WR_RX_LOCAL_ENV	INDOOR	INDOOR	INDOOR	INDOOR
ILK_WR_PROPAG_ENV	BELOW ROOF	ABOVE ROOF	BELOW ROOF	BELOW ROOF
ILK_WR_LF	0	0	0	0
ILK_WR_B	1	1	1	1
ILK_WR_DROOM	4	4	4	4
ILK_WR_HFLOOR	3	3	3	3
ILK_WR_WL_II	0	0	0	0
ILK_WR_WL_IO	15	15	15	15
ILK_WR_WL_STD_DEV_II	0	0	0	0
ILK_WR_WL_STD_DEV_IO	0	0	0	0
ILK_WR_SPH_WATER				
ILK_WR_SPH_EARTH				
ILK_WR_SPH_GRAD				
ILK_WR_SPH_REFRAC				

Victim Link	Victim values
General	
VLK_REFERENCE	BT 1 mW
VLK_DESCRIPTION	BT 1 mW
VLK_FREQUENCY	2450
VLK_CHECK_TX	N
VLK_DRSS	-70
Receiver	
VLK_RX_REFERENCE	BT 1 mW
VLK_RX_DESCRIPTION	BT 1 mW
VLK_RX_CI	18
VLK_RX_CNI	0
VLK_RX_NIN	3
VLK_RX_NOISE_FLOOR	-100
VLK_RX_BLOCKING	60
VLK_RX_ATTENUATION_SELECTION	user-defined
VLK_RX_SENSITIVITY	-71
VLK_RX_BANDWIDTH	1000
VLK_RX_INTERMOD	0
VLK_RX_CHECK_PC_MAX	N
VLK_RX_PC_MAX_INCREASE	
VLK_RX_ANT_HEIGTH	1.5 m
VLK_RX_AZIMUTH	0
VLK_RX_ELEVATION	0
Antenna Rx	
VLK_RX_ANT_REFERENCE	BT 1 mW
VLK_RX_ANT_DESCRIPTION	BT 1 mW
VLK_RX_ANT_PEAK_GAIN	0
VLK_RX_ANT_CHECK_HPATTERN	N
VLK_RX_ANT_HOR_PATTERN	
VLK_RX_ANT_CHECK_VPATTERN	N
VLK_RX_ANT_VER_PATTERN	

Interferer Link	Values I1	Values I2	Values I3	Values I4
General				
ILK_REFERENCE	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
ILK_DESCRIPTION	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
ILK_FREQUENCY	2446-2454	2446-2454	2450	2402 - 2480
Transmitter				
ILK_TX_REFERENCE	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
ILK_TX_DESCRIPTION	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
ILK_TX_POWER_SUPPLIED	30	21	20	20
ILK_TX_UNWNTED(F)	Mask	Mask	Mask	Mask
ILK_CHECK_NOISE FLOOR	N	N	N	N
ILK_TX_UNWANTED0(F)				
ILK_TX_BANDWIDTH	8000	8000	15000	78000
ILK_TX_REF_BANDWIDTH	350	350	15000	1000
ILK_TX_CHECK_POWER_CENTRO	N	N	N	N
ILK_TX_ANT_HEIGTH	1.5 m	1.5 m	2.5 m	1.5 m
ILK_TX_AZIMUTH	0.360	0.360	0	0
ILK_TX_ELEVATION	0	0	0	0
ILK_TX_PC_STEP_SIZE				
ILK_TX_PC_MIN				
ILK_TX_PC_MAX				
Coverage radius parameters				
ILK_COVERAGE_RADIUS_MODE	user-defined	user-defined	user-defined	user-defined
ILK_COVERAGE_RADIUS	0.01 km	0.01 km	0.1 km	0.1 km
ILK_TX_REF_ANT_HEIGTH				
ILK_RX_REF_ANT_HEIGTH				
ILK_REF_POWER				
ILK_REF_FREQUENCY				

Transmitter	
Wanted transmitter	
VLK_TX_REFERENCE	BT 1 mW
VLK_TX_DESCRIPTION	BT 1 mW
VLK_TX_POWER_SUPPLIED	0
VLK_TX_ANT_HEIGTH	1.5 m
VLK_TX_AZIMUTH	0
VLK_TX_ELEVATION	0
Coverage radius parameters	
VLK_COVERAGE_RADIUS_MODE	user-defined
VLK_COVERAGE_RADIUS	0.1 km
VLK_TX_REF_ANT_HEIGTH	
VLK_RX_REF_ANT_HEIGTH	
VLK_REF_POWER	
VLK_REF_FREQUENCY	
VLK_MIN_DIST	
VLK_MAX_DIST	
VLK_TX_AVAILABILITY	
VLK_TX_FADING	
VLK_TX_TRAFFIC_DENSITY	
VLK_TX_TRAFFIC_NBR_CHANNE	
VLK_TX_TRAFFIC_USERES	
VLK_TX_TRAFFIC_FRRQ_CLUST	
Antenna Tx	
VLK_TX_ANT_REFERENCE	BT 1 mW
VLK_TX_ANT_DESCRIPTION	BT 1 mW
VLK_TX_ANT_PEAK_GAIN	0
VLK_TX_ANT_CHECK_HPATTERN	N
VLK_TX_ANT_HOR_PATTERN	
VLK_TX_ANT_CHECK_VPATTERN	N
VLK_TX_ANT_VER_PATTERN	
WTx VRx path	
Relative location	
VLK_CHECK_DISTANCE	N
VLK_LOC_DISTANCE	

cont. Coverage radius parameters				
ILK_MIN_DIST				
ILK_MX_DEST				
ILK_TX_AVAILABILITY				
ILK_TX_FADING				
Simulation radius parameters				
ILK_TX_NBR_ACTIVE	Variable	Variable	Variable	Variable
ILK_TX_DENS_ACTIVE	Variable	Variable	Variable	Variable
ILK_TX_PROB_TRANS	1	1	1	1
ILK_TX_ACTIVITY	1	1	1	1
ILK_TX_TIME	5	5	5	5
ILK_TX_TRAFFIC_DENSITY				
ILK_TX_TRAFFIC_NBR_CHANNE				
ILK_TX_TRAFFIC_NBR_USERS				
ILK_TX_TRAFFIC_FREQ_CLUST				
Antenna Tx				
ILK_TX_ANT_REFERENCE	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
ILK_TX_ANT_DESCRIPTION	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
ILK_TX_ANT_PEAK_GAIN	6 dBi	6 dBi	0 dBi	0 dBi
ILK_TX_ANT_CHECK_HPATTERN	Y	Y	N	N
ILK_TX_ANT_HOR_PATTERN	43° (15 dB)	43° (15 dB)		
ILK_TX_ANT_CHECK_VPATTERN	N	N	N	N
ILK_TX_ANT_VER_PATTERN				
Wanted receiver				
ILK_RX_REFERNCE	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
ILK_RX_DESCRIPTION	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
ILK_RX_ANT_HEIGTH	1.5 m	1.5 m	2.5 m	1.5 m
ILK_RX_AZIMUTH	0.360	0.360	0	0
ILK_RX_ELEVATION	0	0	0	0
Antenna Rx				
ILK_RX_ANT_REFERENCE	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
ILK_RX_ANT_DESCRIPTION	RFID 3a	RFID 3b	RLAN 2	BT 100 mW
ILK_RX_ANT_PEAK_GAIN	6 dBi	6 dBi	0 dBi	0 dBi
ILK_RX_ANT_CHECK_HPATTERN	Y	Y	N	N
ILK_RX_ANT_HOR_PATTERN	43° (15 dB)	43° (15 dB)		

VLK_LOC_ANGLE	
VLK_DELTAX	
VLK_DELTAY	

Propagation model	
VLK_PROPAGATION_SELECTION	HATA
VLK_CHECK_MEDIAN_LOSS	Y
VLK_CHECK_VARIATION	Y
VLK_GEN_ENV	URBAN
VLK_TX_LOCAL_ENV	INDOOR
VLK_RX_LOCAL_ENV	INDOOR
VLK_PROPAG_ENV	BELOW ROOF
VLK_LF	0
VLK_B	1
VLK_DROOM	4
VLK_HFLOOR	3
VLK_WL_II	0
VLK_WL_IO	15
VLK_WL_STD_DEV_II	0
VLK_WL_STD_DEV_IO	0

VLK_SPH_WATER	
VLK_SPH_EARTH	
VLK_SPH_GRAD	
VLK_SPH_REFRAC	

ILK_RX_ANT_CHECK_VPATTERN	N	N	N	N
ILK_RX_ANT_VER_PATTERN				

Itx VRx path				
Relative location				
ILK_CORRELATION_MODE	N	N	N	N
ILK_VR_LOCATION_DISTANCE				
ILK_VR_LOC_ANGLE				
ILK_VR_DELTAX				
ILK_VR_DELTAY				
Propagation model				
ILK_VR_PROPAGATION	Hata	Hata	Hata	Hata
ILK_VR_MEMO_PROPAG				
ILK_VR_CHECK_MEDIAN_LOSS	Y	Y	Y	Y
ILK_VR_CHECK_VARIATION	Y	Y	Y	Y
ILK_VR_GEN_ENV	URBAN	URBAN	URBAN	URBAN
ILK_VR_TX_LOCAL_ENV	INDOOR	OUTDOOR	INDOOR	INDOOR
ILK_VR_RX_LOC_ENV	INDOOR	INDOOR	INDOOR	INDOOR
ILK_VR_PROPAG_ENV	BELOW ROOF	BELOW ROOF	BELOW ROOF	BELOW ROOF
ILK_VR_LF	0	0	0	0
ILK_VR_B	1	1	1	1

