

# Global Coverage Mobile Satellite Systems: System Availability versus Channel Propagation Impairments

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## 1 Abstract

Mobile Satellite Systems (MSS) in Highly Elliptical (HEO) and circular Earth orbits at Medium (MEO) and Low (LEO) altitudes have been intensively studied in the last few years as an effective means of providing global communication services. Such global coverage MSS networks are also expected to mitigate typical channel impairments usually encountered in geostationary Land Mobile Satellite (LMS) systems. In the design stages of these satellite networks, information regarding the mobile propagation channel is needed to assess the overall link availability versus elevation angle and environmental scenarios. For multisatellite LMS configurations, the mobile user on the Earth surface sees at any given time more than one satellite of the constellation. In our paper, it is shown that, under certain working assumptions regarding the statistics of the propagation channel, an improvement of the link availability may be achieved through the use of a multisatellite constellation. The analyses have been carried out using the European Space Agency (ESA) LMS propagation data base which presently covers a wide range of elevation angles and environmental scenarios.

## 2 Introduction

For a geostationary (GEO) LMS system, large implementation margins are usually required to compensate for signal blockage due to man-made or natural obstacles and for multipath effects. Unfortunately a consistent part of the potential users re-

sides in locations around the world (Europe, North America, Commonwealth of Independent States, Australia and Japan) where the elevation angle is almost always below 30-40 degrees; under these conditions, as a satellite is power limited, we must accept a degradation in the quality of the communication link. Alternative satellite constellations in HEO and MEO configurations (MAGSS-14, M-HEO, [1]-[2]) have been recently studied, at the European Space Research and Technology Centre (ESTEC); these systems can provide a very large coverage (global for MAGSS-14), enhanced in the regions between 30° and 60°. An additional feature of MAGSS-14 and M-HEO is the multivisibility, i.e. the intrinsic possibility for the mobile (or hand-held) terminal to have in sight more than one satellite of the constellation; the user equipped with a smart receiver may therefore be able to select the one presenting the best propagation conditions. The number of the satellites simultaneously seen by the receive terminal depends on the location and varies within the day. For each of these satellite-mobile communication links we have different elevation angles and certainly different propagation statistics, these varying in a uniform environment only with the elevation angle. The objective of this paper is to estimate whether, statistically-wise, an improvement of the overall link availability can be achieved with respect to a GEO system. The analysis has been performed making use of a comprehensive propagation data base, owned by ESA. These experimental data and the corresponding empirical model currently cover a wide range of elevation angles and environments. In this paper, we have limited our effort to the analysis of tree-shadowed

environments only.

### 3 The channel model

Several experimental campaigns have been carried out in the last decade to collect narrowband data for the characterisation of the LMS propagation channel, ([3]). The European Space Agency has embarked in a number of projects to investigate these propagation impairments as a function of frequency (L- and S-bands), elevation angle and environments, ([4]-[6]). Recently ([7]), a modified version of the Empirical Roadside Shadowing model, originally developed by Vogel and Goldhirsh ([3]), has been elaborated and validated with the ESA LMS propagation data base. In our Modified ERS (MERS) model, the range of elevation angles spans from 20° to 80° and the Percentage of Optical Shadowing (POS) from 35% to 85%; the roadside trees were also of deciduous variety, as in the ERS model. The empirical expression, obtained in two different forms by curve fitting the measured cumulative fade distributions, is given, in dB, by:

$$F(Pr, \theta) = -A(\theta)\ln(Pr) + B(\theta) \quad (1)$$

$$F(Pr, \theta) = \alpha(Pr)\theta^2 + \beta(Pr)\theta + \gamma(Pr) \quad (2)$$

where  $Pr$  is the percentage of the distance (and time, with a vehicle at constant speed) over which the fade is exceeded and  $\theta$  is the elevation angle. With respect to the ERS model, we have extended and validated the equations (1) and (2) for values of  $Pr$  up to 30%. In terms more familiar to system engineers,  $Pr$  is an indication of the outage experienced in the channel given a certain fade margin on the link. The parameters  $A$  and  $B$ , in dB, only depend on the elevation angle:

$$A(\theta) = a_1\theta^2 + a_2\theta + a_3 \quad (3)$$

with  $a_1 = 1.117 \cdot 10^{-4}$ ,  $a_2 = -0.0701$ ,  $a_3 = 6.1304$

$$B(\theta) = b_1\theta^2 + b_2\theta + b_3 \quad (4)$$

with  $b_1 = 0.0032$ ,  $b_2 = -0.6612$ ,  $b_3 = 37.8581$ .

