CEPT ECC
Electronic Communications Committee

ECC Report 211

Technical assessment of the possible use of asymmetrical point-to-point links

Approved 31 January 2014

0 EXECUTIVE SUMMARY

It is recognised that with the move to more data intensive applications by mobile users the consequent traffic in the access network has become asymmetric in nature, with more data being downloaded than uploaded. Whilst it is agreed that the amounts of data are application dependant and that new applications such as cloud computing, instant messaging, VoIP and social networking, might still change this trend, this report was produced to examine the impact of current asymmetry trends in the access network on the backhaul network. This report primarily focuses on the use of asymmetric channel widths within the traditional bi-directional link allocation. It should also be noted that whilst the presence of asymmetry in the access network is agreed, the degree of this asymmetry differs from operator to operator based on the services offered. This report considers some examples ratio.

The report considered different network architectures and geographic deployments and concluded that for the considered traffic parameters rural deployments did not show a level of asymmetry that justified the use any of the techniques and the ring architectures are symmetrical. Therefore the report concentrated upon the urban deployment of star networks.

This report could not be conclusive on the different asymmetry levels within the same network related to core or tail. This report only studies the application with fixed degree of asymmetry in the whole network. A mix of different asymmetry levels may be applied. Mobile backhaul is a the predominant application for microwave point to point links but when other point to point applications share the same spectrum they do not exhibit the level of asymmetry discussed in this report. This will present additional challenges for administrations in order to manage the coordination of both symmetric and asymmetric links in an efficient way.

One of the prime motivators in allocating spectrum for bi-directional links in an asymmetric manner is a potential saving of spectrum. The report highlights that, to be of use, this saved spectrum must be available for re-use, ideally also for other symmetric point to point applications, and not left orphaned. This means that for asymmetric deployment flexibility in the go and return frequency assignment is to be considered.

With existing tools and processes, with fixed duplex spacing, the ability to re-use the saved spectrum appears to be limited. On the other hand, fully flexible duplex spacing that can be configured to any required size is impractical from a radio design perspective, therefore a compromise situation needed to be found. The compromise reached after examining multiple possible permutations of channel allocation is to limit the variation in duplex spacing to the tuning range of the duplexer in the radio of each vendor. This means that the national spectrum authorities will have to consider the frequency coverage required by the applicant and may require the upgrade of their assignment tools to cope.

This report has shown that for maximizing the spectrum saving by the asymmetry deployment, the planning method has to be modified (i.e. to consider C/I and I/N where appropriate). It should be noted, that to implement the planning method described in the simulation one needs to change current planning tools, which commonly do not offer the C/I option.

Another factor, touched upon only briefly in the report, is the co-existence of symmetrical links with asymmetrical links within the same band and thus the same band plan. This report suggests that asymmetric allocation is easier to be implemented within block allocated spectrum where a single operator is free to utilise that spectrum to meet his own needs in whatever manner he requires.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
3G	Third Generation digital cellular network
4G	Fourth Generation digital cellular network
AMC	Adaptive Modulation and Coding
BER	Bit Error Rate
CAGR	Compound Annual Growth Rate
CEPT	European Conference of Postal and Telecommunications Administrations
CS	Channel Spacing or Channel Separation
DSL	Digital Subscriber Line
ECC	Electronic Communications Committee
eNB	Evolved NodeB – base station in LTE
ETSI	European Telecommunication Standard Institute
FDD	Frequency Division Duplex
FM	Fade Margin
GSM	Global System for Mobile Communications
HSPA	High-Speed Packet Access
HSPA+	Evolved HSPA
IMT	International Mobile Telecommunications
IMT-2000	International Mobile Telecommunications-2000
IMT-Advanced	International Mobile Telecommunications Advanced: requirements for 4G Standards
IP	Internet Protocol
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output
MW	Microwave
NFD	Net Filter Discrimination
NGMN	Next Generation Mobile Networks
PHY	Physical Layer
P-MP	Point-to-Multipoint
POP	Point of Presence
P-P	Point-to-Point
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RPE	Radiation Pattern Envelope
RSL	Received Signal Level
SW	Software
TDD	Time Division Duplex
TDM	Time-Division Multiplexing
XPIC	Cross Polarization Interference Cancellation

1 INTRODUCTION

1.1 SCOPE

It is commonly understood that, while in the old GSM times when only voice/SMS signals were used the DL/UL traffic was symmetric, in the new generation of mobile access the DL/UL data traffic has become asymmetric. This may be also reflected in the relevant backhauling network.

It is undoubted that if a P-P link may be deployed with DL/UL asymmetric channel size there is, in principle, some spectrum saving; however, it is still needed to be analysed if such “unidirectional” spectrum saving can effectively be reused in the same area network and which is the possible additional burden in term of frequency coordination and equipment complexity.

It should be noted that even if the asymmetry of the traffic may justify the use of asymmetrical links in mobile backhauling, symmetric links will continue to be needed in networks and other P-P applications (e.g. for ring protection configurations and other reasons further described in this report).

Therefore, the possible use of asymmetric go/return capacity in P-P links for mobile backhauling networks, while adding flexibility for the user and potential spectrum saving, poses a number of questions for its practical application. The main differences from conventional symmetric applications are related to the unavoidable variable transmit-receive frequency separation, which may change the existing design considerations. In a specific frequency band, this separation should be indicated by each equipment producer.

Standing the significant impact, the possible asymmetric P-P link practice is intended as a “medium-long term” improvement; therefore, it should be seen in the light of the most updated forecast on the expected DL/UL user data asymmetry. In addition, the asymmetry factor can be influenced by the access network asymmetry in both FDD and TDD deployments.

Consequently, the content of this Report aims to address:

1. The possible amount, in forthcoming data usage patterns in LTE and HSDPA+ networks backhauling, of the uplink/downlink asymmetry and its distribution in links carrying aggregated traffic in different segments of backhauling network from periphery to the core network gateways;
2. The possible benefits in terms of spectrum saving, downlink capacity increase, network versatility, of using asymmetric go/return in Point-to-Point links within the backhauling networks;
3. The impact of go/return asymmetry (“channel size asymmetry” implying also a variable transmit/receive separation on typical P-P equipment design;
4. The impact of such asymmetric links practice on the conventional link-by-link coordinated assignment and of the necessary coexistence of symmetric links (e.g. for the conventional high capacity core networks) with asymmetric links.
5. The impact of go/return “channel size asymmetry” on recommended channel arrangements and the consequent frequency assignments in bands where symmetric and constant duplex arrangements are currently established.
6. New possible guidelines for accommodating within those arrangements both symmetric and asymmetric go/return channels, while minimizing coordination and equipment hardware problematic.

1.2 ASYMMETRIC LINKS DEPLOYMENT OPPORTUNITIES IN CURRENT REGULATIONS

1.2.1 Bands where conventional link-by-link licensing is applied

In principle, in most countries the licensing procedures (as a link by link assignment or self-coordination, when applicable) formally permit the assignment of separate go and return links as “unidirectional” in the same or different bands.

From the equipment HW point of view, the radio terminal may remain bidirectional and would still contain Tx and Rx functionality. This report analysis the practical variation of the duplex frequency between the Tx and Rx inside the equipment (more detailed discussion is presented in section 4.6).

Therefore, if mixed symmetric and asymmetric link deployment would be foreseen for a significant nodal capacity in a network, some regulatory guideline should be adopted for permitting the simultaneous coverage of both options. This would allow the user to define the symmetry, asymmetry and degree of asymmetry on link-by-link basis according its needs, without impacting the equipment purchase forecast and delivery time.

1.2.2 Bands where block assignment/auction is foreseen

Where block assignment is used, the possibility of asymmetric connections is already recognised in some ECC Recommendations (e.g. ECC/REC(01)04 [2]) referring to the 42 GHz band, typically for P-MP applications, but, when technology neutrality is foreseen in the auction rules or P-P infrastructures are explicitly anticipated, the concept is easily extendable to the P-P networks as well.

The rationale is that, in block assignment environment, the following conditions, that in the general case could highly impact the balancing between equipment design and coordination versus the possible benefits, are already limited to an acceptable degree rendering attractive, when needed, the asymmetric P-P use:

- The owner may uniquely define any degree of asymmetry and any other requirements for his network; therefore, he may autonomously define a suitable subdivision of the blocks providing asymmetrical UL/DL channel sizes as already recognised in some ECC Recommendations for PMP applications (see [1]).

- The limited portion of spectrum implicitly reduces the degree of variance of the duplex separation.

- The owner is fully responsible of its own coordination process (from technical and economical point of view).

Therefore the content of this report may be regarded also as guidance for the block owner, in cases where he wishes to establish asymmetric links within the block.

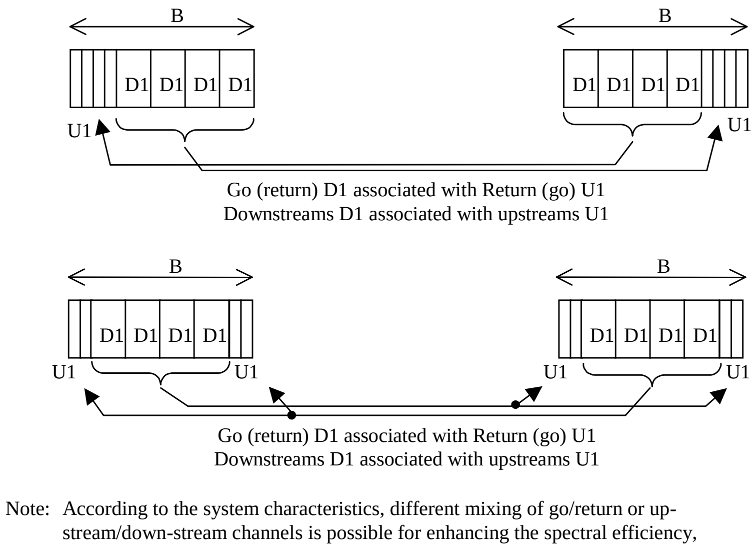


Figure 1: Examples of FDD asymmetric systems within an assigned block (reprinted from ECC/REC/(01)04 [2])

1.3 RADIO TECHNOLOGY

In principle, the radio technology used to support asymmetrical links is not different than that used for the symmetrical links. The main difference is that systems intended for asymmetrical links need to support a range of variable T/R spacing (see section 4.6) and to provide different modem configurations for Tx and Rx path. In this respect, the same equipment can be used in a specific network for both symmetrical and asymmetrical links.

In symmetrical systems (referring to the non-AMC case) the modulator and demodulator are configured to the same symbol rate.

In an asymmetrical system the modulator (Tx) and demodulator (Rx) located on the same site of the link are configured to different symbol rates and modulations according to the specific system serving as a DL transmitter or UL transmitter. Typically the Tx symbol rate of the DL Transmitter is higher than the Rx symbol rate, while the Tx symbol rate of the UL transmitter is lower than the Rx symbol rate.

1.4 PLANNING TOOLS

For analysing the frequency coordination impact, both the commercially available planning SW and the administrations tools should be considered.

From the point of view of commercially available planning tools, if the planning method used in asymmetric deployment would remain the same used for symmetric one, planning an asymmetrical link is not different from planning a symmetrical link due to the following reasons:

1. Propagation – Symmetrical and Asymmetrical links behave the same, with the only difference being in planning for a different working point looking from transmitter or receiver point of view. The actual receiver sensitivity in the two directions, and the consequent licensed EIRP in the two corresponding stations, will become different.
2. Planning – Commercially available radio planning software is either ready or will be adapted to support the planning of asymmetrical links. Planning an asymmetrical link requires different parameters within the same framework of inputs (C/I, NFD…). Both stations of the P-P link being coordinated are independently assessed in terms of the interference they receive from the existing network and the interference they present to the existing network, such that the asymmetric link co-ordination is not a paradigm-change.

It should also be considered that most administrations have developed their proprietary radio planning SW and administrative procedures which presently foresee frequency coordination in a symmetric way. In case that asymmetric planning will be adopted, that SW and administrative procedures will have to be adapted as appropriate.

Finally, whenever the more efficient planning of asymmetric links described in section 4.2.1 (i.e. based on both C/I and I/N methods) is desired, it should be considered that conventional planning tools do not currently implement such feature.

1.5 FREQUENCY BANDS

All ECC recommendations for channel arrangements in various frequency bands have been considered in this report; an overall picture if a possible asymmetric channel use could fit or not in their present formulation is also given with guidelines on the possible actions for harmonising their regulatory frame.

2 DEFINITIONS

Term	Definition
T/R spacing	The frequency difference between the centre of the transmit and receive channels of an individual link
T/R deviation	The difference between the duplex separation of transmit and receive frequency channels and the T/R spacing
Tri-cell	Three cells in a mobile system, each cell using its own antennas. Three cells belongs to the same eNB.

3 ASYMMETRY OF THE USER DATA AND THE BACKHAUL OF ACCESS NETWORK

3.1 BACKGROUND

In the past, the main usage of mobile networks was to facilitate voice communication. This in turn, influenced the symmetrical nature of the protocols in use (SDH, PDH) and the symmetrical nature of the transport networks.

The major part of today's and future mobile device use is data and video streaming oriented, which suggests an asymmetrical orientation of the actual user data. This in turn influences the utilization of the transport networks as the largest P-P spectrum users (Mobile network operators: ref. 4.1.1 of ECC Report 173 [1]) move their transport networks from TDM to packet data oriented, which leads to P-P links being designed to meet actual traffic requirements in downlink (DL) direction, leaving the possible lesser utilization of links in uplink (UL) direction.

There are two main causes contributing to the asymmetrical behaviour of the cellular networks:

1. Physical limitations of the UL/DL wireless access network capacity (e.g. for LTE);
2. Real traffic asymmetry.

It should be considered that the forecast of real traffic asymmetry, as well as the actual uplink and downlink capacity may change in future and while the access system would adapt to a new situation, the backhauling should also be upgraded in capacity and possibly also in asymmetry.

The traffic asymmetry analysis for new/reconfigured backhauling networks is generally based on measured data from present networks and on forecast on future network evolution. The first guidance on the asymmetry ratio to be used in backhaul dimensioning has been provided by NGMN Alliance in [3]. As indicated in [3], the guidance is based on simulations assessing the maximum access network capacity and not on real traffic measurements or forecast.

NGMN analysis of backhauling capacity has been evaluated based only on FTP traffic capability of the Release 8 - based LTE access network equipment (eNodeBs and available/foreseen LTE terminals). NGMN evaluation was intended for deriving an "upper bound" of the maximum possible traffic in downlink and in uplink.

Nevertheless, when actual traffic (present and forecasted) is concerned, various literature and field tests are available, suggesting, from one hand larger DL/UL asymmetry (then a potential more efficient use of the spectrum) and, on the other hand, a significant variation of the DL/UL asymmetry ratio between different networks and forecast (increasing the importance of producing the right guess on future backhauling traffic evolution, before deploying/upgrading the actual network).

Therefore, both approaches have to be carefully considered for choosing the optimum solution for the network under consideration.

In the following a panoramic view is presented for:

- NGMN Alliance methodology for traffic estimation (Section 3.2);
- Other factors affecting the need for symmetric/asymmetric links (Section 3.3);
- Actual mobile networks traffic evaluation - reports and test results (Section 3.4).

3.2 NGMN ALLIANCE - PROVISIONING GUIDELINES

The mobile system behaviour is such that introduces some difference between the DL/UL achievable system capacity. This depends on the technology choices for the system design.

The amount of DL/UL asymmetry in future LTE networks, to which this report is focused, is subject of various studies from major mobile operators. A specific study was made in a NGMN (Next Generation Mobile Networks Alliance) white paper [3] based on the characteristics of the LTE-Release 8 based systems; comparing the DL/UL achievable access network capacity while using the FTP traffic model in [4].

For the FDD 10 MHz or 20 MHz used channel (both cases assumed to implement 2x2 MIMO in downlink direction), it can be derived (see Figure 2) that the degree of asymmetry will range from 2:1 (for the traffic collected by a single tricell eNodeB, horizontal lines portion) to approximately. 1.5:1 (for aggregation of more than three tricells eNodeBs, slanted lines portions). Figure 2 (reprinted from the NGMN white paper [3]) gives the summary results as function of the number of aggregated eNodeBs.

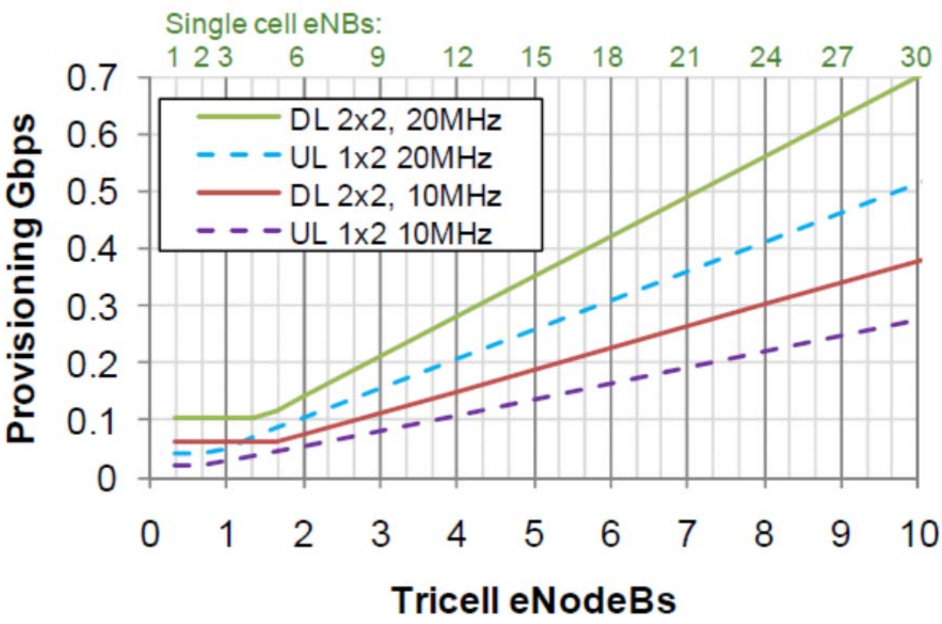


Figure 2: LTE Transport Provisioning for Downlink and Uplink (no IPsec) (from[3])

More background on the interpretation of NGMN study may be found in ANNEX 1: and ANNEX 2:.

In the elaboration of this report, it was found out that there is no one value in terms of asymmetric ratio that can be agreed upon as it depends on different operators network topology and service offerings. A number of European operators participating in the elaboration of this report have confirmed they will use the above mentioned NGMN guidance.

3.3 OTHER FACTORS AFFECTING THE SYMMETRIC/ASYMMETRIC TRANSPORT CAPACITY

3.3.1 Factors related to the network configuration

Other considerations, forbidding or limiting the possible use of asymmetric deployment in mobile backhauling, should be taken into account, e.g.:

- Links shared with fixed radio core network

The backhauling links for mobile stations are often shared with the fixed core network (this is common for previous incumbent operators). This is especially true when there is the need to deploy high capacity links (i.e. for links already carrying aggregated traffic from several eNodeB). High capacity radio links are needed in areas where it is impossible to deploy optical fibre network, or it is economically too expensive. In these conditions, the radio link(s) are used to backhaul traffic of the fixed network. These kinds of links have different levels of asymmetry. The overall level of asymmetry should therefore take into account all these varying figures.

- Ring configuration

The need for protection of the higher capacity aggregated traffic against failure suggests the building of "ring configuration" also in the backhauling layer. Asymmetry is not possible in such ring structures.

- Enterprise network access traffic

Service level agreement for enterprises, where high QoS bidirectional data transfer is generally privileged, should be taken into account before considering lower QoS asymmetric traffic for generic public access.

3.3.2 Carrier aggregation

Carrier aggregation, introduced in 3GPP Release 9 for LTE and HSPA+ and in IEEE 802.16m, is the main standardized approach for supporting the DL-centric access networks, as it allows aggregating more downlink carriers than uplink carriers.

3.3.3 TDD in LTE standards

TDD systems can more easily manage different degrees of traffic asymmetry without requiring a corresponding managing of UL/DL frequency sub-bands. The asymmetry degree can be set according the actual/forecast traffic and eventually changed whenever the traffic composition shows a different trend.

Therefore, TDD usage in LTE networks is an important factor in considering the asymmetrical allocations for the LTE backhauling. The largest new access spectrum resides in newly opened bands such as 2.6 GHz, 3.5GHz and 3.7 GHz bands; the last two bands will likely host a majority of TDD systems.

The backhauling of the TDD base stations should use the asymmetry factors as considered by operators. Table 2 represents the various degree of asymmetry resulting from the LTE PHY standard [11], in its "Frame structure 2".

Table 1: Supported spectrum resource asymmetry in a TDD frame

Uplink-downlink configuration	DL/UL asymmetry	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	0.42	D	S	U	U	U	D	S	U	U	U
1	1	D	S	U	U	D	D	S	U	U	D
2	2.33	D	S	U	D	D	D	S	U	D	D
3	1.85	D	S	U	U	U	D	D	D	D	D
4	3	D	S	U	U	D	D	D	D	D	D
5	5.7	D	S	U	D	D	D	D	D	D	D
6	0.67	D	S	U	U	U	D	S	U	U	D

U: Uplink
D,S: Downlink, Special (also Downlink)

It can be seen that there is a quite large asymmetry in the time-frequency resource allocation for DL/UL, ranging from 0.4 to 5.7. From 7 possibilities, 4 are dedicated to DL centric traffic, 1 is perfectly symmetric and 2 even privileged UL traffic.

3.4 ACTUAL MOBILE NETWORKS TRAFFIC EVALUATION - REPORTS AND MEASUREMENT RESULTS

Besides what may be derived from the actual access system capabilities, as in the NGMN Alliance example above, the real asymmetry is determined by the statistic behaviour (time of the day, number of user contemporarily accessing the network, kind of services used, ….) of actual user traffic. This is dynamically varying and has been subject to measurement of current situation and estimation of future evolution. Also a measurement on an actual large 3G network is presented.

All sources recognize that a certain degree of asymmetry is always present, but actual figures are significantly different. Therefore, a unique asymmetry definition seems not possible to be determined; however, this can be done on a case-by-case basis, if the operator wish to pre-define the asymmetry degree expected in his network.

Nevertheless, adapting to this new reality gives rise to the opportunity to adjust the bandwidth of the lesser used direction of transmission to the traffic load. The saved spectrum may be either used elsewhere in network or, when combined with novel frequency allocation approaches, may provide an additional spectrum resource in the downlink direction, allowing capacity increase such to satisfy the user traffic demands.

In continuation are provided details related to the major traffic-generating applications: Video streaming, Internet browsing and file sharing.

3.4.1 Reports on asymmetry

The justifications of the traffic asymmetry are contained in several reports with measurement and forecast of future composition of the mobile access traffic. These reports, indicating asymmetry factors today existing related to the predominance of the video streaming, are provided in ANNEX 3:. Most of these studies are related to the “access traffic” (i.e. that generated/received by the terminals in the mobile network, necessary for dimensioning the “mobile” systems themselves) and few or no indications are given on its reflection in the backhauling traffic. However the overheads not related to user traffic are typically under 10% of the backhaul capacity.

3.4.2 Measured mobile backhaul asymmetry

The addressed network is a real network using the 3G technology for providing services to its subscribers. The data was collected during a time period of three months. The network segments are located in Austria, and consist of more than 5400 wireless terminals which were recorded for 3 months. This is the first time that the traffic analysis is performed on different backhaul aggregation levels of a real live network, for showing backhaul traffic patterns in terms of UL/DL ratios.

The data is presented for several network aggregation levels. Tail sites were considered as aggregation level 0. Each upper aggregation level is accumulating the traffic coming from the level beneath, thus increasing the traffic amount at each level.