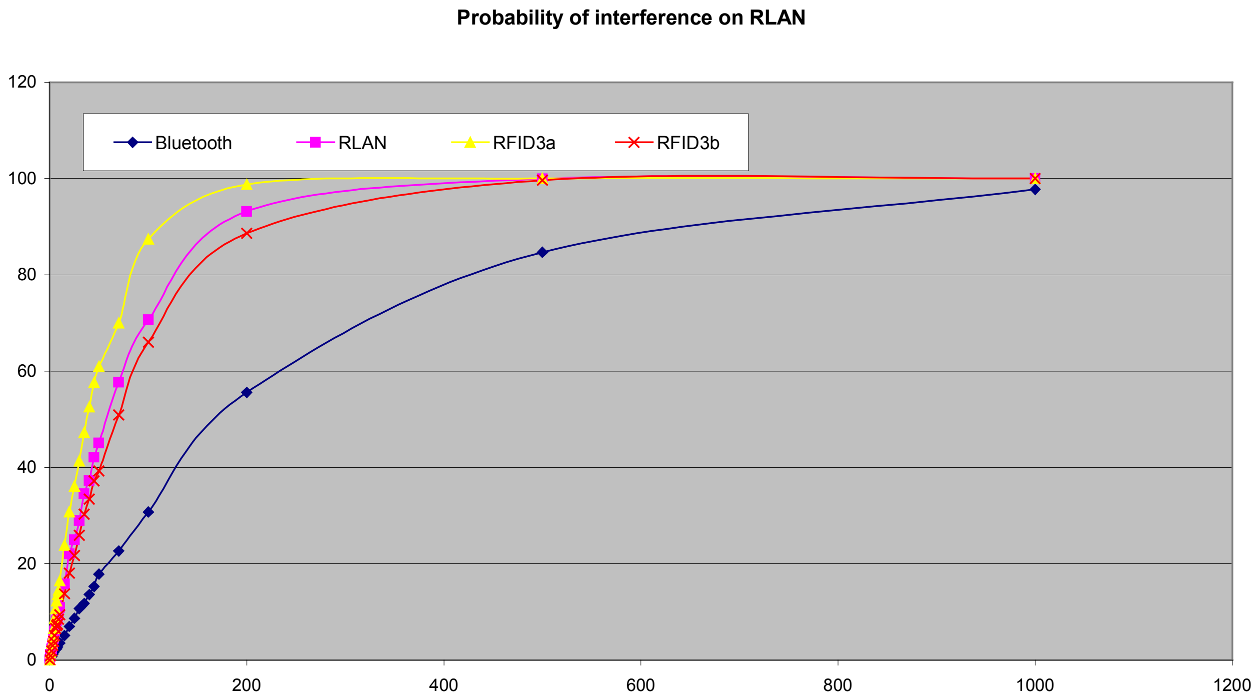
cont. Propagation model				
ILK_VR_DROOM	4	4	4	4
ILK_VR_HFLOOR	3	3	3	3
ILK_VR_WL_II	0	0	0	0
ILK_VR_WL_IO	15	15	15	15
ILK_VR_WL_STD_DEV_II	0	0	0	0
ILK_VR_WL_STD_DEV_IO	0	0	0	0

ITX WRx path				
Relative location				
ILK_CHECK_DISTANCE	N	N	N	N
ILK_WR_LOC_DISTANCE				
ILK_WR_LOCAL_ANGLE				

Propagation model

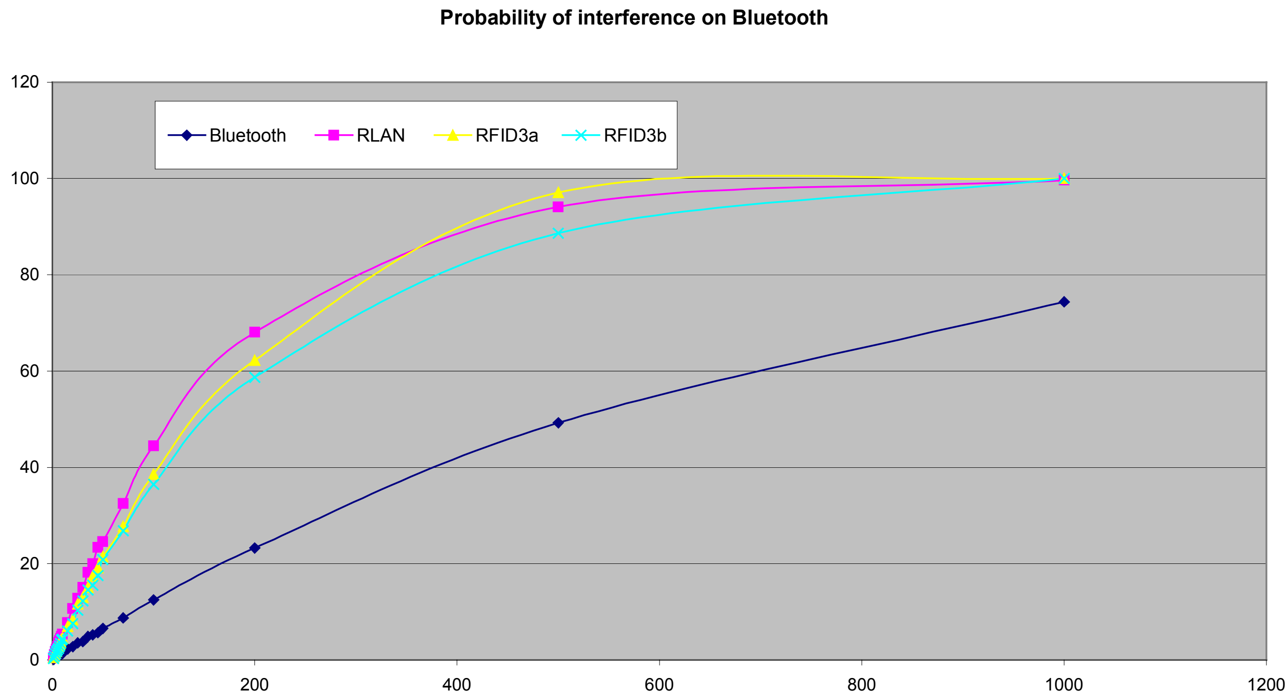
ILK_WR_PROPAGATION	Hata	Hata	Hata	Hata
ILK_VR_MEMO_PROPAG				
ILK_WR_CHECK_MEDIAN_LOSS	Y	Y	Y	Y
ILK_WR_CHECK_VARIATION	Y	Y	Y	Y
ILK_GEN_ENV	URBAN	URBAN	URBAN	URBAN
ILK_WR_TX_LOCAL_ENV	INDOOR	OUTDOOR	INDOOR	INDOOR
ILK_WR_RX_LOCAL_ENV	INDOOR	INDOOR	INDOOR	INDOOR
ILK_WR_PROPAG_ENV	BELOW ROOF	ABOVE ROOF	BELOW ROOF	BELOW ROOF
ILK_WR_LF	0	0	0	0
ILK_WR_B	1	1	1	1
ILK_WR_DROOM	4	4	4	4
ILK_WR_HFLOOR	3	3	3	3
ILK_WR_WL_II	0	0	0	0
ILK_WR_WL_IO	15	15	15	15
ILK_WR_WL_STD_DEV_II	0	0	0	0
ILK_WR_WL_STD_DEV_IO	0	0	0	0
ILK_WR_SPH_WATER				
ILK_WR_SPH_EARTH				
ILK_WR_SPH_GRAD				
ILK_WR_SPH_REFRAC				

Annex C.2. Results of interference calculations with SEAMCAT using conventional C/I



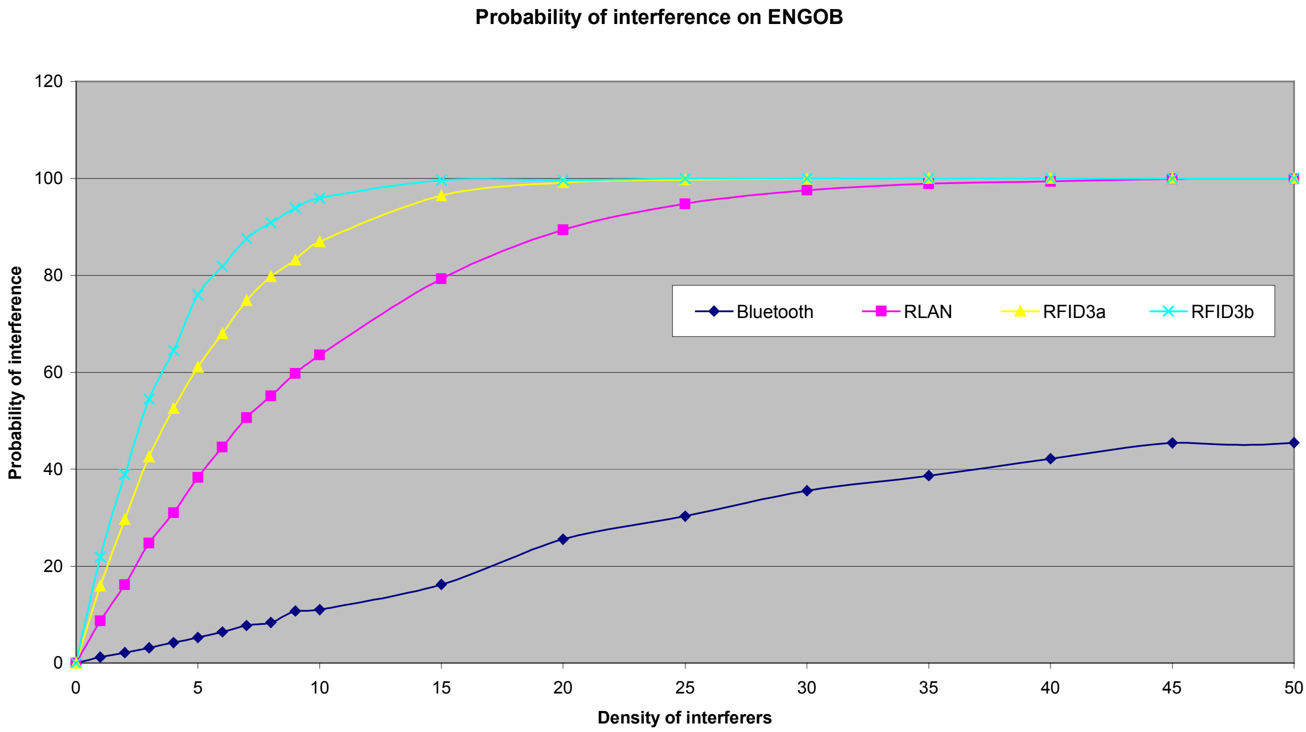
Victim RLAN

Density	Interferers			
	Bluetooth	RLAN	RFID3a	RFID3b
0	0	0	0	0
1	0.38	1.16	1.51	0.89
2	0.74	2.3	3.46	1.88
3	1.18	3.37	4.91	2.99
4	1.55	4.46	6.5	3.84
5	2.08	5.99	8.67	5.1
6	2.22	7.29	10.67	6.55
7	2.35	8.13	12.29	7.1
8	2.7	8.51	13.57	7.37
9	3.38	9.5	14.49	8.44
10	3.55	10.92	16.4	9.42
15	5.1	15.78	23.83	13.77
20	6.97	22.03	30.7	18.08
25	8.68	25.01	36.08	21.67
30	10.7	28.95	41.36	25.92
35	11.73	34.56	47.29	30.27
40	13.62	37.26	52.6	33.42
45	15.29	42.1	57.63	37.17
50	17.83	45.03	60.92	39.28
70	22.67	57.67	70.04	50.9
100	30.71	70.66	87.45	66.04
200	55.58	93.16	98.77	88.63
500	84.69	99.95	100	99.66
1000	97.76	100	100	100



