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REPORT ON CO-FREQUENCY CO-COVERAGE SHARING ISSUES BETWEEN TWO CDMA SYSTEMS

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REPORT ON CO-FREQUENCY CO-COVERAGE SHARING ISSUES BETWEEN TWO CDMA SYSTEMS

1 EXECUTIVE SUMMARY

This paper is the synthesis of the studies presented in SE28 meetings on the co-frequency co-coverage frequency sharing issues between CDMA systems.

These studies have been performed by simulations of two CDMA systems sharing the uplink frequencies. As synchronisation between mobiles is not possible in the uplink, the internal noise of a CDMA system is greater in the uplink than in the downlink. Thus, it is generally agreed that the downlink is less critical than the uplink for the co-frequency co-coverage sharing issues. Some preliminary studies have been made also on the downlink, but the efforts have been concentrated on the uplink issue.

The presented simulations have been run with the following working assumptions:

- The chosen fading probability law applies for the rural environment (*Goldhirsh, Julius and Wolfhard J. Vogel, Propagation Effects for Land Mobile Satellite Systems: Overview of Experimental and Modeling Results, NASA Reference Publication 1274, 1992*);
- It is assumed that the two systems have coordinated their CDMA codes according to the ITU-Rec 1186 so that they don’t use the same CDMA codes;
- The traffic volume distribution between vehicle mounted mobile and handheld mobile is assumed to be 90% for the handheld terminals and 10% for vehicle mounted mobiles. This distribution is used in the average case via the fading factor calculation and in the blinding interference scenario;
- The user terminal power range depends on the type of the terminals (handheld or vehicle mounted mobile);
- Simulations based on the average case used characteristics of Globalstar and Odyssey systems. Simulations to determine outage probability (blinding interference) assume identical systems with Globalstar characteristics. It should be noted that some preliminary studies have been made with the Courier system;
- The value of the cross polarisation between the two systems can be estimated to be between 0 and 5 dB. It should be noted that, in case of sharing between more than two systems, the cross polarisation advantage is not available (⇒ 0dB).

A first set of simulations was based on an average case. These simulations showed that, if no cross polarisation is taken into account, the maximum global capacity of two sharing CDMA systems is equal to the larger maximum capacity of one single system. Thus, with no cross-polarisation and the characteristics of Globalstar and Odyssey, the calculations give the following figures: For Odyssey the maximum capacity is $3{,}3.10^{-5}$ active users per Hz. Globalstar maximum capacity is $4{,}4.10^{-5}$ active users per Hz. And in the case of co-frequency co-coverage sharing between Globalstar and Odyssey, the maximum global capacity is $4{,}4.10^{-5}$ active users per Hz. If a cross-polarisation advantage of 5 dB is considered, then the maximum global capacity of the 2 sharing CDMA systems is greater than the larger capacity of one single system: in the case of co-frequency co-coverage sharing between Globalstar and Odyssey, the maximum global capacity is $6{,}5.10^{-5}$ active users per Hz.

In order to quantify the loss of capacity, when the two systems have the same volume of traffic with no cross-polarisation advantage, the study of a theoretical self sharing scenario was proposed. That means that two CDMA systems have exactly the same characteristics. Considering two systems with Globalstar characteristics and the same volume of traffic, the simulation results show that the loss of the capacity is from 9% to 28%, depending on the volume of traffic.

The scenario, where one terminal of one system blinds one spot beam of the other system, has also been discussed: The percentage of « blinding » interference with 5 dB cross polarisation isolation, given by the simulation with the working assumptions described above and the Globalstar and Odyssey characteristics, is from 0,02% in the case of a low volume of traffic (3.10^{-6} active users /Hz) for the interference produced by Globalstar into Odyssey to 3,4% in the case of a high volume of traffic ($1{,}7.10^{-5}$ active users /Hz). According to the CDMA operators at SE28, these values for interference probabilities will be acceptable for low, average and high volume of traffic.

An upper bound on outage probability, for 0 dB cross polarisation isolation can be obtained by modifying the tables, which are based on 5dB isolation.This is carried out by increasing the threshold level by 5 dB. In this case, it can be seen that the outage probability about doubles compared to the above levels, note that it is an upper bound because while the threshold is increased the number of users does not increase.

The percentage of «blinding» interference, given by the simulation with two identical systems with the Globalstar characteristics and the working assumptions described above, is from 0,06% in the case of a low volume of traffic (3.10^{-6} active users /Hz) to 1,9% in the case of a high volume of traffic ($1,5.10^{-5}$ active users /Hz). It shall be noted that in the case of the maximum volume of traffic predicted by the self-sharing simulation ($1,8.10^{-5}$ active users /Hz), the « blinding » interference percentage is 3,6%. As in the case of Globalstar and Odyssey, this value shows the limitation of the simulation based on the average case. According to the CDMA operators, these values for interference probabilities will be acceptable for low, average and high volume of traffic.

In conclusion, with the simplistic assumptions given previously, there is no prohibiting reason against frequency sharing between two CDMA systems. However, a more realistic analysis incorporating urban and suburban cases and CDMA systems with different characteristics other than those of Globalstar and Odyssey is needed in order to conclude on the efficiency of co-frequency co-coverage sharing. These further studies will be carried out subject to the availability of an appropriate model (e.g. fading model in urban and suburban area).

2 INTRODUCTION

This report is the synthesis of the studies presented in SE28 meetings on the sharing feasibility of two CDMA S-PCN systems on a co-frequency co-coverage basis.

The papers first studied an average case. That was completed by the set of studies on a « blinding » interference case.

Most of the studies have been performed by simulations based on the characteristics of Globalstar and Odyssey. Thus, the examples of application of the methodology, which are presented in the main part of this report, are based on the Globalstar-Odyssey sharing issue.

3 THE AVERAGE CASE STUDY

In this section, we study the capacity which will remain available for 2 CDMA systems sharing the same frequency band.

3.1 Methodology

3.1.1 Introduction

Let's consider two CDMA systems, system A and system B with co-frequency co-coverage sharing. These two systems have their own characteristics and a specific volume of traffic. We can study the uplink and the downlink.

Assuming a volume of traffic, the system A can support a maximum external interference level ($I_{\text{ext max for A}}$) and produces a level of noise in the other system ($N_{\text{from A into B}}$).

Similarly, the system B can support a maximum external interference level ($I_{\text{ext max for B}}$) and produces noise into the system A ($N_{\text{from B into A}}$), assuming a volume of traffic.

By comparison between the noise produced by one system into the other and the maximum level of interference the system can bear, we will be able to derive the feasibility or non-feasibility of a co-frequency co-coverage sharing between the systems A and B.

As synchronisation between mobiles is not possible in the uplink, the internal noise of CDMA system is greater in the uplink than in the downlink. **Thus, it is generally agreed that the downlink is less critical than the uplink for the co-frequency co-coverage sharing issue. That is why this methodology includes only the uplink study.**

3.1.2 The maximum external interference

The maximum external interference level bearable by one system can be derived from the following equation:

N total = Nth + Next + Nint

The total noise in one channel of one spot beam equals the thermal noise in this spot beam and in this channel plus the external noise in this spot beam and in this channel plus the internal noise in this spot beam and in this channel.

The internal noise in one spot beam and in one channel is the noise of the other users in this spot beam and in this channel plus the noise of the users of the other spot beams of all the satellites operating this channel. The noise of the other channels is considered as insignificant.

$$N_{int} = N_{\text{other spots, same channel}} + N_{\text{same spot, same channel}}.$$

With:

$N_{\text{other spots, same channel}} = r \cdot \Delta \cdot M \cdot C.$
$N_{\text{same spot, same channel}} = \Delta \cdot (M-1) \cdot C.$

and

r = Aggregated spatial rejection factor of the spot beams.
Δ = Power control factor models the imperfection of the power control.
M = Capacity: number of active users per beam and per channel.
C = **Received power at the satellite** for one user per spot and per channel.

Moreover, the total noise can be expressed thanks to C, the received power at the satellite for one user (in a spot beam and in a channel), and the required carrier to noise ratio. Thus, we can obtain:

$$C \cdot \left(\left(\frac{C}{N} \right)_{req} \right)^{-1} = N_{th} + I_{ext\ max} + C \cdot \Delta \cdot (M \cdot (1+r) - 1).$$

Thus, the equation giving the maximum external interference bearable by a system can be derived as follows:

$$\boxed{I_{ext\ max} = C \cdot \left(\left(\frac{C}{N} \right)_{req}^{-1} - \Delta \cdot \left(M\,(1+r) - 1 \right) \right) - N_{th}} \quad (1)$$

With:

I_{ext} = Maximum external interference bearable by the system per spot and per channel.
C = **Received power at the satellite** for one user per spot and per channel.
r = Aggregated spatial rejection factor of the spot beams which are not perfectly disjoined.
Δ = Power control factor models the imperfection of the power control.
M = Capacity: number of active users per beam and per channel.
N_{th} = Thermal noise at the satellite of the system.
$\left(\frac{C}{N} \right)_{req}$ = Required carrier to noise ratio.

Nota Bene:

For the moment, it is not an average case. The received power at the satellite is assumed to be the same for each mobile operating in this spot beam and this channel thanks to the power control in order to maximise the capacity of the system. This is an intrinsic feature of all CDMA systems.

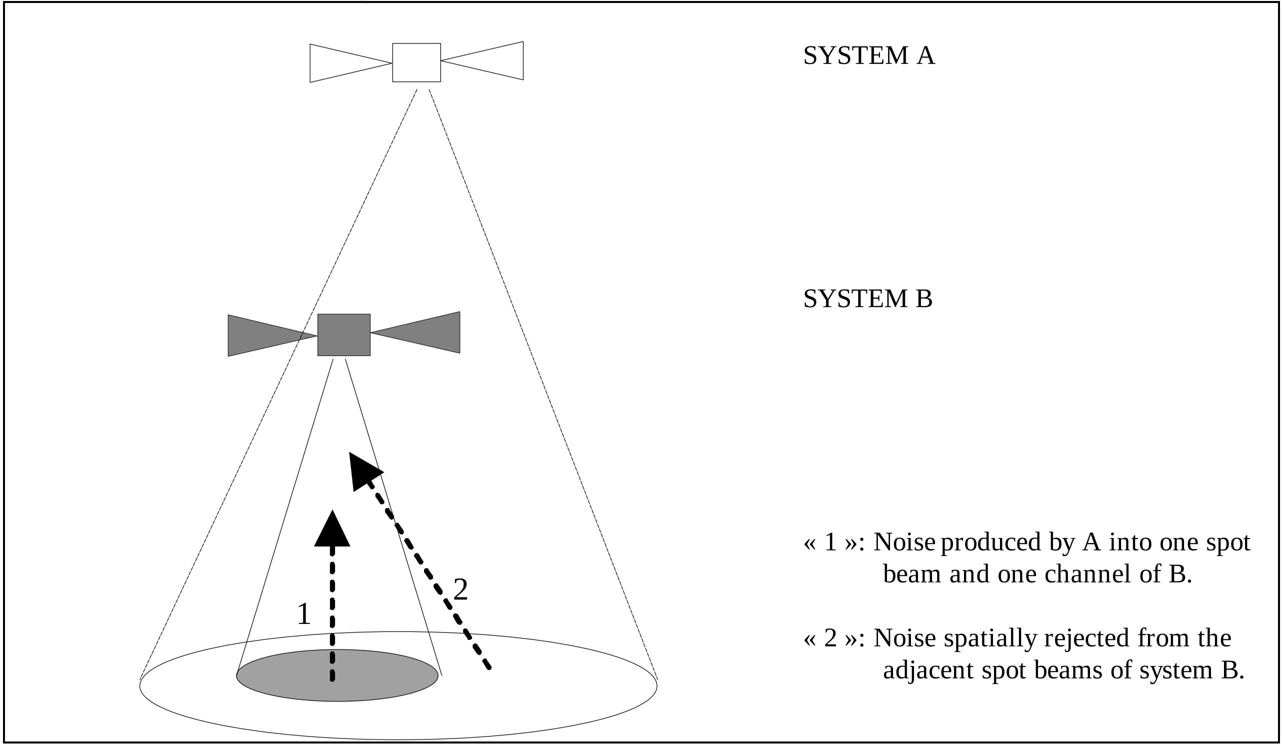
3.1.3 Average noise produced by the system A into the system B

Considering two CDMA systems, system A and system B with a co-frequency co-coverage sharing. These two systems have their own characteristics and a specific volume of traffic. The total noise produced for example by A into one channel and one spot beam of the system B is the addition of the following types of noise:

- the noise produced by one channel of one spot beam of the system A into the co-frequency channel and the co-coverage spot beam of the system B.
- the aggregated spatial rejection of the adjacent spot beams noise of the system B.
- the noise of non-co-frequency channels from A into the system B, but this type of noise is considered as insignificant.

To summarise, the total noise produced by the system A into one spot beam and one channel of the system B is the noise produced by one spot beam and one channel of A into the spot beam of B (shown as « 1 » in the **Figure 1**) plus the noise spatially rejected from the adjacent spot beams of system B (shown as « 2 » in the **Figure 1**). The **Figure 2.1.a** explains these two types of noise.

Figure 1: Noise produced by the system A into the system B.



The total noise produced by the system A into one spot beam and one channel of the system B is given by the following equation:

$N\_total_{\text{from A into B}} = (1 + r_B) \cdot N_{\text{by one spot beam of A into B}}$

With:

$N\_total_{\text{from A into B}}$ = Total noise produced by A into one spot beam and one channel of B.
r_B = Aggregated spatial rejection factor of the system B.
$N_{\text{by one spot beam of A into B}}$ = Noise produced by one spot beam of A into one spot beam of B.

The noise produced by the system A into the system B, considering only one spot beam, can be calculated thanks to the following formulae:

$$N_{\text{by one spot beam of A into B}} = M_A \cdot \frac{Spot\_size_B}{Spot\_size_A} \cdot \frac{Ant\_Gain_{satellite\_A}}{Ant\_Gain_{satellite\_B}} \cdot \left(\frac{Alt_A}{Alt_B}\right)^2 \cdot \frac{BW_B}{BW_A} \cdot \Gamma_{B \to A} \cdot C_A$$

With:

$N_{\text{by one spot beam of A into B}}$ = Noise produced by the user terminals of A into the satellite of B.
M_A = Capacity of A (number of active users per beam and per channel).
$\frac{\mathrm{Spot\_size_B}}{\mathrm{Spot\_size_A}}$ = Spot area ratio between the system B and the system A.

$\frac{\mathrm{Ant\_Gain}_{\mathrm{satellite\_B}}}{\mathrm{Ant\_Gain}_{\mathrm{satellite\_A}}}$ = Satellite antenna gain ratio between the systems B and A.