Since the data has been analysed per actual traffic and not per the provisioned capacity, the traffic ranges based on the measured traffic levels for each aggregation level are presented in Table 2.

Table 2: Traffic Range per Aggregation Level

Aggregation level	Traffic range
0	0…25 Mbps
1	25…50 Mbps
2	50…100 Mbps
3	100…200 Mbps
4	200…400 Mbps

Analysing the throughput data from the measured radio terminals, it can be seen in Figure 3 the UL/DL ratio indicated as the asymmetry level per each network aggregation level and the number of terminals with such asymmetry for each aggregation level (e.g. for aggregation level 3, 1:4 asymmetry is experienced in 16 radio terminals, or 8 radio links).

The peak capacity has been recorded over each 15 minutes time slots and the experienced UL/DL link ratio (Note: the asymmetry ratio is derived from measuring the maximum throughput in the UL/ DL) is reported in the graph of Figure 3.

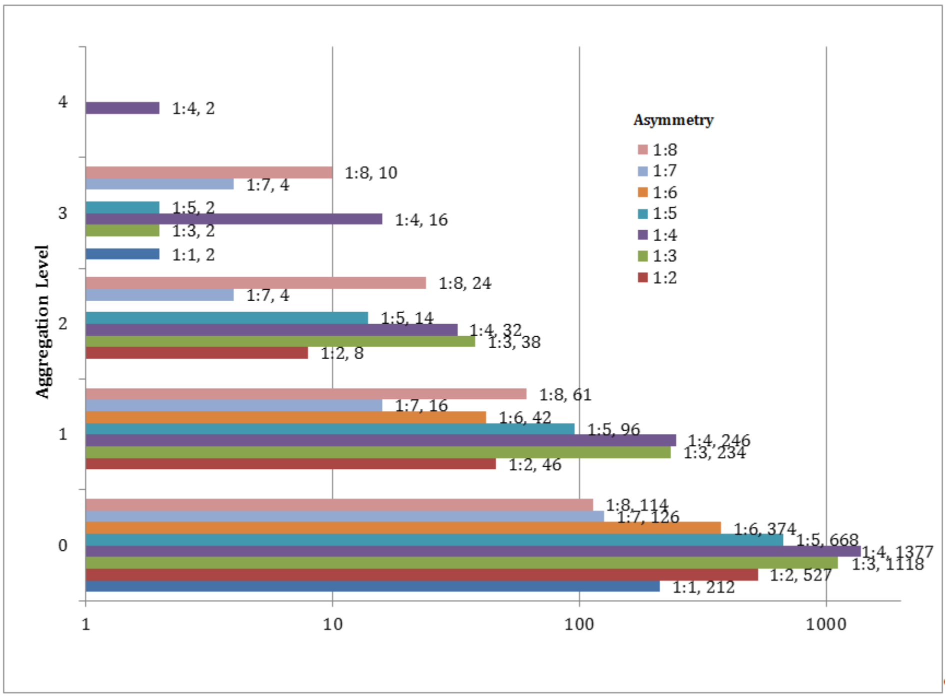


Figure 3: Traffic aggregation levels versus asymmetry and number of radio sites

As can be seen from the graph in Figure 3, for every aggregation level most of the links are asymmetrical and the majority of the links have a peak asymmetry ratio of 1:3 and higher.

The next aggregation level does not show a trend to a more symmetrical data usage. A level 4 aggregation link still shows a relatively high asymmetry level which gives some indication for the general asymmetry of backhaul links.

4 IMPACT OF ASYMMETRICAL CHANNELS USAGE WITHIN CONVENTIONAL SYMMETRIC CHANNEL ARRANGEMENTS

For a more effective asymmetry improvement, also the channel size might be, in principle, rendered more flexible than the present doubling rate (e.g. 7, 14, 28, 56 MHz) of current ECC channel arrangements, which, assuming the same modulation format is used in both directions would permit only the 2^n asymmetry degree.

4.1 SIMPLE EXAMPLE OF ASYMMETRICAL FREQUENCY USAGE

The following simple examples show the potential benefit, with respect to a symmetric deployment, in term of spectrum saving and utilisation or capacity in a single aggregation site. The examples and relevant considerations should be considered only indicative; the actual situation depends on the local situation of the design parameters e.g. TX power relative difference among converging links, incoming angles, antenna directivities and so on.

The methods presented in the following examples are not intended to replace or make redundant any of the currently used techniques, such as the application of frequency reuse as far as possible. In fact, the asymmetrical planning is intended to be added to the tool-box of a network planner as another tool in the design arsenal.

It is well known that, for the obvious saving of frequency (and fees), the links converging in a node make, as far as possible, use of the same channel (i.e. whenever the angular separation of links permits enough antenna decoupling (e.g. at least for angles > 90° this is commonly true).

For simplicity and graphical effectiveness, the examples are made assuming a channel size granularity of n x 7 MHz, while, in the actual study, this additional flexibility will not be used (see section 4.3).

The example shows how downlink capacity can be added by re-allocating 7 MHz channels of spectrum in an asymmetrical way and adding only two 7 MHz channels. In the left-hand side of Figure 4 the symmetrical allocated spectrum uses 4 channels in DL and 4 channels in UL. On the right-hand side, the addition of DL capacity is shown either in conventional symmetric way or in asymmetric (e.g. with 3:1 ratio in this example).

The asymmetric expansion will obviously save a number of 7 MHz slots (the dashed ones in the rightmost part of Figure 4) because only two channels are used in the UL direction towards the higher level aggregation node, while the DL uses 6 channels, to match an asymmetry rate of 1:3. In the second hops versus lower level aggregation nodes, only 4 slots are used in each tail, preserving the same asymmetry rate of 1:3.

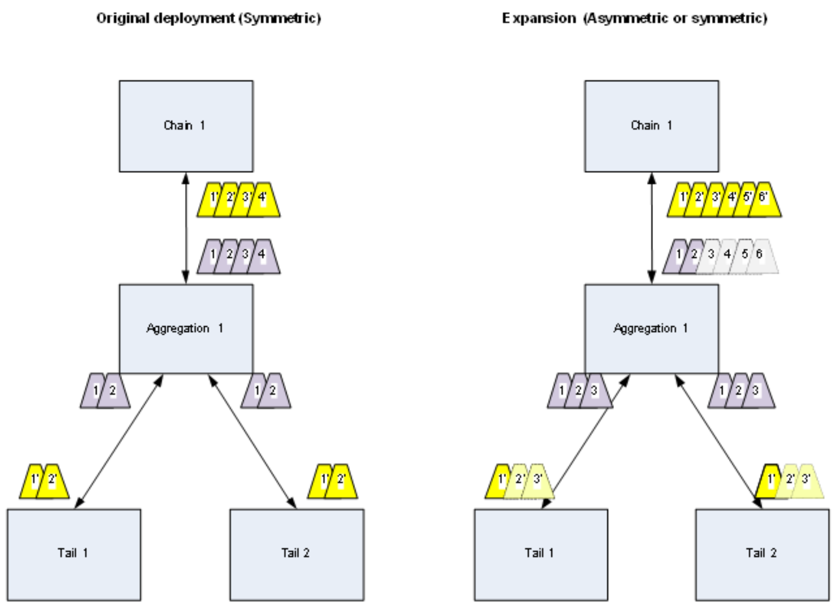


Figure 4: Asymmetrical usage of the spectrum – capacity expansion

Redistributing the 7 MHz channels in a different way and assuming that a 3:1 DL/UL ratio responds to the user needs, allows to increase the downlink capacity leaving some (i.e. formally 1/3 of the total in symmetric case) unpaired spectrum resources unused for possible further asymmetric use in the network.

Section 6 presented a number of examples of real networks planned in symmetric way and in a 1:2 or 1:4 asymmetric way assumed valid for the whole network.

4.2 POTENTIAL INCREASE OF SPECTRAL SAVING AND UTILISATION

4.2.1 Planning Method

In principle, asymmetric links can be planned with the same method also used for symmetric links, which is usually based on evaluating the interference impact for each link as the maximum permitted I/N for limiting the link threshold degradation (see also ECC/REC(01)05 [14]).

However, a greater benefit can be obtained by combining the asymmetrical links concept with a planning method based on a less stringent metric derived from minimum co-channel C/I for a given modulation scheme. This method should be applied only where interfering and wanted signals are originated from the same site because their fading is correlated (assuming rain is the dominant fading factor).

This can be applied to the outbound links from each node. Inbound links are planned with conventional method based on maximum I/N for limited threshold degradation.

ETSI EN 302 217-2-2 [13] gives the current harmonised co-channel C/I values for 1 dB and 3 dB threshold degradations.

The method is hereby described in more detail:

In a hub planning scenario, one can save downlink outbound channels from the hub by using asymmetrical links as follows.

When assigning outbound channels to downlinks from the hub, an attempt is made to reuse the same channel over and over as much as possible and thus conserve spectral resources.

This reuse however, is currently limited to keeping an angle of roughly ≥ 90° between two outbound links from the same site due to two interference scenarios. Figure 5 shows the different interference scenarios.

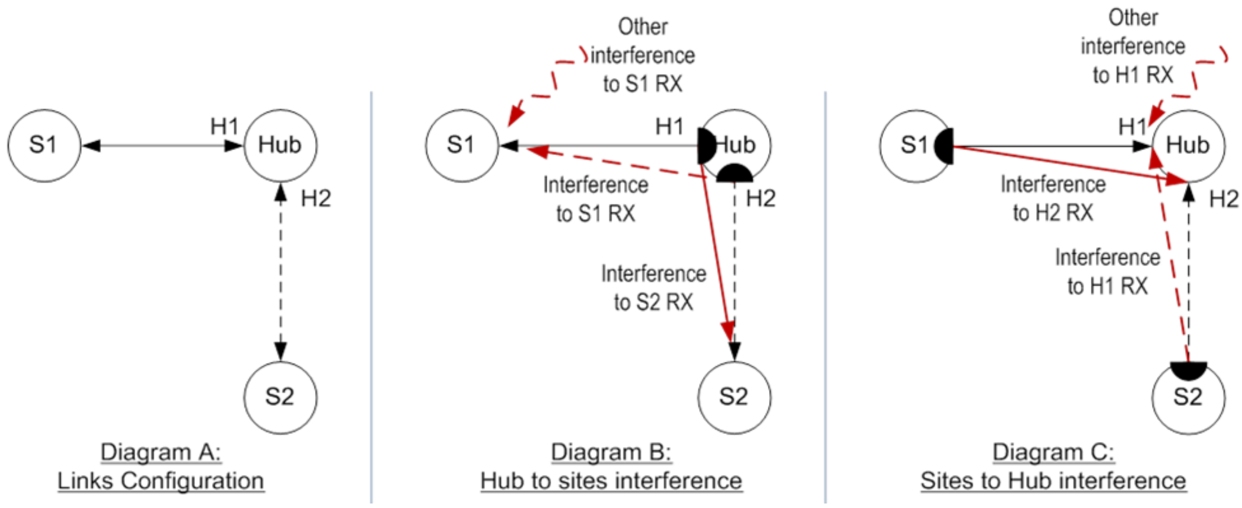


Figure 5: Interference in inbound and outbound links scenarios

- Diagram B – Downlink interference to outbound S1 and S2 reception from the hub H1→S2, H2→S1 and interference coming from other links using the same channel.
- Diagram C – Uplink interference to inbound H1 and H2 reception from the sites S1→H2, S2→H1 and interference coming from other links using the same channel.

Managing interference with asymmetrical planning:

- To manage the interference depicted in Diagram B the design tool was altered to calculate interference with respect to co-channel C/I+3dB of the receiver. C/I for 1 dB or 3 dB threshold degradation, depending on the target degradation and the balance with other interference, are to be derived from ETSI EN 302 217-2-2 [13]. This can be done only for the case of H2→S1 (When interference and wanted signal are originated from the same location). Other interferences to S1 are considered with respect to the thermal noise.

  The reason for changing this planning rule is due to the fact that fading occurrence on TX signals from H2 and H1 is correlated as the signals run over the same geographical path, It should be noted that this is also true for symmetrical planning, but being inbound and outbound channels restricted to be of the same bandwidth, it will not add any benefit.

- The inbound interference depicted in Diagram C is much easier to manage with asymmetrical planning as, for UL directions, different frequency channels can be selected improving through the NFD (Net Filter Discrimination) the interference scenario depicted in Diagram C.

The following presents a quantitative example:

Assuming that the links between the hub and the sites (H1←→S1, H2←→S2) have the following parameters:

- Frequency band = 38GHz
- Link distance = 3.5Km
- TX Power = 14dbm
- Modulation 256QAM
- DL Channel BW = 56MHz
- UL Channel BW = 14MHz
- Antenna = 0.6 ft

The received signal level of the "wanted" signal is at: -35dBm

The Noise floor is at: -114 + 10*log (56[MHz]) + NF = -90dbm

Managing interference:

- In the DL direction, considering a C/I of 40dB for 256QAM we need to reduce interference to 43dB (co channel C/I+3dB). Looking again at the antenna pattern, one can see that for 43dB we only need 10°.
- In the UL direction, to avoid threshold degradation the interfering signal (Diagram C) should be reduced to noise floor. This means that the antenna needs to reject the interfering signal by at least 55dB (-35-(-90) = 55dB). From the antenna pattern below one can see that to reject 55dB an angle of 70° must be kept between the two links.

When planning a symmetrical network the limiting factor is the UL interference (Diagram C), limiting to a “frequency reuse angle” of 70°. In the asymmetrical planning scheme this limitation can be overcome by assigning a different uplink frequency to both links.

This means that the only limiting factor for the “frequency reuse angle” in the asymmetrical case is the DL interference (Diagram B) which limits the angle only by 15°.

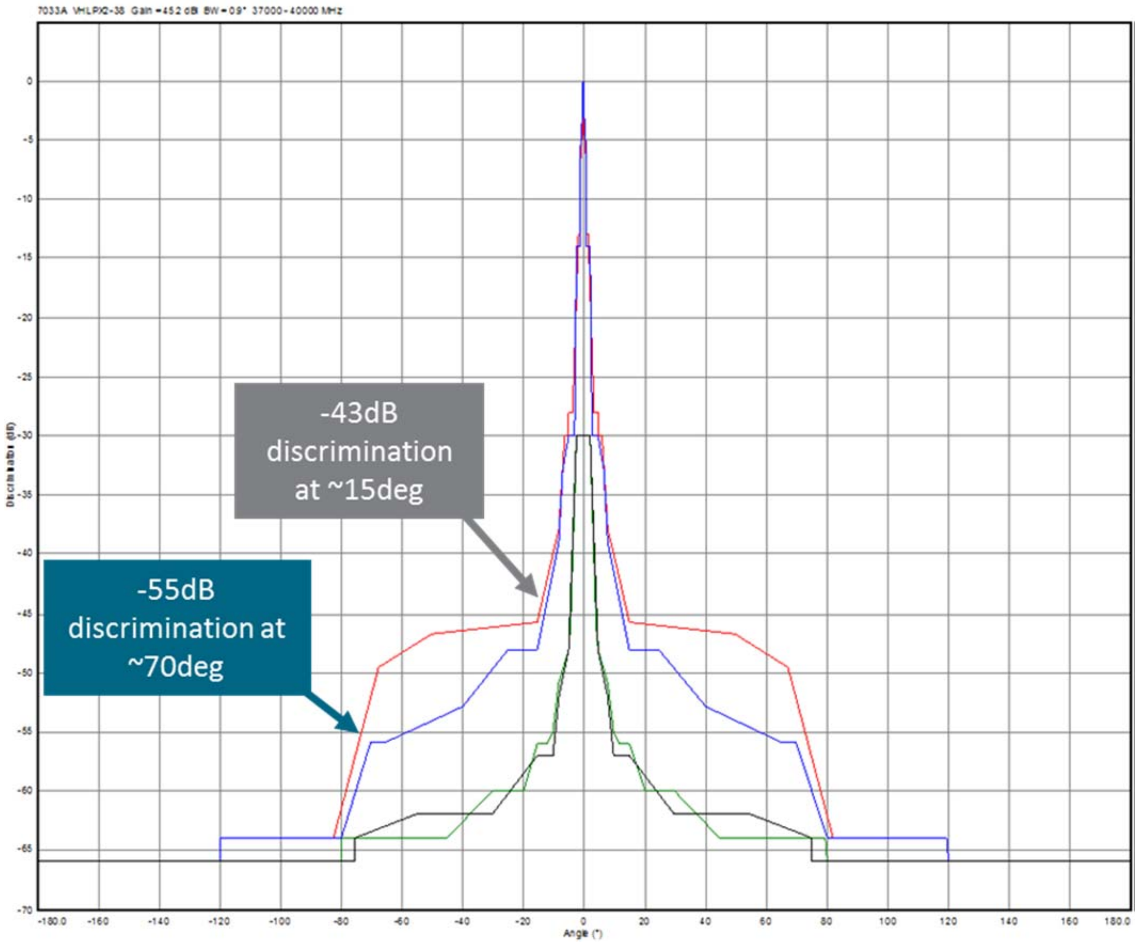


Figure 6: Practical Antenna Radiation Pattern (Andrew Valuline)

The following factors should be considered when defining the proper co-channel C/I to be used:

- For adaptive modulation systems the target C/I should take into account the maximum modulation format and not only that of the “reference mode” defined in ETSI EN 302 217-2-2 [13]). e.g. 1024QAM the C/I is expected to be 6 dB worse than the 256 QAM used in the simulations in sections 6.2.
- ATPC (i.e. when ATPC is used the C/I should be evaluated with appropriate TX power, clear sky for C and maximum in fading conditions for I). This might be avoided if the outbound links influencing each other apply ATPC synchronization so that when one link fades closer angles links also increase their TX power. This can be applied in accordance with the user requirement unless the ATPC is mandated by the administration.

4.2.2 Nominal spectrum saving and utilisation

From the example in section 4.1, considering an asymmetric deployment with the same DL capacity and a correspondingly reduced UL traffic, the spectrum saved can be evaluated from the asymmetry ratio itself; for example 1:2 and 1:4 ratios will lead to a nominal spectrum saving of:

- 1:2 asymmetry: Spectrum Asymmetric / Spectrum Symmetric = 3/4 (i.e. 25% spectrum saved)
- 1:4 asymmetry: Spectrum Asymmetric / Spectrum Symmetric = 5/8 (i.e. 37.5% spectrum saved).

This does not take into consideration further improving synergy, due to different planning method described in section 4.2.1.

This may be considered as the ideal upper bound of the spectrum saving. However, it is common practice in backhauling networks that, before using a new frequency channel, to reuse those already used in the same

High/Low sub-band as much as possible, by the same or different nodes; therefore, the spectrum can be considered truly saved only as far as it can be actually reused for other links or other applications.

“For example, the nodal capacity, i.e. overall capacity exiting from the node within a given bandwidth (sum of different channels bandwidth), would be determined only by the DL wider bandwidth of the asymmetric links in the node. In the bigger nodes (where most of the frequency congestions are usually experienced) only one UL branch (that towards the higher level aggregation point) will have a reduced bandwidth with respect to the symmetric case; then the majority of the DL branches will still dominate as in the symmetric case.

In all cases, for an effective evaluation, the planning example should be made over a significantly larger network as in the examples of section 6.

4.2.3 Bidirectional spectrum saving

A more appropriate method for comparing different systems on the same network is to consider, with respect to the spectrum used when symmetric deployment is considered, the amount of spectrum unused by the asymmetric deployment, which can actually be reused for bidirectional links (i.e. paired in both go/return sub-bands and freely useable also for other symmetric links)..

From regulators point of view, that is a practical measure of savings in spectrum usage, because only saved spectrum that can be reused can be considered truly saved.

When comparing symmetric and asymmetric deployments on the same network (i.e. assuming that the real UL capacity needed is that defined by the asymmetry ratio) the useable bidirectional spectrum saving is determined only by the ratio of the used bandwidth in the two cases (number of bidirectional channels, preferably contiguous, used in the deployed network).

4.3 ERVICE GRANULARITY USING NX7 MHZ

For asymmetric links deployment different degrees of asymmetry may be envisaged; in Ethernet/IP based traffic, the actual link capacity may be selected on a case by case basis, without the need of a defined granularity; however, for fitting broadband capacity within the current channel arrangement, a 7 MHz granularity of the channels size may be considered.

The reason for this change in approach is to allow full flexibility to operators planning new services such that they can apply a granularity of increment commensurate with likely minimum service capacity increase of approximately 50Mb/s (e.g. using 256QAM in a 7MHz channel, without packet compression techniques applied).

4.3.1 All 7 MHz multiples possible

Applying a complete 7 MHz granularity for example up to 56MHz (see Figure 7), implies defining channel sizes of 21, 35, 42 and 49 MHz that are presently not considered in any arrangement, but can be obtained by the suitable aggregation of channels from different arrangements .

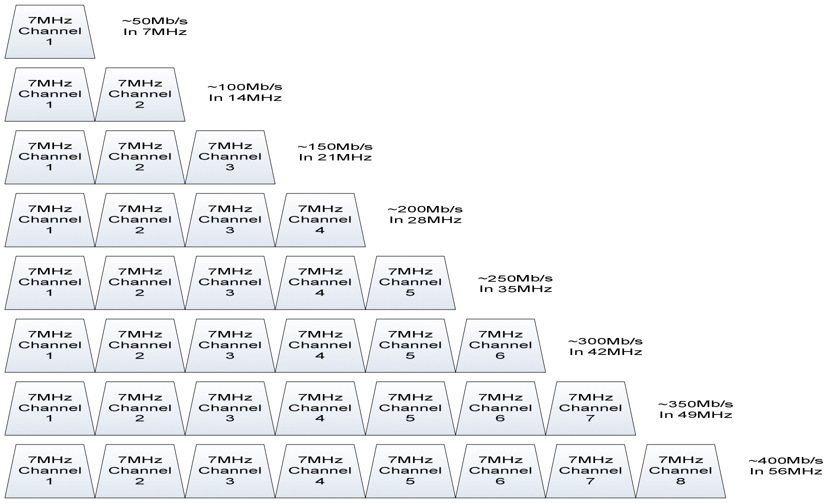


Figure 7: Example of N x 7 MHz (N = 1 to 8) granularity

4.3.2 Even multiples of 7 MHz (N = 1, 2, 4, 8 and 16)

This case fits in general the existing channel arrangements based on 7, 14, 28, 56 and 112MHz already specified in a number of channel arrangements as defined in different ECC Recommendations.

The granularity shown in Figure 8 is compatible with arrangements and assignment in existing networks.

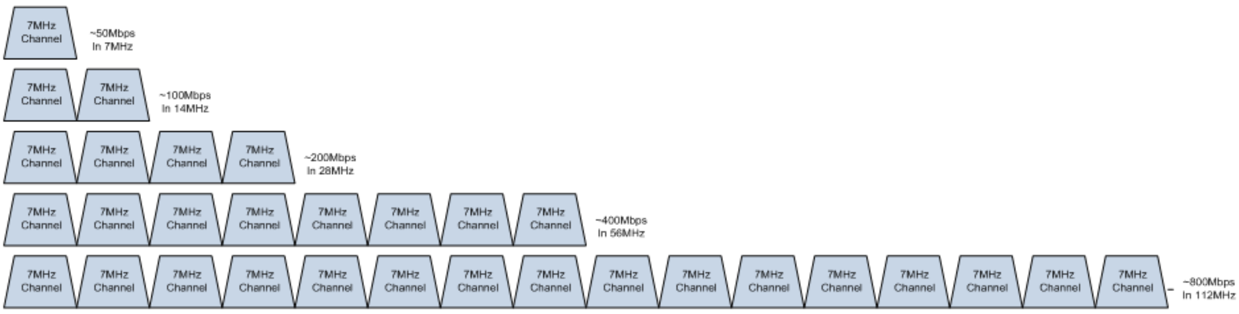


Figure 8: N x 7 MHz even multiples (N = 1, 2, 4, 8 and 16) granularity

4.3.3 Guidelines for channel granularity

In order to support legacy requirements and continuing deployment of symmetric links as well as providing flexibility for the deployment of asymmetric links, the arrangements as shown in Figure 8 would appear to be an acceptable compromise.