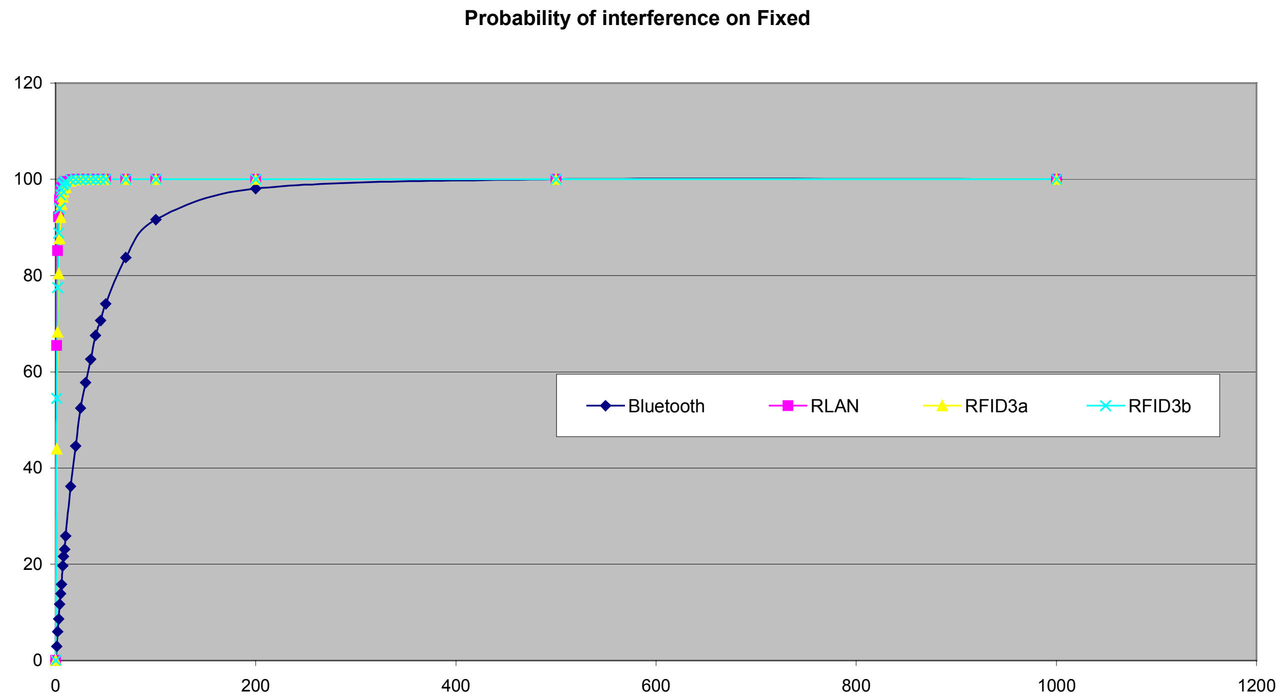
Victim Bluetooth

Density	Interferers			
	Bluetooth	RLAN	RFID3a	RFID3b
0	0	0	0	0
1	0.1	0.41	0.49	0.27
2	0.52	1.09	1.05	0.76
3	0.54	1.72	1.35	1.28
4	0.55	2.18	1.74	1.72
5	0.71	2.83	2.54	2.05
6	0.79	3.63	2.79	2.39
7	1	4.02	3.23	2.89
8	1.07	4.38	3.78	3.45
9	1.25	4.87	4.32	4.18
10	1.38	5.31	4.5	4.3
15	2.28	7.76	6.93	6
20	2.73	10.68	8.35	7.55
25	3.51	12.79	11.59	10.31
30	3.81	15.04	12.99	12.26
35	4.87	18.2	15.06	14.52
40	5.21	19.97	17.38	15.5
45	5.63	23.35	19.12	17.51
50	6.54	24.59	21.43	20.8
70	8.69	32.5	27.68	26.84
100	12.48	44.46	38.56	36.46
200	23.23	68.03	62.23	58.69
500	49.25	94.09	97.09	88.62
1000	74.36	99.64	100	100



Victim ENG/OB3

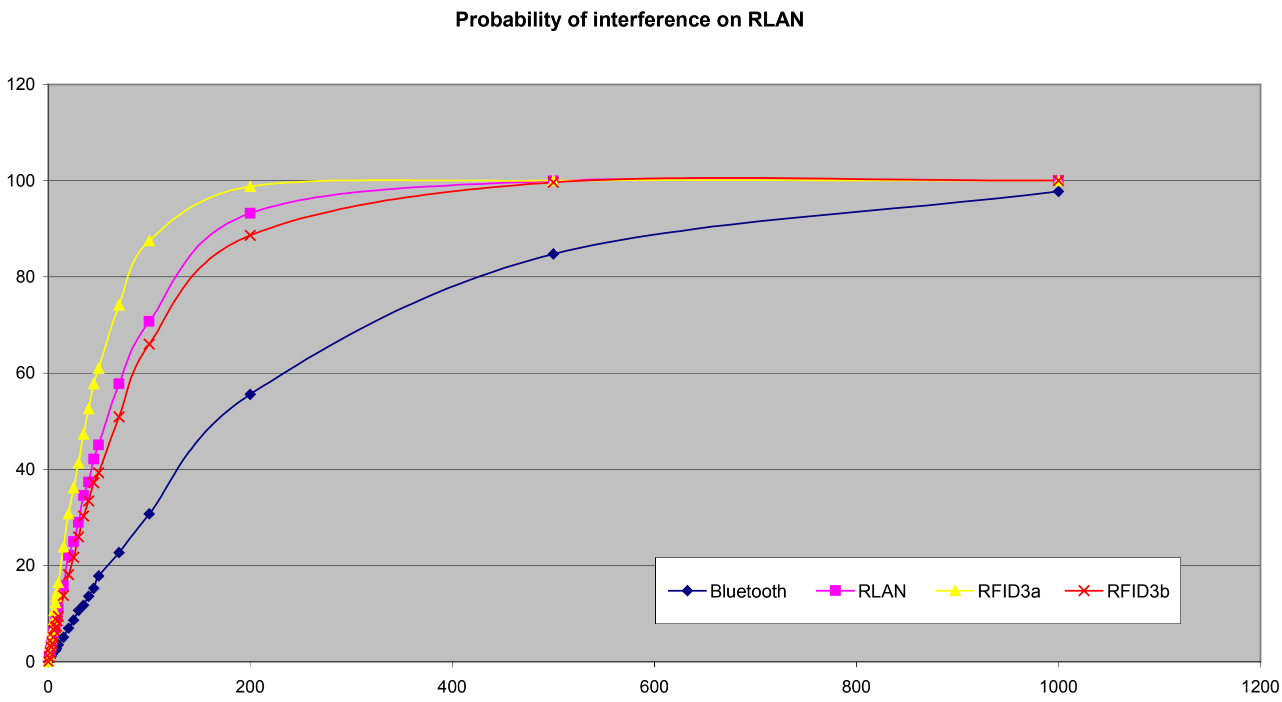
Density	Interferers			
	Bluetooth	RLAN	RFID3a	RFID3b
0	0	0	0	0
1	1.22	8.69	15.91	21.91
2	2.16	16.17	29.63	38.94
3	3.14	24.71	42.56	54.43
4	4.22	31.06	52.52	64.51
5	5.26	38.27	61.04	75.98
6	6.42	44.56	68	81.85
7	7.73	50.62	74.78	87.6
8	8.39	55.12	79.76	90.88
9	10.75	59.71	83.16	93.87
10	11	63.56	86.94	95.98
15	16.2	79.28	96.47	99.62
20	25.53	89.41	99.16	99.65
25	30.3	94.77	99.72	99.99
30	35.54	97.54	99.94	100
35	38.66	98.94	100	100
40	42.16	99.37	100	100
45	45.43	99.87	100	100
50	45.5	99.91	100	100
70	57.72	100	100	100
100	71.97	100	100	100
200	94.49	100	100	100
500	100	100	100	100
1000	100	100	100	100



Victim Fixed

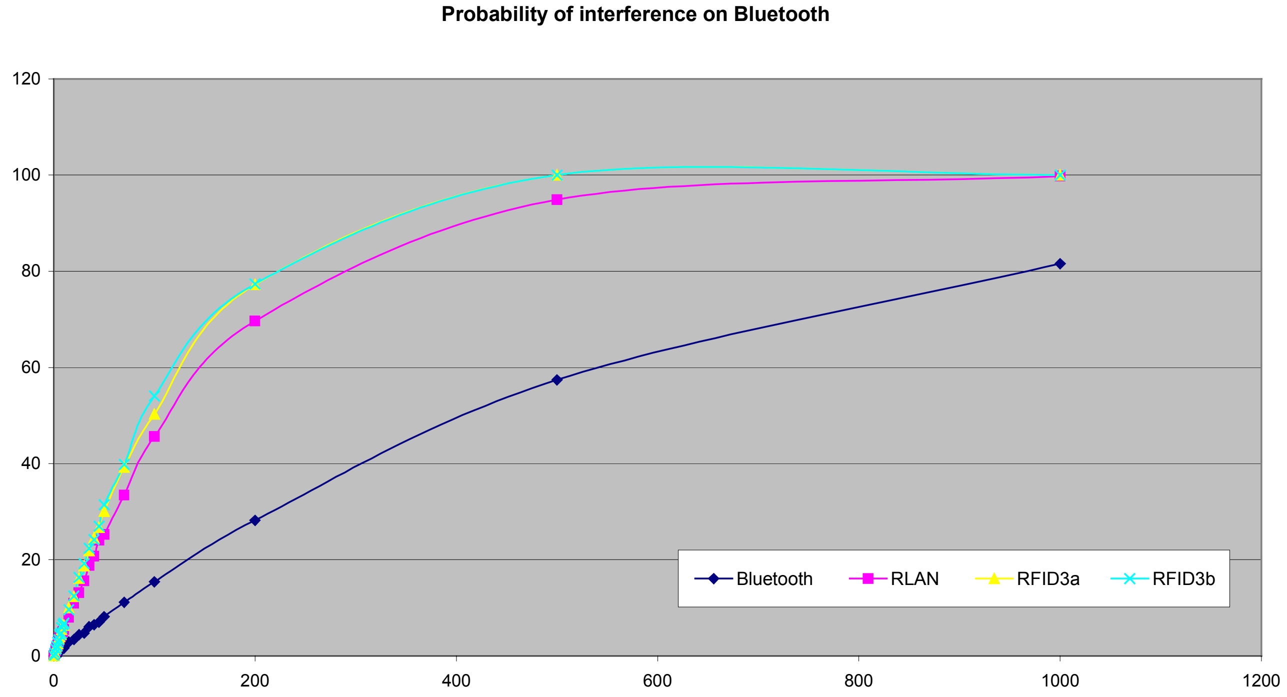
Density	Interferers			
	Bluetooth	RLAN	RFID3a	RFID3b
0	0	0	0	0
1	2.95	65.44	43.96	54.49
2	6	85.14	68.22	77.49
3	8.62	92.18	80.33	88.81
4	11.68	95.73	87.66	93.89
5	13.9	97.57	92.06	96.71
6	15.84	98.23	94.77	97.8
7	19.66	98.9	96.33	98.77
8	21.66	99.16	97.4	99.04
9	23.12	99.5	98.27	99.45
10	25.86	99.53	98.42	99.54
15	36.19	99.92	99.59	99.93
20	44.56	99.95	99.81	99.97
25	52.44	99.99	99.95	100
30	57.75	100	99.98	100
35	62.61	100	100	100
40	67.53	100	100	100
45	70.66	100	100	100
50	74.08	100	100	100
70	83.72	100	100	100
100	91.62	100	100	100
200	98.09	100	100	100
500	100	100	100	100
1000	100	100	100	100