$\left(\frac{Alt._{\mathrm{A}}}{\mathrm{Alt.}_{\mathrm{B}}}\right)$ = Altitude ratio.

$\frac{\mathrm{BW}_{\mathrm{B}}}{\mathrm{BW}_{\mathrm{A}}}$ = Frequency bandwidth ratio.

$\Gamma_{\mathrm{B}\rightarrow\mathrm{A}}$ = Fading factor which models the propagation difference.

C_{A} = **Received power at the satellite** of A for one user of A (1spot.channel).

Thus, by combining the two previous equations, we can easily derive the equation given the total noise produced by the system A into one spot of the system B:

$$\boxed{\begin{array}{c}\mathrm{N\_total}_{\text{from A into B,}\textbf{at t}} = (1 + \mathrm{r_B}) \ . \\ M_A \cdot \frac{Spot\_size_B}{Spot\_size_A} \cdot \frac{Ant\_Gain_{satellite\_A}}{Ant\_Gain_{satellite\_B}} \cdot \left(\frac{Alt_A}{Alt_B}\right)^2 \cdot \frac{BW_B}{BW_A} \cdot \Gamma_{B\rightarrow A,at\_t} \cdot C_A\end{array}} \qquad (2)$$

With:

$\mathrm{N\_total}_{\text{from A into B,}\textbf{at t}}$ = Total noise produced by A into one spot and one channel of B, at one instant t.

$\mathrm{r_B}$ = Aggregated spatial rejection factor of the system B.

$\mathrm{M_A}$ = Capacity of A (number of active users per beam and per channel).

$\frac{\mathrm{Spot\_size}_{\mathrm{B}}}{\mathrm{Spot\_size}_{\mathrm{A}}}$ = Spot area ratio between the system B and the system A.

$\frac{\mathrm{Sat\_ant\_gain}_{\mathrm{B}}}{\mathrm{Sat\_ant\_gain}_{\mathrm{A}}}$ = Satellite antenna gain ratio between the systems B and A.

$\left(\frac{Alt._{\mathrm{A}}}{\mathrm{Alt.}_{\mathrm{B}}}\right)$ = Altitude ratio between system A and B.

$\frac{\mathrm{BW}_{\mathrm{B}}}{\mathrm{BW}_{\mathrm{A}}}$ = Frequency bandwidth ratio.

$\Gamma_{\mathrm{B}\rightarrow\mathrm{A},\ \textbf{at t}}$ = Fading factor which models the propagation difference, at one instant t.

C_{A} = **Received power at the satellite** of A for one user of A (1spot.channel).

Nota Bene:

At one instant *t* the equation (2) does not model an average case, but a real case. To study the average case, the **average** value of the fading factor $\Gamma_{\mathrm{B}\rightarrow\mathrm{A}}$ over the time shall be used. This average value leads to the **average** total noise produced by one system into the other. (See paragraph 2.2.2 on the calculation of the fading factor for more details).

If in one spot beam and in one channel, the fading factor is higher, we can expect that it will not be the case for other spot beams and/or other channels, so that the overall capacity remains stable. That is why it is interesting to study the average case over time trials. Thus we will use the equation (3):

$$N\_total_{\text{from A into B}} = (1 + r_B) \cdot M_A \cdot \frac{Spot\_size_B}{Spot\_size_A} \cdot \frac{Ant\_Gain_{satellite\_A}}{Ant\_Gain_{satellite\_B}} \cdot \left(\frac{Alt_A}{Alt_B}\right)^2 \cdot \frac{BW_B}{BW_A} \cdot \Gamma_{B\rightarrow A,} \cdot C_A \qquad (3)$$

With:

$N\_total_{\text{from A into B}}$ = **Average** total noise produced by A into one spot and one channel of B.

r_B = Aggregated spatial rejection factor of the system B.

M_A = Capacity of A (number of active users per beam and per channel).

$\frac{\text{Spot\_size}_B}{\text{Spot\_size}_A}$ = Spot area ratio between the system B and the system A.

$\frac{\text{Sat\_ant\_gain}_B}{\text{Sat\_ant\_gain}_A}$ = Satellite antenna gain ratio between the systems B and A.

$\left(\frac{Alt._A}{\text{Alt.}_B}\right)$ = Altitude ratio between system A and B.

$\frac{\text{BW}_B}{\text{BW}_A}$ = Frequency bandwidth ratio.

$\Gamma_{B\rightarrow A}$ = **Average** fading factor = $\underset{time}{Mean}$ ($\Gamma_{B\rightarrow A,\ \text{at t}}$)

C_A = **Received power at the satellite** of A for one user of A (1 spot.channel)

3.2 Calculations and working assumptions

In order to calculate the two equations given the maximum level of bearable external interference and the total produced by one system into the other, we have first to calculate the elements of these equations.

3.2.1 For the calculation of Iext

To calculate the value of the maximum bearable external interference, the following characteristics are needed:

- **r, the aggregated spatial rejection factor**

  The purpose of this factor is to take account of the internal noise produced in one spot beam by the other spot beams operating the same frequency band.
  If the system also uses FDMA techniques, that means that two adjacent spot beams do not operate in the same frequency band, then the aggregated spatial rejection factor is a function of the diversity, that means the number of satellites a mobile earth station can see. Thus, r equals the percentage of time that a mobile earth station can be covered by two spot beams operating in the same frequency band but from different satellites.
  If all the spot beams operate over the whole frequency band, then the aggregated spatial rejection factor is a function of the diversity and also of the spot beams` re-covering ratio. In this case, r equals the percentage of time, that a mobile earth station can be covered by two spot beams operating the same frequency band from different satellites, plus the spot beams` re-covering ratio between spot beams which are not perfectly disjoined.

- **D, the power control factor**

  The purpose of this factor is to model the imperfection of the power control. If the power control process was perfect, the Δ factor would be equal to 1. To ensure a communication the transmitted power of the mobile earth station has to be greater or equal than the transmitted power required by the required carrier to noise ratio. Thus the Δ factor is greater than 1.

- **M, the capacity**

The capacity is the number of active users per beam and per channel. In a CDMA system, the protection margin against the external interference is decreasing when the capacity is increasing.

- **Nth, the thermal noise**

The thermal noise at the satellite of the system is a classic system data.

- **The required carrier to noise ratio**

$\left(\frac{C}{N}\right)_{req}$ is also a classic system data.

- **C, the received power at the satellite**

C is the received power at the satellite antenna for one active user per spot and per channel. The power control is aiming to adjust the power emission of all the MESs in order to get the same received power at the satellite level.

It is difficult to evaluate the value of this received power at the satellite, because it depends on the volume of traffic of all the systems operating the frequency band.

We can express C as follows:

$$C_{\text{received by one MES of B by B}} = \left(\frac{C}{N}\right)_{req\_B} \cdot \left(N_{th\_B} + N_{ext\_B} + N_{\text{int}\_B}\right)$$

The external noise received by B in one spot beam and one channel depends on the volume of traffic of the system A, which produces some noise into B. The internal noise depends on the volume of traffic of the system B in the spot beam and the channel. Thus the received power C depends on the volumes of traffic of each system.

Thus, to be independent with this fact, we assume in this study 3 types of received power as a function of a volume of traffic:

- a *maximum* received power for high volume of traffic: each terminal is transmitting at the higher level and no fading is considered but the average distance between mobile and satellite is taken into account to calculate the free space loss.
- a *minimum* received power for low volume of traffic: the received power is just the power which would be received if each carrier to noise ratio was equal to the required carrier to noise ratio plus two dB (to model the imperfection of the power control).
- an *average* received power for average volume of traffic: it is the average between the maximum and the minimum received power.

3.2.2 For the calculation of the total noise produced by one system into the other

To calculate the value of the total noise produced by the system A into the system B, the following characteristics are needed:

- **Several system data**

  Spot_size, Sat_ant_gain, Alt and BW are respectively the spot size in m², the satellite antenna gain in dB, the altitude of the satellites in m and the channel bandwidth in Hz. These values are needed for both systems.

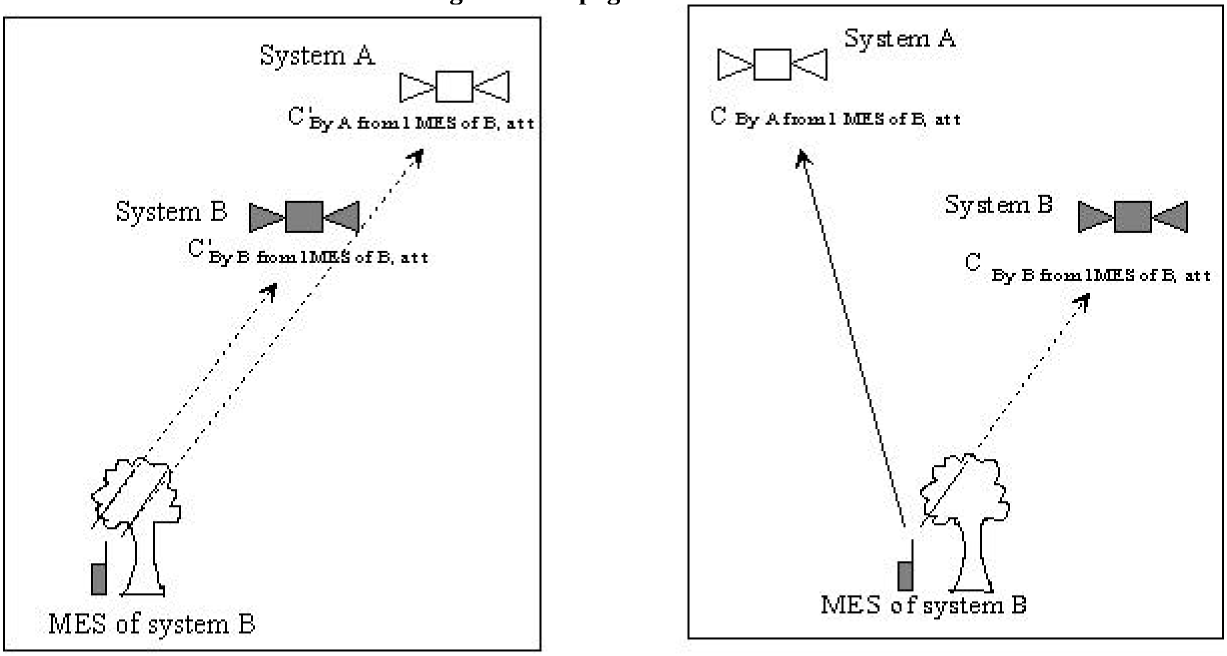
- **$G_{B® A}$, the average fading factor**

  The purpose of this chapter is to define what this fading factor is, and to explain how it is calculated. We will first have a look at a single mobile earth station, and then we will examine the case of one spot beam and one channel.

<u>Fading factor for a single mobile earth station (noted « MESi »)</u>

The **figure 2** describes the propagation difference that the fading factor shall model.

Figure 2: Propagation difference



Assumption of the same propagation		Assumption of differentpropagations

1/ With the assumption of the same propagation:

As a first approach, we can assume that the two propagation paths between one MES and the two systems are equal, but the free space loss is different. Thus, we obtain:

$$\boxed{C'_{\text{By A from MESi of B, at t}} = C'_{\text{By B from MESi of B, at t}} - 20 \cdot \log\left(4 \cdot \Pi \cdot \frac{\Delta(alt)}{l}\right)} \quad (4)$$

With:

$C'_{\text{By A from MESi of B, at t}}$ = Received power at the satellite of the system A from one mobile earth station (MESi) of the system B, at one instant *t*, considering the same propagation assumption (in one spot beam and one channel).

$C'_{\text{By B from MESi of B, at t}}$ = Received power at the satellite of the system B from one mobile earth station (MESi) Of the system B, at one instant *t*, considering the same propagation assumption (in one spot beam and one channel).

$\Delta(alt)$ = Difference between the altitude of the two systems.

λ = wave length for the given frequency.

2/ With the assumption of different propagation

In a more realistic case, the two propagation paths between one MES and the two systems are different because of the fading phenomena. We have:

$C_{\text{By B from MESi of B, at t}} = C'_{\text{By B from MESi of B, at t}}$
$C_{\text{By A from MESi of B, at t}} = \Gamma_{\text{B}\rightarrow\text{A, MESi, at t}} \cdot C'_{\text{By A from MESi of B, at t}}$

With:

$C_{\text{By B from MESi of B, at t}}$ = Received power at the satellite of the system B from one mobile earth station (MESi) of the system B, at one instant *t*, considering the different propagation assumption (in one spot beam and one channel).

$C'_{\text{By B from MESi of B, at t}}$ = Received power at the satellite of the system B from one mobile earth station (MESi) of the system B, at one instant *t*, considering the different propagation assumption (in one spot beam and one channel).

$C_{\text{By A from MESi of B, at t}}$ = Received power at the satellite of the system A from one mobile earth station (MESi) of the system B, at one instant *t*, considering the same propagation assumption (in one spot beam and one channel).

$C'_{\text{By A from MESi of B, at t}}$ = Received power at the satellite of the system A from one mobile earth station (MESi) of the system B, at one instant *t*, considering the same propagation assumption (in one spot beam and one channel).

$\Gamma_{\text{B}\rightarrow\text{A, MESi, at t}}$ = the fading factor for the mobile earth station MESi at one instant *t*.

Considering also the equation (4), we obtain the following definition of the Γ factor for one active user, at the instant *t*:

$$\Gamma_{B\rightarrow A,\ \text{MESi, at t}} = \frac{C_{\text{By A from MESi of B, at t}}}{C_{\text{By B from MESi of B, at t}} - 20\cdot\log\left(4\cdot\Pi\cdot\frac{\Delta(alt)}{l}\right)} \tag{5}$$

With:

$C_{\text{By A from MESi of B, at t}}$ = Received power at the satellite of the system A from one mobile earth station (MESi) of the system B, at one instant *t*, considering the different propagation assumption (in one spot beam and one channel).

$C_{\text{By B from MESi of B, at t}}$ = Received power at the satellite of the system B from one mobile earth station (MESi) of the system B, at one instant *t*, considering the different propagation assumption (in one spot beam and one channel).

$\Delta(alt)$ = Difference between the altitude of the two systems.

λ = wave length for the given frequency.