In general, the granularity is provided in most of the channel arrangements, but some of the recommendations may not contain enough granularities in the defined channel width. They have to be treated on a case by case basis.

It should be noted that the 7MHz granularity does not apply in some bands e.g. where 29 MHz, 29.65MHz, 30 MHz, 40 MHz, 55 MHz channel width are applicable. In these cases, other arrangements based on similar principles are available or might be studied. However, it should be noted that, apart from the 55 MHz case (limited to 18 GHz band), all other cases are confined in bands < 12 GHz; these bands are used for longer hops, generally for high capacity connections between different areas of the networks (which may not foresee no or very limited asymmetric traffic) or, very seldom, for rural connections, where the benefits of asymmetric deployment is not significant (see real network planning examples in section 11). Therefore, the opportunity of introducing smaller or different granularity in these cases should be carefully considered.

The following are the ERC Recommendations that provide arrangements not based on usual 28 MHz raster:

- ERC/REC 12-08 (Harmonised radio frequency channel arrangements and block allocations for medium and high capacity systems in the band 3600 MHz to 4200 MHz).
  This Recommendation provides options with 40/20 MHz or 30/15 MHz or 29 MHz only (the latter being the one presently used in most countries) are provided.
  In this case, if considered appropriate, specific revision of the arrangement for smaller channel sizes subdivision would be needed.

- ERC/REC 14-01 (Radio-frequency channel arrangements for high capacity analogue and digital radio-relay systems operating in the band 5925 MHz - 6425 MHz).
  In this Recommendation is defined only the 29.65 MHz channel arrangement (59.3 MHz channels are also possible when administrations foresee the need). Besides the fact that the band is presently designated for “high capacity” (presently mostly STM-1), potential subdivision in smaller channel sizes with the conventional halving of the wider channels seems problematic. In some countries alternative 28 MHz plan is used (according Annex 2 of ITU-R F.383-8), which may be more suitable for conventional subdivision in smaller channel sizes.
  In this case, if considered appropriate, specific revision of the arrangement would be needed.

- ERC/REC 14-02 (Radio-frequency channel arrangements for high, medium and low capacity digital fixed service systems operating in the band 6425-7125 MHz)
  In this case, the optional arrangement providing 30 MHz channels already defines also the subdivision into 14 and 7 MHz channels (60 MHz channels are also possible when administrations foresee the need).

- ERC/REC 12-06 (Preferred channel arrangements for fixed service systems operating in the frequency band 10.7 - 11.7 GHz).
  In this case besides the older 40 MHz arrangement (80 MHz channels are also possible when administrations foresee the need), new optional arrangements with 28 MHz channels have recently been added. In the latter case, a note mention that, on a national level, CEPT administrations not implementing ERC DEC(00)08 (requiring only 140 Mbit/s or higher capacity links), may wish to use 14 MHz, 7 MHz channel arrangement by subdividing the 28 MHz channel arrangement.

- ERC/REC 12-03 (Harmonised radio frequency channel arrangements for digital terrestrial fixed systems operating in the band 17.7 GHz to 19.7 GHz)
  In this case the arrangement provides channel sizes of 110 MHz, 55 MHz, 27.5 MHz and 13.75 MHz, which seems quite sufficient for possible asymmetric use.

4.4 ARRANGEMENTS COMPATIBLE WITH THE EXISTING CHANNEL ARRANGEMENT

In comparison to symmetric deployment, when the asymmetric deployment is considered the T/R separation would impose an amount of variation from the nominal duplex separation of the relevant channel arrangement. All equipment has HW constraints (see section 4.6 on the impact on system hardware design), which implies that it is not possible to have complete freedom in the T/R separation; therefore, it is important that the degree of T/R freedom will be defined by some ECC guidelines.

4.4.1 Using both DL/UL frequencies within the same wider channel

This is the simplest way of using asymmetry; no specific subdivision of the band for wider and narrower channels was done.

In the example for 28MHz and 14 MHz (DL/UL 2:1) of Figure 9, the coordination of narrower “return” channels has only two choices within the same wider return channel. The duplex variation is limited to T/Rasym = T/Rsym ± 7 MHz.

This solution is the simpler and would not imply implementation problems for current symmetric-based equipment HW. However, the flexibility of using the spectrum saving is very limited.

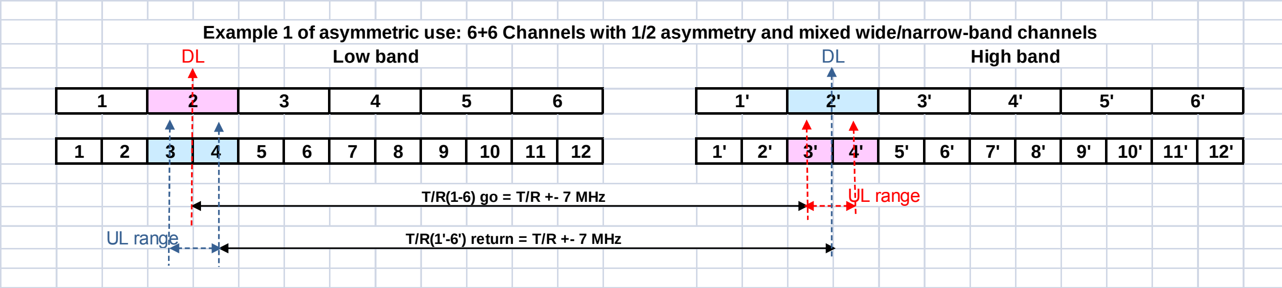


Figure 9: Simplest asymmetrical channel plan: smaller channels within the larger ones

4.4.2 Using both DL/UL frequencies close to the same wider channel

For having more flexibility, the return channels could be selected also in some adjacent 28MHz, e.g. channels 1'…6' of the 14 MHz plan, in the Figure 10 below. The duplex variation increases to T/Rasym = T/Rsym ± 35 MHz. This higher flexibility in the selection of the narrower UL channel, would give more possibility of efficient deployment of asymmetric links.

However, in such cases the HW limitation shown in section 4.6 should also be taken into account and it would imply additional constraints in the DL/UL frequency selection (i.e. depending on the actual DL channel position, the UL channel variation, while remaining of the same entity (i.e. 70 MHz in this example) could not be kept centred (see Figure 11 in section 4.6).

Therefore, while the principle shown in Figure 10 may be assumed to fit the flexibility requirements for symmetric/asymmetric common deployment, further guidance is needed for an efficient licensing of asymmetric links maintaining a cost-effective design of the radio equipment.

With the increased flexibility proposed above in selecting the narrower uplink channel, additional information will be needed by the administration in order to assign the most appropriate channel pairing.

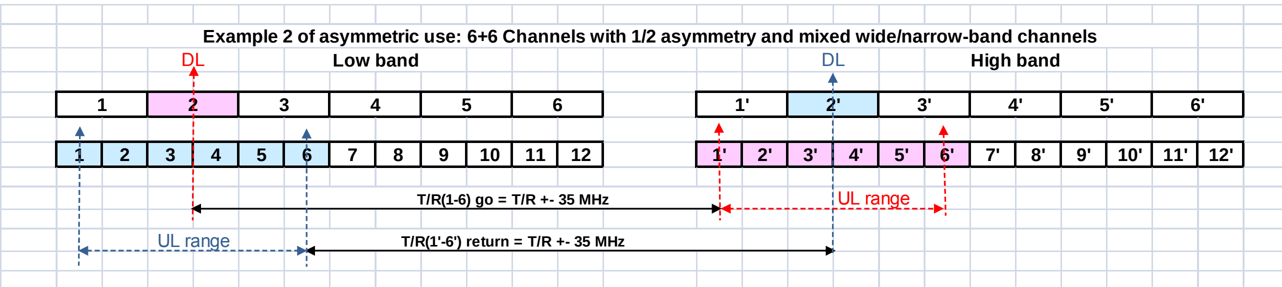


Figure 10: More flexible asymmetrical channel plan: smaller channels within adjacent larger ones

4.5 ARRANGEMENTS NOT- COMPATIBLE WITH THE EXISTING CHANNEL ARRANGEMENT

In principle, channel arrangements could be completely redesigned for maximising the flexibility of the asymmetric deployment; however, the following considerations should be taken into account:

- All bands available for P-P licensed links are regulated by current channel arrangements and a large number of existing symmetric links are in place;
- Therefore, the new channel arrangement should in any case provide also symmetric channels of various sizes;
- Also the asymmetric channels would still need a set of various channel sizes and of different degrees of go/return asymmetry.

The approach of completely new channel arrangement might be considered only for newly opened (or emptied) bands. In addition a suitably flexible design seems very complex and possibly resulting with small or no benefit with respect of the “compatible” use of current arrangement described in previous section.

Therefore, this report would not explore any asymmetric use that does not fit the present channel arrangements.

4.6 CONSIDERATIONS ON FLEXIBILITY OF DUPLEX SEPARATION IN RADIO EQUIPMENT

With the current symmetric use of PP links, the T/R separation (i.e. the go/return frequency difference between Tx and Rx in any single equipment supplied for a certain radio frequency band) is constant, whichever is the actual channel selected for a particular link.

If asymmetry is sought, the T/R separation shall be variable because the go and return centre frequency lays on different channel arrangements and are not uniquely linked together.

This implies that:

- Tx and Rx frequency synthesisers shall be independent;
- The duplex variation should not make the Tx and Rx frequencies falling outside the RF duplex filters coverage;

The first problematic might impact few cases of very simple equipment implementation where sometimes Tx and Rx frequency generation is synchronised to a single reference counting on the constant duplex shift; however, in modern equipment designed for maximum flexibility, this simplified approach is no longer used and would not impact the potential market for asymmetric links. On the contrary, the impact to the RF duplex filters, which guarantee the suitable Tx and Rx local isolation, should be considered very carefully.

In most cases of current radio frequency channel arrangements, the relatively small centre-gap prevents the practical design of one single filter covering all channels of the arrangement. The common practice implies that each channel arrangement is covered by a number of such duplex filters as shown in the example of Figure 11, where three different filters are used.

As it may be seen in Figure 11, the use of asymmetric Tx and Rx in the equipment is relatively simple as far as the wider channel in DL direction and the smaller channel in UL direction lay within the same duplex filter (e.g. 56 MHz channels 3 and 4, 28 MHz channels 5 to 8 and 14 MHz channels 9 to 16 might be coupled each other). Coupling a DL channel falling within one duplex RF filter with an UL channel falling in different duplex frequency will require specific hardware design (which, depending of the difference between the DL/UL separations may not be possible).

It should further be noted that only in higher frequency bands (i.e. above 17 GHz) the number of channels and the wider duplex spacing would permit significant flexibility inside relatively large filter bandwidth. In lower bands (e.g. 6 to 8 GHz with far smaller duplex spacing) the filters are sensibly narrower and the permitted flexibility becomes hardly enough for an effective asymmetric deployment.

In addition, it should be taken into account that the subdivision of the channel arrangement will be different amongst different suppliers, as this subdivision is not subject to any standardisation.

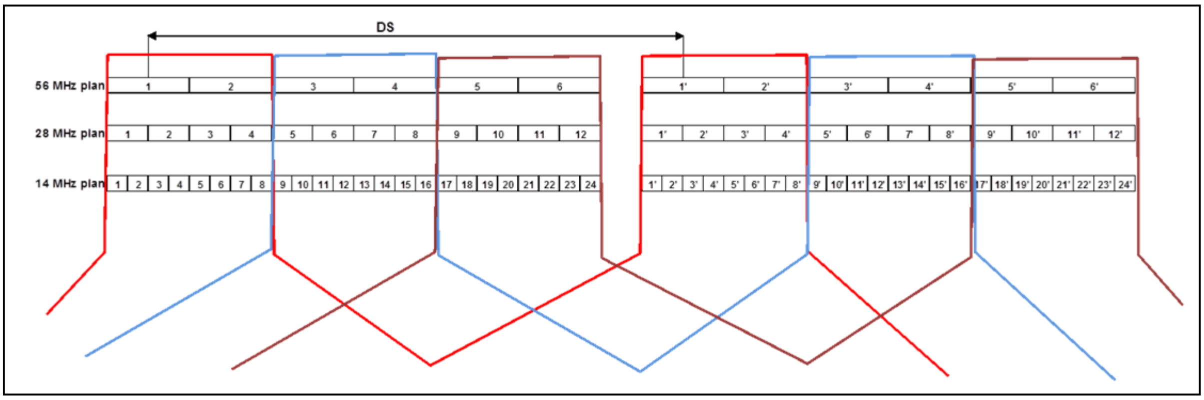


Figure 11: Example of RF duplex filter subdivision in a given channel arrangement

It would be beneficial to all the stakeholders that both symmetric and asymmetric deployments can be realised with the same hardware.

4.7 COMPATIBLE ASYMMETRIC PLANNING SOLUTIONS

From the aforementioned background, any planning method for assigning asymmetric links has to take into account the limitations of the hardware design in terms of Tx and Rx possible centre frequencies within the same equipment.

This section analyses the most common spectrum assignment methodologies already used for the P-P fixed service. In this Report the word “planning” is taken to mean the technical process for defining the appropriate channels for a specific link in a network.

4.7.1 Auctioned blocks of frequencies

It is commonly understood that, if the auction conditions permit the use of fixed links inside the auctioned block and the technical conditions are still met, any TDD or FDD asymmetry can be applied within the boundaries of the blocks.

The block owner is responsible of link planning and can possibly exploit asymmetry according his needs.

The block owner is free to negotiate with equipment suppliers a specific hardware design best fitting its own blocks.

4.7.2 Centralised link by link planning made by the regulator

In this case, the regulator has full control on the frequency assignment of each link. In general the frequency assignment is made on the basis of the first interference free channel (e.g. starting from lowest channel onwards) available for each link.

On this basis, in case of asymmetric link, for fitting also the hardware constraint of duplex filters, two solutions have been identified:

1. Limit the flexibility of the DL/UL frequencies so that the narrower UL channel frequency should remain within the DL wider paired channel.
2. Each channel assignment should be made under the constraint that both UL/DL frequencies remains within the frequency sub-bands of hardware coverage of the equipment as eventually declared by user/manufacturer. This information shall be included in the link license request.

However, option 1 would hardly result in actual spectrum saving. Implementation of asymmetric assignments is then left to national regulatory authorities.

4.7.3 Link planning made by the user under delegated permission of the regulator

In a number of countries, while the regulator still maintains the full responsibility of the network planning, it is nevertheless a common practice to let mobile operators make the preliminary planning of their own network over a limited number of contiguous wider channels (e.g. N x 28 MHz channels), within which narrower channels or wider channels (e.g. 7MHz,14 MHz, 56MHz, etc.) might also be used, generally in symmetric way; where general national planning rules and assumptions have to be respected.

At the end of the process the operator communicate the chosen channel, frequency and station parameters to the regulator who could control the planning, possibly but not often requires some changes, due to national or international coordination constraints, and finally adds the new links into the national data base.

This case is, in practice and from the point of view of the frequency planning, very similar to the “block auctioning”; therefore, if asymmetric links are desired, they can easily be planned within the very same set of contiguous wider channels where the operator is preferably confined.

This solution also avoids the necessity for the regulator to know the hardware limitation of all manufacturers providing equipment in the national network; each operator would autonomously enquiry equipment suppliers for such information and would plan the links accordingly.

4.7.4 Self-coordinated approach

In some cases administrations foresee that the frequency planning procedure, and the consequent possible interference assessment, is under full responsibility of the user of the link.

This process is often identified as “light licensing” and generally consists of a simple (on-line) notification of the link parameters to the administration that maintain a national data base to be used for planning new links by the user. In most cases also a channel arrangement is not imposed.

The administration takes no action for cross-checking the user’s planning assumptions, nevertheless it is usually expected that such planning is made with appropriate technical methodology and due care .

Therefore, from the point of view of the use of asymmetric links, there should be no particular differences from the case described in previous section 4.5.3. Administrations may only render the notification interface capable of describing different go/return system parameters.

4.8 VARIOUS ASYMMETRICAL LICENSING SOLUTIONS

In order to provide asymmetrical capacity in a point-to-point link the bandwidth of both directions is different.

The need of asymmetry (either for a new link or for adding DL capacity to an existing symmetric link) can be satisfied by an administration with different solutions, which depend on the current status (more or less congested) of the frequency band under consideration.

Two cases may be envisaged:

4.8.1 Already congested bands

Option 1: In-band solution

The asymmetric capacity may be obtained by a basic symmetric link license plus a second license (see Figure 12) for unidirectional (DL direction) additional link in an available free channel arbitrarily selected (i.e. without considering the impact on system hardware design in section 4.6).

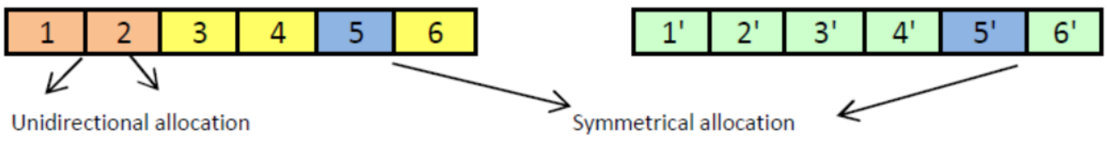


Figure 12: Combined symmetrical and unidirectional allocations

Option 2: Adjacent bands solution

The asymmetric capacity may be obtained by a basic symmetric link license in the original band plus a second license for unidirectional (DL direction) additional link in a close-by frequency band, such that both the symmetrical and the unidirectional link will have similar path losses; see the example of 38 and 42 GHz bands, provided that they are both available for link by link planning, in Figure 13.

This example may also have the advantage that existing usage in the 37 - 39.5 GHz band is not mixed with uni-directional links.

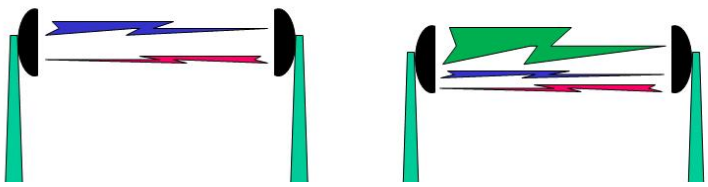


Figure 13: Symmetrical duplex in 37 - 39,5 GHz (red/blue link) combined with uni-directional (green link) in 40.5 - 43.5 GHz.

However, these solutions, while possibly solving special cases or capacity expansion of some existing links or other unavoidable national constraints, is not preferable for a long term general solution of the asymmetric case, because it requires to double the number of equipment and, standing the present antenna on the market, also of the antenna itself.

4.8.2 Bands where congestion is not experienced

The second case, possible whenever the congestion of the band is not yet reached, is to examine the solutions that follow the planning guidelines for taking into account the impact on system hardware design (section 4.6). These solutions imply that the normal equipment used for symmetric deployment can be used (for new links) or reconfigured (for upgraded DL capacity) can be used for the asymmetric deployment.

This second case solutions are preferable because imply no additional hardware (in term of number of equipment and antenna).

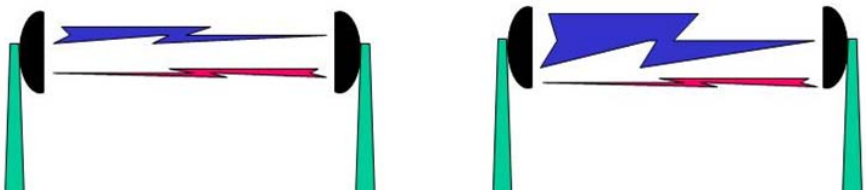
Below we present three licensing solutions based on spectrum aggregation in the same band.

In all options below the equipment constraints (see section 4.6) should be taken into account in defining the actual DL/UL channels.

The following options assume that a brand-new asymmetric link is to be licensed.

Option 3: Using asymmetrical channel licensing

The spectrum asymmetry is obtained by licensing a unique pairing of channels of different bandwidths for the DL/UL paths.

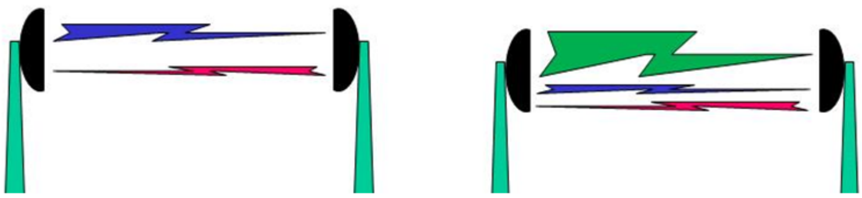


(a) Symmetrical link (b) asymmetrical link

Figure 14: Symmetrical and asymmetrical links as considered above

Option 4: Spectrum aggregation with an additional unidirectional link

Another approach is to add to a symmetrical bi-directional point-to-point link an extra unidirectional link (i.e. two radio systems are needed). In principle, this approach involves getting two licenses which may be combined in a single emission, for a new assignment or maintained separate for DL capacity expansion.



(a) Symmetrical link (b) Symmetrical + uni-directional link

Figure 15: Adding a unidirectional link

From the point of Administrations licensing unidirectional links is already possible. An example of the resulting channel allocation, when the asymmetrical and symmetrical frequency channels are located within the same frequency band is shown in the Figure 16:

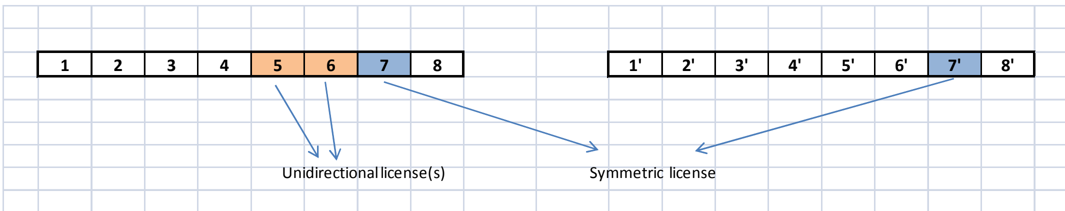
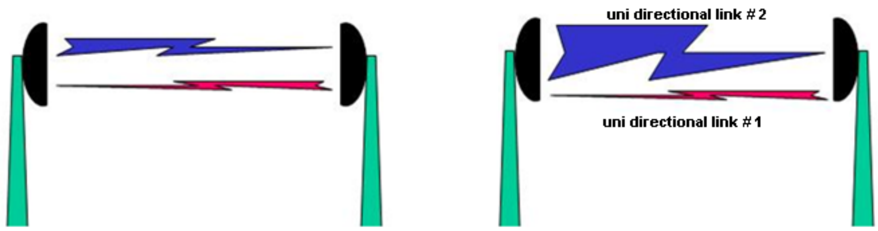


Figure 16: Symmetrical and uni-directional licensing in the same frequency band

Option 5: Spectrum aggregation of unidirectional links

A third option is to generate an asymmetrical link using two unidirectional links with different channel bandwidth.

The unidirectional links are obviously in different go-return sub-bands, respecting the high/low rule for their respective nodes and shall follow the hardware limitations explained in section 4.6.



(a) Symmetrical link (b) asymmetrical link done with two uni-directional links

Figure 17: Aggregation of unidirectional links

4.9 POSSIBLE REGULATORY FRAMEWORK FOR ASYMMETRIC LINKS

From the above considerations, the only viable solution is to maintain the present recommended channel arrangement and introduce guidance and limitations for the possible use of asymmetric links.