Annex C.3. Results of interference calculations with SEAMCAT using (N+I)/N=3 dB



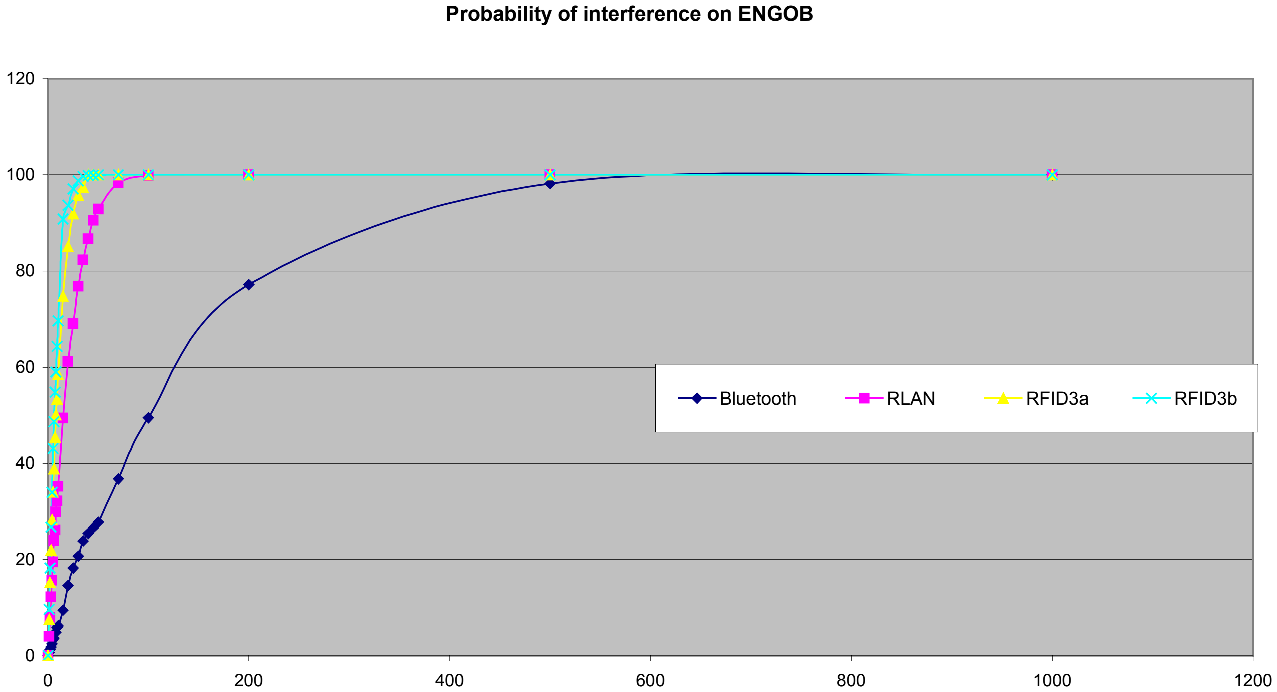
Victim RLAN

Density	Interferers			
	Bluetooth	RLAN	RFID3a	RFID3b
0	0		0	0
1	0.38	1.16	1.51	0.89
2	0.74	2.3	3.48	1.88
3	1.18	3.37	4.92	3.02
4	1.55	4.46	6.51	3.84
5	2.08	5.99	8.67	5.11
6	2.22	7.29	10.68	6.55
7	2.35	8.13	12.31	7.11
8	2.7	8.51	13.64	7.38
9	3.38	9.51	14.49	8.44
10	3.55	10.94	16.42	9.43
15	5.1	15.78	23.86	13.77
20	6.97	22.11	30.76	18.1
25	8.68	25.01	36.12	21.67
30	10.7	28.96	41.36	25.96
35	11.76	34.57	47.34	30.28
40	13.63	37.33	52.61	33.43
45	15.29	42.12	57.71	37.19
50	17.83	45.08	60.98	39.28
70	22.68	57.71	74.09	50.91
100	30.71	70.7	87.47	66.04
200	55.58	93.24	98.77	88.63
500	84.74	99.95	100	99.66
1000	97.76	100	100	100



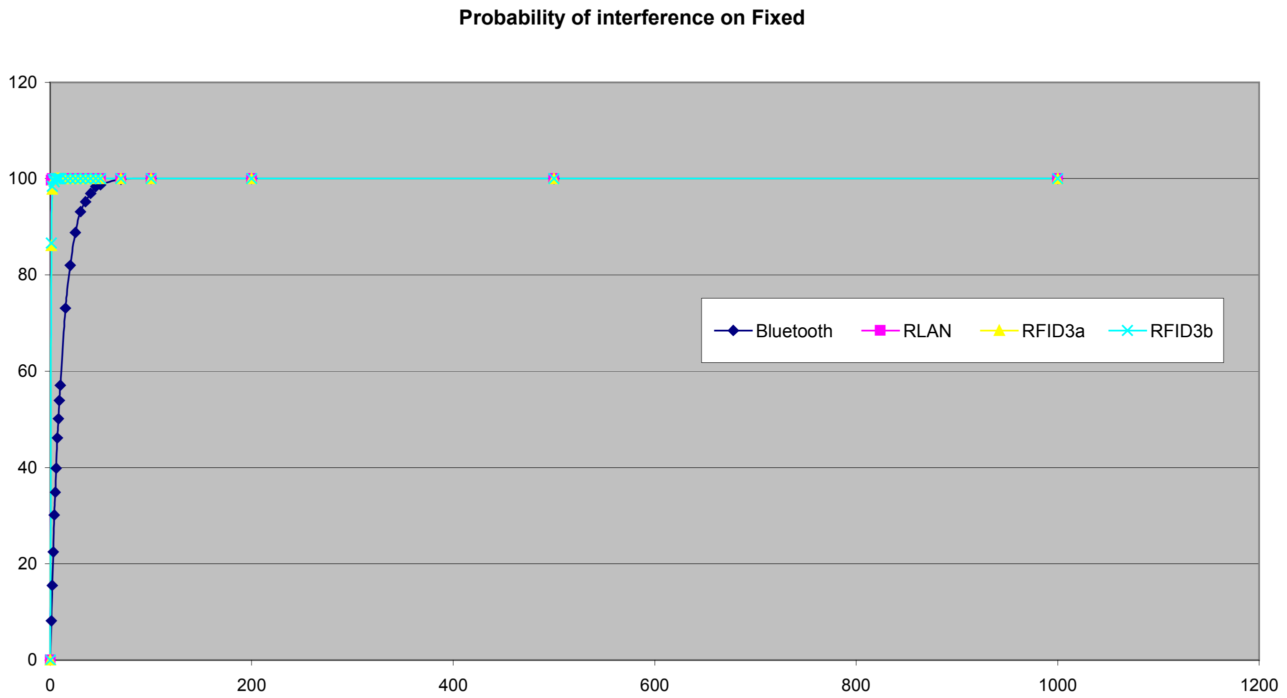
Victim Bluetooth

Density	Interferers			
	Bluetooth	RLAN	RFID3a	RFID3b
0	0	0	0	0
1	0.14	0.41	0.66	0.56
2	0.56	1.12	1.57	1.43
3	0.02	1.75	2.06	2.03
4	0.66	2.25	2.51	2.8
5	0.91	2.95	3.62	3.36
6	1.07	3.76	4.05	4.42
7	1.29	4.13	4.48	4.71
8	1.27	4.53	5.5	5.91
9	1.58	4.99	6.31	6.45
10	1.66	5.5	6.33	6.8
15	2.88	7.99	9.98	9.61
20	3.41	10.94	12.34	12.47
25	4.41	13.14	16.16	16.34
30	4.74	15.6	18.75	19.19
35	6.04	18.81	21.85	22.38
40	6.52	20.72	24.54	24.17
45	7.03	24.01	26.71	26.96
50	8.17	25.27	30.02	31.4
70	11.16	33.45	39.24	39.87
100	15.41	45.61	50.31	54.04
200	28.2	69.65	77.21	77.34
500	57.39	94.85	100	100
1000	81.58	99.76	100	100



Victim ENG/OB3

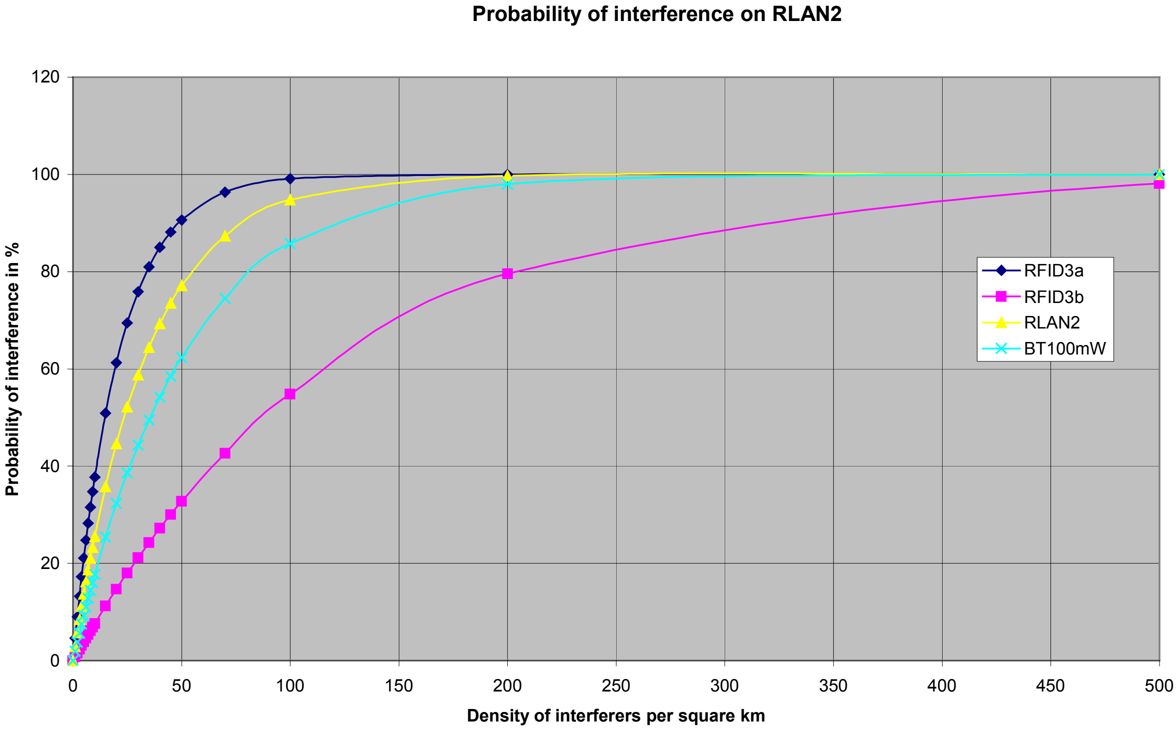
Density	Interferers			
	Bluetooth	RLAN	RFID3a	RFID3b
0	0	0	0	0
1	0.71	4.02	7.49	9.62
2	1.29	7.92	15.21	18.2
3	1.78	12.2	21.91	26.75
4	2.42	15.67	28.25	34
5	3.31	19.44	34.03	43.09
6	3.65	23.95	38.86	48.7
7	4.79	26.08	45.38	54.8
8	4.84	29.95	50.07	59.01
9	5.88	32.14	53.33	64.28
10	6.2	35.23	58.46	69.67
15	9.44	49.43	74.8	90.8
20	14.6	61.19	85.09	93.63
25	18.22	69.07	91.83	97.06
30	20.7	76.8	95.75	98.73
35	23.84	82.33	97.4	99.62
40	25.42	86.67	100	99.87
45	26.53	90.55	100	99.93
50	27.78	92.84	100	99.98
70	36.77	98.29	100	100
100	49.47	99.83	100	100
200	77.18	100	100	100
500	98.19	100	100	100
1000	100	100	100	100