If the received powers $C_{\text{By A from MESi of B, at t}}$ and $C_{\text{By B from MESi of B, at t}}$ are detailed as a function of the transmitting power of the mobile earth station (MESi) $C_{\text{tx, MESi, at t}}$ of system B, the fading loss trial (***fad***(MESi→SAT)) and the free space loss (***fsl***(MESi→SAT)), then the following equation can be derived:

$$\Gamma_{B\rightarrow A,\ \text{MESi, at t}} = \frac{C_{tx,MESi,att} - fad\left(MESi_B \rightarrow SAT_A\right) - fsl\left(MESi_B \rightarrow SAT_A\right)}{C_{tx,MESi,att} - fad\left(MESi_B \rightarrow SAT_B\right) - fsl\left(MESi_B \rightarrow SAT_B\right) - 20\cdot\log\left(4\cdot\Pi\cdot\frac{\Delta(alt)}{l}\right)}$$

With:

$C_{\text{tx, MESi, at t}}$ = Transmitted power of the mobile earth station of system B.

fad(MESi→SAT) = Trial of the fading loss between a mobile earth station and a satellite.

fsl(MESi→SAT) = Free space loss between a mobile earth station and a satellite.

$\Delta(alt)$ = Difference between the altitude of the two systems.

λ = wave length for the given frequency.

Fading factor for one spot beam and one channel

The received power by the system A from the mobile earth stations of the system B in one spot beam and one channel is the sum of the received power by the system A of each mobile earth station (MESi) of the system B in this spot beam and this channel. Thus we have:

$$\forall t,\ C_{B\rightarrow A,\ \text{at t}} = \sum_{MESi} C_{\text{By A from MESi of B, at t}}$$

With:

$C_{A\rightarrow B,\ \text{at t}}$ = Received power at the satellite of the system A from the mobile earth stations of the system B, in one spot beam and one channel considering the different propagation assumption, at the instant *t*.

$C_{\text{By A from MESi of B, at t}}$ = Received power at the satellite of the system A from one mobile earth station (MESi) of the system B, at one instant *t*, considering the different propagation assumption (in one spot beam and one channel).

If we use the equation (5), we obtain:

$$\forall t,\ C_{A\to B,\text{ at t}} = \sum_{MESi} \Gamma_{B\to A,\text{ MESi, at t}} \cdot \left(C_{\text{By B from MESi of B, at t}} - 20\cdot\log\left(4\cdot\Pi\cdot\frac{\Delta(alt)}{l}\right)\right)$$

With:

$C_{\text{By B from MESi of B, at t}}$ = Received power at the satellite of the system B from one mobile earth station (MESi) of the system B, at one instant *t*, considering the different propagation assumption (in one spot beam and one channel).

Thanks to the power control, we can consider:

$$\forall (MESi,t),\ C_{\text{By B from MESi of B, at t}} = \text{Constant}$$

Thus we have:

$$\forall t,\ C_{B\to A,\text{ at t}} = \sum_{MESi} \left(\Gamma_{B\to A,\text{ MESi, at t}} \cdot C_{\text{By B from MESi of B, at t}} \right) - 20\cdot\log\left(4\cdot\Pi\cdot\frac{\Delta(alt)}{l}\right)$$

$$\Rightarrow \forall t,\ C_{B\to A,\text{ at t}} = \sum_{MESi} \left(\Gamma_{B\to A,\text{ MESi, at t}} \cdot C_{\text{B, at t}} / M_B \right) - 20\cdot\log\left(4\cdot\Pi\cdot\frac{\Delta(alt)}{l}\right)$$

With:

$C_{\text{B, at t}}$ = Received power at the satellite of the system B from the mobile earth stations of the system B, in one spot beam and one channel considering the different propagation assumption, at the instant *t*.

M_B = Number of active user in one spot beam and one channel for B.

$$\Rightarrow \forall t,\ C_{B\to A,\text{ at t}} = C_{\text{B, at t}} \cdot \sum_{MESi} \left(\Gamma_{B\to A,\text{ MESi, at t}} / M_B \right) - 20\cdot\log\left(4\cdot\Pi\cdot\frac{\Delta(alt)}{l}\right)$$

$$\Rightarrow \forall t,\ C_{B\to A,\text{ at t}} = C_{\text{B, at t}} \cdot \underset{MESi}{Mean} \left(\Gamma_{B\to A,\text{ MESi, at t}} \right) - 20\cdot\log\left(4\cdot\Pi\cdot\frac{\Delta(alt)}{l}\right)$$

$$\Rightarrow \forall t,\ C_{B\to A,\text{ at t}} = C_{\text{B, at t}} \cdot \Gamma_{B\to A,\text{ at t}} - 20\cdot\log\left(4\cdot\Pi\cdot\frac{\Delta(alt)}{l}\right)$$

Finally, we obtain:

$$\boxed{\Gamma_{B\to A,\text{ at t}} = \frac{C_{B\to A,\text{ at t}}}{C_{\text{B, at t}} - 20\cdot\log\left(4\cdot\Pi\cdot\frac{\Delta(alt)}{l}\right)} = \underset{MESi}{Mean}\left(\Gamma_{B\to A,\text{ MESi, at t}} \right)} \tag{6}$$

$C_{A\to B,\text{ at t}}$ = Received power at the satellite of the system A from the mobile earth stations of the system B, in one spot beam and one channel considering the different propagation assumption, at the instant *t*.

$C_{\text{B, at t}}$ = Received power at the satellite of the system B from the mobile earth stations of the system B, in one spot beam and one channel considering the different propagation assumption, at the instant *t*.

$\Delta(alt)$ = Difference between the altitude of the two systems.

λ = wave length for the given frequency.

To find the value of the fading factor $\Gamma_{B\rightarrow A,\ at\ t}$, we ran a simulation, which trailed the location of the mobile earth stations, the satellites, the fading levels and the types of terminal (portable or vehicle mounted). Thanks to this simulation, we obtain a set of fading factor values, which allow the value of the average fading factor to be calculated, which is the average value over time of the fading factor.

The fading factor at one instant t will be noted: $\Gamma_{B\rightarrow A,\ at\ t}$.
The average fading factor is noted: $\Gamma_{B\rightarrow A}$.

$$\boxed{\Gamma_{B\rightarrow A} = \underset{time}{Mean}(\Gamma_{B\rightarrow A,\ at\ t})} \qquad (7)$$

All the details of the simulation which allow the values of the fading factor ($\Gamma_{B\rightarrow A,at\ t}$) and the average fading factor ($\Gamma_{B\rightarrow A}$) to be calculated are presented in the Annex A with the results for the system Globalstar and Odyssey.

Nota Bene:

The equation giving the G factor for one single mobile earth station shows very clearly that it depends on the range of transmitting power of the mobile earth stations and on the fading probability chosen. Moreover the fading probability depends on the type of environment and on the geographical distribution of the mobile earth stations. Finally, the transmitted power of a mobile depends on the type of this mobile: is it a handheld station or a vehicle mounted station. Thus we have to make some working assumptions for the type of environment, for the geographical distribution of the mobile earth stations and the distribution of volume of traffic, either by portable mobile earth stations or vehicle mounted mobile earth stations.

- **C_A, the received power at the satellite for one user of A (/spot.channel)**

C_A is the power received by the satellite of the system A from one active user of the system A. The level of this received power is assumed to be independent of the active user (location, fading value, etc.), because of the control power.
As for C_B, we have to define three levels of received power:

- a *maximum* received power for high volume of traffic: each terminal is transmitting at the higher level and no fading is considered but the average distance between mobile and satellite is taken into account to calculate the free space loss.
- a *minimum* received power for low volume of traffic: the received power is just the power which would be received if each carrier to noise ratio was equal to the required carrier to noise ratio plus 2 dB (to model the imperfection of the power control).
- an *average* received power for average volume of traffic: it is the average between the maximum and the minimum received power.

3.2.3 Conclusion on the working assumptions

We have seen in the previous paragraphs that some working assumptions may have an influence on the calculation of elements of the equations given the maximum external bearable interference and the total noise produced by one system into the other.

The purpose of this paragraph is to summarise the working assumptions that we have to state:

- several system data are required in the calculations (e.g. the required carrier to noise ratio, the altitude of the satellites, the channel bandwidth, the type of constellation, etc.). **Thus it is clear that this methodology can only be applied to existing systems, whose characteristics are known**
- the **geographic distribution** of the terminals (trial of their locations) has to be chosen.

- the **distribution of volume of traffic by type of terminals** (either portable mobile earth stations or vehicle mounted mobile earth stations) has to be decided.
- the **type of environment** (rural, suburban or urban) **and the fading probability** have to be chosen.

The working assumptions are proposed to be as follows:

- **Characteristics of existing systems**
  We will use the characteristics of Globalstar and Odyssey (see Chapter 4 for more details).

- **Distribution of traffic by type of terminals**
  It is assumed that the volume of traffic is distributed as follows: 10% for the vehicle mounted station and 90% for the handheld terminals.

- **Geographic distribution**
  A uniform distribution is assumed.

- **Fading Probability and type of environment**
  The chosen probability function of fading as a function of the elevation angle of a satellite in a rural environment is from the document referred «Goldhirsh, Julius and Wolfhard J. Vogel, Propagation Effects for Land Mobile Satellite Systems: Overview of Experimental and Modeling Results, NASA Reference Publication 1274, 1992»:

  The following equation predicts the probability, P%, that the fade depth will be greater than a given level of A dB, for a given elevation angle f to a single satellite:

  $P\% = 67\ (1 - A/a)$
  Fade depth A dB is exceeded with probability P%
  Where $a = A(P=1\%) = 0.29 \times (90° - f)$ *dB at L-Band*
  f *= elevation angle to a single satellite.*

  For an urban or suburban environment, it is difficult to find an appropriate fading model (if this model has not been given by Dct Kokkos). Moreover it is difficult to predict if a rural, suburban or urban environment is better or worse for a co-frequency co-coverage sharing. Some have the opinion it will be worse because of the fading propagation increase. Others think that either the communication is possible because there is a free path through at least one satellite or the path is blocked and thus as there is no communication, there is no interference.

3.3 Application with the characteristics of Globalstar and Odyssey systems

Working system figures

Odyssey system (OD)

1- system values

altitude (m)	10355000
spot size ratio: Odyssey/G*	0,78
ratio: Gsat_Odys. / Gsat_G*	25,76
bandwidth ratio: Odys./G*	2,03
bandwidth (Hz)	2,50E+06
channel number	4
(Eb/N0)req (dB)	5,5
average user data rate (bit/s)	2400
(C/N)req (dB)	-24,68
k	1,38E-23
delta: power ctrl factor	1,17
alpha: voice activity factor	0,5
r: spot co-coverage factor	0
system noise temperature (K)	410
Nth (dBW/ 2,5MHz)	-138,49
frequency (Hz)	1,61E+09
capacity max per channel	8,95E+01
frequency re-use factor	**3**
users / 2,5 MHz and spot	90
cross-polarisation with Globalstar (dB)	5

2- Maximum received power in a spot beam for one Odys. voice user

average distance mob-sat (m)	1,1905E+07
max. tx power (dBW/2,5MHz)	3,3
free space loss (dBW)	-178,9
satellite antenna gain (dB)	28
max received pow.(dBW/2,5MHz)	*-146,79*
C/Nth (dB)	-8,30
G (Odys. -> Gl*)	**0,75**

3- Minimum received power in a spot beam for one Odys. voice user

min. received pow.(dBW/2,5MHz)	*-161,17*
C/Nth (dB)	-22,68
G (Odys. -> Gl*)	**1,26**

4- Average received power in a spot beam for one Odys. voice user

av. received pow. (dBW/2,5MHz)	*-149,65*
C/Nth (dB)	-11,15
G (Odys. -> Gl*)	**0,93**

Globalstar system

1- System values

altitude (m)	1414000
spot size ratio: G*/Odys.	1,28
ratio: Gsat_G* / Gsat_Odys.	0,04
bandwidth ratio: G*/Odys.	0,49
bandwidth (Hz)	1,23E+06
channel number	9
(Eb/N0)req (dB)	4,1
average user data rate (bit/s)	2880
(C/N)req (dB)	-22,20
k	1,38E-23
delta	1,35
alpha	0,375
r	1,1
system noise temperature (K)	520
Nth (dBW/1,23MHz)	-140,55
frequency (MHz)	1,61E+09
frequency re-use factor	**1**
capacity max per channel	4,40E+01
cross-polarisation with Odyssey (dB)	5

2- Maximum received power in a spot beam for one G. voice user*

Avg. mobile satellite distance(m)	2,80E+06
tx power (dBW/1,23MHz)	0
Free space loss (dB)	-165,52
Sat antenna Gain (dB)	13,89
max received pow. (dBW/1,23MHz)	*-151,63*
C/Nth (dB)	-11,08
G (Gl*-> Odys.)	**1,41**

3- Minimum received power in a spot beam for one G. voice user*

min received pow.(dBW/1,23MHz)	*-160,75*
C/Nth (dB)	-20,20
G (Gl*-> Odys.)	**2,34**

4- Average received power in a spot beam for one G. voice user*

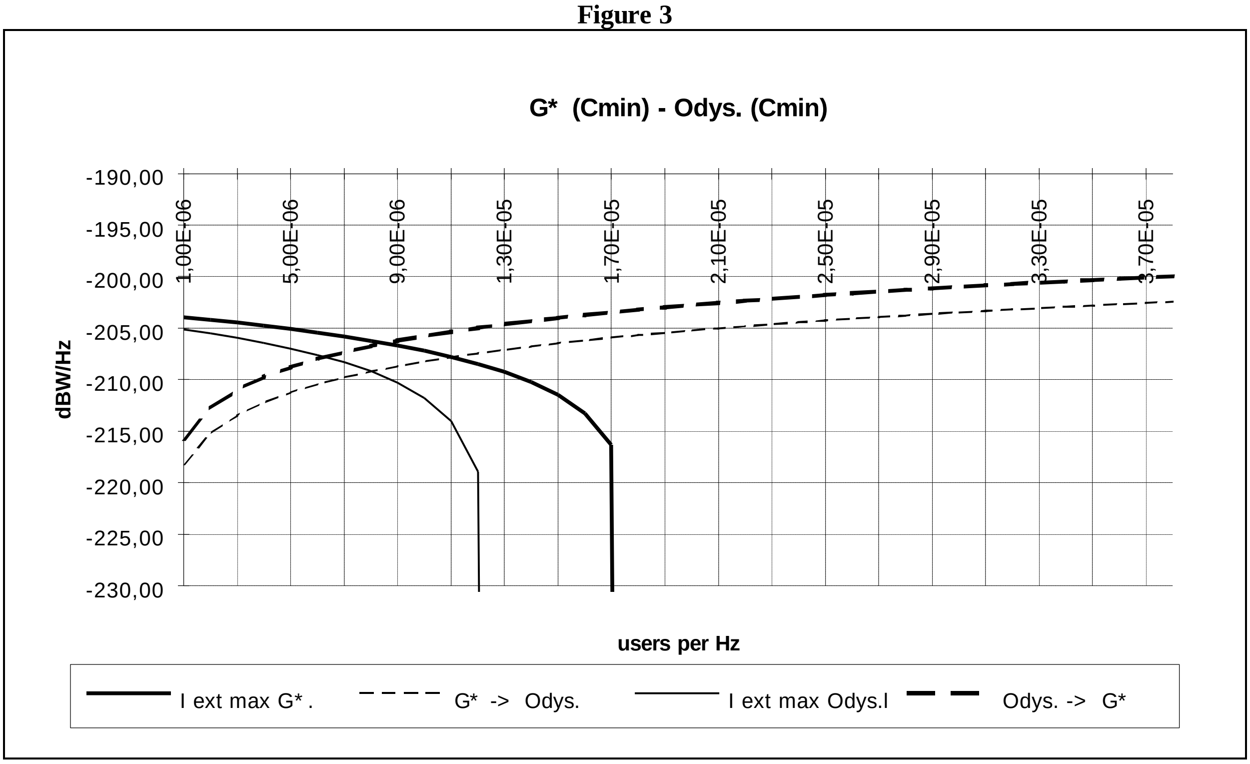
avg. received pow. (dBW/1,23MHz)	*-154,13*
C/Nth (dB)	-13,59
G (Gl*-> Odys.)	**1,65**

3.4 Results

If no cross-polarisation isolation is considered:

Consider both systems operating at the minimum levelIn **Figure 3,** we can see 4 curves: I_{ext}_max bearable by Globalstar in one of its carriers, assuming a capacity of active users per Hz, the noise produced by Globalstar into one Odyssey channel of a spot in function of the capacity of the Globalstar system, and the same type of curves for Odyssey.