Two possible solutions may be envisaged for their harmonised introduction:

1. Add a specific annex to each ECC recommendation for suitable bands.
2. Produce one single ECC Recommendation with the harmonised guidelines for introducing asymmetric links in current channel arrangements for suitable bands.

The first option implies to revise all the relevant recommendations (about 15 recommendations for bands above 5GHz) for introducing an Annex that would be, in practice, nearly the same for all of them. The revision should address background, considering and recommends parts which may result in other unpredictable changes (e.g. updating the older ones).

The second option would require the same effort for producing the technical content (similar with the annexes in Option 1) and would offer the possibility of specific development of text for background, considering and recommends which would be automatically valid for all channel arrangements where administrations foresee implementing asymmetric links.

4.10 ASYMMETRIC LINKS IMPACT ON FEES CALCULATION

Definition of fees is a national responsibility however this report examines the impact of asymmetric channel arrangement on fee structures. It can be expected that in some countries, by applying current fee calculation, introduction of asymmetric microwave links would affect the total amount of fees paid by operator. If fees are calculated proportionally according to the bandwidth used, decrease in used bandwidth for one direction of the link might mean lower licence fees. This would also be a motif for operators to change existing licences for links (of course if there is a real transport capacity asymmetry) thus again increasing administration workload.

A change in the planning process for asymmetric assignment may have an impact also on the fees side and may require further consideration at national level as these 2 processes (i.e. planning and fees) may be treated by different entities.

In some cases, the fee is composed by two different macro-factors, one related to the cost of the actual planning process and one related to the right of use of the frequency.

Besides the possible dependence of the used frequency band, fees are, typically, related to:

- Bi-directionality or uni-directionality of the link; uni-directional link fees are in most cases lower than bi-directional ones;
- Occupied channel size CS.

Sometimes also the spectral efficiency (or link capacity) is considered among fees parameter; however, in the general assumption that DL/UL modulation remains the same, this could be neglected.

Therefore, depending on how the asymmetric link license is formally established (see section 4.8) the resulting fee might be different.

For the same asymmetric link, the 5 licensing options in section 4.8 produce different calculation:

Option 1 and Option 4 (symmetric bi-directional + uni-directional links in the same band): sum of the two specific fees:

Option 2: (bi-directional + uni-directional links in different bands): sum of the two specific fees, which, may differ also for band aspect.

Option 3 (true bi-directional asymmetric link): specific fee should be defined on the basis of e.g. CSmax and 1:X asymmetry.

Option 5 (two different size uni-directional links):sum of the two specific fees

Depending on the national spectrum fees policy, the 5 possible values so derived might result different.

In all cases, for a given network, the total amount of link fees is expected to reduce with respect to a symmetric network deployment.

5 THE IMPACT ON ADMINISTRATION WORKLOAD

5.1 IMPACT ON COORDINATION PROCESS

With respect to cross border coordination with countries which do not follow this asymmetry proposal, additional inter-country co-ordination is not needed as long as the existing channel arrangements are respected.

For mixed symmetric and asymmetric deployment in homogeneous networks, as part of standard frequency co-ordination practices, for each link, in each direction, at both transmitter and receiver, the interference is assessed for inclusion into the existing network. There is no difference whether the link is asymmetric or symmetric to this process because the co-ordination is made separately in both directions. Furthermore, the addition of asymmetric (or unidirectional) capability will decouple the dependence of co-ordination on both directions' ability to achieve co-ordination at the fixed duplex, thereby allowing more efficient spectrum planning.

5.2 MODIFICATIONS TO PLANNING TOOLS USED BY ADMINISTRATIONS

One change of the planning tools that may be necessary is to allow Tx and Rx to be set to different channel bandwidth per transceiver. This ability to set parameters of Tx and Rx differently may be already feasible, following the logic of assessing AMC-enabled systems which operate at different modulations in Tx and Rx.

Depending on the free-frequency channel searching algorithm employed, it should be made possible, when necessary to iteratively step, for using different channel bandwidths in each direction of the link, while using the standard rasters according to the channel bandwidth described by the equipment used.

However, it should still be possible to limit the frequency relationship between Tx and Rx centre frequencies in the same station within a certain range for avoiding that they exceed the equipment Tx and Rx mutual tuning capability (see section 4.6).

An optional limitation of the frequency band searching range to describe soft-partitions is needed, but most likely if a regulator uses this method, this capability already exists.

It is to be noted that it is not only administrations that are using planning tools, but manufacturers and operators also use such tools.

Most ixf not all of current versions of microwave planning tools do not have the possibility to deal with bi-directional links that have a different bandwidth in different direction of the link. Also these tools presume that channel raster is fixed i.e. carrier frequency in one direction (go channel) is directly linked with carrier in return channel.

At the moment, a possibility is to create a link with asymmetrical use of channels by creating two individual unidirectional links following different frequency rasters. There are a number of drawbacks of this approach. For example- these two unidirectional links are treated by planning tool as two completely separate links thus preventing automatic frequency assignment (free-frequency/channel searching algorithm) or similar software functions. In other words, to avoid drawbacks of this approach, implementation of asymmetrical links as functionality in new version of planning tools would be advisable.

Finally, whenever the more efficient planning of asymmetric links described in section 4.2.1 (i.e. based on both C/I and I/N methods) is desired, it should be considered that conventional planning tools do not currently implement such feature.

Mentioned software upgrades also include related changes to databases and electronic support of licence issuing process, which would impose considerable financial requirements to the administrations. This is also a time consuming process since symmetry of microwave links has a long legacy.

5.3 EFFORT/WORKLOAD IMPACT FOR THE ADMINISTRATION

- Administrative impact

For the case described in Figure 17, for those administrations able to manage unidirectional links and to charge per unidirectional link, there is an extra amount of work and complexity created because two (unidirectional) links must be configured (and stored in a database) instead of one, and interference calculations has to be done for the two unidirectional links.

In addition, it may be necessary for those administrations to further investigate how to address the case where the asymmetrical link is used to reduce the link fee, but without any possibility for the administrations to re-use the spectrum saved compared to the symmetrical case usage.

For the coordination procedure, there is no changes foreseen compared to the current practice where 4 records (2 for Transmitter part, 2 for Receiver part) are exchanged.

Similar considerations apply for Figure 15.

- Planning/licensing tools revision impact.

Cost to the regulator can be associated with:

1. Any of the changes outlined above in relation to software programming for the frequency planning.
2. Advising customers of change of policy, maybe updating online link licensing application forms. This is covered by normal website maintenance associated with regular policy updates therefore should not be factored in.

Benefit to the regulator can be substantial savings of spectrum through efficiency of use, allowing more users & therefore more potential income from link licensing.

- Workload impact

Frequency planning of asymmetric microwave links is much more complicated than frequency planning of symmetrical links. The reason is that for one link, uplink and downlink (go and return) channels have to be planned individually as if those were two uncorrelated links. However, while choosing channels, one must keep in mind that the polarisation of both go and return channels must be the same because one microwave link (symmetrical or asymmetrical) uses one antenna in each direction (which is in most cases single polarised antenna). Because of that choice of polarisation, the choice of channel also becomes more complicated.

Having in mind aforesaid, it is obvious that in cases where frequency planning of microwave links falls under administrations responsibility (i.e. in cases where there is no block assignment to one operator), workload for the administration increases.

Since the whole process of issuing licences in particular country is defined by different legal and technical documents (law, ordinances, frequency plans, interfaces etc.) it is expected that possible introduction of asymmetric microwave links would require at least some of those documents to be changed. This process can in some cases be quite time consuming. All of that would also be accompanied by possible need to change software that is supporting the whole process, as mentioned in previous section.

The following are examples of workload impact with respect to the various options with respect to asymmetric licensing as described in Section 4.8.

Congested bands

Option 1: the asymmetric capacity is obtained by a basic symmetric link license plus a second license for unidirectional additional link in an available free channel arbitrarily selected (i.e. without considering the Impact on system Hardware design).

Administrative issues:

- Administrative fee
    - extra administrative fee for an individual licence for unidirectional additional link is required.
- Database impact
    - extra item (unique number) in database represented by an unidirectional additional link is necessary;
    - extra invoice for the right for using granted frequencies is necessary.
- Workload impact
    - creation of an extra unidirectional additional link includes particularly;
    - creating of a new item in a database by duplication of a symmetric link (same location of sites, operator's name, reference number of a request can be used to improve working efficiency);
    - selection of a radio equipment, editing relevant technical parameters (TX power, ATPC on/off);
    - selection of an antenna, editing relevant technical parameters (feeder loss, height above ground, polarization).

      If radio equipment and antennas are same for site A and site B, copying function can be used. If not, manual entering of site B parameters is necessary
        - selection of a frequency raster;
        - export to a radio planning tool;
        - after a technical examination in a radio planning tool, an extra paper decision for granting frequencies / request rejection is necessary.

Technical issues:

- Database impact
    - extra item (unique number) in database represented by an unidirectional additional link is necessary.
- Workload impact
    - processing of an extra unidirectional additional link includes particularly;
    - import the item created in administrative tool;
    - extra channel assignment to find possible interference free channels or channels where level of interference could be assumed as an acceptable level;
    - extra detailed interference analysis;
    - export frequencies back to administrative tool (if channel assignment and interference analysis were successful).

<u>Note 1:</u> In Option 1, if frequency coordination of an additional unidirectional link is not possible, all activities related to a symmetric link could be useless work. Because of two links (symmetric and unidirectional) it is difficult to detect these "link couples" in a radio planning tool at this moment. Additional information describing "link couples" could be achieved by modification of an interface between administrative and radio planning tool.

Option 2: The asymmetric capacity may be obtained by a basic symmetric link license in the original band plus a second license for unidirectional additional link in a close-by frequency band, such that both the symmetrical and the unidirectional link will have similar path losses.

Administrative issues are same as in Option 1.

Technical issues are same as in Option 1 except some necessary steps:

- Workload impact
    - another High/Low examination is necessary for a close-by frequency band.

<u>Note 2:</u> As mentioned in Note 1, additional improvement of radio planning tool would be necessary to improve working efficiency. The risk of request rejection is higher, because an extra High/Low clash can be experienced for unidirectional link in a different frequency band.

Bands where congestion is not experienced

Option 3: The spectrum asymmetry is obtained by licensing a unique pairing of channels of different bandwidths for the DL/UL paths.

Administrative issues:

- Administrative fee
    - no extra fee
- Database impact
    - one extra item in a database
- Workload impact
- creation of an unique asymmetric link includes particularly
    - copying function can't be used (Tx and Rx values differ for both sites). This represents necessity of manual entering radio equipment for both sites.

Technical issues:

- Database impact
    - no extra item in a database.
- Workload impact
    - N/A when channel assignment fails due to frequency raster incompatibility (see details in Note 3).

Note 3: This solution seems to be the most effective way to implement a link asymmetry. The main disadvantages are absence of copy function and complexity in radio equipment database (many combinations of Tx and Rx asymmetry ratio). This will result in extra workload compared to standard link symmetry. Channel assignment function failure can also occur if a radio planning tool expects frequency raster created in a symmetric way (carrier frequency in one direction is directly linked with one exact carrier in opposite direction).

Option 4: (Spectrum aggregation with an additional unidirectional link) another approach is to add to a symmetrical bi-directional point-to-point link an extra unidirectional link (i.e. two radio systems are needed). In principle, this approach involves getting two licenses which may be combined in a single emission, for a new assignment or maintained separate for DL capacity expansion.

Administrative issues are same as in Option 1

Technical issues are same as in Option 1

Option 5: (Spectrum aggregation of unidirectional links) generate an asymmetrical link using two unidirectional links with different channel bandwidth. The unidirectional links are obviously in different go-return sub-bands, respecting the high/low rule for their respective nodes and shall follow the hardware limitations.

Administrative issues are same as in Option 1.

Technical issues are same as in Option 1.

Note 5: This option seems to be a second best approach. However, as mentioned in Note 1, it is difficult to detect "link couples" in a radio planning tool at this moment. Another disadvantage is that two items representing one real link are necessary.

- Change to the link application form and process

The link application form and process whether online or paper copy, will require additional information in order to accommodate the flexibility in duplex spacing described in section 4.4. This information is manufacturer specific and is possibly known only by the applicant/operator. In such a way the administration will know the limitations of the hardware prior to assigning the appropriate channel pair for any link.

6 DEFINITION OF STUDY CASE ON LARGE SCALE FOR THE LINK BY LINK ASSIGNMENT CASE

The appropriate evaluation of the improvement of frequency usage with asymmetric link deployment should be made over a significantly large network. This will show how the spectrum nominally saved by the asymmetry deployment itself can effectively be reused for other links of the network.

For this reason some example of real networks have been proposed and their planning have been simulated, with the conventional target of reusing as much as possible the same frequency slots before using a new one. Comparisons, with all other parameter fixed (e.g. antennas, Tx and Rx and propagation parameters and link performance objectives) have been carried out with symmetric and asymmetric deployment with 1:2 and 1:4 ratio.

6.1 SIMULATION 1: RURAL SCENARIO – ASYMMETRICAL ONLY CASE 1:2 AND 1:4

6.1.1 Network Topology

The site locations and the linking topology were provided based on an existing real case scenario.

The links average length is fitted for 13/15 GHz connections, the links labelled with (6) constitute a ring configuration (therefore symmetric by nature); then only links of levels (1) to (5) could be planned in asymmetric way.

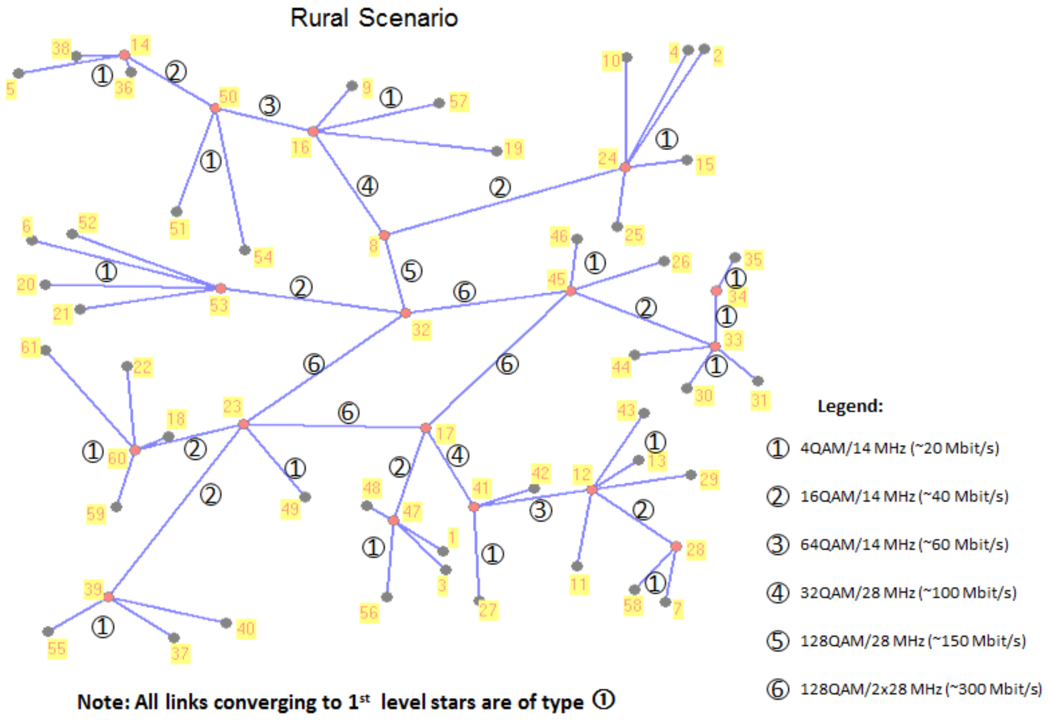


Figure 18: Topology and connectivity of the Rural scenario

6.1.2 Results

It has been concluded that this rural scenario, with the link capacities proposed in Figure 18, will not benefit on the use of asymmetrical links, since the links in this scenario are severely underutilized from the capacity point of view. Planning this scenario with asymmetrical links will not show a major benefit in spectrum saving nor in capacity upgrade.

6.2 SIMULATION 2: URBAN SCENARIO –ASYMMETRICAL ONLY CASE 1:2 AND 1:4

6.2.1 Network topology

The urban deployment scenario was selected in the studies related to the asymmetrical spectrum usage for evaluating the benefits of asymmetrical planning on a “real life” network. The following map shows the geographic connectivity of the nodes. In this case ring protections have not been considered.

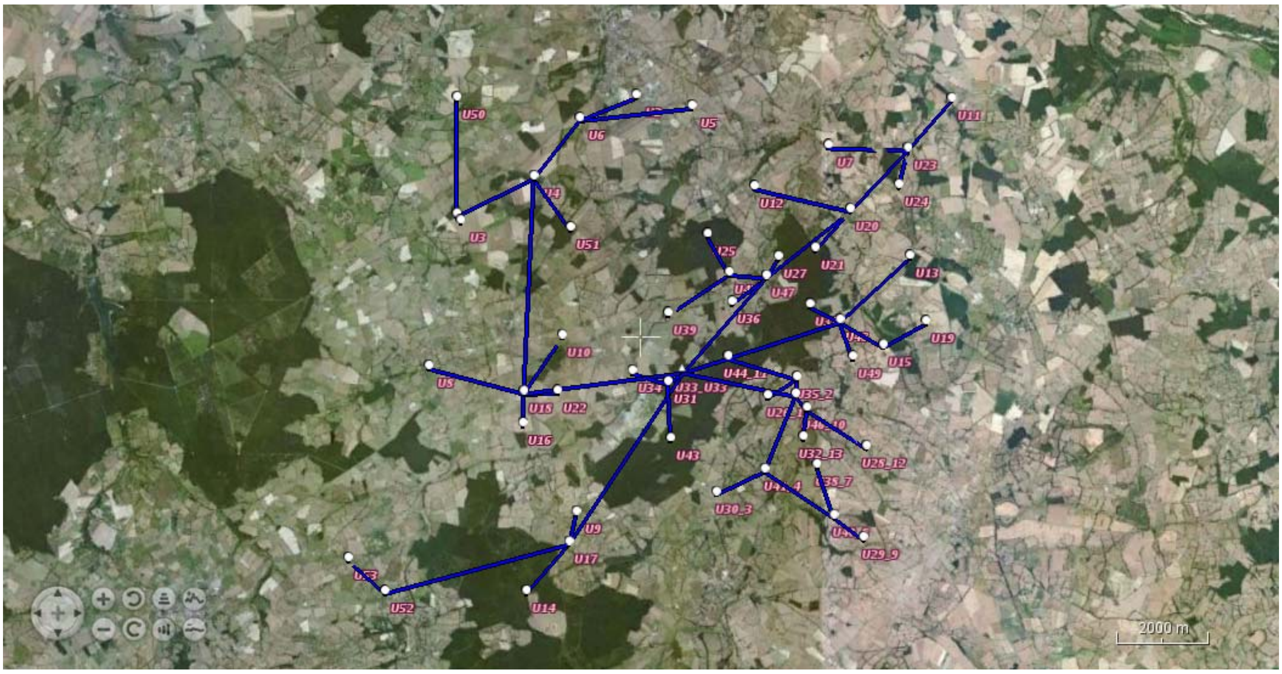


Figure 19: Deployment topology

6.2.2 Parameters

The parameters which were used in the planning of this network for both symmetrical and asymmetrical approaches are as follows:

- Average link length fit for 38 GHz band connections
- Availability objective: 99.995% for BER=10^-6;
- The fade margin used for the availability calculation includes the threshold degradation due to the interference;
- Maximum threshold degradation is 3dB;
- Rain zone: K;
- Maximum antenna size: 3ft;
- Antennas type: class 3;
- Propagation model: ITU-R P.530-14 (the latest available model) for inland flat terrain, with pL=20% ;
- Presence of LOS between all sites (no losses due to terrain obstacles);
- Apply frequency reuse techniques as much as possible.

Data dimensioning:

- Capacity for aggregated link of “N” base stations = Max (Peak capacity, NxBTM)
  - Peak capacity = 130Mbps;
  - BTM = Busy Time Mean = 72Mbps.
- Asymmetry Ratio
  - Traffic ratio A, used as reference point: 1:1, symmetrical traffic;
  - Traffic ratio B: 1:2, uplink to downlink;
  - Traffic ratio C: 1:4, uplink to downlink.

It should be noted that the minimum size of the channel spacing has been limited to 7 MHz; therefore, in the 1:4 simulation case, for a number of the peripheral links requiring a DL capacity fit for 14 MHz channel width, the 1:2 asymmetry, instead of 1:4 asymmetry, has been maintained (i.e. 7 MHz UL channel size).

6.2.3 Results: Spectrum Usage

The following tables show the difference between the symmetrical and asymmetrical spectrum planning. The frequency rasters that were used to all the simulation are in line with the ECC recommended channel arrangements and don't require any channelization changes. The tables present the comparison between the asymmetrical planning for the traffic ratios of 1:2 and 1:4 relative to the existing 1:1 (symmetrical) planning.

The symmetrical planning has been done using two planning variants. The difference between the simulations, consists mainly in the initial frequency assignment of the central aggregation node "U33", where SIM2 succeeded in saving additional 4 x 7MHz slots with respect to SIM1.

It should be noted that the asymmetric planning was done using the planning method described in section 4.2.1. Each of the graphs shows the number of links per channel in the upper and lower frequency bands, in all the graphs we can see the results of the symmetrical simulation SIM1 and SIM2 as explained above:

- Figure 20: Planning approach 1:1 (symmetrical) and 1:2 (asymmetrical) in the low frequency band;
- Figure 21: Planning approach 1:1 and 1:2 in the high frequency band;
- Figure 22: Planning approach 1:1 and 1:4 in the low frequency band;
- Figure 23: Planning approach 1:1 and 1:4 in the high frequency band.

Looking at the entire spectral usage, the design utilized 24 x 7MHz for the SIM1 symmetrical planning and 20 x 7MHz for the SIM2 symmetrical planning.

6.3 COMPARISON OF PLANNING RESULTS FOR TRAFFIC RATIO A(1:1) AND B(1:2)

The low frequency band usage of the channels is presented in Figure 20. The bar graph indicates how many times the same frequency channel was used in different links.