Victim fixed

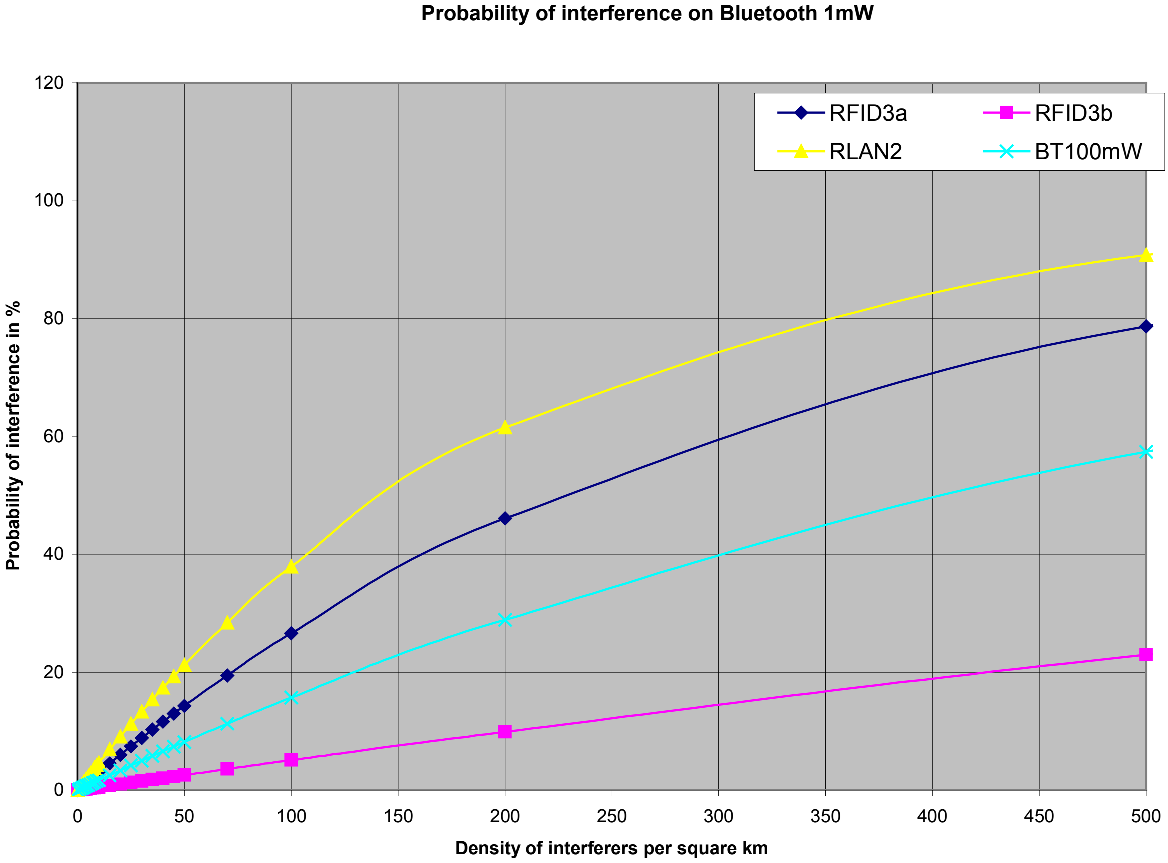
	Interferers			
Density	**Bluetooth**	**RLAN**	**RFID3a**	**RFID3b**
0	0	0	0	0
1	8.16	99.63	86.12	86.63
2	15.51	100	97.8	98.42
3	22.48	100	99.71	99.84
4	30.12	100	99.91	99.38
5	34.86	100	100	100
6	39.85	100	100	100
7	46.11	100	100	100
8	50.12	100	100	100
9	53.94	100	100	100
10	57.08	100	100	100
15	73.11	100	100	100
20	81.99	100	100	100
25	88.83	100	100	100
30	93.14	100	100	100
35	95.21	100	100	100
40	96.94	100	100	100
45	98.37	100	100	100
50	98.71	100	100	100
70	99.85	100	100	100
100	100	100	100	100
200	100	100	100	100
500	100	100	100	100
1000	100	100	100	100

Annex C.4. Results of interference calculations with MCL using (N+I)/N=3 dB



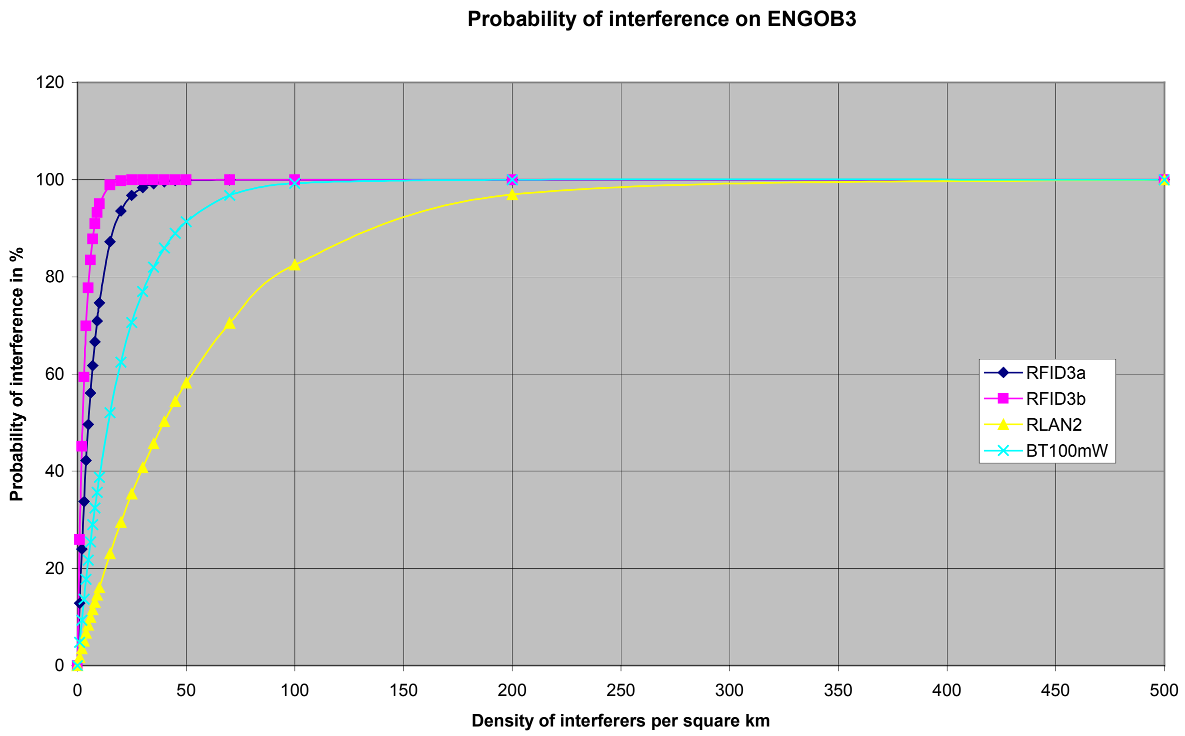
Victim RLAN2

Density	Interferers			
	RFID3a	RFID3b	RLAN2	BT100mW
0	0	0	0	0
1	4.632174	0.791148	2.90901	1.933729
2	9.049778	1.576037	5.733396	3.830065
3	13.26275	2.354717	8.47562	5.689731
4	17.28057	3.127236	11.13807	7.513436
5	21.11228	3.893643	13.72307	9.301875
6	24.7665	4.653987	16.23288	11.05573
7	28.25144	5.408315	18.66967	12.77567
8	31.57496	6.156676	21.03558	14.46235
9	34.74453	6.899116	23.33266	16.11642
10	37.76728	7.635682	25.56292	17.7385
15	50.90602	11.23202	35.77798	25.39036
20	61.27088	14.68833	44.59121	32.33046
25	69.44748	18.01006	52.195	38.625
30	75.89781	21.20246	58.75532	44.33402
35	80.98634	24.27055	64.41536	49.512
40	85.00055	27.21918	69.29866	54.20833
45	88.16728	30.05301	73.51183	58.46782
50	90.66544	32.7765	77.14682	62.33109
70	96.38481	42.6505	87.33733	74.50962
100	99.12866	54.81001	94.77732	85.81053
200	99.99241	79.57864	99.72724	97.98659
500	100	98.11543	99.99996	99.99425
1000	100	99.96448	100	100