Figure 3



With:

for Globalstar: Creceived=Cmin
for Odyssey: Creceived=Cmin

This figure shall be interpreted as follows:

The horizontal axis represents the active users per Hz of each system. For example, the point at 1,3e-5 users per Hz means for Globalstar 1,3e-5*1,23MHz, thus 16 active users per channel and per beam. For Odyssey, it means 1,3e-5*2,5MHz, thus 32,5 active users per channel. This is twice as large as for Globalstar, but it is logical because the Odyssey channel bandwidth is twice that of the Globalstar one. The active users per Hz concept is one way to compare efficiently the level of traffic, because it's independent of the channel bandwidth of the systems.

The I_{ext} max curve represents the external interference levels which a system can support, assuming a traffic level. The higher the traffic , the less external interference the system can support. We can see on this first figure that Globalstar can support a higher traffic level than Odyssey. This because Odyssey does not reuse the whole spectrum in each beam, but has a 1/3 frequency re-use factor. Assuming that Globalstar received power and Odyssey received power are both minimum, the curves show that the maximum capacity is around 1,7e-5 active users per Hz for Globalstar and 1,2 e-5 active users per Hz for Odyssey. It is interesting to check that the same maximum values appear in **Table 1** below.

To increase this maximum capacity, the received power of each system shall be increased.

The figure can be read as follows: assuming a number N' of active users per Hz for the Globalstar system (for example), it allows a number Nod. of Odyssey active users, but this number Nod. of active users allows Ngl. of Globalstar active users that may be lower than N'. Thus the global active users number is Nod. + min(N' , Ngl).

Table 1

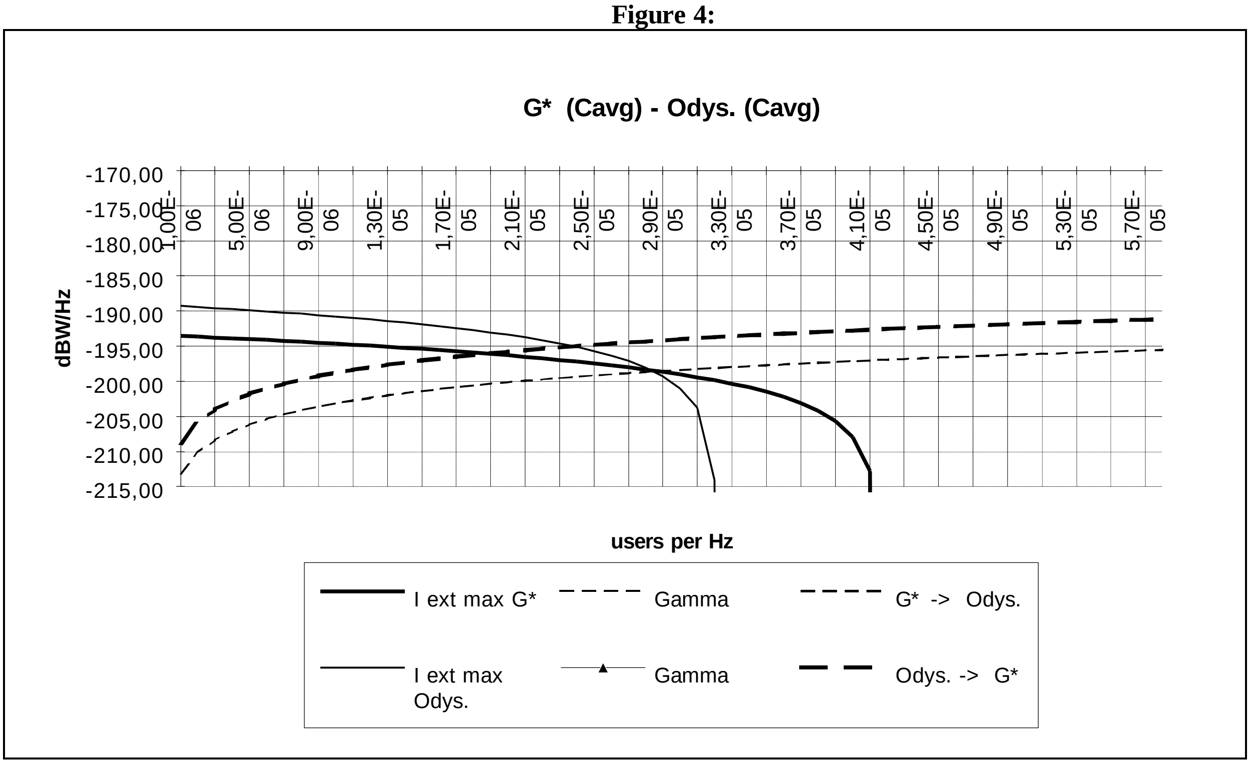
N' (e-6)	1	3	5	7	9	11	13	15	17
Nod. (e-6)	12	11	9	8	6	5	4	4	0
Ngl. (e-6)	0	2	7	8	11	11	13	13	17
N total (e-6)	**12**	**13**	**14**	**15**	**15**	**16**	**17**	**17**	**17**

At a low level of traffic, which is equivalent to the Cmin hypothesis, the sharing seems to be feasible.

It is interesting to stress the point that the global capacity, which means the total active users per Hz, tends towards the capacity of the system which has the higher traffic level. To increase the number of active users per Hz, that means to increase the traffic, the system will require a greater received power.

Thus let us consider the case of an average received power.

Figure 4:



With this figure, the maximum global capacity for Globalstar is 4,1e-5 active users per Hz, and for Odyssey, it is 3,2e-5 active users per Hz. The**tables** of the active users can be built:

Table 2

N' (e-6)	**Nod (e-6)**	**Ngl (e-6)**	**N total (e-6)**	**Comment on the traffic**
1	32	0	32	Odyssey=100% of the traffic
3	32	0	32	
5	31	1	32	
7	31	1	32	....
9	31	1	32	
11	30	4	34	
13	30	4	34	
..	...			
25	29	7	36	Odyssey and Globalstar shares the traffic
27	28	9	37	
29	28	9	37	
31	28	9	37	...
...	...			
40	28	9	37	Odyssey and Globalstar shares the traffic

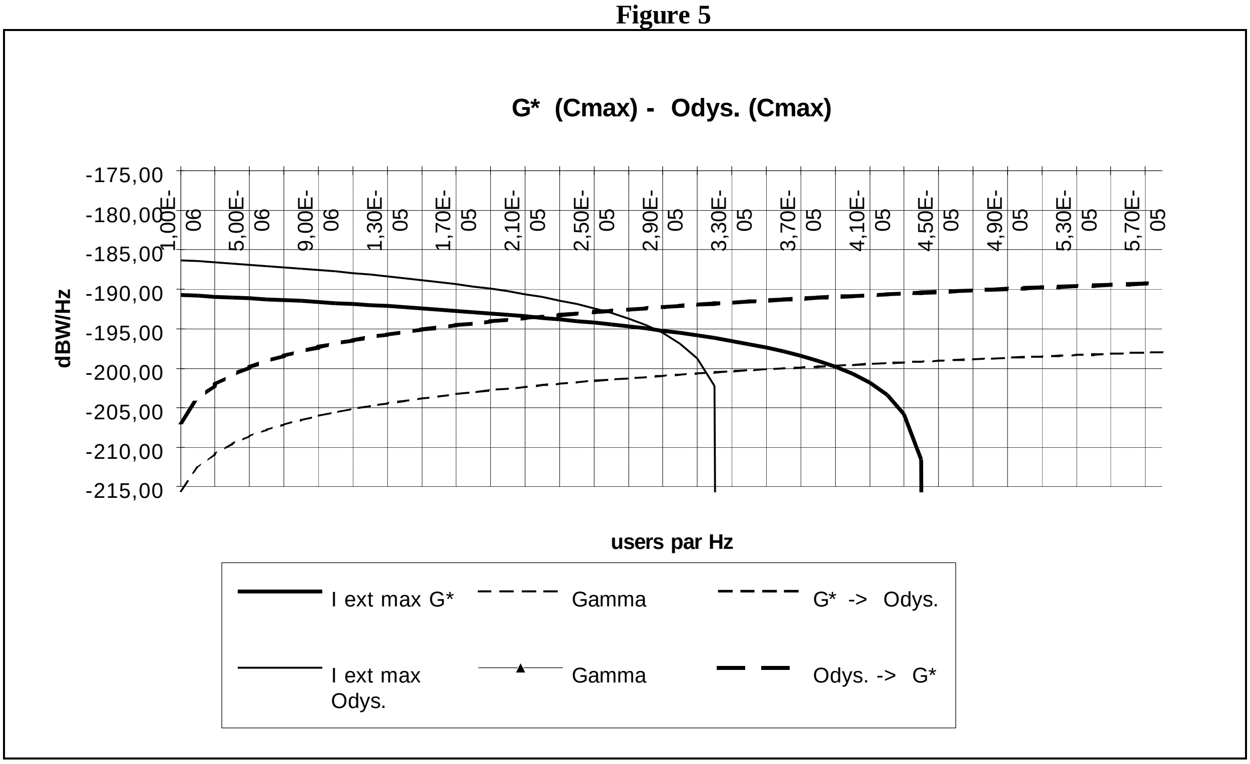
Table 3

Nod' (e-6)	**Ngl (e-6)**	**Nod. (e-6)**	**N total (e-6)**	**Comment on the traffic**
1	40	25	41	Globalstar=100% of the traffic
3	38	28	41	
5	35	29	40	
7	33	29	40	...
9	30	29	39	
11	29	29	40	
13	27	29	40	Odys. and G* shares ~50/50
15	23	29	38	
17	21	29	38	
19	19	30	38	
21	15	30	36	....
23	13	30	36	
25	11	30	36	
27	9	30	36	
29	5	30	34	
31	3	32	34	Odyssey is about 90% of the traffic

As in the case of Cmin, the maximum global capacity tends towards the capacity of the system which has the higher traffic level. Thus, sharing is also feasible with a mean level of traffic.

Thus let us look at the case with a maximum received power for the both systems.

Figure 5



With:

for Globalstar: Creceived=Cmax
for Odyssey: Creceived=Cmax

For Odyssey, the maximum capacity is 3,3e-5 active users per Hz. Globalstar maximum capacity is 4,4 e-5 active users per Hz.

The **tables** of the active users numbers are:

Table 4

N' (e-6)	Nod. (e-6)	Ngl. (e-6)	N total (e-6)	Comment on the traffic
1	32	0	32	Odyssey=100% of the traffic
3	32	0	32	
...	...	...	...	
25	32	0	32	...
27	32	0	32	
29	31	11	44	Odys. and G* shares
31	31	11	44	
...	...	...	...	
43	31	11	44	Odys. and G* shares

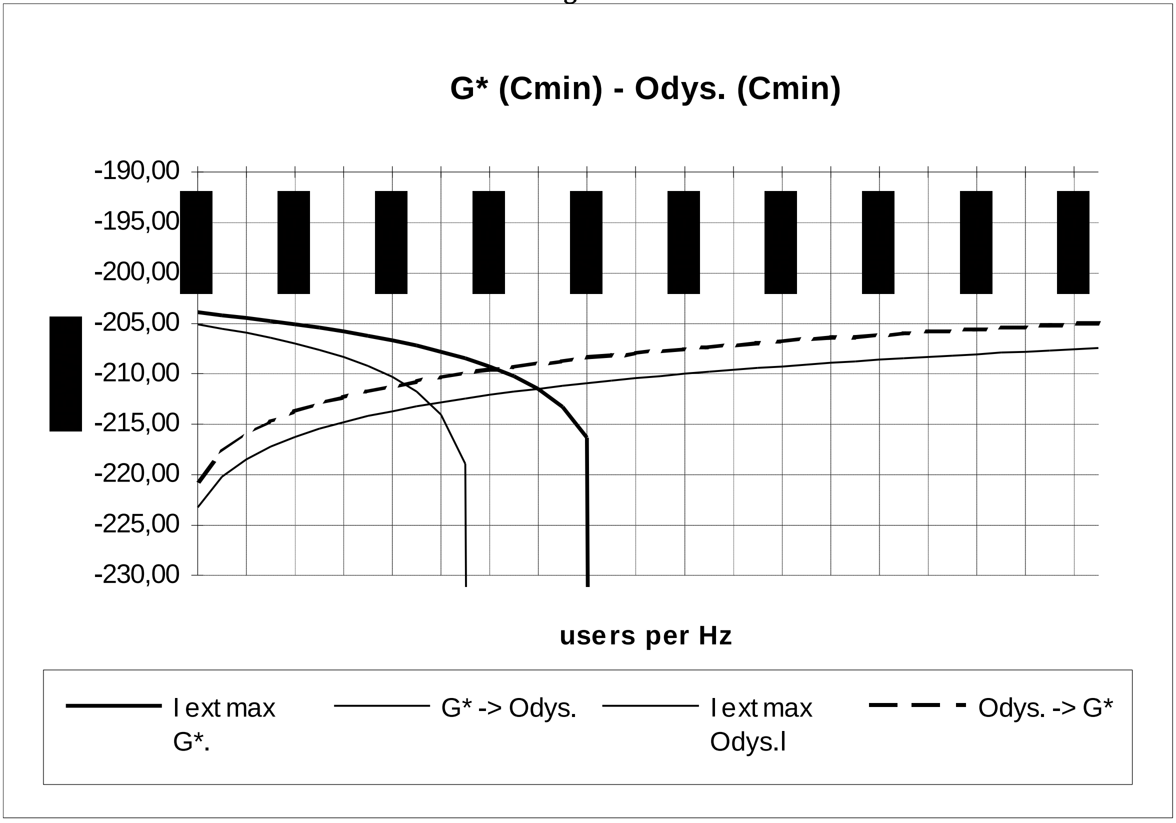
Table 5

Nod (e-6)	Ngl. (e-6)	N'od. (e-6)	N total (e-6)	Comment on the traffic
1	43	21	44	Globalstar ~ 100% of the traffic
3	41	21	44	
5	39	23	44	
7	37	23	44	...
9	35	23	44	
11	33	23	44	
13	31	23	44	
15	29	24	44	
17	27	25	44	Odys. and G* shares ~50/50
19	25	25	44	
21	21	26	42	....
23	21	32	44	
25	19	32	44	
27	15	32	42	
29	13	32	42	
31	13	32	44	Odyssey leads the traffic

If a cross polarisation isolation of 5 dB is considered:

Let us consider Globalstar and Odyssey operating at the minimum level. On the first figure, we can see 4 curves: $I_{ext_}$max bearable by Globalstar in one of its carriers, assuming a capacity of active users per Hz, the noise produced by Globalstar into one Odyssey channel of a spot as a function of the capacity of the Globalstar system, and the same type of curves for Odyssey.