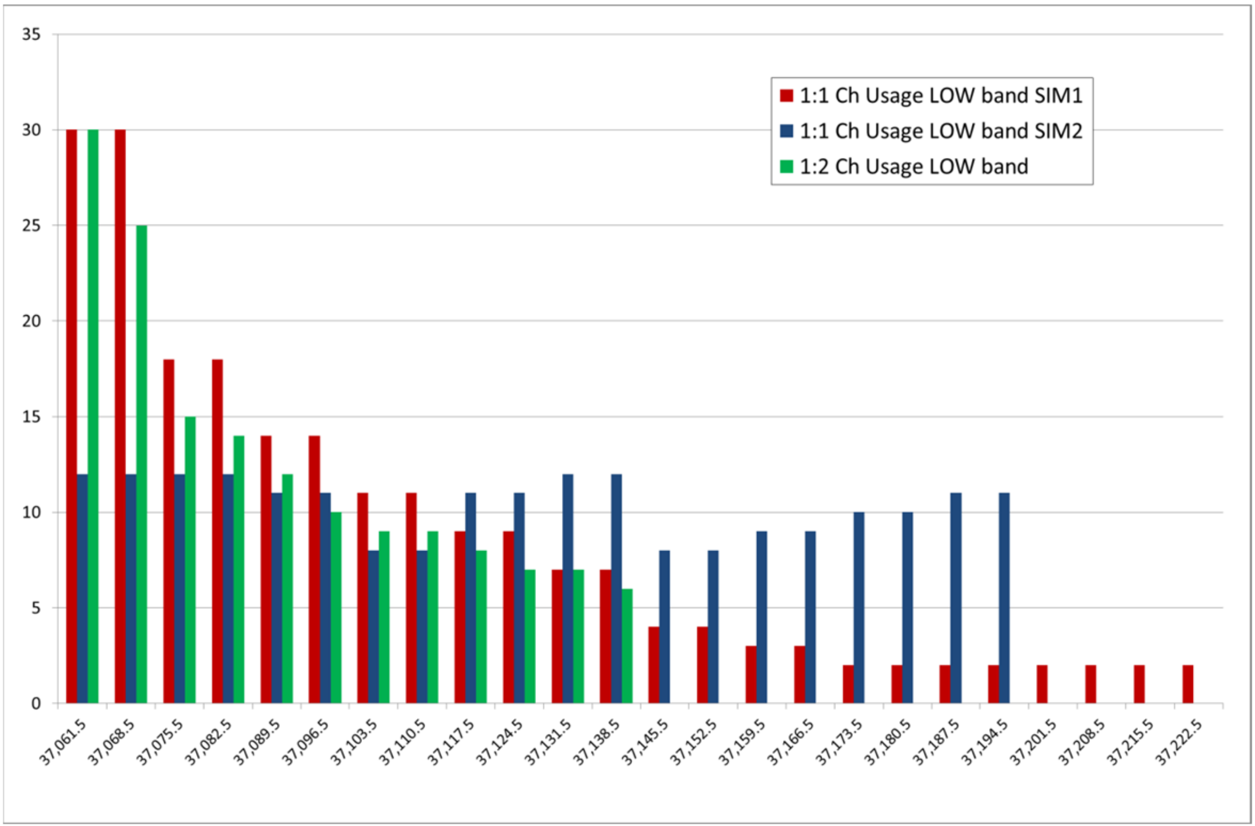


Figure 20: Comparison of 1:1 and 1:2 planning approaches in the low band

It can be observed that using the asymmetrical planning for the 1:2 traffic asymmetry 12 contiguous channels are saved in comparison to SIM1 and 8 contiguous channels in comparison to SIM2

The high frequency band usage of the channels is presented below:

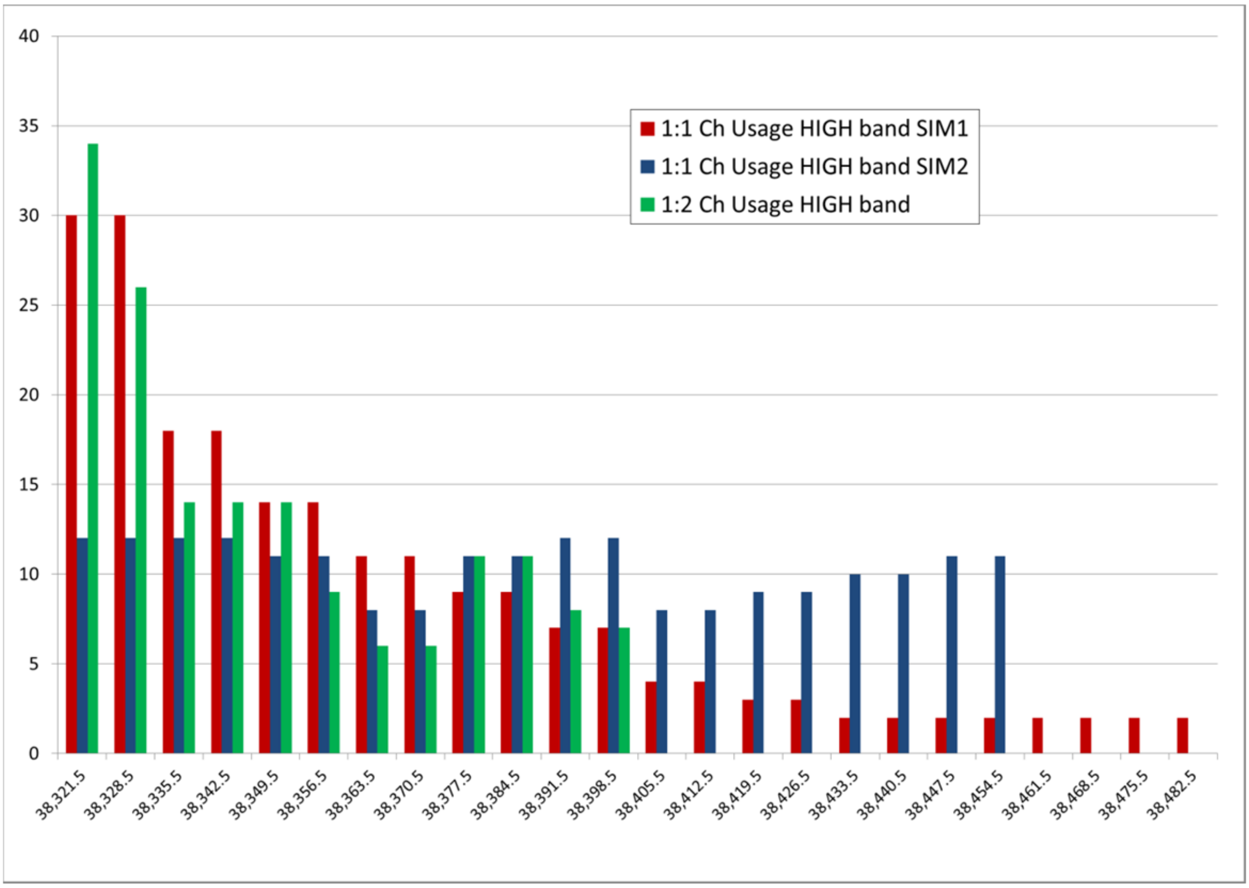


Figure 21: Comparison of 1:1 and 1:2 scenarios in the high band

It can be observed that using the asymmetrical planning for the 1:2 traffic asymmetry 12 contiguous channels are saved in comparison to SIM1 and 8 contiguous channels in comparison to SIM2

Overall planning the network asymmetrically at 1:2 ratio can save 8 to 12 bi-directional contiguous channels.

6.4 COMPARISON OF THE PLANNING RESULTS FOR TRAFFIC RATIO A(1:1) AND C(1:4)

The low frequency band usage of the channels is presented below:

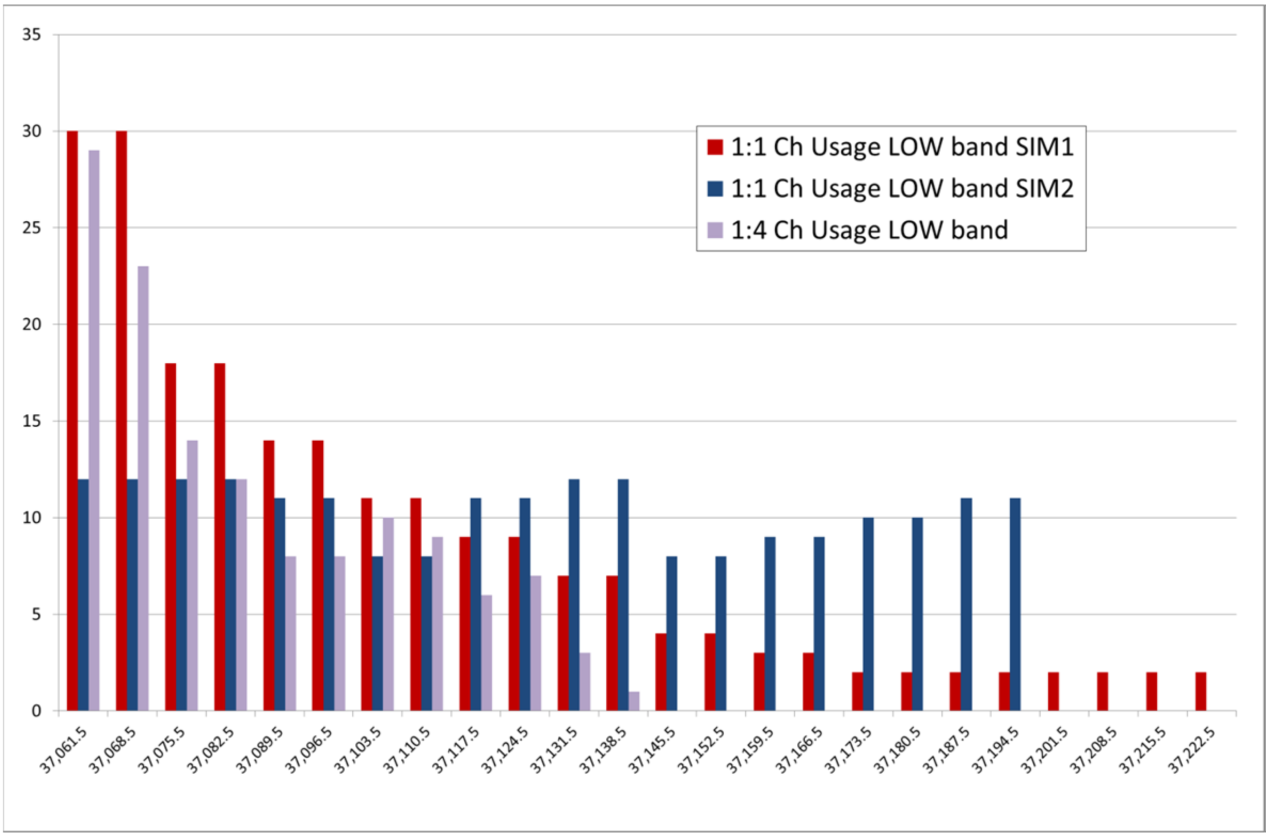


Figure 22: Comparison of 1:1 and 1:4 scenarios in the low band

It can be observed that using the asymmetrical planning for the 1:4 traffic asymmetry 12 contiguous channels are saved in comparison to SIM1 and 8 contiguous channels in comparison to SIM2.

The high frequency band usage of the channels is presented below:

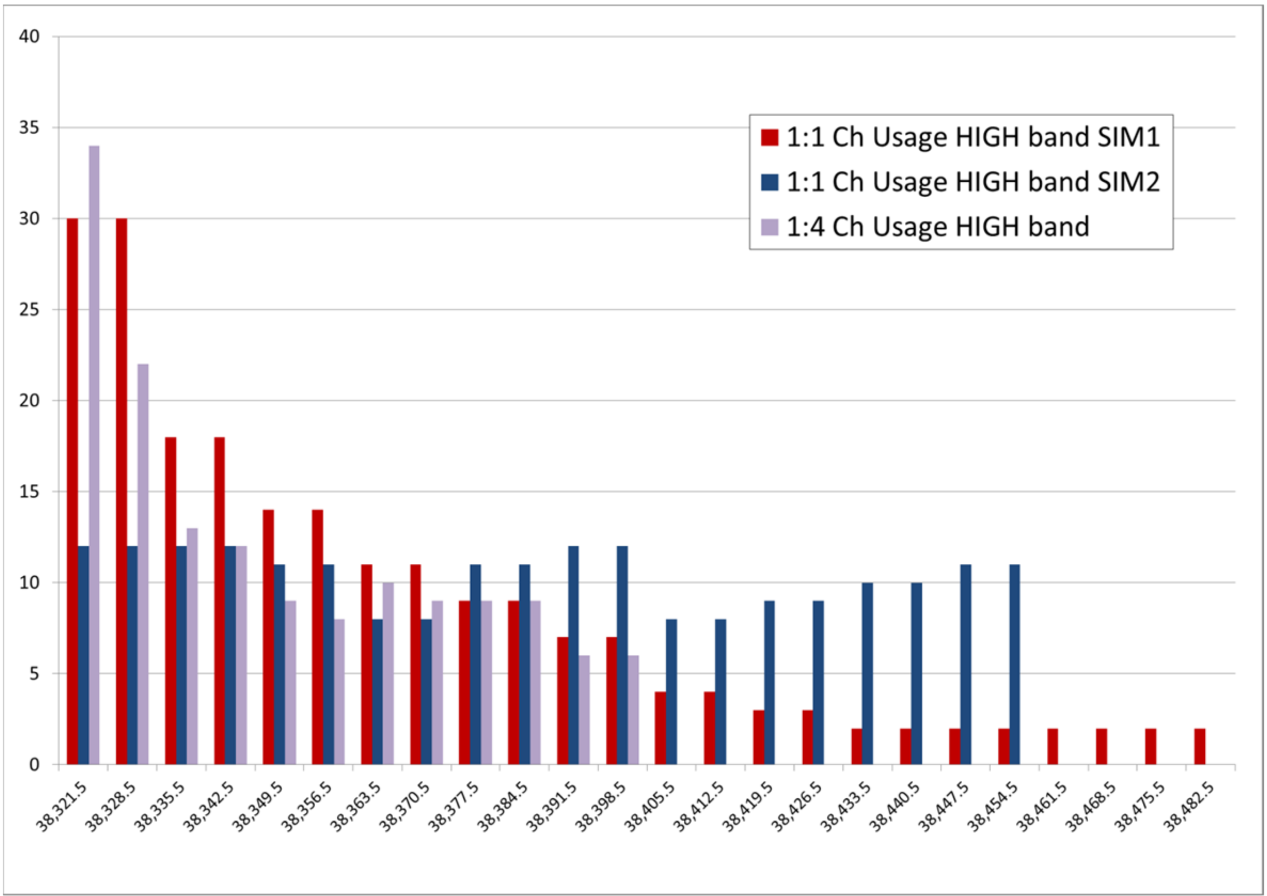


Figure 23: Comparison of 1:1 and 1:4 scenarios in the high band

It can be observed that using the asymmetrical planning for the 1:4 traffic asymmetry 12 contiguous channels are saved in comparison to SIM1 and 8 contiguous channels in comparison to SIM2The amount of saved spectrum is partly due to the use of a different planning method (effective only with asymmetric deployment) in combination with asymmetrical planning.

In this simulation we don’t see a difference in the benefit of using 1:4 or 1:2 in term of bi-directional channels saving. It should be noted however that the 1:4 asymmetrical planning still maintains the following potential benefits:

Planning in more congested hub sites, may in principle be easier and allow for more channel reuse due to more options for the uplink channel.

When planning in block allocation scenarios a non-standard centre frequency for uplink channels may be used thus again contributing to more options for channel reuse.

The overall BW usage for each planning approach is presented in Table 3.

Table 3: Summary of the spectrum usage for different symmetrical and asymmetrical simulations

	1:1 SIM1	1:1 SIM2	1:2	1:4
Total BW used - high band [MHz*number of links]	1.456	1.456	1.120	1.029
Total BW used - low band [MHz*number of links]	1.456	1.456	1.064	910
High Band un-used spectrum [%]			23%	29%
Low Band un-used spectrum [%]			27%	38%

	1:1 SIM1	1:1 SIM2	1:2	1:4
Total channels used	24	20	12	12
Bi-directional channels saved compared to symmetrical simulation[%]			SIM1:50% SIM2:40%	SIM1:50% SIM2:40%

Planning the network asymmetrically can save spectrum in the uplink but also reduce the total number of bi-directional channels used. The results also indicate a unidirectional spectrum save in the uplink of an average of 25% for the 1:2 scenario and an average of 33% for the 1:4 scenario. The results of this simulation indicate bi-directional channel savings of 40% or 50% (depends to which symmetrical simulation is compared to). The difference between the two figures is explained by the use of the planning method suggested in section 4.2.1.

Detailed simulation results can be found in the embedded Excel file. A description on the parameters can be found in Table 4.

Table 4: Parameters and there description used in the embedded Excel File

Parameter	Description
LINK_ID	Link indication on the map
LENGTH	Link length in [km]
LEVEL	Aggregation level of the link, the last link connecting the tail site is aggregation 4, while links stemming from the hub is level 1
RD TRAFFIC	Required Downlink Traffic [Mb/s]
CD TRAFFIC	Actual Downlink Traffic [Mb/s]
RU TRAFFIC	Required Uplink Traffic [Mb/s]
CU TRAFFIC	Actual Uplink Traffic [Mb/s]
RATIO	Downlink to Uplink capacity ratio
DIAM_DL	Antenna diameter downlink [m]
CH_DL	Channels numbers for Downlink. Example: 001->004;V means: ch1 to ch4 in Vertical polarization (each channel is a 7MHz channel)
TX DL	Downlink Transmitter High or Low
FREQ_DL	Center frequency Downlink [GHz]
BW_DL	BW Downlink [MHz]
TX Power DL	TX power Downlink [W]
DIAM_UL	Antenna diameter uplink [m]
CH_UL	Channels numbers for Uplink. Example: 001->004;V means: ch1 to ch4 in Vertical polarization (each channel is a 7MHz channel)
TX_UL	Uplink Transmitter High or Low
FREQ_UL	Center frequency Uplink [GHz]
BW_UL	BW Uplink [MHz]
TX POWER UL	TX power Uplink [W]
CARRIERS	Number of carriers used for this link
XPIC	Is the link deployed in XPIC configuration
MOD_DL_1	Modulation scheme for Downlink
MOD_UL_1	Modulation scheme for Uplink
RSL_DL_1	Received Signal Level Downlink [dBm]
RSL_UL_1	Received Signal Level Uplink [dBm]
FM_DL_1	Fade Margin Downlink [dB]
FM_UL_1	Fade Margin Uplink [dB]
TD_DL	Threshold degradation Downlink [dB]
TD_UL	Threshold degradation Uplink [dB]
AV_AN_DL_1	Availability for Downlink
AV_AN_UL_1	Availability for Uplink

Note:

Downlink site – A site which transmits the higher capacity needed for downlink
Uplink site – A site which transmits the lower capacity needed for uplink

The detailed planning results are presented in the embedded Excel file:

Urban Scenario
Simulation results.xlsx

6.5 SIMULATION 3: COMBINED SYMMETRICAL AND 1:2, 1:4 ASYMMETRICAL

The simulation gives some insight into the effects of using combined symmetrical and asymmetrical microwave links on the overall network spectrum usage. The study was performed on two real network scenarios ("rural" and "urban" one) which are in use in one administration and with flexible channel arrangements in order to get the most benefit of the asymmetric approach. A goal of the simulation was to assess impact and benefits of possible introduction of asymmetric microwave links into existing microwave networks. Simulated rural scenario was delivered from a real-life network topology used by one of the operators in a typical rural environment, with the difference that all links in the tested scenario operate in the same frequency band. Geographical configuration and link capacities have been preserved. Tested urban scenario is delivered from a real-life network in a typical urban scenario, so the actual RF channels used have been preserved.

In both cases the total spectrum used in the whole network for symmetric and asymmetric case has been compared.

6.5.1 Frequency plan

Channel arrangement used for asymmetric links was idealistic with fully flexible duplex; Figure 24 shows only the lower frequency DL and upper frequency UL situation, but for H/L nodes alternation, also the mirror lower frequency UL and upper frequency DL situation is used. For symmetric links deployment, typical channel arrangement was used.

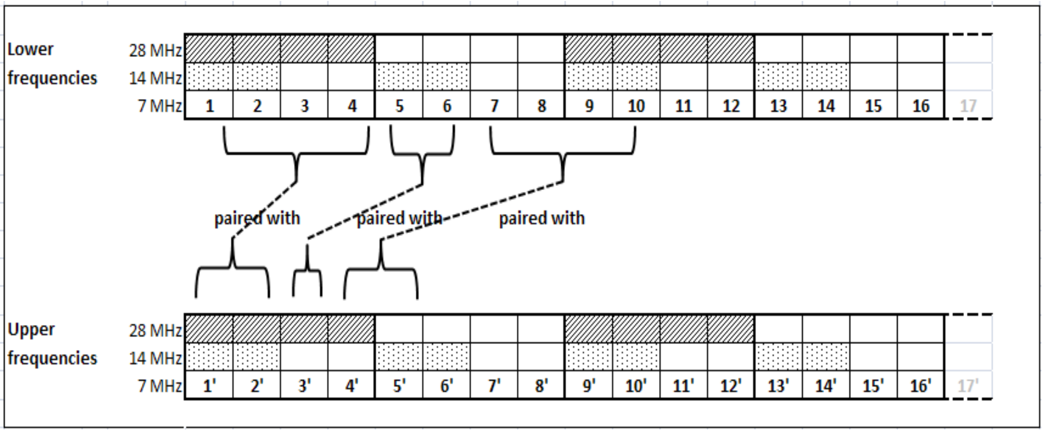


Figure 24: Frequency assignment table for asymmetric case (mirror upper/lower frequencies arrangement is also used)

Both sub-bands consist of 7 MHz raster only. Other channels are derived by channel aggregation, meaning that there is a possibility to combine as many 7 MHz channels as needed to create a larger one (e.g. 28 MHz would consist of four 7 MHz channels). Frequency assignment was done following some standard principles: applying frequency reuse and avoiding high-low conflict. Frequency reuse was applied only if links were separated more than 90°, which is in most cases enough to avoid interferences between links, taking into account criteria such as threshold degradation of up to 1 dB or C/I > 40 dB etc. Alternation of polarization was also used in planning the network.

In real case, asymmetry ratio is related to capacity of the link. In this analysis approximation is used and asymmetry ratio is related to channel bandwidth (e.g.. for 1:4 asymmetry 28 MHz channel is used in one direction and 7 MHz is used in other direction of the link). Used approximation correlates with real case quite well, as can be seen in following examples:

- Example 1: Symmetrical link uses 28 MHz channel, 256 QAM modulation meaning the capacity of the link is around 172 Mbit/s. Using asymmetry ratio of 1:4, other direction of the link would have capacity of 172/4 = 43 Mbit/s. . Approximation used in this simulation: asymmetry ratio of 1:4 means that for 28 MHz in one direction of the link, 28 / 4 = 7 MHz is used in other direction. Keeping the same modulation type (256 QAM), 7 MHz channel gives capacity of approximately 41 Mbit/s which is very close to 43 Mbit/s.
- Example 2: 28 MHz channel, 64 QAM modulation gives 140 Mbit/s. 1:2 asymmetry ratio gives capacity of 70 Mbit/s in other direction of the link. Approximation in this simulation: 28 MHz one way, 14 MHz other way (1:2 asymmetry), using 64 QAM -> 65 Mbit/s. 70 Mbit/s ≈ 65 Mbit/s.

As shown in previous examples, approximation that is used in simulations corresponds quite well to the real situation and there is no need to know exact capacity of every link.

When looking at spectral efficiency, considering assigned spectrum to the operator, using the same type of modulation as in examples above, there is no gain if asymmetric links are used.

For the above examples:

Table 5: Example 1: 28 MHz, 256 QAM, 172 Mbit/s, 1:4 asymmetry

	1:1	1:4
Downlink Capacity [Mbps]	172	172
Uplink Capacity [Mbps]	172	43 / (41)
Total Available Capacity [Mbps]	344	215 / (213)
Spectrum used - low band [MHz]	28	28
Spectrum used - high band [MHz]	28	7
Total used spectrum [MHz]	56	35

Table 6: Example 2: 28 MHz, 64 QAM, 140 Mbit/s, 1:2 asymmetry

	1:1	1:4
Downlink Capacity [Mbps]	140	140
Uplink Capacity [Mbps]	140	70 / (65)
Total Available Capacity [Mbps]	280	210 / (205)
Spectrum used - low band [MHz]	28	28
Spectrum used - high band [MHz]	28	14
Total used spectrum [MHz]	56	42

6.5.2 Rural scenario

The rural network under consideration Figure 25 was taken from a real-life network used by one of the operators in a typical rural environment Figure 26, with the difference that all links in tested scenario operate in the same frequency band. It consists of 43 nodes (marked with numbers) and 42 links, typical chain or star configurations. Downlink capacity was the same for both symmetric and asymmetric case. Link capacities were grouped into three categories with respect to the spectrum needed: 8-30 Mbps (channel width 7 MHz), 31-79 Mbps (channel width 14 MHz) and more than 80 Mbps (channel width 28 MHz). In this scenario, 1:2 asymmetric cases was applied.