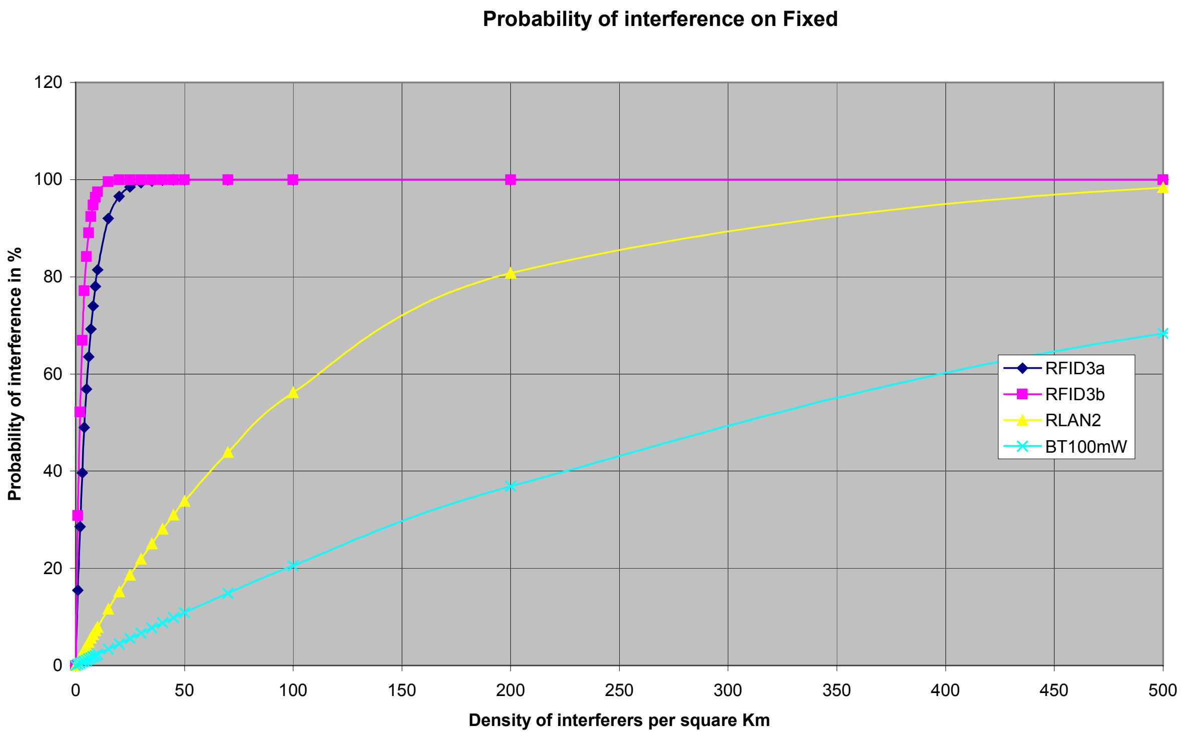
Victim Bluetooth 1 mW

Density	Interferers			
	RFID3a	RFID3b	RLAN2	BT100mW
0	0	0	0	0
1	0.308626	0.052159	0.476072	0.170581
2	0.616299	0.10429	0.949877	0.340872
3	0.923022	0.156394	1.421427	0.510872
4	1.228799	0.208471	1.890732	0.680582
5	1.533632	0.260521	2.357802	0.850002
6	1.837525	0.312544	2.822649	1.019134
7	2.140479	0.364539	3.285283	1.187977
8	2.442499	0.416508	3.745714	1.356532
9	2.743586	0.468449	4.203954	1.524799
10	3.043744	0.520363	4.660012	1.69278
15	4.530697	0.779529	6.90794	2.528393
20	5.994845	1.038019	9.102867	3.356904
25	7.436538	1.295836	11.24604	4.178373
30	8.856121	1.552981	13.33868	4.992859
35	10.25393	1.809456	15.38199	5.800422
40	11.63031	2.065263	17.37711	6.60112
45	12.98557	2.320404	19.3252	7.395013
50	14.32006	2.57488	21.22735	8.182158
70	19.45644	3.586171	28.39792	11.26439
100	26.58947	5.08346	37.94869	15.69484
200	46.10894	9.908503	61.49635	28.9264
500	78.67978	22.9612	90.8007	57.41361
1000	95.45448	40.65023	99.15373	81.86399



Victim ENG/OB3

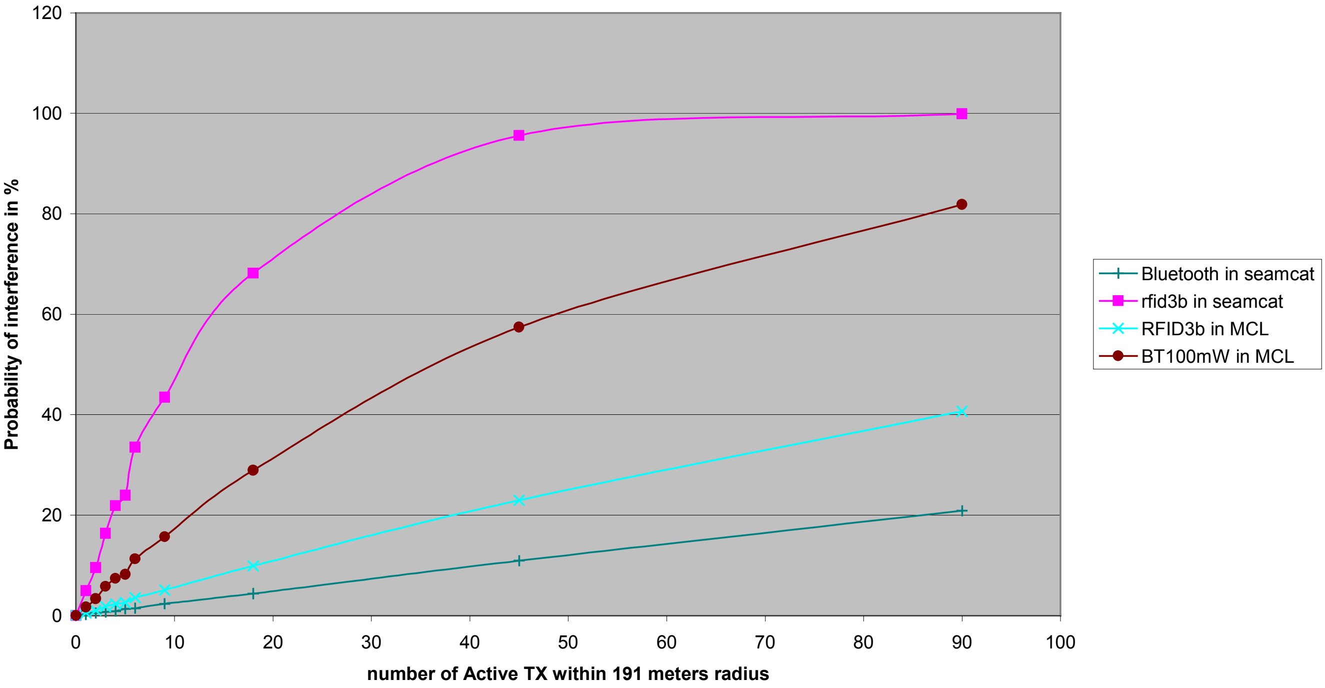
Density	Interferers			
	RFID3a	RFID3b	RLAN2	BT100mW
0	0	0	0	0
1	12.82225	25.93226	1.727879	4.781211
2	24.00039	45.13969	3.425903	9.333823
3	33.74525	59.36621	5.094587	13.66876
4	42.2406	69.90347	6.734437	17.79644
5	49.64665	77.70818	8.345954	21.72677
6	56.10308	83.48895	9.929625	25.46918
7	61.73165	87.77064	11.48593	29.03265
8	66.63851	90.94199	13.01535	32.42575
9	70.91621	93.29094	14.51834	35.65662
10	74.6454	95.03075	15.99536	38.73301
15	87.23311	98.89226	23.00635	52.04435
20	93.57144	99.75307	29.4322	62.46356
25	96.76301	99.94495	35.32176	70.61902
30	98.37007	99.98773	40.71977	77.00256
35	99.17927	99.99726	45.66727	81.99916
40	99.58674	99.99939	50.20186	85.91016
45	99.79191	99.99986	54.35799	88.97143
50	99.89522	99.99997	58.16725	91.36758
70	99.99326	100	70.47955	96.7597
100	99.99989	100	82.50021	99.25481
200	100	100	96.93757	99.99445
500	100	100	99.98359	100
1000	100	100	100	100



Victim Fixed

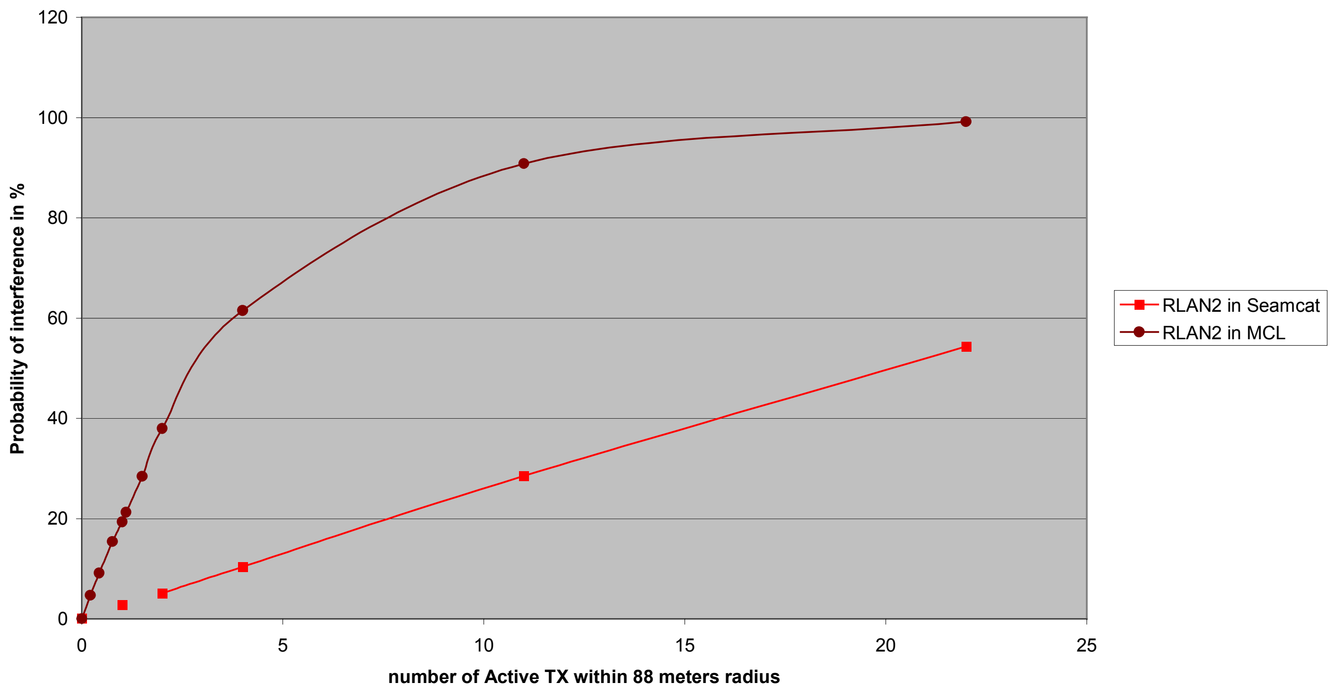
Density	Interferers			
	RFID3a	RFID3b	RLAN2	BT100mW
0	0	0	0	0
1	15.49472	30.83174	0.821086	0.229851
2	28.58857	52.15751	1.635431	0.459173
3	39.65357	66.90818	2.443089	0.687968
4	49.00408	77.11096	3.244116	0.916237
5	56.90575	84.16805	4.038565	1.143982
6	63.58308	89.04931	4.826491	1.371203
7	69.22578	92.4256	5.607948	1.597901
8	73.99416	94.76092	6.382989	1.824079
9	78.02369	96.37622	7.151665	2.049737
10	81.42886	97.49349	7.91403	2.274876
15	91.9969	99.60317	11.63298	3.392834
20	96.55113	99.93717	15.20174	4.498002
25	98.51373	99.99005	18.62637	5.590527
30	99.3595	99.99843	21.9127	6.670554
35	99.72398	99.99975	25.06631	7.738226
40	99.88105	99.99996	28.09255	8.793683
45	99.94874	99.99999	30.99658	9.837067
50	99.97791	100	33.78333	10.86851
70	99.99924	100	43.84942	14.87765
100	100	100	56.15353	20.55578
200	100	100	80.77487	36.88616
500	100	100	98.37941	68.35454
1000	100	100	99.97374	89.98565