Figure 6



With:

for Globalstar: Creceived=Cmin
for Odyssey: Creceived=Cmin

This figure shall be interpreted as follows:

The horizontal axis represents the active users per Hz of each system. For example, the point at 1,3e-5 users per Hz means for Globalstar 1,3e-5*1,23MHz, thus 16 active users per channel and per beam. For Odyssey, it means 1,3e-5*2,5MHz, thus 32,5 active users per channel. This is twice as large as for Globalstar, but it is logical because the Odyssey channel bandwidth is twice the size of the Globalstar one. The active users per Hz concept is one way to compare efficiently the level of traffic, because it is independent of the channel bandwidth of the systems.

The $I_{ext_}$max curve represents the external interference levels which a system can support, assuming a traffic level. The higher the traffic is, the less external interference the system can support. We can see on this first figure that Globalstar can support higher traffic level than Odyssey. It is because Odyssey does not reuse the whole spectrum in each beam, but has a 1/3 frequency re-use factor. Assuming that Globalstar received power and Odyssey received power are both minimum, the curves show that the maximum capacity is around $1,7.10^{-5}$ active users per Hz for Globalstar and $1,2.10^{-5}$ active users per Hz for Odyssey. It is interesting to check that the same maximum value appears in the **table** below.

To increase this maximum capacity, the received power of each system shall be increased.

The figure can be read as follows:
First, let u assume a number x of Globalstar active users per Hz.

1. These x Globalstar users can bear a maximum of A dBW/Hz of interference and produce B dBW/Hz of noise into Odyssey.
2. Moreover, A dBW/Hz of noise are produced by y Odyssey active users, and these y Odyssey active users can bear a maximum of C dBW/Hz of interference.
3. If B ≤ C than we can consider that x Globalstar active users and y Odyssey active users can operate
4. Else y = y-1 and back to line 2.

The figures in the two following **tables** are expressed in 10^{6} active users per Hz.

Table 6

x users G*	1	3	5	7	9	11	13	15	17
y users Od.	12	12	11	11	10	10	10	8	3
total	13	15	16	18	19	21	23	23	20

Table 7

x users Od.	1	3	5	7	9	11	12
y users G*	17	17	16	15	14	9	3
total	18	20	21	22	23	20	15

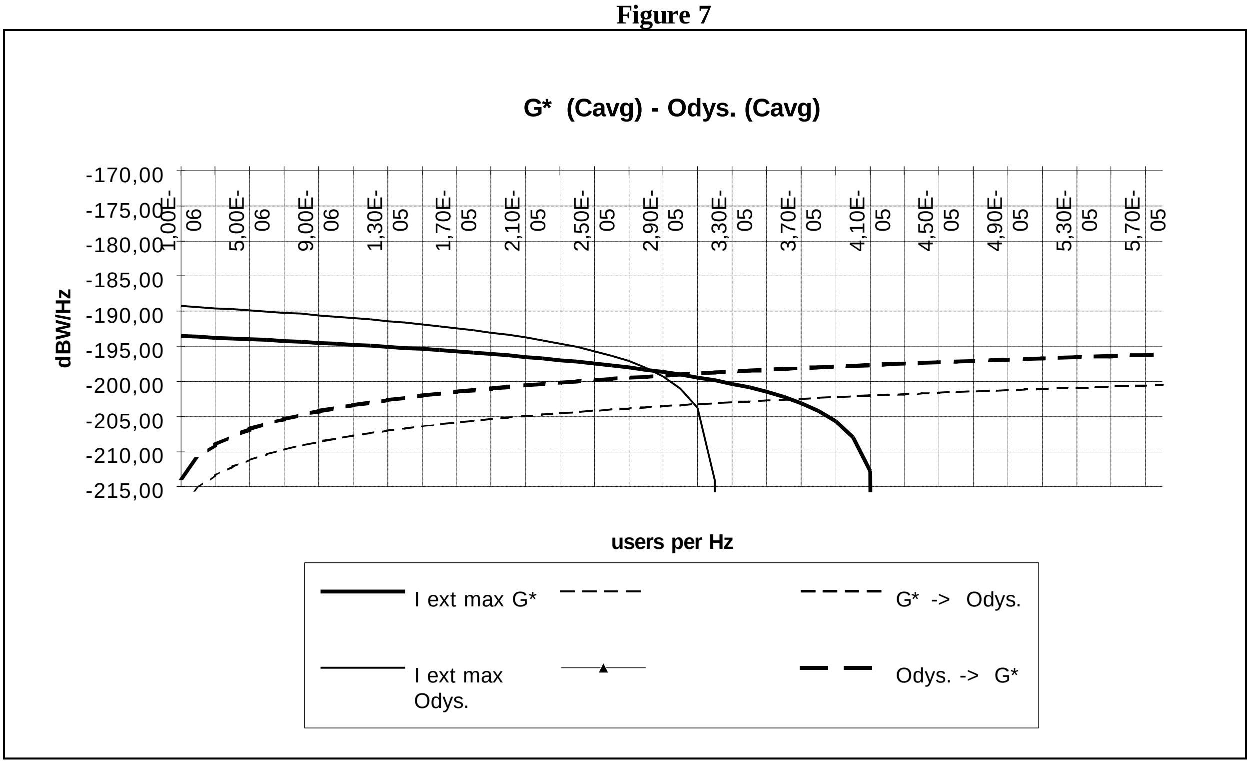
At a low level of traffic (see the two **tables** above), which is equivalent to the Cmin hypothesis, the sharing seems to be feasible.

We can see that thanks to the cross-polarisation (5dB), if the volumes of traffic are equivalent for the two systems, then the global capacity when sharing is higher than the global capacity of one single system (=when not sharing).

It is also interesting to stress the point that the global capacity, which means the total active users per Hz, tends towards the capacity of the system which has the higher traffic level. To increase the number of active users per Hz, that means to increase the traffic, the system will require a greater received power.

Thus let us consider the case of an average volume of traffic (Þ average received power).

Figure 7



With this figure, the maximum global capacity for Globalstar is 4,1.10^{-5} active users per Hz, and for Odyssey, it is 3,2.10^{5} active users per Hz. The **tables** of the active users can be built:

The figures in the two following **tables** are expressed in 10^6 active users per Hz.

Table 8

x users G*	1	3	5	7	9	11	13	...	25	**27**	**29**	**31**	33	35	37	39	41
y users Od.	32	31	31	31	31	31	31	31	31	**31**	**29**	**27**	23	17	11	6	2
total	33	34	36	38	40	42	43	...	56	**58**	**58**	**58**	56	52	48	45	43

Table 9

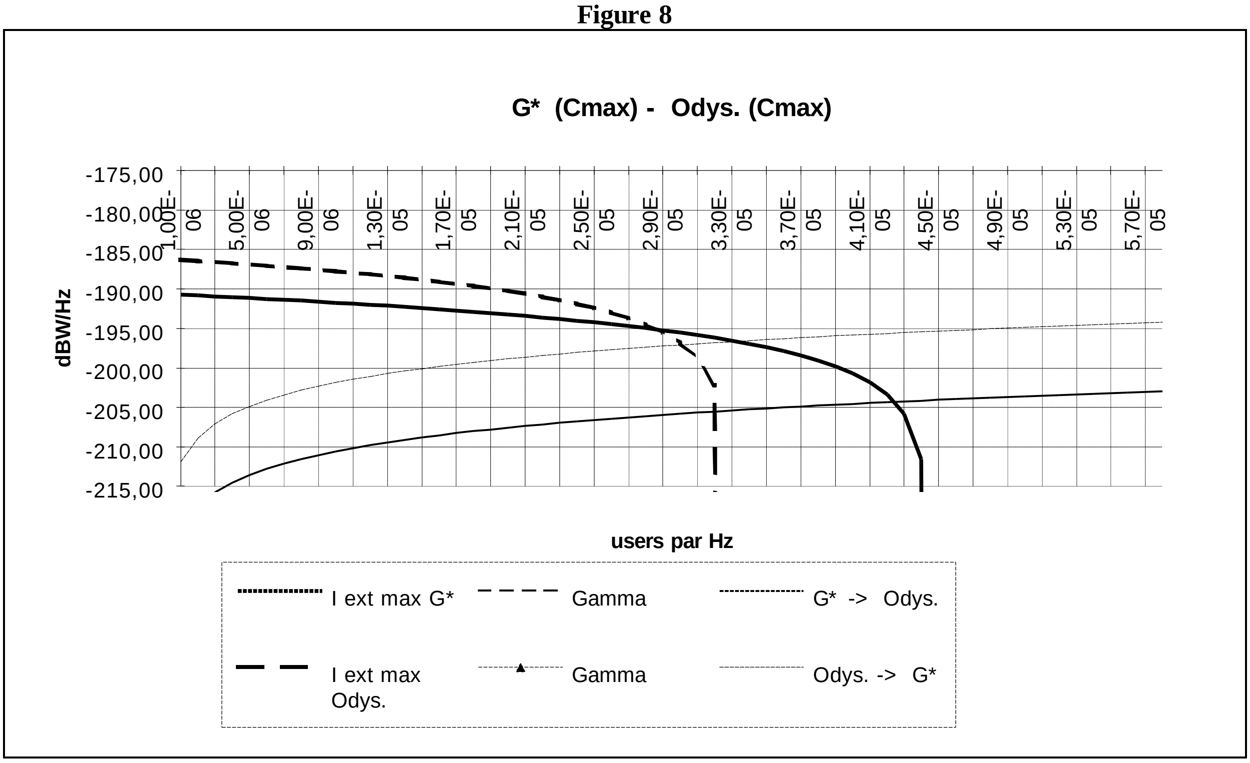
x users Od.	1	3	5	7	9	11	13	15	17	19	21	23	25	**27**	**29**	**31**	32
y users G*	41	40	39	38	37	37	37	35	35	33	33	31	31	**31**	**29**	**27**	3
total	42	43	44	45	46	48	50	50	52	52	54	54	56	**58**	**58**	**58**	35

As in the case of Cmin, the maximum global capacity tends towards the capacity of the system, which has the higher traffic level. One more time, it is interesting to notice that thanks to the cross-polarisation and similar volumes of traffic, the global capacity increases significantly.

Thus, in this case the sharing seems to be more appropriate than band splitting.

Thus let us look at the case with a maximum volume of traffic (⇒ max. received power) for both systems.

Figure 8



With:

for Globalstar: Creceived=Cmax
for Odyssey: Creceived=Cmax

For Odyssey, the maximum capacity is $3,3.10^5$ active users per Hz. Globalstar maximum capacity is $4,4 .10^5$ active users per Hz.

The figures in the two following **tables** are expressed in 10^6 active users per Hz.

Table 10

x users G*	1	3	5	7	9	11	13	15	...	27	29	31	33	35	37	39	41	43	44
y users Od.	32	32	32	32	32	32	32	32	32	32	32	32	32	27	23	15	10	4	1
total	33	35	37	39	41	43	45	47	...	**59**	**61**	**63**	**65**	**62**	**60**	54	51	47	45

Table 11

x users Od.	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	32
y users G*	44	43	42	41	41	41	40	39	38	38	37	37	35	35	35	33	33
total	45	46	47	48	50	52	53	54	55	57	58	**60**	**60**	**62**	**64**	**64**	**65**

We can see that the global capacity is still increasing (65. 10^{-6}). The best results are obtained when the volume of traffic are similar (~30. 10^{-6} Globalstar users and ~30. 10^{-6} Odyssey users).

Remark:

> It should be said that if the cross-polarisation advantage is not taken into account, the maximum global capacity is the maximum capacity of one single system. Thus the increase of the global capacity is a consequence of the cross-polarisation advantage, thus the results are closely linked with this factor.

3.5 Conclusion

The presented simulations have been run with the following working assumptions:

- The chosen fading probability law applies for rural environment (*Goldhirsh, Julius and Wolfhard J. Vogel, Propagation Effects for Land Mobile Satellite Systems: Overview of Experimental and Modeling Results, NASA Reference Publication 1274, 1992*).
- It is assumed that the two systems have coordinated their CDMA codes according to the ITU-Rec 1186 so that they don’t use the same CDMA codes.
- The traffic volume distribution between vehicle mounted mobile and handheld mobile is assumed to be 90% for the handheld terminals and 10% for vehicle mounted mobiles. This distribution is used in the average case via the fading factor calculation.
- The user terminal power range depends on the type of the terminals (handheld or vehicle mounted mobile).
- Simulations based on average case used characteristics of Globalstar and Odyssey systems.
- Cross-polarisation advantage is in the range 0-5 dB.