The coefficients  $\alpha$ ,  $\beta$  and  $\gamma$  in equation (2) depend only on the outage probability  $Pr$ ; they are reported in Table 1.

$Pr$ (%)	$\alpha(Pr)$	$\beta(Pr)$	$\gamma(Pr)$
1	0.0038	-0.7147	38.7381
5	0.0021	-0.4605	26.4910
10	0.0026	-0.4603	23.1121
15	0.0030	-0.4815	21.4773
20	0.0033	-0.4851	20.0729
30	0.0032	-0.4533	17.4575

Table 1. MERS parameters, as in equation (2).

In Fig. 1, the parametrical curves obtained from the MERS model, equation (1), are plotted with the actual experimental data; the computed rms error is in this case 0.5 dB. For equation (2) the best fit to the experimental data was found to be practically the same. Equation (1) will be used for the computation of  $Pr$  for any of the satellites of the constellation visible to the mobile terminal at any given time, within a period of 24 hours.

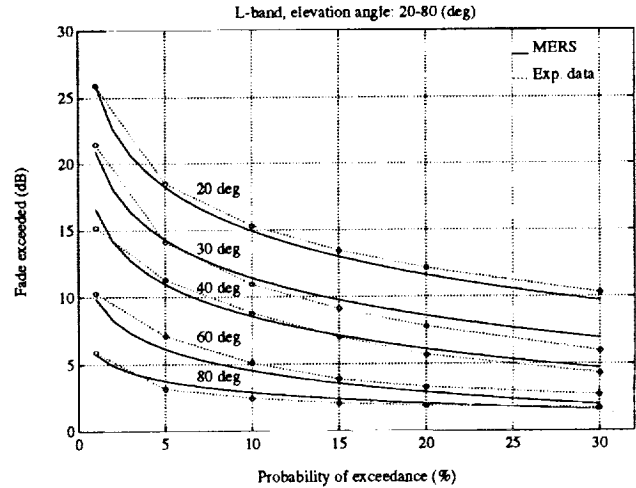


Fig. 1 MERS model vs. experimental data

### 4 Multivisibility

We will now apply the MERS model presented in the previous section to estimate whether an improvement in the overall link availability can be expected in a multisatellite LMS system with respect to a geostationary one. It has to be stressed that we are not considering here multivisibility as a true diversity scheme; we have limited our work only to optical and geometrical considerations. A true diversity technique would have a strong impact on

the coverage achievable by the multisatellite LMS, on its frequency plan and number of satellites, on the receiver design and so forth. The MAGSS-14 ([1]) mobile satellite constellation is hereafter taken into account; three European locations have been selected to test the applicability of the multivisibility concept, namely Rome, Noordwijk (ESTEC) and Stockholm. The mobile or hand-held terminals are assumed to roam, during the duration of a call (we have not considered for the time-being broadcasting services) in uniform wooded areas in the outskirts of the cities previously mentioned, where the MERS model is expected to be applicable. A short description of the main features of the LMS system under consideration will be now given.

### MAGSS-14

Within the framework of its ARCHIMEDES project, ESA is examining the possibility of exploiting the potential advantages of multiregional or global coverage LMS systems for mobile, portable and hand-held terminals. The communication services currently investigated span from voice and data channels (up to 4.8 kbit/s) to high quality broadcasting. The orbital parameters of relevance for our application are reported in the following table. For other details on the MAGSS-14 overall objectives at system level, see references [1].

	MAGSS-14
No. of satellites	14
Orbital period (hours)	6
Apogee altitude (km)	10354
Perigee altitude (km)	10354
Inclination (degrees)	56

Table 2. MAGSS-14 orbital parameters

#### 4.1 Overall link availability

The following assumptions on the channel statistics have been taken into account to estimate the overall link availability in case of multivisibility:

- the MERS channel model, within its range of applicability, is herein considered to compute fade margins and outage probabilities, (eq. 1);
- due to the intrinsic limitations of our empirical channel model, satellites seen from the termi-

nal location at elevation angles below  $20^\circ$  are disregarded;

- satellites at elevation angles higher than  $80^\circ$  present channel statistics identical to those at  $80^\circ$ ;
- the wooded environments for the locations under test have all the same general physical characteristics;
- these physical characteristics and the associated channel statistics do not change in azimuth and during the day;
- longitude and latitude of the receive terminal remain constant during the duration of the call (3 minutes, as working assumption).