ANNEX C-5 Comparison of MCL versus Seamcat interference scenarios, bluetooth is the victim of RFID3b and BT100mW



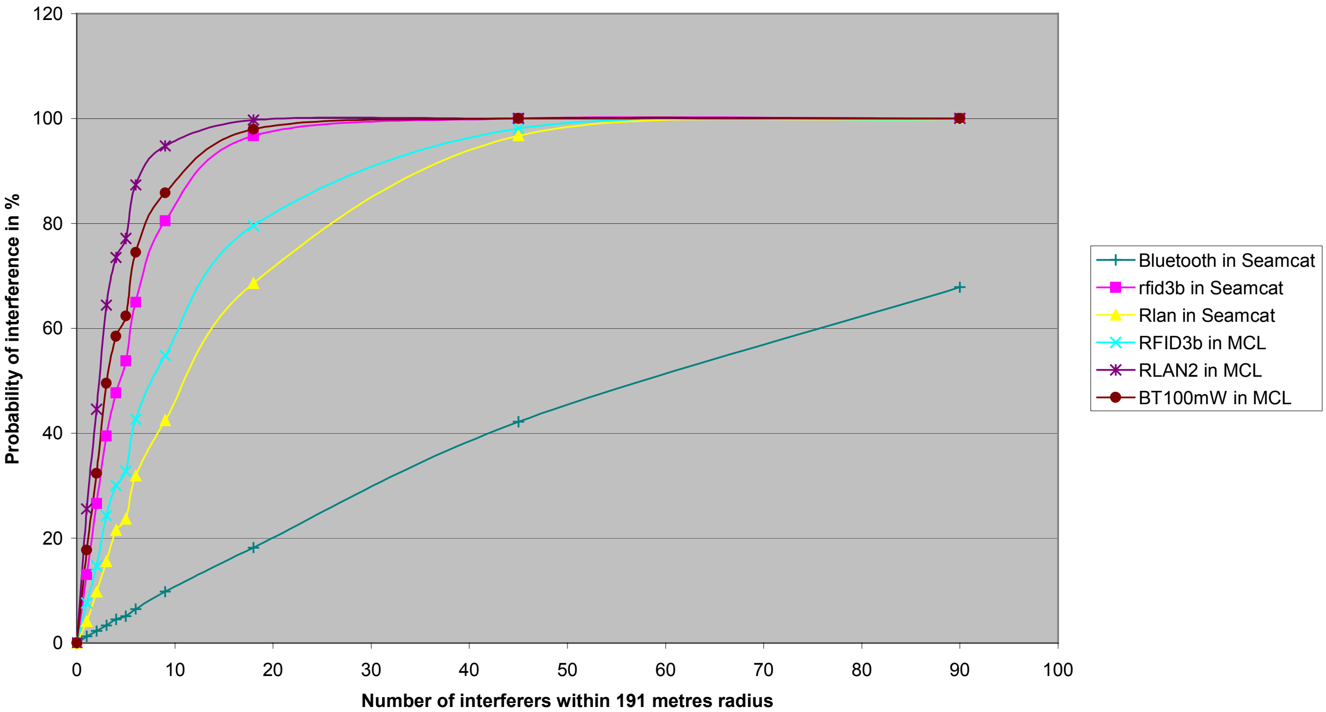
Density	Simulation Radius	Number of active TX	Number of interferer	Bluetooth in SEAMCAT	RFID3b in SEAMCAT	RFID3b in MCL	BT100mW in MCL
0	0.191	0	0	0	0	0	0
10	0.191	1	1	0.24	4.96	0.5203634 15	1.6927796 44
20	0.191	2	2	0.53	9.54	1.0380190 49	3.3569042 58
35	0.191	3	3	0.7	16.35	1.8094562 13	5.8004218 34
45	0.191	4	4	0.91	21.89	2.3204038 79	7.3950131 18
50	0.191	5	5	1.33	23.92	2.5748798 02	8.1821576 75
70	0.191	6	6	1.48	33.5	3.5861711 08	11.264394 73
100	0.191	9	9	2.38	43.46	5.0834595 44	15.694838 31
200	0.191	18	18	4.36	68.15	9.9085034 78	28.926397 12
500	0.191	45	45	10.94	95.55	22.961201 17	57.413609 86
1000	0.191	90	90	20.87	99.88	40.650234 75	81.863993 75

ANNEX C-5 Comparison of MCL versus Seamcat interference scenarios, bluetooth is the victim of RLAN2



Density	Simulation Radius	Number of active TX	Number of interferer	Density to enter in SEAMCAT	RLAN in SEAMCAT	RLAN2 in MCL
0	0.088	0	0	0	0	0
10	0.088	0.21642845	0.21			4.660011835
20	0.088	0.4328569	0.43			9.102866567
35	0.088	0.757499575	0.76			15.38198605
45	0.088	0.973928025	1	41.12491446	2.74	19.32519552
50	0.088	1.08214225	1.1			21.22734773
70	0.088	1.51499915	1.5			28.39791715
100	0.088	2.164284501	2	82.24982892	5.1	37.94869254
200	0.088	4.328569001	4	164.4996578	10.4	61.49635242
500	0.088	10.8214225	11	452.3740591	28.5	90.80070207
1000	0.088	21.642845001	22	904.7481181	54.31	99.15372918

ANNEX C-5 Comparison of MCL versus SEAMCAT interference scenarios, RLAN is the victim



Density	Simulation Radius	Number of interferers	Bluetooth in SEAMCAT	RFID3b in SEAMCAT	RLAN in SEAMCAT	RFID3b in MCL	RLAN2 in MCL	BT100mW in MCL
0	0.191	0	0	0	0	0	0	0
10	0.191	1	1.29	13.05	4.13	7.635682	25.56292	17.7385
20	0.191	2	2.28	26.57	9.71	14.68833	44.59121	32.33046
35	0.191	3	3.36	39.44	15.56	24.27055	64.41536	49.512
45	0.191	4	4.53	47.7	21.51	30.05301	73.51183	58.46782
50	0.191	5	5.1	53.76	23.67	32.7765	77.14682	62.33109
70	0.191	6	6.46	65	31.89	42.6505	87.33733	74.50962
100	0.191	9	9.82	80.51	42.45	54.81001	94.77732	85.81053
200	0.191	18	18.18	96.69	68.62	79.57864	99.72724	97.98659
500	0.191	45	42.19	100	96.74	98.11543	99.99996	99.99425
1000	0.191	90	67.84	100	100	99.96448	100	100

Annex D. Simulation model

D.1. Introduction

This Annex describes the simulation model that was used in the analysis interference from RFID, and RLAN into Bluetooth receivers.

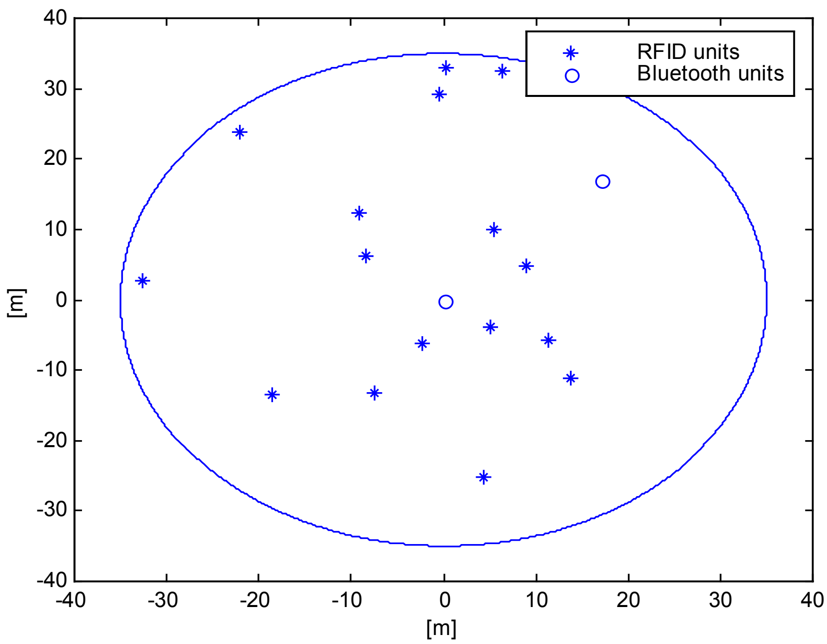
The simulation methodology and models, which are described with related formulas, can be characterised as a Monte-Carlo approach in the sense that Bluetooth traffic and RFID interference are randomly generated and are averaged over ensembles of random scenarios.

D.2. Scenario

D.2.1. General

A hot-spot scenario with randomly placed RFID readers within a circle of radius of 35 meters is assumed. The Bluetooth receiver victim is placed at the centre of the circle and the Bluetooth transmitter is placed at a varying distance from the victim, where the receiver sensitivity is not below the sensitivity limit S_0=-70 dBm, according to the Bluetooth specification.

Fig. D.2.1: Hot spot scenario for the case of 16 RFID units



D.2.2. Algorithm used

To generate an RFID distribution within a circle with radius R the following algorithm were used:

1) Generate two independent uniformly distributed random variables ρ_1 and ρ_2:

$$\rho_1 = rand(0,1) \text{ and } \rho_2 = rand(0,1)$$

2) Compute the random variables

$$\Phi = 2\pi\rho_1$$

$$Q = R\rho_2^{\alpha}$$

3) Then the desired coordinates are obtained:

$$X = Q\cos(\varphi)$$
$$Y = Q\sin(\varphi)$$

If the parameter α=0.5, the distribution of RFID units is even, see fig D.2.2.1. It becomes somewhat more peaky towards the centre of the 35 m circle in the case α=0.7, see Fig. D.2.2.2. For both cases total of 3000 units were generated. For the actual simulation α=0.5 was used.