A first set of simulations was based on an average case. These simulations show that, if no cross polarisation is taken into account, the maximum global capacity of two sharing CDMA systems is equal to the larger maximum capacity of one single system. Thus, with no cross-polarisation and the characteristics of Globalstar and Odyssey, the calculations give the following figures: For Odyssey the maximum capacity is $3,3.10^{-5}$ active users per Hz. Globalstar maximum capacity is $4,4.10^{-5}$ active users per Hz. And in the case of co-frequency co-coverage sharing between Globalstar and Odyssey, the maximum global capacity is $4,4.10^{5}$ active users per Hz. If a cross-polarisation advantage of 5 dB is considered, then the maximum global capacity of the 2 sharing CDMA systems is greater than the larger capacity of one single system: in case of co-frequency co-coverage sharing between Globalstar and Odyssey, the maximum global capacity is $6,5.10^{-5}$ active users per Hz.

In order to quantify the loss of capacity, when the two systems have the same volume of traffic with no cross-polarisation advantage, the study of a theoretical self-sharing scenario was proposed. That means that two CDMA systems have exactly the same characteristics. Considering two systems with Globalstar characteristics and the same volume of traffic, the simulation results show that the loss of the capacity is from 9% to 28%, depending on the volume of traffic.

4 THE OUTAGE CASE

4.1 Introduction

This chapter presents the study of the blinding interference probabilities between two CDMA systems having the same volume of traffic. The objective is to complete the previous study on the co-frequency co-coverage sharing feasibility issue based on the average case.

Considering the same volume of traffic for each system, what is the probability that one of the active terminals of one system produces harmful interference into the spot of the other system?

A self-sharing scenario was also envisaged. The results are presented in the Annex B.

4.2 Probability calculation

The probability that one of the active terminals of one system produces harmful interference into the spot of the other system can be expressed as follows:

Blind. proba $= \mathbf{E}\,[\,P_{\text{received from one user of the system B into the A satellite}} \geq I_{ext\_max\_A}]$

$$= E\left[\frac{EIRP_{MES\_of\_B}\cdot Ant\_Gain_{satellite\_of\_A}}{Fsl_{to\_satellite\_of\_A}\cdot FAD_{to\_satellite\_of\_A}} \geq I_{ext\_max\_A}\right]$$

The EIRP of a mobile earth station of the system B can be expressed thanks to the required carrier to noise ratio and the losses of the path to the satellite of system B:

$EIRP_{MES\ of\ B} = C_{\text{received by B from one MES}}\cdot Fsl_{\text{to satellite of B}}\cdot FAD_{\text{to satellite of B}} / Ant\_Gain_{\text{satellite of B}}$

$$= \left(\frac{C}{N}\right)_{req}\cdot Ntotal_{received\_by\_B}\cdot\frac{Fsl_{to\_satellite\_of\_B}\cdot FAD_{to\_satellite\_of\_B}}{Ant\_Gain_{satellite\_of\_B}}$$

Thus the blinding probability by one active user of B of one spot beam of satellite of system A is:

$$E\left[\left(\frac{C}{N}\right)_{req}\cdot Ntotal_{received\_by\_B}\cdot\frac{Fsl_{to\_satellite\_of\_B}\cdot FAD_{to\_satellite\_of\_B}\cdot Ant\_Gain_{satellite\_of\_A}}{Fsl_{to\_satellite\_of\_A}\cdot FAD_{to\_satellite\_of\_A}\cdot Ant\_Gain_{satellite\_of\_B}} \geq I_{ext\_max\_A}\right]$$

$$E\left[\frac{Fsl_{to\_satellite\_of\_B}\cdot FAD_{to\_satellite\_of\_B}}{Fsl_{to\_satellite\_of\_A}\cdot FAD_{to\_satellite\_of\_A}} \geq \left(\frac{N}{C}\right)_{req}\cdot\frac{I_{ext\_\max\_A}\cdot Ant\_Gain_{satellite\_of\_B}}{Ntotal_{received\_by\_B}\cdot Ant\_Gain_{satellite\_of\_A}}\right]$$

With:

$I_{ext\_max\_A}$: Maximum external interference bearable by a satellite of system A in one spot beam and in one channel. This value is available on the curves (ref des courbes) in function of the number of active users/Hz.

$Fsl_{\text{to satellite of A (or B)}}$: Free Space Loss to satellite of system A (or B).

$FAD_{\text{to satellite of system A (or B)}}$: Fading Loss to satellite of system A (or B).

$Ant\_Gain_{\text{satellite\_of\_A (or B)}}$: Antenna gain of satellite of system A (or B).

$N\ total_{\text{received by B}}$: Total noise received by satellite of system B in one spot and in one channel, with $N\ total_{\text{received by B}} = Nth_B + Nint_B + Next_B$.

4.3 Algorithm

```
1- Variables initialisation, e.g.: the volume traffic ⇔ number of users per spot (Nb users/spot)
2- Calculation of the threshold $(I_{ext\_max\_A} - (C/N)_{req\ B} \cdot Ntotal_{received\ by\ B})$
3- Calculation loop (10000):
    3.1- trial of the elevation of A satellite for each of the Nb users of the spot
    3.2- calculation of the free space loss as a function of the elevation
    3.3- calculation of the fading attenuation as a function of the elevation
    3.4- trial of the elevation of B satellite for each of the Nb users of the spot
    3.5- calculation of the free space loss as a function of the elevation
    3.6- calculation of the fading attenuation as a function of the elevation
    3.7- calculation for each of the users of the spot:
        $FSL_{UT\rightarrow B} - FSL_{UT\rightarrow A} + FAD_{UT\rightarrow B} - FAD_{UT\rightarrow A}$
    3.8- if, for one of the users of the spot, we have:
        $FSL_{UT\rightarrow B} - FSL_{UT\rightarrow A} + FAD_{UT\rightarrow B} - FAD_{UT\rightarrow A} \geq I_{ext} - (C/N)_{req\ B} \cdot N_{received\ by\ B}$
    then:   interference ← interference + 1
4- Interference probability = $\frac{interference}{10000} \cdot 100$
```

3.4 Application to Globalstar and Odyssey systems

The purpose of this paragraph is to explain the calculation of the threshold $(I_{ext\_max\_A} - (C/N)_{req\ B} - Ntotal_{received\ by\ B})$, assuming the «blinding» interference from one Globalstar user into one spot beam of Odyssey and the «blinding» interference from one Odyssey user into one spot beam of Globalstar.
The analysis was carried out under the assumption of 5 dB cross polarisation isolation.

1/ « Blinding » interference from one Globalstar user into one spot beam of Odyssey

Thus, we have seen that the threshold can be expressed as follows:

$$\text{Threshold (dB)} = (I_{ext\_max\_Odyssey} + Ant\_Gain_{sat.\ Globalstar} - Ant\_Gain_{sat.Odyssey} - (C/N)_{req\ Globalstar} - Ntotal_{received\ by Globalstar})$$

- The maximum external interference bearable by a satellite of the Odyssey system can be read from the curves (ref. de la Courbe), assuming a volume of traffic and consequently a number of active users per Hz:

Table 12

Volume of traffic	Number of active users per Hz	$I_{ext\_max\_Odyssey}$ (dBW/Hz)
low	3.10^{-6}	-187
average	$1,1.10^{-5}$	-188
high	$1,7.10^{-5}$	-189
maximum	$2,1.10^{-5}$	-191

- The value of the satellite antenna gain for the system Odyssey is 28 dB.

- The required carrier to noise ratio for the Globalstar system is equal to -22.20 dB, and the gain of the satellite antenna is equal to 14 dB.

- The noise received by a satellite of Globalstar in one spot and in one channel can be expressed thanks to the following formula:

$$N\ total_{\text{received by Globalstar}} = Nth_{\text{Globalstar}} + Nint_{\text{Globalstar}} + Next_{\text{Globalstar}}$$

With:

$Nth_{\text{Globalstar}}$ = - 140,55 dBW/1,23MHz = - 201,45 dBW/Hz

$Nint_{\text{Globalstar}} = C_{\text{Globalstar}} \cdot \Delta_{\text{Globalstar}} \cdot (M_{\text{Globalstar}} \cdot (1+r_{\text{Globalstar}})-1)$

$Next_{\text{Globalstar}} \approx N_{\text{received by Globalstar from Odyssey}}$

$Nint_{\text{Globalstar}}$ can be easily calculated thanks to the Globalstar data sheet presented on the page 16 and $Next_{\text{Globalstar}}$ can be read from the curve in Figure 3 as a function of the number of active user.

Table 13

Volume of traffic	Number of active users/Hz	$C_{\text{Globalstar}}$ (dBW/Hz)	$Nint_{\text{Globalstar}}$ (dBW/Hz)	$Next_{\text{Globalstar}}$ (dBW/Hz)	$Nth_{\text{Globalstar}}$ (dBW/Hz)	Ntotal received by G*
low	3.10^{-6}	-221,6	-203	- 202	- 201	-198,3
average	$1,1.10^{-5}$	-215,0	-197	-197	- 201	-192,9
high	$1,7.10^{-5}$	-212,5	-195	-195	- 201	-189,7
maximum	$2,1.10^{-5}$	-212,5	-195	-194	- 201	-188,9

➔ Thus the threshold depends on the volume of traffic:

Table 14

Volume of traffic	Number of active users per Hz	Threshold(dB) For Globalstar into Odyssey
low	3.10^{-6}	27,7
average	$1,1.10^{-5}$	26,7
high	$1,7.10^{-5}$	25,7
maximum	$2,1.10^{-5}$	23,7

2/ « Blinding » interference from one Odyssey user into one spot beam of Globalstar

To calculate the « blinding » interference from one Odyssey user into one spot beam of Globalstar, the following threshold shall be calculated:

$$\text{Threshold} = (I_{\text{ext\_max\_Globalstar}} + \text{Ant\_Gain}_{\text{sat.Odyssey}} - \text{Ant\_Gain}_{\text{sat. Globalstar}} - C/N)_{\text{req Odyssey}} - \text{Ntotal}_{\text{received by Odyssey}})$$

- The maximum external interference bearable by a satellite of the Globalstar system can be read from the curves (ref. de la courbe), assuming a volume of traffic and consequently a number of active users per Hz:

Table 15

Volume of traffic	Number of active users per Hz	$I_{\text{ext\_max\_Globalstar}}$ (dBW/Hz)
low	3.10^{-6}	-191
average	$1,1.10^{-5}$	-192
high	$1,7.10^{-5}$	-192,5
maximum	$2,1.10^{-5}$	-193

- The value of the satellite antenna gain for the system Globalstar is 14 dB.

- The required carrier to noise ratio for the Odyssey system is equal to -22.20 dB, and the gain of the satellite antenna is equal to 28 dB.

- The noise received by a satellite of Odyssey in one spot and in one channel can be expressed thanks to the following formula:

$N\ total_{\text{received by Odyssey}} = Nth_{\text{Odyssey}} + Nint_{\text{Odyssey}} + Next_{\text{Odyssey}}$

With:

$Nth_{\text{Odyssey}} = -136{,}63\ \text{dBW/2,5MHz} = -200{,}6\ \text{dBW/Hz}$
$Nint_{\text{Odyssey}} = C_{\text{Odyssey}} . \Delta_{\text{Odyssey}} . (M_{\text{Odyssey}} .(1+r_{\text{Odyssey}})-1)$
$Next_{\text{Odyssey}} \approx N_{\text{received by Odyssey from Globalstar}}$

$Nint_{\text{Odyssey}}$ can be easily calculated thanks to the Odyssey data sheet presented on the page 15 and $Next_{\text{Odyssey}}$ can be read from the curve in **Figure 3** as a function of the number of active user.

Table 16

Volume of traffic	Number of active users/Hz	C_{Odyssey} (dBW/Hz)	$Nint_{\text{Odyssey}}$ (dBW/Hz)	$Next_{\text{Odyssey}}$ (dBW/Hz)	Nth_{Odyssey} (dBW/Hz)	Ntotal received by Od.
low	3.10^{-6}	-219,8	-217,7	- 211	- 200,6	-200,1
average	$1{,}1.10^{-5}$	-211,4	-201,6	-205	- 200,6	-197,2
high	$1{,}7.10^{-5}$	-210,8	-198,9	-203	- 200,6	-195,7
maximum	$2{,}1.10^{-5}$	-210,8	-197,9	-202	- 200,6	-195,1

➔ Thus the threshold depends on the volume of traffic:

Table 17

Volume of traffic	Number of active users per Hz	Threshold(dB) For Odyssey into Globalstar
low	3.10^{-6}	49.4
average	$1{,}1.10^{-5}$	45,5
high	$1{,}7.10^{-5}$	43,5
maximum	$2{,}1.10^{-5}$	42,3

4.4 Results and conclusion

The results obtained with the algorithm described above are the following:

1/ « Blinding » interference from one Globalstar user of one spot beam into one channel of Odyssey

Table 18

Volume of traffic for each system	users/Hz	Interference probability (*)
low	3.10^{-6}	0,02 %
average	$1{,}1.10^{-5}$	0,04 %
high	$1{,}7.10^{-5}$	0,07 %
maximum	$2{,}1.10^{-5}$	0,11 %

(*) It should be noted that the interference probability figures should not be multiplied by the number of users per spot, because this number has already been taken into account in the calculation.

We can see that the «blinding» interference probability by one user of Globalstar of one spot beam into one channel of Odyssey is extremely low.

2/ « Blinding » interference from one Odyssey user of one spot beam into one channel of Globalstar

Table 19

Volume of traffic for each system	users/Hz	Interference probability (*)
low	3.10^{-6}	0,34%
average	$1,1.10^{-5}$	1,10%
high	$1,7.10^{-5}$	3,40%
maximum	$2,1.10^{-5}$	4,20%

(*) It should be noted that the interference probability figures should not be multiplied by the number of users per spot, because this number has already been taken into account in the calculation.

The blinding interference probabilities of one spot beam and one channel of Globalstar by one Odyssey user are higher than the blinding interference probabilities of one spot beam and one channel of Odyssey by one Globalstar user, but are still acceptable.

The increase of the probabilities is due to:
- higher probabilities of fading loss on the path to the Odyssey satellites.
- higher transmitted power of the Odyssey terminals.
- greater size of the Globalstar spot beam.

5 CONCLUSION

The presented simulations have been run with the following working assumptions:
- The chosen fading probability law applies for a rural environment (*Goldhirsh, Julius and Wolfhard J. Vogel, Propagation Effects for Land Mobile Satellite Systems: Overview of Experimental and Modeling Results, NASA Reference Publication 1274, 1992*).
- It is assumed that the two systems have coordinated their CDMA codes according to the ITU-Rec 1186 so that they do not use the same CDMA codes.
- The traffic volume distribution between vehicle mounted mobiles and handheld mobiles is assumed to be 90% for the handheld terminals and 10% for vehicle mounted mobiles. This distribution is used in the average case via the fading factor calculation and in the blinding interference scenario.
- The user terminal power range depends on the type of the terminals (handheld or vehicle mounted mobile).
- Simulations based on average case used characteristics of Globalstar and Odyssey systems. Simulations to determine outage probability (blinding interference) assume identical systems with Globalstar characteristics. It should be noted that some preliminary studies have been made with the Courier system.
- The value of the cross polarisation between the two systems is 5 dB for the blinding interference scenario. For the average case study the cross-polarisation is not taken into account. It should be noted that, in the case of sharing between more than two systems, the cross polarisation advantage is not available.