The list of links and designated channels for both symmetric and asymmetric case is depicted in Table 7.

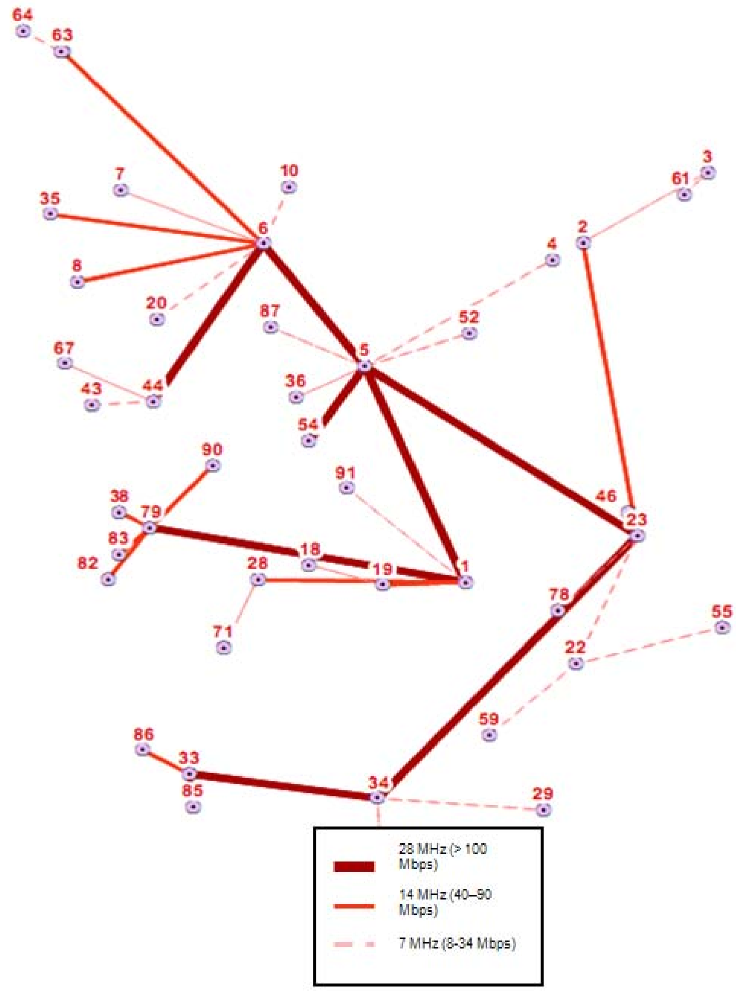


Figure 25: Considered network with all links operating in the same frequency band, with three categories of capacities marked with lines of different width

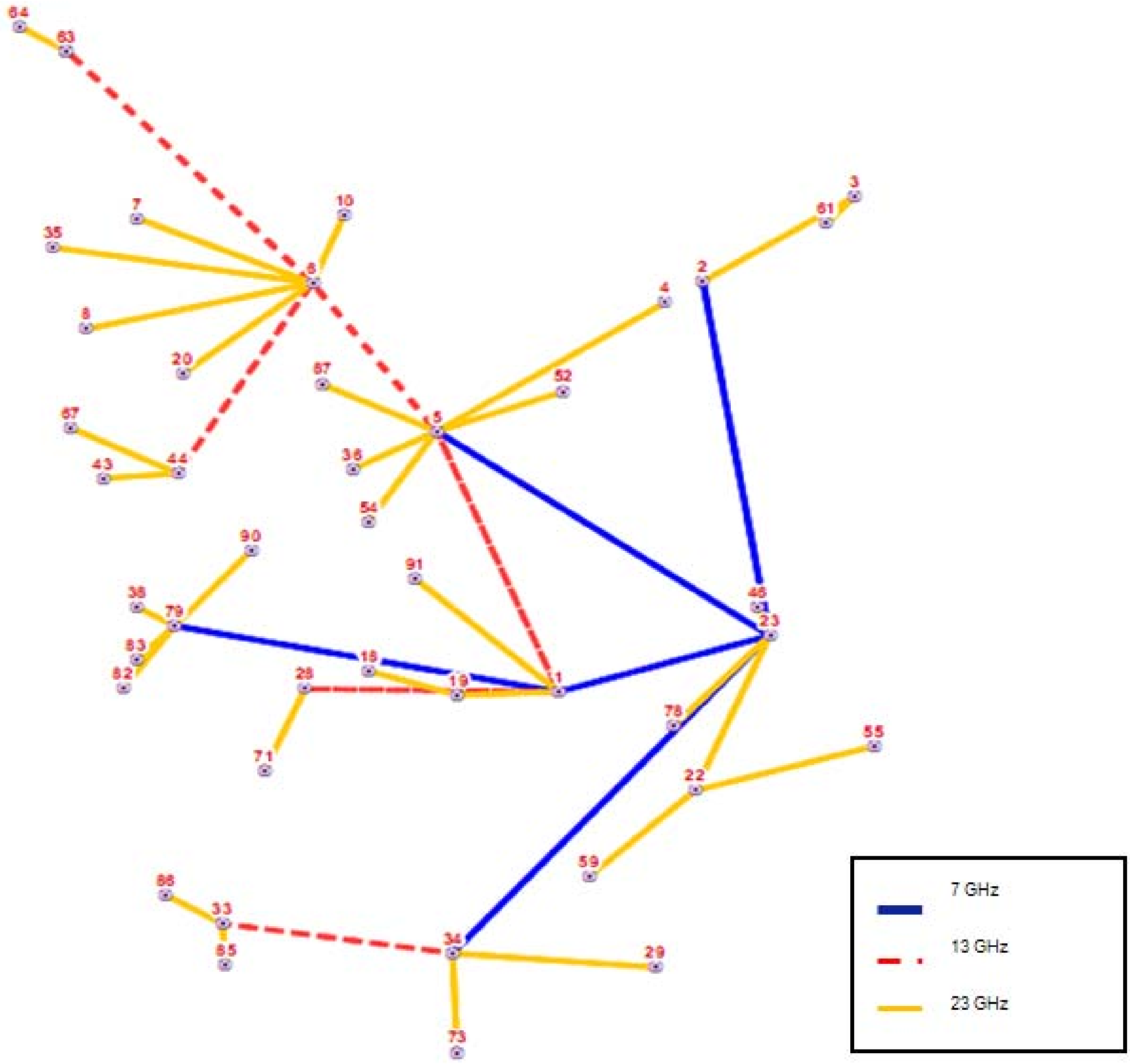


Figure 26: The real network in a typical rural scenario indicating in which frequency band links operate (for info only)

Table 7: List of links in tested network and channels assigned for Symmetric and Asymmetric Case (Rural scenario)

Link (lower - upper)	Symmetrical case		Asymmetrical case	
	Tx ch.	Rx ch.	Tx ch.	Rx ch.
N6 - N5	**1** (28)	**1'** (28)	**1, 2** (14)	**1', 2', 3', 4'** (28)
N1 - N5	**1** (28)	**1'** (28)	**1, 2** (14)	**1', 2', 3', 4'** (28)
N23 - N5	**2** (28)	**2'** (28)	**3, 4** (14)	**5', 6', 7', 8'** (28)
N54 - N5	**3** (28)	**3** (28)	**5, 6** (14)	**9', 10', 11', 12'** (28)
N6 - N44	**2** (28)	**2'** (28)	**3, 4, 5, 6** (28)	**5', 6'** (14)
N1 - N79	**2** (28)	**2'** (28)	**3, 4, 5, 6** (28)	**5', 6'** (14)
N23 - N34	**1** (28)	**1'** (28)	**5, 6, 7, 8** (28)	**1', 2'** (14)
N33 - N34	**1** (28)	**1'** (28)	**1, 2** (14)	**1', 2', 3', 4'** (28)
N6 - N35	**1** (14)	**1'** (14)	**1, 2** (14)	**1'** (7)
N6 - N8	**2** (14)	**2'** (14)	**7, 8** (14)	**2'** (7)
N6 - N63	**3** (14)	**3'** (14)	**3, 4** (14)	**3'** (7)
N1 - N19	**6** (14)	**6'** (14)	**7, 8** (14)	**7'** (7)
N1 - N28	**5** (14)	**5'** (14)	**9, 10** (14)	**8'** (7)
N79 - N90	**1** (14)	**1'** (14)	**1** (7)	**1', 2'** (14)
N79 - N82	**1** (14)	**1'** (14)	**1** (7)	**1', 2'** (14)
N79 - N38	**2** (14)	**2'** (14)	**3** (7)	**5', 6'** (14)
N79 - N83	**3** (14)	**3'** (14)	**2** (7)	**3', 4'** (14)
N23 - N46	**2** (14)	**2'** (14)	**1, 2** (14)	**1'** (7)
N23 - N2	**1** (14)	**1'** (14)	**5, 6** (14)	**2'** (7)
N33 - N86	**1** (14)	**1'** (14)	**1, 2** (14)	**1'** (7)
N33 - N85	**3** (14)	**3'** (14)	**5, 6** (14)	**5'** (7)
N87 - N5	**5** (7)	**5'** (7)	**3** (7)	**5'** (7)
N36 - N5	**6** (7)	**6'** (7)	**4** (7)	**6'** (7)
N4 - N5	**2** (7)	**2'** (7)	**2** (7)	**2'** (7)
N52 - N5	**1** (7)	**1'** (7)	**1** (7)	**1'** (7)
N6 - N10	**1** (7)	**1'** (7)	**1** (7)	**1'** (7)
N6 - N7	**9** (7)	**9'** (7)	**9** (7)	**4'** (7)
N6 - N20	**10** (7)	**10'** (7)	**10** (7)	**7'** (7)
N64 - N63	**1** (7)	**1'** (7)	**1** (7)	**1'** (7)
N67 - N44	**1** (7)	**1'** (7)	**1** (7)	**1'** (7)
N43 - N44	**2** (7)	**2'** (7)	**2** (7)	**2'** (7)
N3 - N2	**3** (7)	**3'** (7)	**3** (7)	**3'** (7)
N3 - N61	**1** (7)	**1'** (7)	**4** (7)	**4'** (7)
N1 - N91	**13** (7)	**13'** (7)	**11** (7)	**9'** (7)
N28 - N19	**1** (7)	**1'** (7)	**1** (7)	**1'** (7)
N23 - N22	**5** (7)	**5'** (7)	**2** (7)	**4'** (7)
N59 - N22	**1** (7)	**1'** (7)	**2** (7)	**2'** (7)
N55 - N22	**6** (7)	**6'** (7)	**1** (7)	**1'** (7)
N23 - N78	**9** (7)	**9'** (7)	**1** (7)	**3'** (7)
N71 - N28	**2** (7)	**2'** (7)	**2** (7)	**2'** (7)
N73 - N34	**1** (7)	**1'** (7)	**2** (7)	**1'** (7)
N29 - N34	**7** (7)	**7'** (7)	**1** (7)	**3'** (7)

Channels are marked with the number and size indicated in brackets. For symmetric case, channel size and number are in line with the typical frequency assignment Table 7 (for example, 1 (14) denotes the first channel in 14 MHz channelization). For asymmetric case, where channel aggregation was applied, numbers correspond to the 7 MHz channelization in Figure 24 and number in brackets indicates the total channel width (e.g. channel 5,6 (14) denotes a 14 MHz channel consisting of 7 MHz channels 5 and 6).

Node 5 (N5) in Figure 25 is the main node of the considered network and the starting position for frequency planning of channels with higher capacity requirement (hereafter, downlink channels - DL). Uplink channels (UL) were assigned for symmetric and asymmetric case accordingly: in symmetric case UL channels were simply paired with assigned DL channels and in asymmetric case UL channels were chosen with respect to the UL/DL ratio being 1:2. For simplicity, links which used 7 MHz channels in the symmetric case remained symmetric as 7 MHz channel was set as the minimum “spectrum element”.

The total RF spectrum used for all links in the network for both symmetric and asymmetric case is represented in the following figures. Figure 27 shows the total RF spectrum used in symmetric case, thus reflecting the actual spectrum usage in the real-life network (as link capacities from the real network have been preserved). Figure 28 depicts the total RF spectrum usage after the re-planning of the rural scenario into the asymmetric case; from top down Figure 27 shows, for the symmetric case: the lower band channel used, the number of time the channels have been used, the total number of time each single 7 MHz slot has been used and the same sequence for the channels used in the upper band.

Figure 29 shows the same results for the asymmetric deployment case.

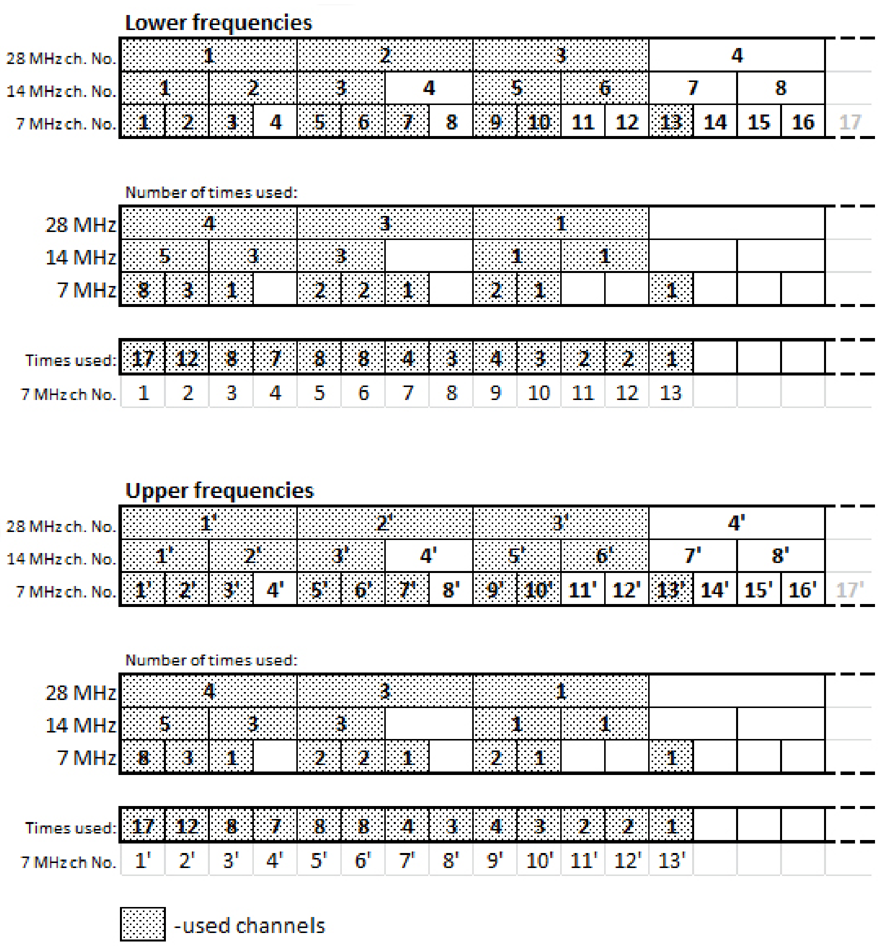


Figure 27: Total spectrum used in symmetric case (rural network)

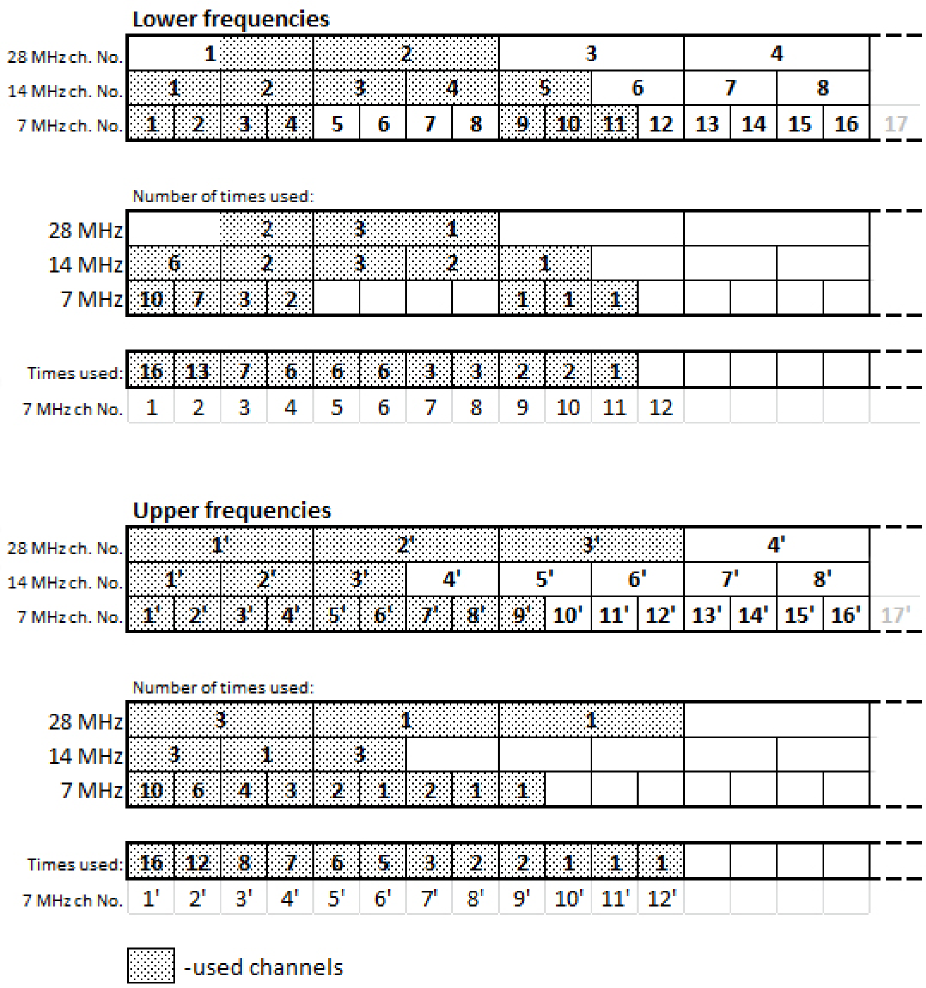


Figure 28: Total spectrum used in asymmetric case (rural network)

In symmetric case, 2x84 MHz in 28 MHz channel raster, 2x70 MHz in 14 MHz and 2x63 MHz in 7 MHz channel raster have been used. It can be noted that channel 4-4' (28 MHz raster) is effectively also occupied due to the assignment of 7 MHz channel 13.

In asymmetric case, 42+84 MHz (lower + upper) in 28 MHz channel raster, 70+42 MHz in 14 MHz and 49+56 MHz in 7 MHz channel raster have been used. Channel 4-4' in 28 MHz channel raster has been preserved.

A comparison of spectrum usage in 7 MHz channel raster between symmetrically and asymmetrically planned networks in rural case is shown on Figure 29.

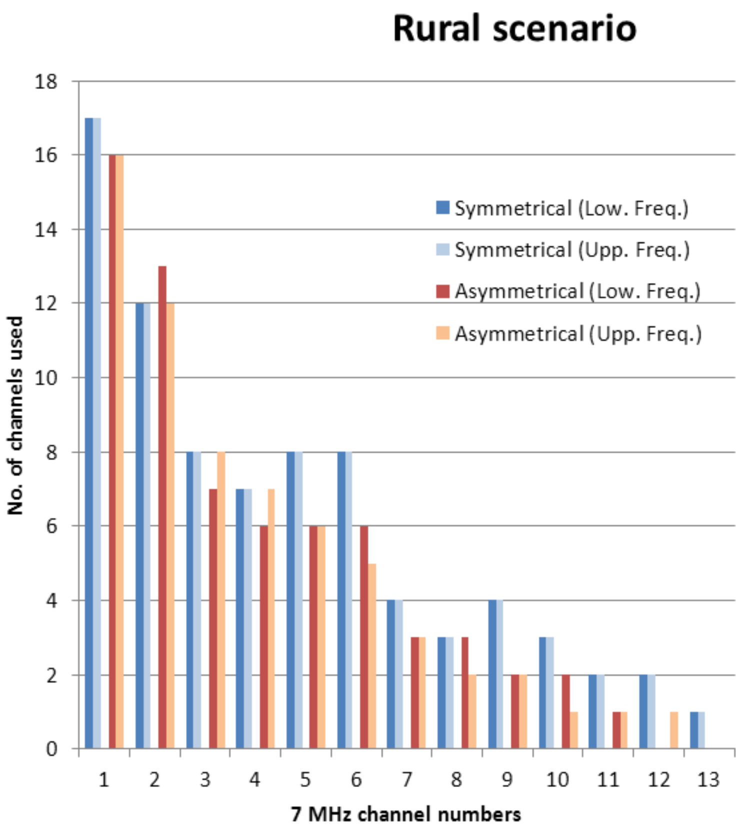


Figure 29: Usage of spectrum in symmetrically and asymmetrically planned networks (rural scenario)

6.5.3 Urban Scenario

The urban scenario network (Figure 30) is a real-network from one of the operators in 38 GHz frequency band. It consists of 41 nodes (marked with numbers) and 40 links, typical chain and star configuration.

Links in the original network have rather different capacities, but this is (mainly) due to different modulation techniques used. On the physical layer, they all operate only on 14 and 28 MHz channels. Since this analysis was focused on the total spectrum usage, only the physical channels used were taken into account, so all links in the considered network were grouped into 2 categories, based on the channel width: 28 MHz links (most of the links) and 14 MHz channel links. When re-planning into the asymmetric case, 1:4 asymmetries was applied for 28 MHz channels and 1:2 for 14 MHz channel links (i.e. 7 MHz channel was used as a smallest frequency segment). There are 5 main nodes (nodes N1, N10, N6, N3 and N8), and links connecting them are kept symmetric.