Figure D.2.2.1: Distribution of RFID units, when α =0.5

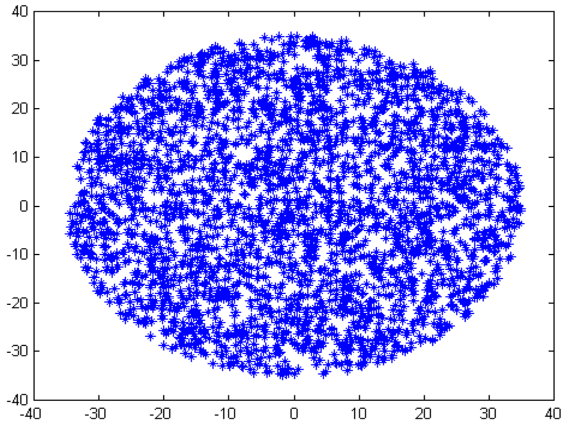
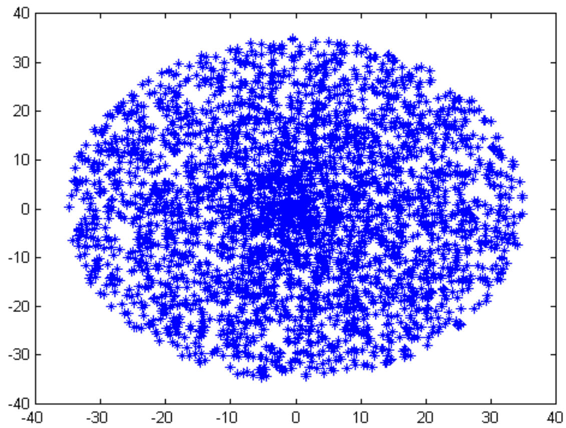


Figure D.2.2.2: Distribution of RFID units, when α =0.7

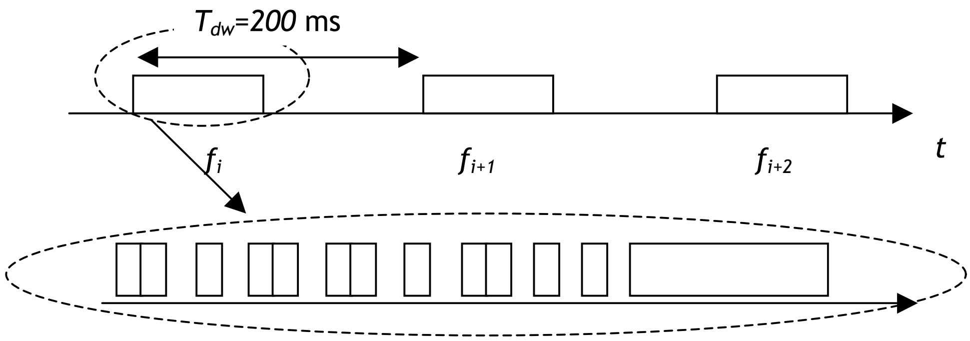


D.3. RFID model

Frequency hopping is used in both the RFID reader and the Bluetooth receiver. The definition of the hopping parameters for RFID units and Bluetooth units respectively are assumed. The RFID channel bandwidth of $B_{RFID}=0.35$ MHz was assumed, the RFID system using 20 hop frequencies in a sub-band of $W_{RFID}=7$ MHz, positioned in the middle of the ISM band.

The RFID transmitter is ASK-modulated with pulse rate equal to hop rate as shown in Fig D.3.1. The dwell time, T_{dw} is between 50 ms and 400 ms. For the actual simulation the value of 200 ms was chosen (hopping rate of *5* Hz), this value being not critical for data transmission. The duty cycle *d* assumes values between 0.035 and 1.0. The on-time for the RFID pulse then becomes $T_{on}=T_{dw}*d$ ms.

Fig. D.3.1: RFID pulsed interference model



The bit rate in the ASK-modulated part is typically 70 kb/s and therefore the on- and off-times are about 14 ms. The peak power of the ASK-modulated RFID interference determines the effective interference from the point of view of C/I performance according to table 6.1. Although an interference pulse strikes the Bluetooth victim less than full time the effective duty cycle will remain the same due to the relationship between hop rates and protocol structure.

$$P_R = \begin{cases} P_{RFID} - 40.2 - 20\log_{10} R, & R < 15\ m; \\ P_{RFID} - 63.7 - 30\log_{10}\left(\frac{R}{15}\right), & R > 15\ m. \end{cases}$$

D.4. Intermodulation

Interference performance arising from 3rd intermodulation and interference are calculated according to the following.

D.4.1. Two channels IM

$$f_{im3}=2f_1-f_2$$

If there are n transmitters, this produces total of $n(n-1)$ number of frequency combinations which meet this criteria, some of which will coincide in frequency.

The corresponding generated 3rd order intermodulation power level is:

$$P_{im3}=2P_1+P_2-2IP_3$$

D.4.2.Three channels IM

$$f_{im3}=f_1+f_2-f_3$$

There are in all $n(n-1)(n-2)$ total number of combinations which satisfy this criterion, some of which will coincide in frequency.

The corresponding generated 3rd order intermodulation power level is:

$$P_{im3}=P_1+P_2+P_3-2IP_3$$

where IP_3= -21 dBm

Calculations of all combinations were automatically taken into account by the simulation program.

D.5. Packet failure condition

It was considered that if the following conditions for C/I, time and frequency collision criteria are not satisfied, then the packet transmission fails.

D.5.1. Frequency collision criteria

Equate $\Delta f=| f_{RFID}-f_{BT} |$ where f_{RFID} and f_{BT} are the centre frequencies of RFID and Bluetooth transmitters respectively. The packet transmission will fail according to the collision criteria in the following table D.5.1 below.

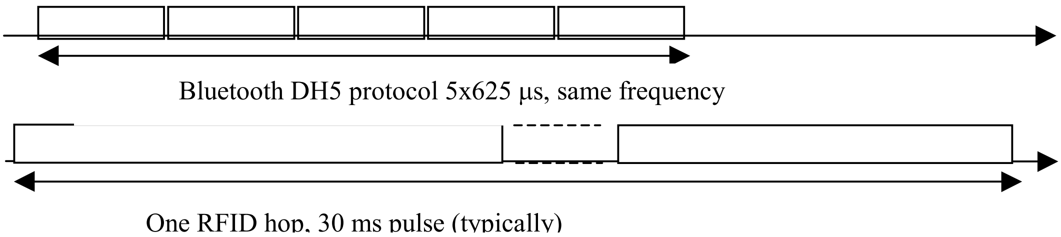
Table D.5.1: Frequency collision criteria

Frequency criteria	C/I criteria, dB	RF mechanism
$\Delta f < 0.5(B_{BT}+B_{RFID}) \equiv \Delta f_1$	*< 11*	Corresponding to co-channel interference
$\Delta f < B_{BT}+0.5(B_{BT}+B_{RFID}) \equiv \Delta f_2$ and $\Delta f > 0.5(B_{BT}+B_{RFID})$	*< 0*	Corresponding to first adjacent channel interference
$\Delta f < 2B_{BT}+0.5(B_{BT}+B_{RFID}) \equiv \Delta f_3$ and $\Delta f > B_{BT}+0.5(B_{BT}+B_{RFID})$	*< -30*	Corresponding to second adjacent channel interference
$\Delta f > 2B_{BT}+0.5(B_{BT}+B_{RFID})$	*< -40*	Corresponding to interference to other channels

D.5.2. Time collision criteria

If during a Bluetooth hop any part of the protocol coincides with a RFID pulse (one bit overlap of the protocol suffices), the time overlap condition is met. This is due to the fact that the protocols DH1, DH3 and DH5 do not have FEC hence one bit error is equivalent to packet error as illustrated in figure D.5.2 below.

Figure D.5.2. Illustration of data packages



D.5.3. Aggregate effects

Contributions from all interferers which coincide in time and fall into different frequency bins Δf_i, i=1,2,3, are added according to the following formula. For definition of Δf_i see table D.5.1.

$$I_{tot} = 10\log_{10}\left[\sum_{\Delta f_n < \Delta_1} 10^{0.1 I_n} + 10^{-1.1} \sum_{\Delta_1 < \Delta f_n < \Delta_2} 10^{0.1 I_n} + 10^{-4.1} \sum_{\Delta_2 < \Delta f_n < \Delta_3} I_n + 10^{-5.1} \sum_{\Delta_3 < \Delta f_n} 10^{0.1 I_n} + Noise\right]$$

The total interference I_{tot} is then regarded as a co-channel interferer.

D.6. Simulation modelling

D.6.1. Description

A flow chart is provided in this section to simplify the understanding of the simulator, which was programmed in MATLAB. The simulation is made in the following numbered steps as shown in figure D.6.2:

1. At the first box, the simulator defines the user matrix and all other parameters such as EIRP, bandwidth, packet type, antenna type, etc. The user matrix is given by:

$$\begin{bmatrix} U_1 \ldots\ldots\ldots\ldots \\ U_2 \ldots\ldots\ldots\ldots \\ .. \\ .. \\ U_n \ldots\ldots\ldots\ldots \end{bmatrix}$$

   where the rows correspond to the RFID and Bluetooth units and the columns to the parameters of the units, such as channel number, the co-ordinates of the position, the number of failed transmissions, the number of succeeded transmission, etc.

2. The distance between the RFID units and the Bluetooth victim is calculated. The distance between the RFID units and the Bluetooth transmitter is not calculated since the acknowledgement from the victim is assumed as a transmission from the transmitter, at a different frequency however. This is a reasonably simplifying assumption.
   Based on Bluetooth-specification, the number of frequency hops is defined to be 79.

3. Hopping sequences are generated for Bluetooth and RFID independent of each other. Bluetooth hopping frequency is 1600 hops/sec and RFID hop-rate is 5 hops/sec.

4. A duty cycle d is selected and since the RFID units are not time synchronised, their transmissions are assumed to be independent of each other.

5. After all parameter have been set, the simulation will start at time 0. Every time step corresponds to one Bluetooth timeslot in the simulation.

6. Every unit will hop in its own independent hopping sequence to allocate a new channel. The Bluetooth units will hop to a new channel in each 625 µs timeslot, while the RFID units will hop to a new channel after 320 timeslots.

7. Based on the given propagation models, the path loss is calculated.

8. The received powers at the Bluetooth receiver from RFID units and Bluetooth transmitter are calculated.

9. Frequency channel differences between the RFID units and the Bluetooth victim are calculated at each hop.

10. The intermodulation and interference performances are calculated.

11. The C/I is evaluated with respect to the frequency differences and packet error performance is calculated according to table D.5.1.

12. Logical decision.

13. If the simulation time ends, the simulation will be stopped and all statistical parameters will be saved, otherwise jump to box no. 6.

Figure D.6.2. Simulation flow chart