A first set of simulations was based on an average case. These simulations showed that two CDMA systems can not have a larger global capacity than a single system, if no cross polarisation is taken into account. Thus, with no cros-polarisation and the characteristics of Globalstar and Odyssey, the calculations give the following figures: For Odyssey the maximum capacity is $3,3.10^{-5}$ active users per Hz. Globalstar maximum capacity is $4,4.10^{-5}$ active users per Hz. And in the case of co-frequency co-coverage sharing between Globalstar and Odyssey, the maximum global capacity is $4,4.10^{-5}$ active users per Hz. In order to quantify the loss of capacity, when the two systems have the same volume of traffic, the study of a theoretical self sharing scenario was proposed. That means that two CDMA systems have exactly the same characteristics. Considering two systems with Globalstar characteristics and the same volume of traffic, the simulation results show that the loss of the capacity is from 9% to 28%, depending on the volume of traffic. (The results are presented in Annex B).

The scenario, where one terminal of one system blinds one spot of the other system, has also been discussed. The percentage of « blinding » interference, given by the simulation with the working assumptions described above, the Globalstar and Odyssey characteristics, is from 0,02% in the case of a low volume of traffic (3.10^{-6} active users /Hz) for the interference produced by Globalstar into Odyssey to 3,4% in the case of a high volume of traffic ($1,7.10^{-5}$ active users /Hz). According to the CDMA operators, these values for interference probabilities will be acceptable for low, average and high volumes of traffic. The percentage of « blinding » interference, given by the simulation with two identical systems with the Globalstar characteristics and the working assumptions described above, is from 0,06% in the case of a low volume of traffic (3.10^{-6} active users /Hz) to 1,9% in the case of a high volume of traffic ($1,5.10^{-5}$ active users /Hz). It shall be noted that in the case of the maximum volume of traffic predicted by the self-sharing simulation ($1,8.10^{-5}$ active users /Hz), the « blinding » interference percentage is 3,6%. As in the case of Globalstar and Odyssey, this value shows the limitation of the simulation based on the average case. According to the CDMA operators, these values for interference probabilities will be acceptable for low, average and high volume of traffic.

In conclusion, with the simplistic assumptions given previously, there is no prohibiting reason against frequency sharing between two CDMA systems. However, a more realistic analysis incorporating urban and suburban cases and CDMA systems with different characteristics such as those of Globalstar and Odyssey is needed in order to conclude on the efficiency of co-frequency co-coverage sharing. This further study will be carried out subject to the availability of appropriate model (e.g. fading model in urban and suburban area).

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ANNEX A

CALCULATION OF FADING FACTOR AND RESULTS

1 Calculation algorithm

The following calculation algorithm of $\Gamma_{S1->S2}$ (for one single UT) gives the distribution of $\Gamma_{S1->S2}$ (for one single UT):

1- Allocation of the S1 and S2 variable and choice of the case which must be treated (Cmin, Cavg or Cmax).

2- Calculation of the probability distribution of the best satellite elevation angle as a function of the constellation parameters, for the two systems.

3- Implementation of the probability function of fading as a function of the elevation angle of a satellite in a suburban environment from the ITU-R 8D approved document:
"*The following equation predicts the probability, P%, that the fade depth will be greater than a given level of A dB, for a given elevation angle f to a single satellite:*
P%= 67 (1-A/a)
Fade depth A dB is exceeded with probability P%
Where a = A(P=1%)=0.29 x (90°- f) dB at L-Band
f = elevation angle to a single satellite".

4- Loop on 10 000 trials:

- Trial of the S1 satellite elevation angle, i.e., the location of the user terminal.
- Calculation of the fading probability on the path towards the S1 satellite=> Fad-path_S1.
- Calculation of the user terminal EIRP in order to achieve the $C_{\text{received by S1 from S1}}$ specified in the simulation (Cmin, Cavg or Cmax). The obtained value is tested to be sure that it is in the interval [EIRPmin; EIRPmax].
- Trial of the S2 satellite elevation angle.
- Calculation of the fading probability on the path towards the S2 satellite=>Fad_path_S2.
- $C'_{\text{received by S2 from UT1}} = \text{EIRP\_UT}_{S1} - \text{Fsl}(\text{elev}_{sat2}, \text{alt}_{S2}) - \text{Fad\_path\_S2} + \text{Gs2}$.
- $C_{\text{received by S2 from UT1}} = \frac{Gs2}{Gs1}\left(\frac{R1}{R2}\right)^2 . C_{\text{received by S1 from S1}}$.
- $\Gamma_{S1->S2} \text{ (for one single UT)} = \frac{C' \text{ received by S2 from UT1}}{C \text{ received by S2 from UT1}}$

The previous algorithm can be easily adaptable for more than one single user terminal: instead of having just one elevation angle, we have several elevation angles (i.e. the location of several user terminals). The formulae: C' received by S2 from S1 = Σ C' received by S2 from UTs, applies. Thus, for each trial, we calculate: $\Gamma_{S1->S2} = \text{Mean}[\ \Gamma_{S1->S2}\text{(for each UT)}\ ]$. After 10 000 trials, a distribution of Γ is obtained.

2 Simulation results for Globalstar / Odyssey

The simulation ran with 100 000 trials.

Considering just one user terminal, the Γ distribution is quite wide. For example, in the case of Cmin, $\Gamma_{\text{Globalstar->Odyssey}}$ may exceed 30 (14,8 dB), but the probability of having a $\Gamma_{\text{Globalstar->Odyssey}}$ so high is below 0,01%.

As soon as we consider more than one terminal, the range of Γ is decreasing strongly because of the average effect. In the case of Cmin, which is the worst case, for 5 terminals, the maximum value of $\Gamma_{\text{Globalstar->Odyssey}}$ is 13 (11 dB) with a probability of 0,01% and for 10 terminals, the maximum is 8 (9 dB) with a probability of 0,05%.

In all cases, the distribution curves show that with a level of traffic greater or equal to 10 active terminals, the mean value of Γ may be applied in the formulae given the power received by a satellite as a function of the other system satellite received power.

Table 20

	mean ($\Gamma_{\text{Globalstar->Odyssey}}$)			mean ($\Gamma_{\text{Odyssey->Globalstar}}$)		
	Γ5% (1UT)	Γ5% (5UT)	Γ5% (10UT)	Γ5% (1UT)	Γ5% (5UT)	Γ5% (10UT)
Cmin	2,34			1,26		
	6.17	5.41	4.62	3.45	2.99	2.52
Cavg	1,65			0,93		
	5.10	2.91	2.5	2.27	1.41	1.27
Cmax	1,41			0,75		
	3.37	2.15	1.93	1.42	1.03	0.96

The mean Γ varies from 2,34 (3,7 dB) for $\Gamma_{\text{Globalstar->Odyssey}}$ in the case of the Cmin hypothesis to 0,75 (-1,25dB) for $\Gamma_{\text{Odyssey->Globalstar}}$ in the case of the Cmax hypothesis.

ANNEX B

SELF-SHARING SCENARIO
APPLICATION WITH THE GLOBALSTAR CHARACTERISTICS

1 Introduction

This theoretical case of a self-sharing scenario was suggested in order to work with simplistic assumptions. It was proposed to make the studies on the sharing scenario for two CDMA systems having exactly the same characteristics.

2 Calculation of the fading factor

Let us consider the auto-sharing scenario for Globalstar, i.e., let us assume the following scenario:
Globalstar_a has to share the same frequency band with another system, which has exactly the same characteristics, Globalstar_b.

Table 21: mean values of G for these cases:

Γ (Gl*_a <-> Gl*_b)	1 UT	5 Uts	10 UTs
Cmin	2,0	2,0	2,0
Cavg	1,4	1,4	1,4
Cmax	1,2	1,2	1,2

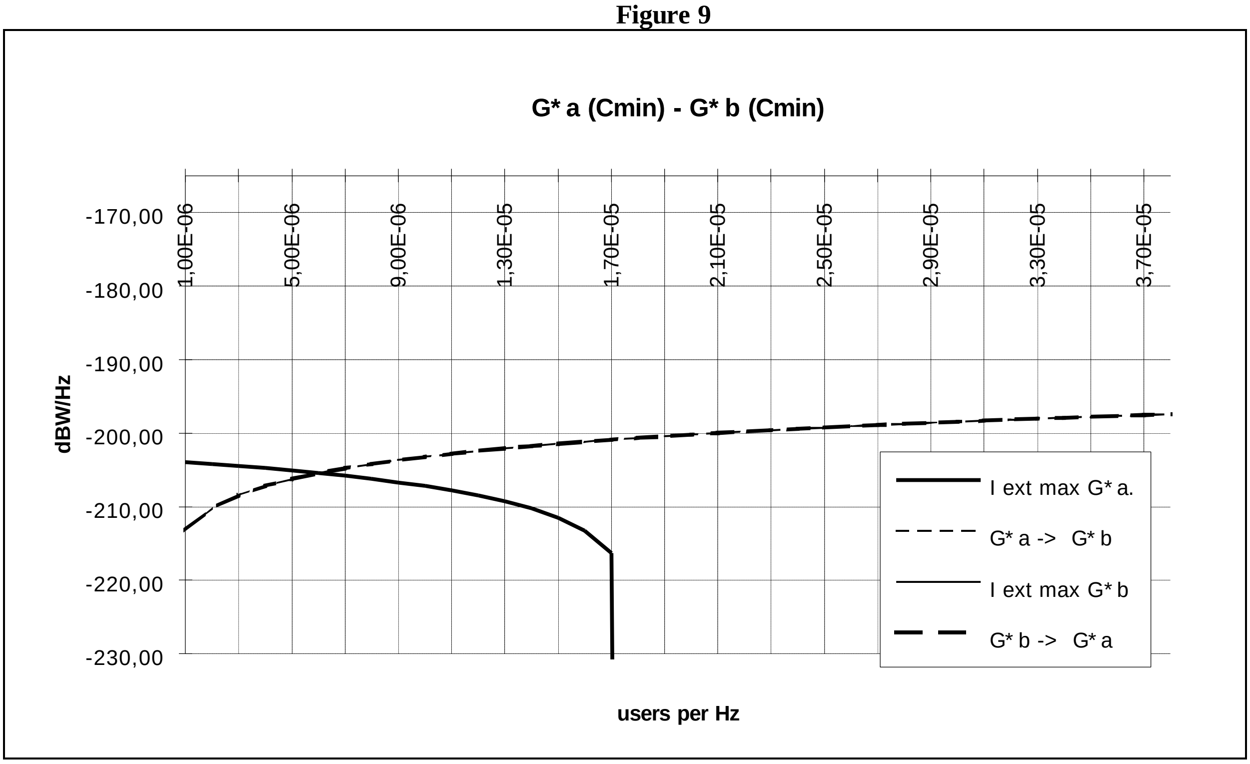
Table 22: 5% values of G for these cases:

Γ (Gl*_a <-> Gl*_b)	1 UT	5 Uts	10 UTs
Cmin	5,3	4,5	4,0
Cavg	4,3	2,5	2,1
Cmax	3,1	1,8	1,6

3 The average case

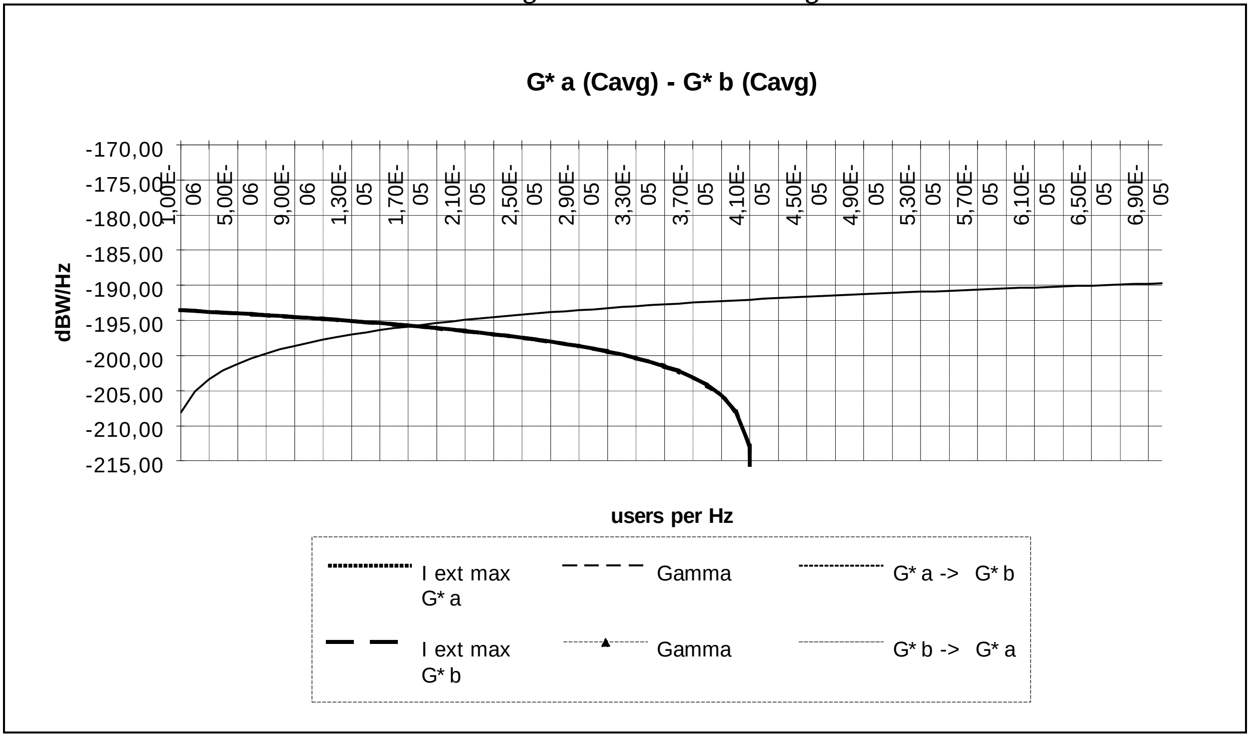
Let us now look at the sharing curves. In the hypothesis where Globalstar_a and Globalstar_b are with Cmin, the curve is the following:

Figure 9



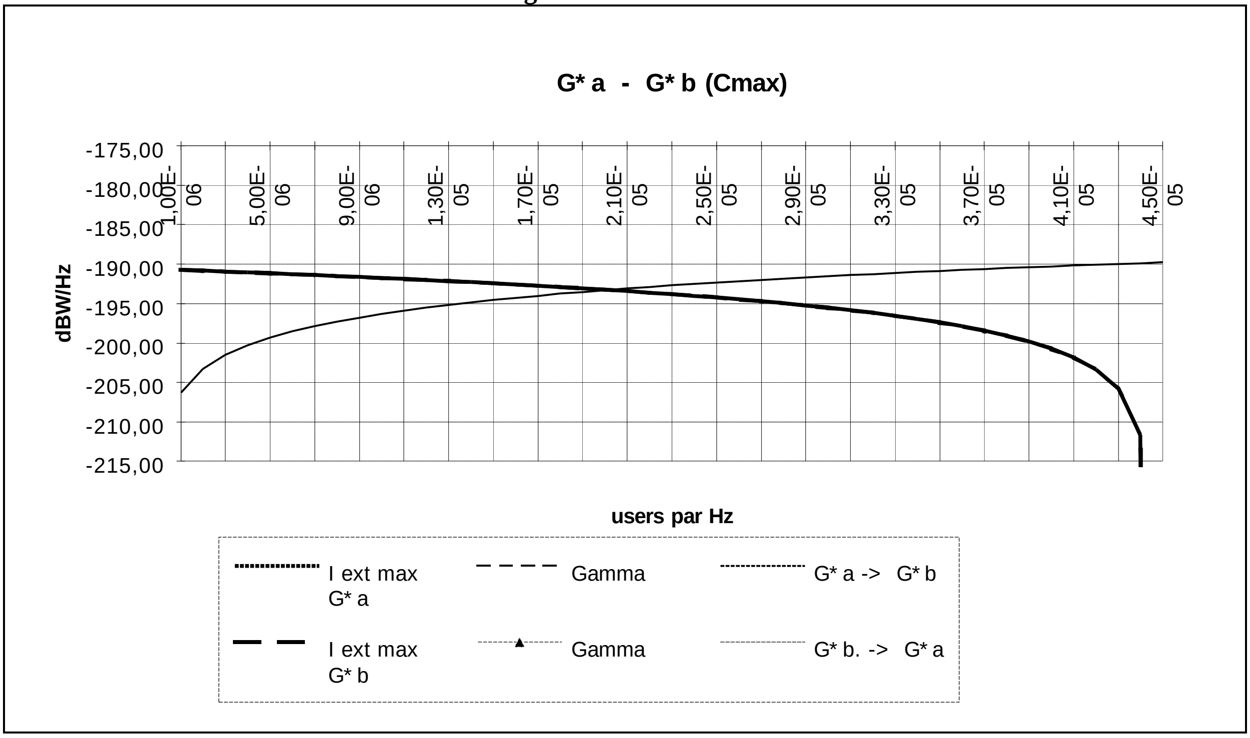
In the case of only one system, the maximum global capacity is 1,7e-5 active users per Hz. With the sharing scenario, the maximum global capacity is about 1,2 e-5 active users per Hz, thus one system looses a maximum of 64 % of its capacity when it shares the frequency band with another system. The ideal case would be 50%. This is an extreme case because we at the limits of the validity of the simulation.

Figure 10: The case of Cavg:



In the case of only one system, the maximum global capacity is 4,1e-5 active users per Hz. With the sharing scenario, the maximum global capacity is about 1,7 e-5 active users per Hz, thus one system loses a maximum of 57 % of its capacity when it shares the frequency band with another system.

Figure 11: the case of Cmax:



In the case of only one system, the maximum global capacity is 4,4e-5 active users per Hz. With the sharing scenario, the maximum global capacity is about 2,4 e-5 active users per Hz, thus one system loses a maximum of 54,5 % of its capacity when it shares the frequency band with another system. This figure is quite optimistic, considering that here we also reach the limits of the validity of the simulation.

4 The outage case

The results obtained with the algorithm described above are the following:

Table 23

Volume of traffic for each system	users/Hz	users/spot	users/ channel	I_{ext} (dBW/Hz)	$N_{\text{received by}}$ B (dBW/Hz)	Interference probability
low	3.10^{-6}	33	3,6	-191	-202	0,06 %
average	$1{,}1.10^{-5}$	121	13,4	-192	-196	1,00 %
high	$1{,}5.10^{-5}$	166	18,5	-192,5	-195	1,90 %
maximum	$1{,}8.10^{-5}$	199	22,1	-193	-194	3,40 %

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ANNEX C

APPLICATION WITH COURIER FIGURES

Courier system (CR)

1- system values

altitude (m)	800000	
spot size ratio: Courier/G*	0,182799824	assumed
ratio: Gsat_CR. / Gsat_G*	1,506607066	
bandwidth ratio: CR/G*	0,89	
bandwidth (Hz)	1,10E+06	
channel number	10	
(Eb/N0)req (dB)	5	assumed
average user data rate (bit/s)	2880	assumed
(C/N)req (dB)	-20,82	
k	1,38E-23	
delta: power ctrl factor	1,35	assumed
r: sopt co-coverage factor	1,1	assumed
system noise temperature (K)	450	
Nth (dBW/1,1MHz)	-141,66	
frequency (MHz)	1,61E+09	

2- Maximum received power in a spot beam for one CR user

average distance mob-sat (m)	1,58E+06	assumed
max. tx power (dBW/1,1MHz)	6,9	
free space loss (dBW/1,1MHz)	-160,55	
satellite antenna gain (dB)	15,67	
max received pow.(dBW/1,1MHz)	*-137,98*	
C/Nth (dB)	3,67	

3- Minimum received power in a spot beam for one CR user

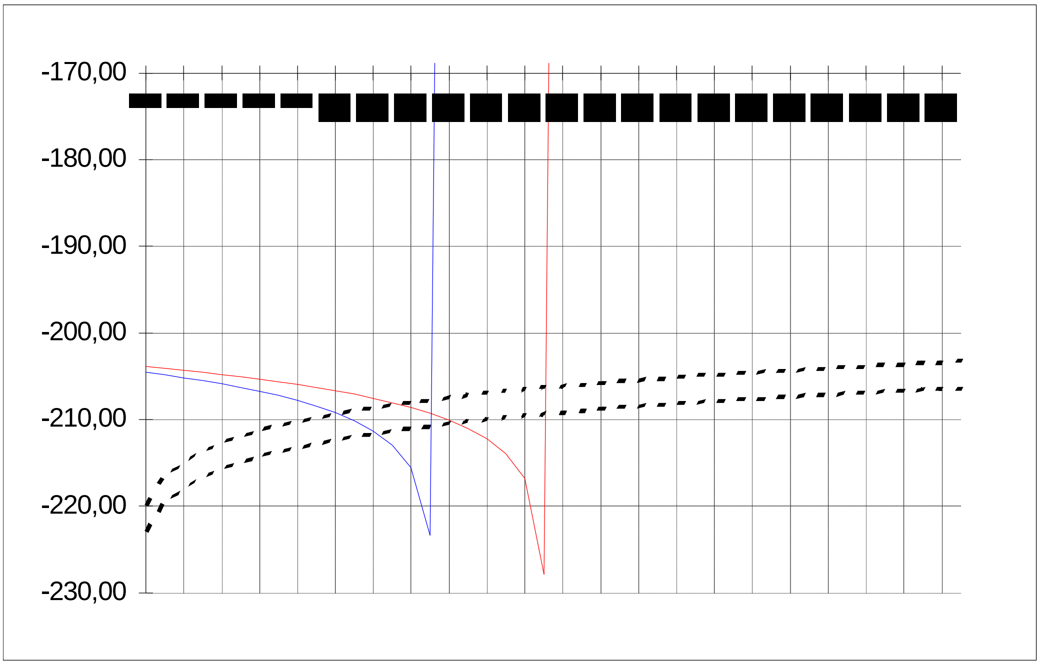
min. received pow.(dBW/1,1MHz)	-160,48
C/Nth (dB)	-18,82

4- Average received power in a spot beam for one CR user

av. received pow. (dBW/1,1MHz)	-140,97
C/Nth (dB)	0,69

Let us consider both systems operating at the minimum level. On the first figure, we can see 4 curve: $I_{ext_}$max bearable by Globalstar in one of its carriers, assuming a capacity of active users per channel and per beam, the noise produced by Globalstar into one Courier channel of a spot as a function of the capacity of the Globalstar system, and the same type of curves for Courier.

Figure 12: I_{ext} max and Interference from one system into the other



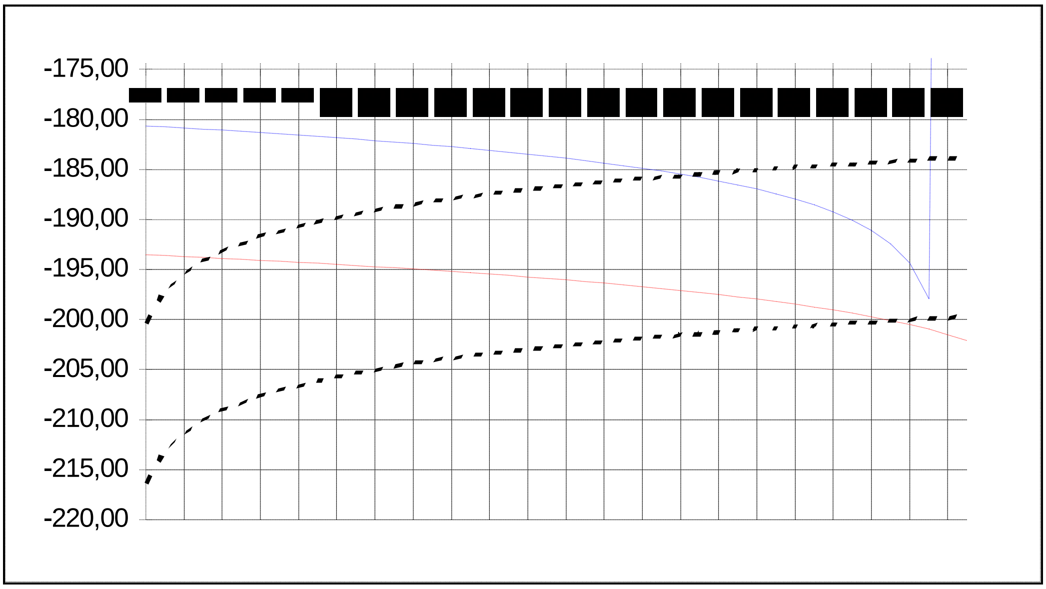
With:

for Globalstar: Creceived=Cmin
for Courier: Creceived=Cmin

We can see that under a certain capacity for each system, there is no harmful interference. But if the capacity is bigger, there will be harmful interference. In this case the system will require its terminals to have a greater transmit power level.

Thus let us consider the case of an average received power.

Figure 13: I_{ext} max and Interference from one system into the other



With:

for Globalstar: Creceived=Cmoy
for Courier: Creceived=Cmoy

We can see on this figure that Globalstar does not produce harmful interference into Courier, but Courier produces harmful interference into Globalstar. We can derive from the curve the following figures:

Table 24

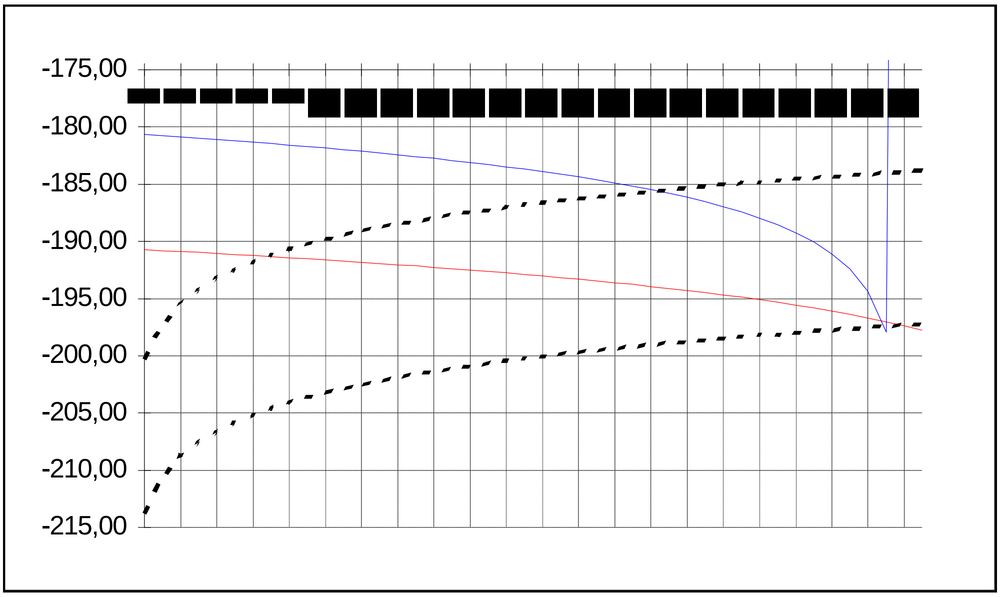
CR capacity	0	1	2	3	4	5	6...	...40
G* capacity	44	40	29	16	4	1	0...	...0

This table can be read as followed: If there are no Courier active users, then the capacity of the Globalstar system is 44. If there is 1 active user per channel and per beam in the Courier system, then the capacity of the Globalstar system will decrease to 40 users per beam and per channel, etc., down to if there are 6 active users per channel and per beam in the Courier system, then the Globalstar capacity is 0.

Thus the Globalstar system will require its terminals to transmit with a higher power level.

Globalstar will have a maximum received level and Courier will still have an average received power.

Figure 14: I_{ext} max and Interference from one system into the other



With:

for Globalstar: Creceived=Cmax
for Courier: Creceived=Cmoy

We can see that Courier still produces harmful interference into Globalstar, and Globalstar does not produce harmful interference into Courier (except around the point A, which is at the limit of capacity). The **table** of the shared capacity is now:

Table 25

CR	0	1	2	3	4	5	6	7	8	9	10...	...40
G*	44	44	44	35	29	25	18	11	8	3	0.....	0

CONCLUSIONS

We can see that the results depend very much on the received power, and thus on the transmit power, on the power control and on the propagation channel model.

If the number of the active users increases, self-interference increases also and the level of external interference the system can support is decreasing. Moreover, it produces more interference into the other system.

In a general case, Courier produces harmful interference into Globalstar, without being interfered by Globalstar.

This study shows that the system with the more powerful terminal will drive the traffic.

The limits of this simulation are the following:

- The simulation takes into account only the uplink.
- The fact that the polarisation may be different has not been taken into account.
- The power modelling may be improved.
- Some figures about Courier have to be confirmed.