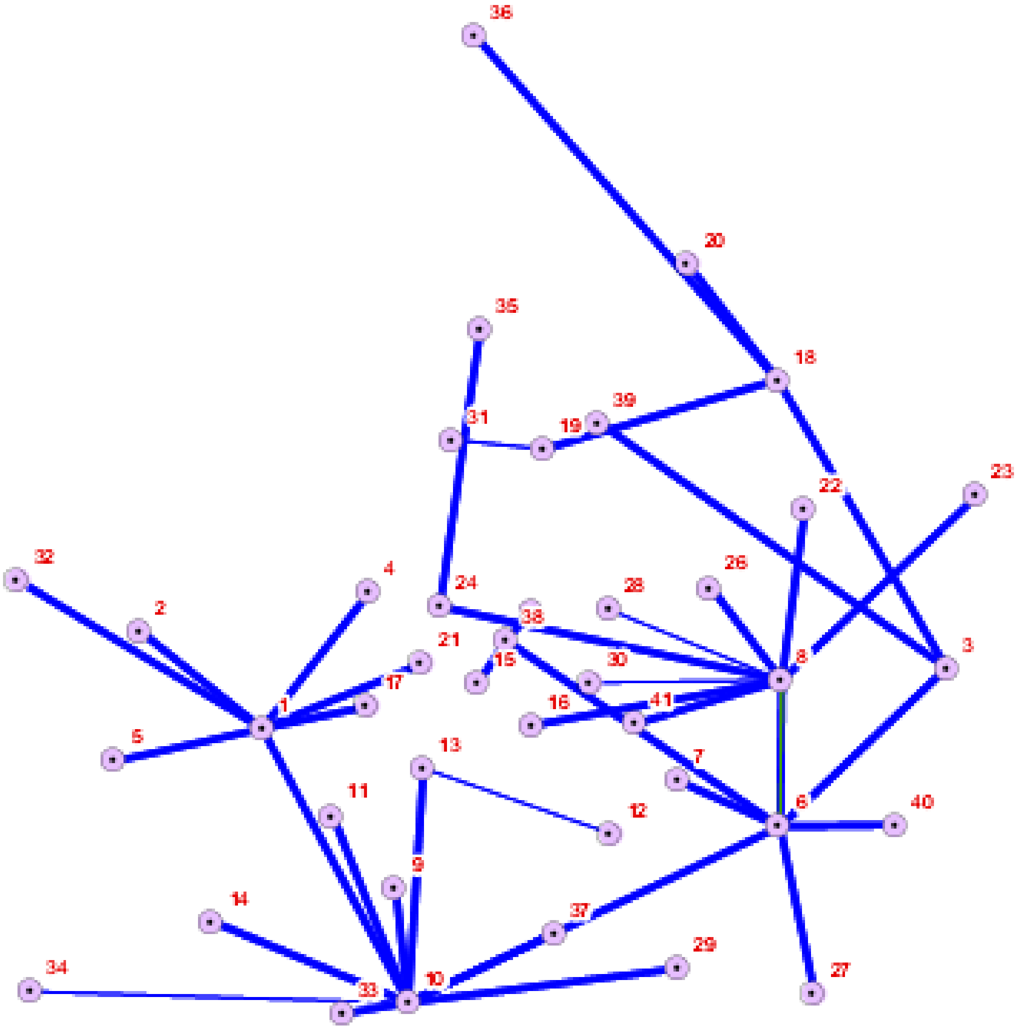


Figure 30: Considered network for urban scenario. Thinner lines represent 14 MHz links, the thicker ones 28 MHz links

The list of links and designated channels for both symmetric and asymmetric case in urban scenario is depicted in Table 8.

Table 8: List of links in tested network and channels assigned for Symmetric and Asymmetric case (urban scenario)

Link (lower - upper)	Symmetrical case			Asymmetrical case		
	Tx ch.	Rx ch.	Polarization	Tx ch.	Rx ch.	Polarization
N10 - N33	$2_{(28)}$	$2'_{(28)}$	V	$3_{(7)}$, $4_{(7)}$, $5_{(7)}$, $6_{(7)}$	$2'_{(7)}$	V
N10 - N34	$1_{(14)}$	$1'_{(14)}$	H	$1_{(7)}$, $2_{(7)}$	$1'_{(7)}$	H
N10 - N14	$3_{(28)}$	$3'_{(28)}$	H	$7_{(7)}$, $8_{(7)}$, $9_{(7)}$, $10_{(7)}$	$3'_{(7)}$	H
N10 - N1	$2_{(28)}$	$2'_{(28)}$	V	$1_{(7)}$, $2_{(7)}$, $3_{(7)}$, $4_{(7)}$	$7'_{(7)}$, $8'_{(7)}$, $9'_{(7)}$, $10'_{(7)}$	V
N5 - N1	$1_{(28)}$	$1'_{(28)}$	H	$1_{(7)}$	$1'_{(7)}$, $2'_{(7)}$, $3'_{(7)}$, $4'_{(7)}$	V
N32 - N1	$3_{(28)}$	$3'_{(28)}$	H	$3_{(7)}$	$6'_{(7)}$, $7'_{(7)}$, $8'_{(7)}$, $9'_{(7)}$	V
N2 - N1	$2_{(28)}$	$2'_{(28)}$	V	$1_{(7)}$	$1'_{(7)}$, $2'_{(7)}$, $3'_{(7)}$, $4'_{(7)}$	H
N4 - N1	$3_{(28)}$	$3'_{(28)}$	H	$3_{(7)}$	$9'_{(7)}$, $10'_{(7)}$, $11'_{(7)}$, $12'_{(7)}$	H
N21 - N1	$2_{(28)}$	$2'_{(28)}$	V	$1_{(7)}$	$5'_{(7)}$, $6'_{(7)}$, $7'_{(7)}$, $8'_{(7)}$	V
N17 - N1	$1_{(28)}$	$1'_{(28)}$	H	$2_{(7)}$	$1'_{(7)}$, $2'_{(7)}$, $3'_{(7)}$, $4'_{(7)}$	H
N10 - N11	$1_{(28)}$	$1'_{(28)}$	H	$6_{(7)}$, $7_{(7)}$, $8_{(7)}$, $9_{(7)}$	$3'_{(7)}$	V
N10 - N9	$4_{(28)}$	$4'_{(28)}$	V	$11_{(7)}$, $12_{(7)}$, $13_{(7)}$, $14_{(7)}$	$5'_{(7)}$	V
N10 - N13	$3_{(28)}$	$3'_{(28)}$	H	$1_{(7)}$, $2_{(7)}$, $3_{(7)}$, $4_{(7)}$	$2'_{(7)}$	H
N12 - N13	$5_{(14)}$	$5'_{(14)}$	V	$1_{(7)}$	$1'_{(7)}$, $2'_{(7)}$	V
N10 - N37	$2_{(28)}$	$2'_{(28)}$	V	$5_{(7)}$, $6_{(7)}$, $7_{(7)}$, $8_{(7)}$	$1'_{(7)}$	V
N10 - N29	$1_{(28)}$	$1'_{(28)}$	H	$1_{(7)}$, $2_{(7)}$, $3_{(7)}$, $4_{(7)}$	$2'_{(7)}$	H
N10 - N6	$4_{(28)}$	$4'_{(28)}$	V	$10_{(7)}$, $11_{(7)}$, $12_{(7)}$, $13_{(7)}$	$4'_{(7)}$, $5'_{(7)}$, $6'_{(7)}$, $7'_{(7)}$	H
N27 - N6	$1_{(28)}$	$1'_{(28)}$	V	$1_{(7)}$	$1'_{(7)}$, $2'_{(7)}$, $3'_{(7)}$, $4'_{(7)}$	V
N40 - N6	$2_{(28)}$	$2'_{(28)}$	H	$5_{(7)}$	$5'_{(7)}$, $6'_{(7)}$, $7'_{(7)}$, $8'_{(7)}$	H
N3 - N6	$1_{(28)}$	$1'_{(28)}$	V	$1_{(7)}$, $2_{(7)}$, $3_{(7)}$, $4_{(7)}$	$1'_{(7)}$, $2'_{(7)}$, $3'_{(7)}$, $4'_{(7)}$	V
N8 - N6	$2_{(28)}$	$2'_{(28)}$	H	$5_{(7)}$, $6_{(7)}$, $7_{(7)}$, $8_{(7)}$	$5'_{(7)}$, $6'_{(7)}$, $7'_{(7)}$, $8'_{(7)}$	H
N38 - N6	$1_{(28)}$	$1'_{(28)}$	V	$1_{(7)}$	$1'_{(7)}$, $2'_{(7)}$, $3'_{(7)}$, $4'_{(7)}$	V
N7 - N6	$3_{(28)}$	$3'_{(28)}$	V	$3_{(7)}$	$6'_{(7)}$, $7'_{(7)}$, $8'_{(7)}$, $9'_{(7)}$	V
N38 - N25	$1_{(28)}$	$1'_{(28)}$	V	$1_{(7)}$, $2_{(7)}$, $3_{(7)}$, $4_{(7)}$	$1'_{(7)}$	V
N38 - N15	$1_{(28)}$	$1'_{(28)}$	V	$1_{(7)}$, $2_{(7)}$, $3_{(7)}$, $4_{(7)}$	$1'_{(7)}$	V
N8 - N23	$2_{(28)}$	$2'_{(28)}$	H	$1_{(7)}$, $2_{(7)}$, $3_{(7)}$, $4_{(7)}$	$1'_{(7)}$	V

Link (lower - upper)	Symmetrical case			Asymmetrical case		
	Tx ch.	Rx ch.	Polarization	Tx ch.	Rx ch.	Polarization
N8 - N22	$1_{(28)}$	$1'_{(28)}$	V	$5_{(7)}$, $6_{(7)}$, $7_{(7)}$, $8_{(7)}$	$2'_{(7)}$	H
N8 - N26	$3_{(28)}$	$3'_{(28)}$	H	$1_{(7)}$, $2_{(7)}$, $3_{(7)}$, $4_{(7)}$	$1'_{(7)}$	V
N8 - N28	$3_{(14)}$	$3'_{(14)}$	H	$5_{(7)}$, $6_{(7)}$	$2'_{(7)}$	H
N8 - N30	$4_{(14)}$	$4'_{(14)}$	V	$9_{(7)}$, $10_{(7)}$	$3'_{(7)}$	H
N8 - N16	$3_{(28)}$	$3'_{(28)}$	H	$5_{(7)}$, $6_{(7)}$, $7_{(7)}$, $8_{(7)}$	$2'_{(7)}$	V
N8 - N41	$1_{(28)}$	$1'_{(28)}$	V	$1_{(7)}$, $2_{(7)}$, $3_{(7)}$, $4_{(7)}$	$1'_{(7)}$	H
N8 - N24	$4_{(28)}$	$4'_{(28)}$	V	$11_{(7)}$, $12_{(7)}$, $13_{(7)}$, $14_{(7)}$	$4'_{(7)}$	V
N35 - N24	$1_{(28)}$	$1'_{(28)}$	H	$1_{(7)}$	$1'_{(7)}$, $2'_{(7)}$, $3'_{(7)}$, $4'_{(7)}$	H
N3 - N39	$2_{(28)}$	$2'_{(28)}$	H	$5_{(7)}$, $6_{(7)}$, $7_{(7)}$, $8_{(7)}$	$2'_{(7)}$	V
N3 - N18	$1_{(28)}$	$1'_{(28)}$	V	$1_{(7)}$, $2_{(7)}$, $3_{(7)}$, $4_{(7)}$	$1'_{(7)}$	H
N36 - N18	$2_{(28)}$	$2'_{(28)}$	H	$2_{(7)}$	$5'_{(7)}$, $6'_{(7)}$, $7'_{(7)}$, $8'_{(7)}$	H
N20 - N18	$1_{(28)}$	$1'_{(28)}$	V	$3_{(7)}$	$9'_{(7)}$, $10'_{(7)}$, $11'_{(7)}$, $12'_{(7)}$	V
N19 - N18	$4_{(28)}$	$4'_{(28)}$	V	$1_{(7)}$	$1'_{(7)}$, $2'_{(7)}$, $3'_{(7)}$, $4'_{(7)}$	V
N19 - N31	$5_{(14)}$	$5'_{(14)}$	V	$1_{(7)}$, $2_{(7)}$	$1'_{(7)}$	H

The total RF spectrum used for all links in the network for both symmetric and asymmetric case, including the number of times each channel was used in the network, is represented in the following figures. Figure 31 shows the total RF spectrum used in symmetric case, thus reflecting the actual spectrum usage in the real-life network (as link capacities from the real network have been preserved). Figure 32 depicts the total RF spectrum usage after the re-planning into the asymmetric case. It can be noticed that in some cases the polarization of the link was changed, which is due to frequency planning "rules" described above.

As for rural scenario, comparison between usage of 7, 14 and 28 MHz channels and spectrum usage in 7 MHz channel raster is also given.

From top down Figure 31 shows, for the symmetric case: the lower band channel used, the number of time the channels have been used, the total number of time each single 7 MHz slot has been used and the same sequence for the channels used in the upper band.

Figure 32 shows the same results for the asymmetric deployment case.

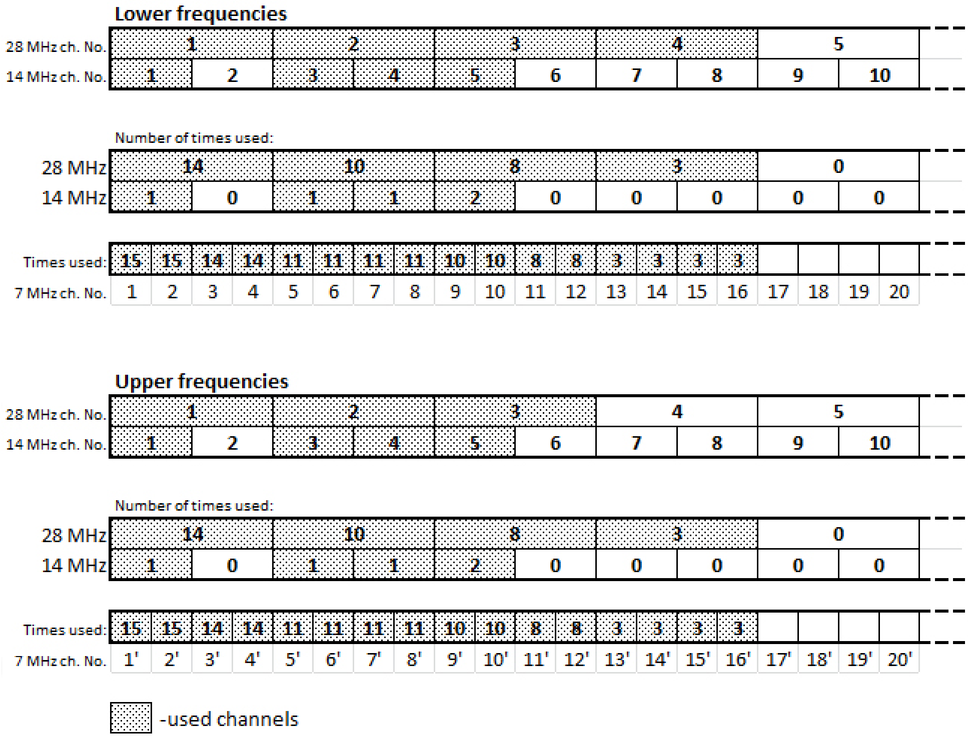


Figure 31: Total spectrum used in symmetric case (urban network), with the number of times a channel was used indicated

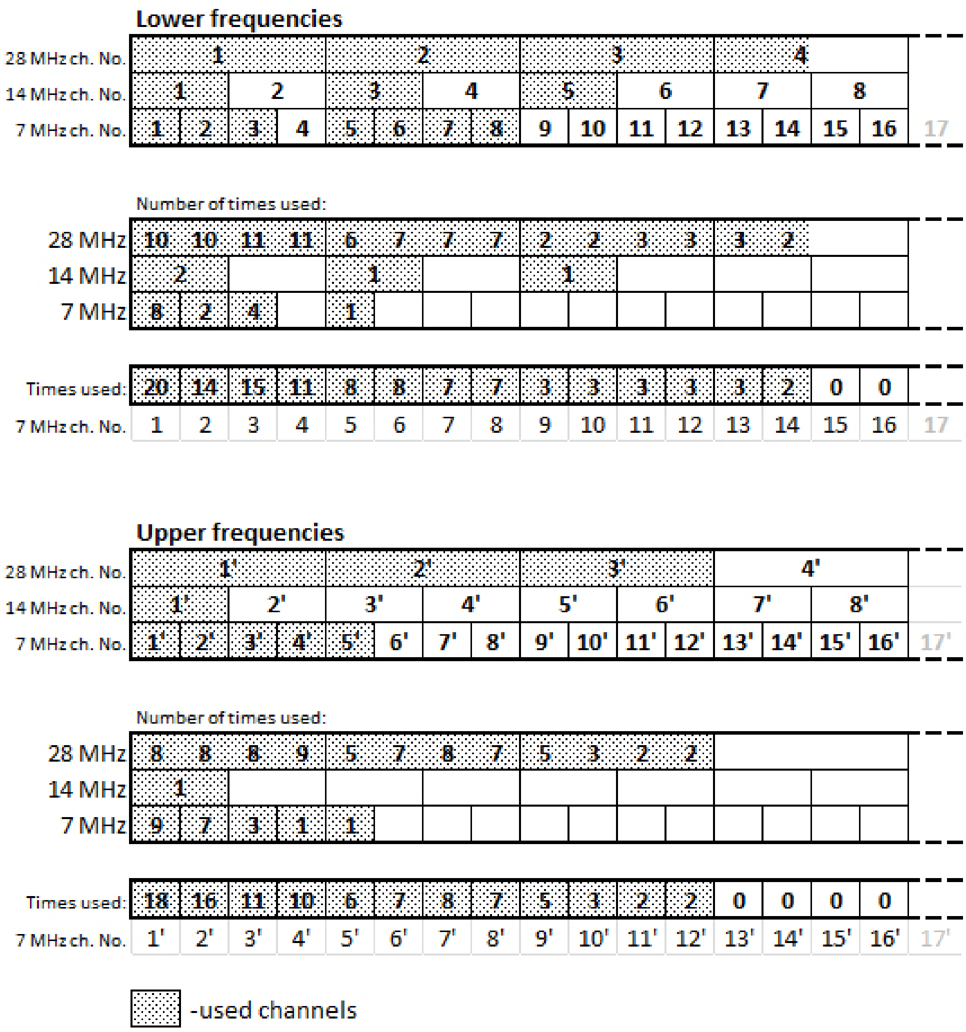


Figure 32: Total spectrum used in asymmetric case (urban network), with the number of times a channel was used indicated

In symmetric case, 4 channels in 28 MHz channel raster (2x112 MHz of spectrum) and 4 channels in 14 MHz raster (2x56 MHz) have been used.

In asymmetric case, 98+84 MHz (lower + upper) in 28 MHz channel raster, 42+14 MHz in 14 MHz and 56+35 MHz in 7 MHz channel raster have been used. It is clear that some amount of spectrum has been saved and it can be argued whether the amount of the saved spectrum is considerable or not having in mind the number of links and the fact that frequency assignment with flexible variable duplex was used. Flexible duplex can also be credited for the grouping of used channels towards the beginning of the band (as depicted in Fig. 8).

On Figure 33 comparison of spectrum usage in 7 MHz channel raster between symmetrically and asymmetrically planned networks for urban scenario is given.

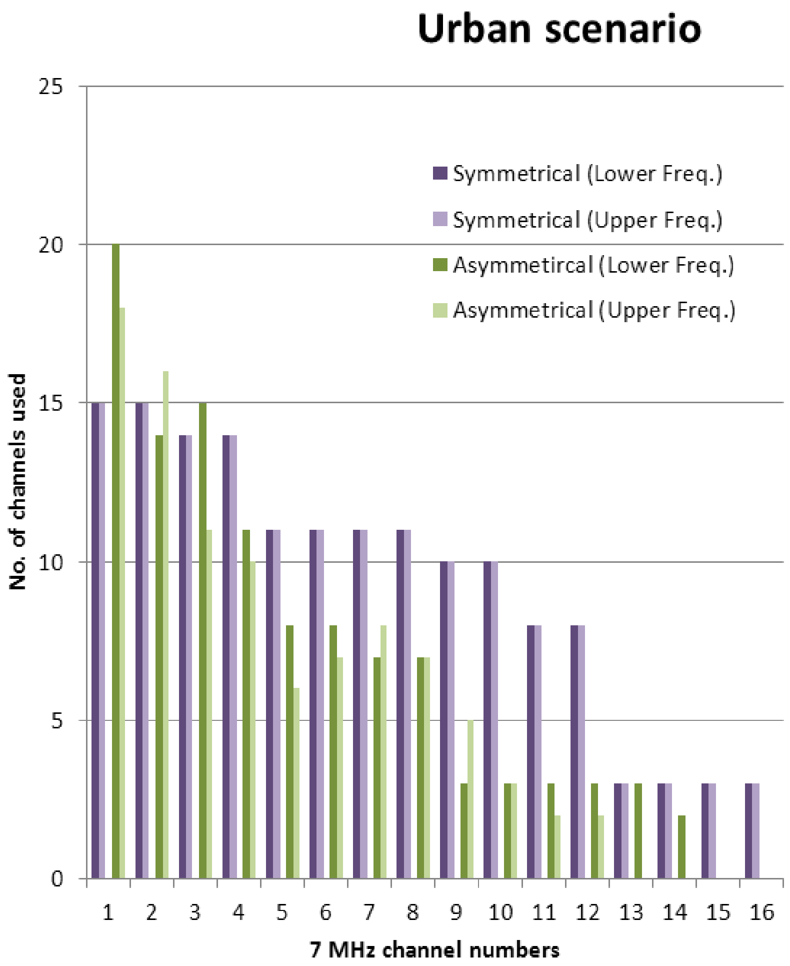


Figure 33: Usage of spectrum in symmetrically and asymmetrically planned networks (urban scenario)

6.5.4 Conclusion of simulation 3

All of the above simulations are valid only if fully flexible duplex is applied (or at least flexibility in Tx and Rx separation shouldn't be less than 112 MHz = 4 x 28 MHz). Also, as mentioned in the introduction, channel aggregation is used, so only 7 MHz channel raster is used as a reference. Having that in mind, usage of spectrum between symmetrically and asymmetrically planned networks can be compared.

In rural network asymmetry shows only vague advantages in spectrum usage (Bidirectional spectrum saved 7.7%).

Results for urban network (where 1:4 asymmetry is used) show that in the combined symmetrically and asymmetrically planned network used spectrum is grouped towards the beginning of the frequency band (or frequency block) somewhat better. In that way, last two 7 MHz channels were saved and higher channels were used less, allowing more “space” for new links.

In the real-life networks in the rural environment, given the large variation in the length of links, different frequency bands are used, so the saved spectrum in the uplink of the asymmetric links (star configuration to one central node) is not reused in the rest of the network since different frequency bands have been used for connection to other nodes.

In urban scenarios the amount of the saved spectrum seems more considerable (Ideal un-used spectrum 32.3% and bidirectional spectrum saving 12.5%). However, it should be noted that some of the saved spectrum in both cases is because of the flexibility in frequency assignment used only in asymmetric case.

Asymmetry provides some benefits in spectrum saving and utilisation but its overall impact when applied on the whole network is rather poor since dominating factor in spectrum saving is still frequency reuse.

Table 9: Summary of the spectrum usage for different asymmetrical scenarios of simulation 3

Example		1 (Rural)		2 (Urban)	
Asymmetry ratio of the network		1:1	1:2 (Note 1)	1:1	1:1/1:2/1:4 (Note 2)
Total BW used - high band [MHz*number of links]		553	448	1050	665
Total BW used - low band [MHz*number of links]		553	455	1050	749
Nominal spectrum saving and utilisation	High Band un-used spectrum [%]	-	19%	-	36%
	Low Band un-used spectrum [%]	-	17.7%	-	28.6%
	Average un-used spectrum [%]	-	18.35%	-	32.3%
Bi-directional channels saved compared to symmetrical simulation [%]	Number of contiguous channel slot used	13	12	16	12
	Bi-directional channels saved compared to symmetrical simulation[%]	-	7.7%	-	12.5%

NOTE 1: In the simulation, a number of links where maintained symmetric.
NOTE 2: In the simulation mixed symmetric and asymmetric (of both 1:2 and 1:4 ratios) links are used

7 CONCLUSIONS

It is recognised that with the move to more data intensive applications by mobile users the consequent traffic in the access network has become asymmetric in nature, with more data being downloaded than uploaded. Whilst it is agreed that the amounts of data are application dependant and that new applications such as cloud computing, instant messaging, VoIP and social networking, might still change this trend, this report was produced to examine the impact of current asymmetry trends in the access network on the backhaul network. This report primarily focuses on the use of asymmetric channel widths within the traditional bi-directional link allocation. It should also be noted that whilst the presence of asymmetry in the access network is agreed, the degree of this asymmetry differs from operator to operator based on the services offered. This report considers some examples ratio.

The report considered different network architectures and geographic deployments and concluded that for the considered traffic parameters rural deployments did not show a level of asymmetry that justified the use any of the techniques and the ring architectures are symmetrical. Therefore the report concentrated upon the urban deployment of star networks.

This report could not be conclusive on the different asymmetry levels within the same network related to core or tail. This report only studies the application with fixed degree of asymmetry in the whole network. A mix of different asymmetry levels may be applied. Mobile backhaul is a the predominant application for microwave point to point links but when other point to point applications share the same spectrum they do not exhibit the level of asymmetry discussed in this report. This will present additional challenges for administrations in order to manage the coordination of both symmetric and asymmetric links in an efficient way.

One of the prime motivators in allocating spectrum for bi-directional links in an asymmetric manner is a potential saving of spectrum. The report highlights that, to be of use, this saved spectrum must be available for re-use, ideally also for other symmetric point to point applications, and not left orphaned. This means that for asymmetric deployment flexibility in the go and return frequency assignment is to be considered.

With existing tools and processes, with fixed duplex spacing, the ability to re-use the saved spectrum appears to be limited. On the other hand, fully flexible duplex spacing that can be configured to any required size is impractical from a radio design perspective, therefore a compromise situation needed to be found. The compromise reached after examining multiple possible permutations of channel allocation is to limit the variation in duplex spacing to the tuning range of the duplexer in the radio of each vendor. This means that the national spectrum authorities will have to consider the frequency coverage required by the applicant and may require the upgrade of their assignment tools to cope.

This report has shown that for maximizing the spectrum saving by the asymmetry deployment, the planning method has to be modified (i.e. to consider C/I and I/N where appropriate). It should be noted, that to implement the planning method described in the simulation one needs to change current planning tools, which commonly do not offer the C/I option.

Another factor, touched upon only briefly in the report, is the co-existence of symmetrical links with asymmetrical links within the same band and thus the same band plan. This report suggests that asymmetric allocation is easier to be implemented within block allocated spectrum where a single operator is free to utilise that spectrum to meet his own needs in whatever manner he requires.

ANNEX 1: NGMN TRAFFIC MODEL

The backhaul capacity and asymmetry were determined by NGMN in simulations and are based only on the FTP traffic model. The considered traffic model and simulation assumption have a big influence on the system capacity and its asymmetrical ratio.

The FTP traffic model used by NGMN in [4] considers separate downlink and uplink simulations, such that there is no relation between the FTP traffic asymmetry and the asymmetry of the backhaul network. As it can be seen, there is a 3 minutes gap time between the FTP sessions of relatively small files (i.e. 2Mbyte in average). Given the very high LTE speeds, with more than 10Mb/s/user, the actual transmission time is less than 2sec. When the user traffic is averaged, the gap time is strongly reducing the traffic average, which conducts to a more realistic dimensioning of the backhaul capacity, as compared with considering peak LTE data rates.

Best effort traffic: FTP

The following definition is for the downlink. For the uplink, the same traffic model shall be used. An FTP session is a sequence of file transfers separated by reading times. The two main FTP session parameters are:

The size S of a file to be transferred

The reading time D, i.e. the time interval between end of download of previous file and the user request for the next file.

Table 10: FTP traffic parameters

Parameter	Statistical characterization
File size S	Truncated Lognormal Distribution Mean = 2 Mbytes, standard deviation = 0.722 Mbytes, Maximum = 5 Mbytes (Before truncation) PDF: $f_x = \frac{1}{\sqrt{2\pi}\sigma x} e^{\frac{-(\ln x-\mu)^2}{2\sigma^2}}, x > 0$, $\sigma = 0.35, \mu = 14.45$
Reading time D	Exponential Distribution Mean = 180 seconds PDF: $f_x = \lambda e^{-\lambda x}, x \geq 0$, $\lambda = 0.006$

ANNEX 2: BACKHAUL DIMENSIONING BASED ON LTE-FDD ACCESS NETWORK CAPACITY

The example in this annex describes the step-by-step process for dimensioning of MW backhauling network based on the NGMN White Paper [1].

It is here reminded that NMGM approach aims to give the maximum DL/UL capacity achievable by the LTE technology itself.

The reader should note that in the NGMN white-paper:

- The term “cell” is used in conjunction with the coverage area of a sector of a base station, equipped with omni or directional antennas.
- The term “tri-cell” is used for identifying a complete eNodeB composed by three “cells” equipped with sector antennas.
- The simulations used only the FTP traffic model.

A2.1 PEAK AND MEAN SINGLE CELL THROUGHPUT TO BE CONSIDERED

With reference to section 2.5 of document [1] (in particular to its Figure 5), the LTE performances in a paired FDD allocation when targeting most common system options using for downlink 2x2 MIMO either with 10 MHz (category 3) and 20 MHz channels (category 4). For the 20 MHz uplink we target 1x2 MIMO, 20 MHz category 3 (50 Mbps): all considerations within this document do not change if we consider other 20 MHz UL solutions having the same MIMO configuration, because cat.3 and cat.4 devices, when used in 20MHz, provide very similar downlink and uplink capacities for the busy time operation. This results in the following reference figures for peak and mean cell throughput.

Table 1 of the NGMN report estimates the available cell capacities. The peak and mean data flow of a single cell is summarised in Table 11. At this level, the possible network overhead is not yet considered because it would be added at complete eNodeB (i.e. tri-cell) level.

Table 11: DL/UL peak and mean cell capacity

LTE Bandwidth	Downlink (DL)		Uplink (UL)	
	Peak	Mean	Peak	Mean
10 MHz	58.5	11	20.8	8
20 MHz	117.7	21	38.2	15

From these figures it is worth noting that:

- Peak to mean ratio is 5:1 for DL and 5:2 for UL
- Therefore, there is a different ratio DL/UL if we consider peak or mean values.

A2.2 ASYMMETRY RATIO FOR THE LAST HOP

The last hop in the access microwave (MW) network is carrying one eNodeB macro site. In general such macro site will be a tri-cell base station as considered in section 3.2 of [1] specifically we can make reference to throughput figures reported in Table 1 of [1], which are reprinted, for the mentioned 10 MHz and 20 MHz channel widths, as Downlink (DL) and Uplink (UL) columns in Table 11.

At this level signalling, transport overheads and the X2 protocol data add a fixed (10%) overhead.

An alternative IPsec optional encapsulation (total overhead 25 %) may be used. It is known that an operator may decide not to use the optional IPsec overhead; however, it should be noted that its use will eventually increase the average required capacity of both UL and DL backhaul, but, the DL/UL asymmetry ratio, subject of the analysis in this ECC Report, would not change. Nevertheless both variants are provided for reader reference.

MW link dimensioning criteria is well represented by formula provided in section 2.3 of the NGMN document [1]:

Backhaul Provisioning for N cells = max (N x busy time mean, Peak)

Which, for the tri-cell base considered (N=3), means the data summarised in Table 12 (derived from Table 1 of NGMN document). It shall be noted that for the tri-cell case (N=3) the peak is still considered equal to that of a single cell (with only the overhead added).

Table 12: DL/UL peak and mean tri–cell site capacity

LTE Bandwidth	Tri-cell Downlink				Tri-cell Uplink				MW backhaul dimensioning			
	Peak		Mean		Peak		Mean		DL (Tri-cell peak)		UL (Tri-cell mean)	
	w/o IPsec	with IPsec	w/o IPsec	with IPsec	w/o IPsec	with IPsec	w/o IPsec	with IPsec	w/o IPsec	with IPsec	w/o IPsec	with IPsec
10 MHz	**64.4**	**73.2**	37.8	42.9	22.8	26	**27.5**	**31.2**	**64.4**	**73.2**	**27.5**	**31.2**
20 MHz	**129.5**	**147.1**	72.1	81.9	42	47.7	**51.5**	**58.5**	**129.5**	**147.1**	**51.5**	**58.5**

As you can see (red values, with IPsec, and green values, without (w/o) IPsec in Table 12) MW dimensioning is driven by:

- peak capacity (of one cell selected also for the tri-cell under same site) for downlink.
- mean capacity (of the 3 cells under same site, equivalent to 3 x 1 cell mean) for uplink.

It results in DL/UL ratio on the MW link dimensioning range from 2.3:1 to 2.5:1.

A2.3 ASYMMETRY RATIO FOR AGGREGATED LINKS

Aggregated links are hops based on capacity of 2 or more eNodeB macro sites ($N \geq 6$). MW link dimensioning criteria for such links is well represented by similar formulas provided in section 4.1 of the NGMN document [3].

That means (i.e. for $N \geq 6$, equivalent to two Tri-cells sites or more) both downlink and uplink will be dimensioned proportional to relevant mean values: for example, from Table 12, the ratios (2 x 42.9)/(2 x 31.2) or (2 x 37.8)/(2 x 27.5) for 10 MHz cases with or w/o IPsec, respectively, a DL/UL ratio of about 1.4:1, slightly less than 3:2, is derived.

The overall asymmetry resulting along the backhauling network is then summarised in Figure 13 of the NGMN document (reprinted as Figure 2 in the main body of the present ECC report)

ANNEX 3: ACTUAL MOBILE NETWORKS TRAFFIC EVALUATION – REPORT ON ASYMMETRY

A3.1 DIGITAL EUROPE

The study in [5] is in support of allocation of “unpaired” spectrum (1452-1492 MHz) actually unused for mobile purpose for additional DL traffic and mobile TDD spectrum (2300-2400 MHz) says that the traffic asymmetry is driven by the asymmetrical applications. This report states that In the access network, the explosion in data traffic has not been symmetrical in both the downlink and uplink directions. It is dominated by downlink data flowing to the consumer (online audio and video, online gaming, mapping requests, apps etc…). Indeed, mobile users download much more data than they upload and this puts more pressure on the downlink spectrum capacity. Downlink traffic on mobile networks is today several orders higher than uplink traffic.

A3.2 ALLOT COMMUNICATIONS REPORT

The report from Allot Communications in [9] discusses, from the very high level perspective, the nature and evolution of mobile traffic per application.

The main findings of this report are:

- “Global mobile broadband traffic grew by 83% in the second half of the year with a CAGR of 234% during 2011.”
- “Video streaming traffic continues to dominate mobile broadband, with a 42% share of all global bandwidth.”
- YouTube now accounts for 24% of global broadband traffic; 14% of total YouTube traffic is high-definition.
- VoIP and Instant Messaging (VoIP & IM) traffic grew by 114%, perhaps substantiating recent reports on the decline of SMS(i) and international voice calls(ii).
- Facebook messenger is an all-time ‘killer app’ on mobile; rising from zero to 22% of total IM traffic in just four months.

The graphic illustration by Allot Communications of the traffic per application is given below.

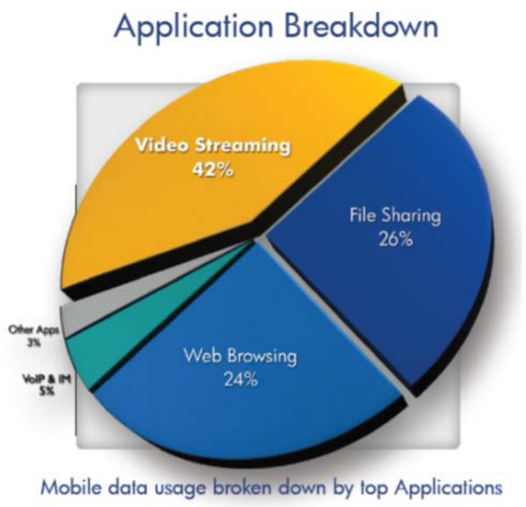


Figure 34: Mobile data usage per application – H2/2011 (Source: Allot Communications [9])

The definition of the main applications in [9] is given below:

- Video Streaming: Refers to communication directed through video sites including either user generated content (UGC) such as YouTube or content provided by sites such as Hulu, cnn.com and BBC iPlayer.
- Web Browsing: Refers to HTTP traffic associated with website browsing or other HTTP traffic which is not downloading or streaming. In addition, web browsing also includes apps delivering real time updates and statistics over HTTP.
- File Sharing: Refers to HTTP download services, in particular from One-Click hosting sites such as RapidShare and Megaupload and P2P applications such as Bittorrent and eMule.

We note that the three major main DL-centric applications have reached a total of 92% in H2-2011. However, the segment of VoIP & Instant Messaging (IM), while relatively small, shows the highest increasing rate trend.

A3.3 CISCO

Also Cisco white paper in [10] refers to the significant increase of the DL-centric applications.

Cisco concluded that:
"*Mobile video traffic exceeded 50 percent for the first time in 2011. Mobile video traffic was 52 percent of traffic by the end of 2011*". Cisco estimation is aligned with the H2/2011 estimation by Allot Communications shown above.

Global mobile data traffic will increase 13-fold between 2012 and 2017. Mobile data traffic will grow at a compound annual growth rate (CAGR) of 66 percent from 2012 to 2017, reaching 11.2 exabytes per month by 2017.

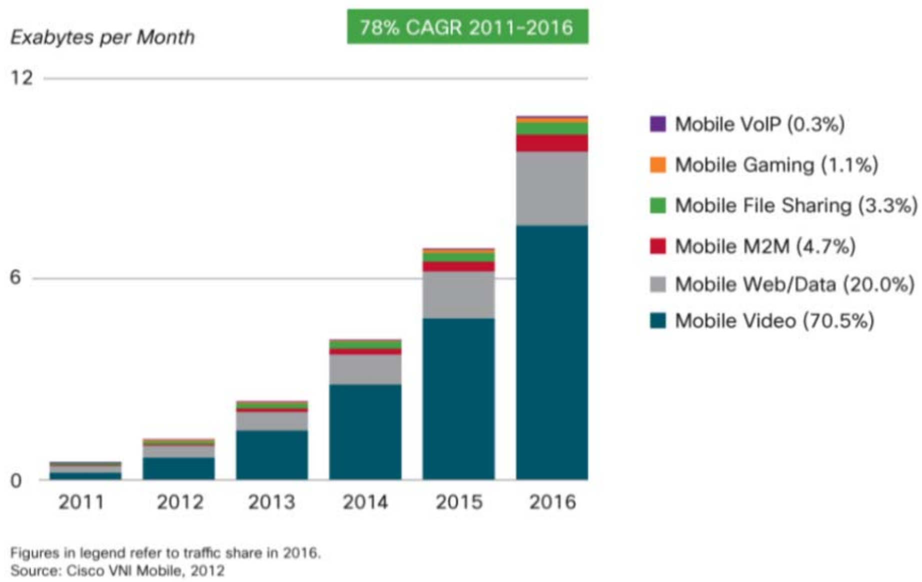


Figure 35: DL-centric applications will generate more than 90% of mobile traffic by 2016

Based on this prediction, the DL-centric application will generate more than 90% of the mobile traffic.

Cisco noted also that significant part of video streaming will be related to "cloud applications":
"*Because many Internet video applications can be categorized as cloud applications, mobile cloud traffic follows a curve similar to video. Globally, cloud applications will account for 71 percent (7.6 exabytes per month) of total mobile data traffic in 2016, compared to 45 percent (269 petabytes per month) at the end of 2011. Mobile cloud traffic will grow 28-fold from 2011 to 2016, a compound annual growth rate of 95 percent*."

Cisco noted also the significant increase of Traffic Offload from Mobile Networks to Fixed Networks:
"*As a percentage of total mobile data traffic from all mobile-connected devices, mobile offload increases from 11 percent (72 petabytes/month) in 2011 to 22 percent (3.1 exabytes/month) in 2016 (Figure 8). Without offload, Global mobile data traffic would grow at a CAGR of 84 percent instead of 78 percent. Offload volume is determined by smartphone penetration, dual-mode share of handsets, percentage of home-based mobile Internet use, and percentage of dual-mode smartphone owners with Wi Fi fixed Internet access at home*."

As has been shown, the DL/UL asymmetry data measured in a number of cellular deployments back in 2010 as well as the downlink-centric existing and predicted mobile services indicate a significant traffic asymmetry factor of the mobile networks (although mitigated by cloud and mobile to fixed offload practices), which has an important influence on the spectrum usage by the transport networks.

A3.4 QUALCOMM REPORT

Qualcomm produced a presentation in [6], with similar considerations of Digital Europe in [5] for supporting the allocation of the same L band for DL and TDD 4G applications. It contains some measured asymmetries (reprinted in Figure 36) in current 2010 mobile networks.

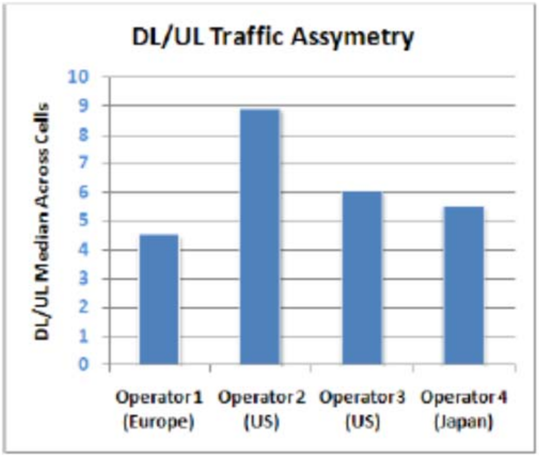


Figure 36: Measured DL/UL Traffic Asymmetry – 2010 (Source: Qualcomm [6])

The impact of smartphone usage was first experimented in US AT&T markets using iPhone, where the traffic asymmetry DL/UL was almost 9. In all the other tested deployments this factor was higher than 4. The evolution of usage patterns of the preponderantly downlink video and Internet browsing can indicate that various degrees of asymmetry ratio will continue to be present in future networks.

A3.5 ERICSSON REPORT

Another important input has been provided by Ericsson, in its Mobility Report [12]. Ericsson states in this Report that "today more than 40% of the world mobile's traffic goes through Ericsson networks and we support customers' networks servicing more than 2.5billion subscribers".

The report presents the global results of the measured traffic and its asymmetry. We provide below a quote summarizing the Ericsson's conclusions on these aspect:

"*Depending on the popularity of different applications and terminals, the overall ratio of uplink traffic volume can vary a lot between networks. However, it can be as low as 10% in networks where there is a lot of HTTP video usage and can reach up to 25% in mobile PC-dominated networks with a lot of P2P file sharing or P-P TV usage.*

In most measured networks, there have been no major changes in uplink-downlink traffic ratios for the past two years. However there are few exceptions, the ratio of uplink traffic volume has slightly decreased in a *few mobile-PC dominated networks with high P2P application usage (mainly in Asia). This is a result of increased smartphone traffic volume shares and hence decreasing P2P traffic share from mobile PC. On the other hand, the proliferation of online storage services (such as Google Drive and iCloud) and increasing popularity of mobile photo and video uploads to social networking sites will increase the uplink traffic volumes in the future*"

The following picture and its description is reproduced from this Report summarizes the DL/UL asymmetry per application. The variation of the results reflects the different results obtained in different networks.

Measurements have been performed at the edge of the packet core network; results for the radio interface will differ slightly (higher uplink traffic ratios) due to additional protocol data headers.

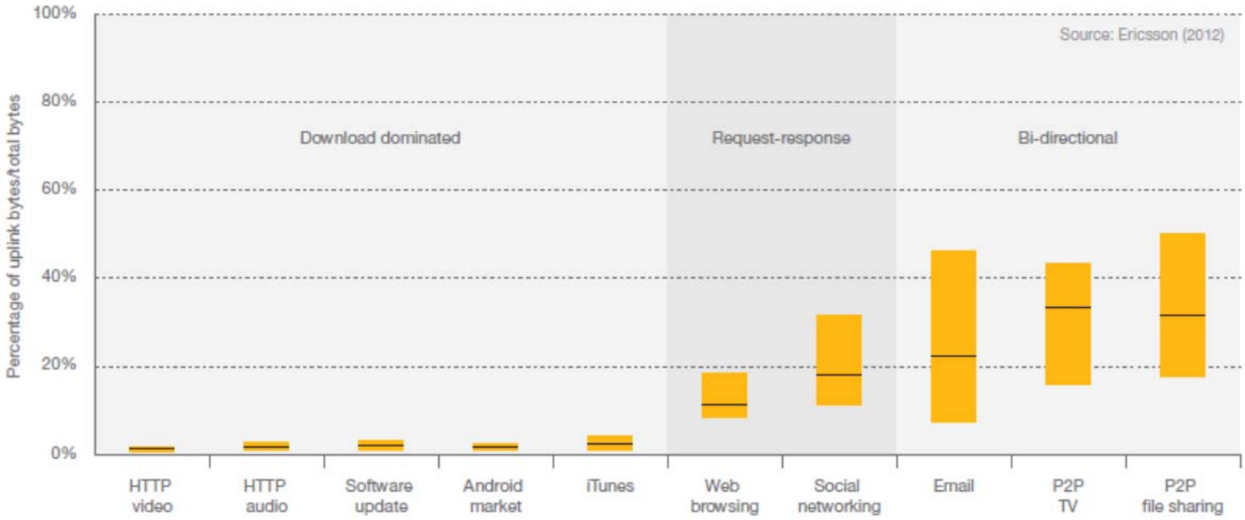


Figure 37: Ratio of uplink traffic volume for different applications (Source Ericsson [12])

Note: Example of how to read this graph: the highest ratio of uplink traffic volume for P2P file sharing in one network was around 50 percent. It can be seen that a high number of applications is download dominated; among them HTTP video, HTTP audio, Software update, Android market, iTunes. The UL average traffic percentage is less than 5%. The application categorized as request-response, including WEB browsing, email and social networking have an average asymmetry of 5:1. Finally, a less used category including P-to-P TV and P-P file sharing are symmetrical. However, Ericsson mentions also that *many applications have popular P2P equivalents motivated by savings on infrastructure cost. For example, Skype for VoIP, PPStream or PPLive for online TV, Spotify for online audio, BitTorrent for file sharing. In P2P systems, content is not provided by dedicated servers but by other regular users (peers) in the system*.

Another important conclusion in the report, which is directly reflected in the capacity (and the spectrum) required by the wireless backhauling links is shown in Figure 38:

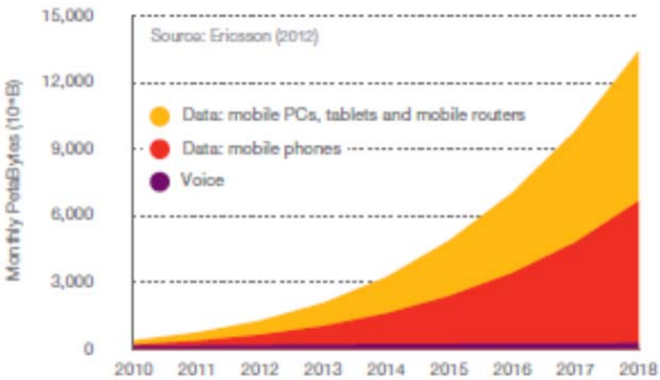


Figure 38: Global mobile traffic: voice and data 2010-2018 (Source: Ericsson [12])

From Figure 38 it can be seen an increase of 12 times between 2012 and 2018, increase which is consistent with other predictions presented above and which will put a high pressure on the spectrum resource for the backhauling links. The current characteristics of the mobile user's data traffic should be carefully used for defining the planning strategies for mobile backhaul networks.

The Mobility Report from Ericson talks about subscribers and subscriber data. It is based on monitoring of Ericsson controller nodes which provide services to end users. Backhauling systems do not provide services directly to subscribers, but services to RAN systems. Those RAN systems that are able to handle the asymmetry in user traffic by themselves do not require any specific dimensioning from the backhaul network. The backhauling network should never become a bottleneck for traffic. That implies it should be dimensioned in order to support traffic peaks and to avoid delays due to high congestion. Moreover, that should be done trying to take into account the likely future evolution of traffic towards a different ratio between UL/DL and in order to avoid the necessity to rebuild the networks architecture after a few years.

ANNEX 4: LIST OF REFERENCES

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