In figures 2 and 3 we have reported, as an example, the number of visible satellites and the elevation angles of the 14 satellites of the constellation during a 24 hours period at ESTEC, respectively.

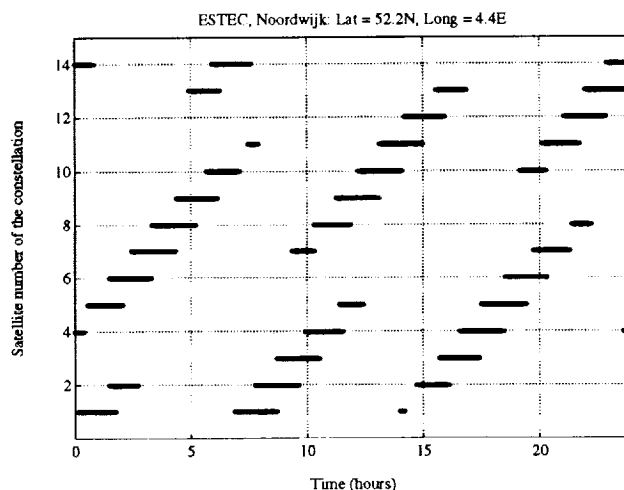


Fig. 2 Visible satellites at ESTEC

A sampling interval of 3 minutes has been used in the simulation. The maximum elevation angle during the day is instead presented in figure 4; it is fairly easy to recognise that the latter is the envelope of the curves in Fig. 3. The computation of the overall link availability in a situation of optical multivisibility requires further assumptions in addition to the ones previously quoted.

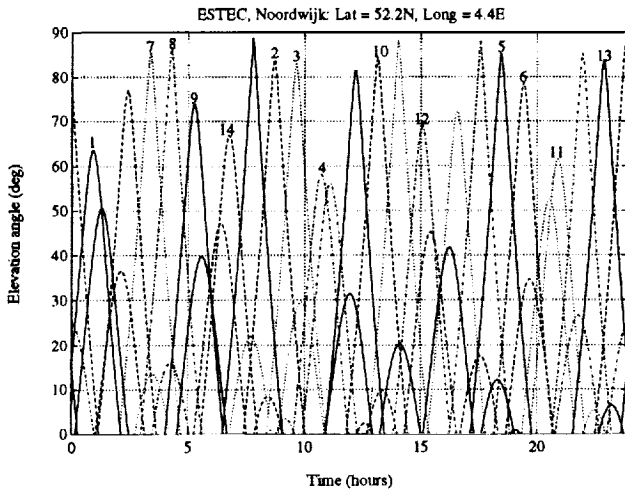


Fig. 3 Elevation angles of the visible satellites

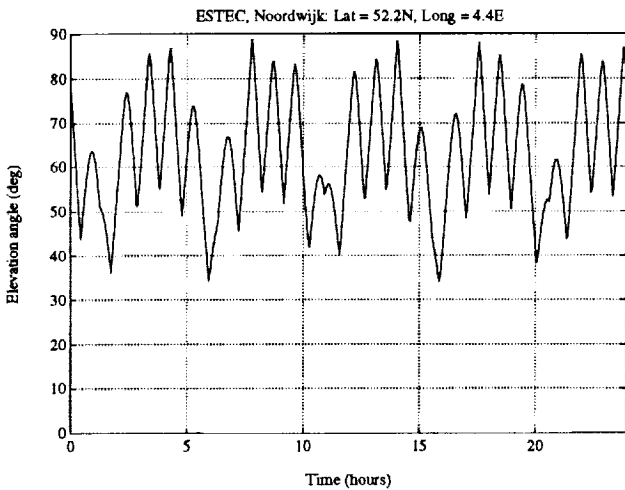


Fig. 4 Maximum elevation angle

With more than one visible satellite to the mobile or hand-held terminal at any given time, we can apply the MERS model to compute, for each of them, the probability of outage  $Pr$ , the elevation angle being the only changing parameter. From a probabilistic point of view, we might consider the multivisibility as the combination of events all characterised by the same distribution function. These events are, in the real world, correlated due to the environment surrounding the receive terminal and to the particular satellite constellation. We should therefore consider the joint probabilities to estimate the overall link availability. This implies, for any  $i$ -th sampling interval, that the multivisibility event can be characterised as:

$$\begin{aligned} S_{multi,i} &= \{S_{1,i}, S_{2,i}, \dots, S_{k,i}, \dots\} \\ &= \{S_{1,i} \cap S_{2,i} \cap \dots \cap S_{k,i} \dots\} \end{aligned} \quad (5)$$

where  $S_{k,i}$  is the event associated to the  $k$ -th satellite visible ( $k$  changes with location and time) to the terminal, during the  $i$ -th sampling interval. The computation of the probability of the event  $S_{multi,i}$  requires, unless additional hypotheses are made, the knowledge of the conditional probabilities  $Pr\{S_{1,i} | S_{2,i}, \dots, S_{k,i}, \dots\}$  and so forth. These are usually not available. We have then decided to estimate boundary conditions assuming, on one hand, uncorrelated events and, on the other, totally correlated; in the attempt to obtaining results as close as possible to actual operational situations, we have also calculated intermediate conditions making quite general working assumptions on the diversity philosophy, at system and receiver levels.

#### Case 1: channels uncorrelated

In practical terms, this means that the presence of vegetation does not play any effective role, probabilistically-wise, on the channel statistics of any visible satellite within a sampling interval. In such a case, we then have:

$$Pr\{S_{multi,i}\} = \prod_k Pr\{S_{k,i}\} \quad (6)$$

This is clearly the best overall propagation channel we can consider in terms of highest link availability.

#### Case 2: channels totally correlated

However low the occurrence of such situation might be (e.g. a receive terminal completely surrounded by uniform vegetation with two satellites in visibility on the same orbital plane, during the sampling interval) we must consider it to determine the other boundary condition. In this case, the selection of one of the visible satellites during the call is assumed absolutely random:

$$Pr\{S_{multi,i}\} = \frac{1}{k} \sum_k Pr\{S_{k,i}\} \quad (7)$$

#### Case 3: channels partly correlated

This is certainly a likely situation and the one which has probably a more direct impact in the implementation of a true diversity scheme. We will assume that the mobile or hand-held terminal is equipped with a receiver capable of selecting at call set-up and for its entire duration (3 minutes) the satellite at the highest elevation angle. In a way, we are trying to find a more realistic estimator possibly closer to an actual system implementation.

The average availability levels are summarised in Table 2 for the three margin figures considered, i.e. 3, 5 and 7 dB. In Figures 5, the overall link availabilities are reported for ESTEC, assuming a fixed margin of 7 dB; the call set-up is uniformly distributed during the 24 hours period. For the figures given in Table 2, the maximum rms error is 9%; such limited fluctuation of the availability figure around its average value confirms that the assumption of a call set-up randomly distributed in the 24 hours period is reasonable.

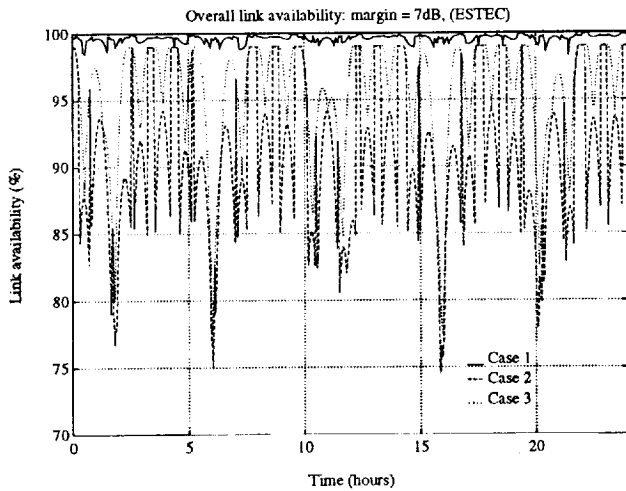


Fig. 5 Link availability for MAGSS-14, ESTEC

Location	Link availability (%)		
	Case 1	Case 2	Case 3
Stockholm, 3 dB	95	79	79
Stockholm, 5 dB	98	88	89
Stockholm, 7 dB	99	90	94
ESTEC, 3 dB	96	81	81
ESTEC, 5 dB	98	89	91
ESTEC, 7 dB	99	91	96
Rome, 3 dB	96	81	81
Rome, 5 dB	98	89	91
Rome, 7 dB	99	91	96

Table 2 Overall link availabilities, MAGSS-14

As expected, the case of channels totally uncorrelated and correlated provide the boundary conditions for the analysis whereas the intermediate situation of partial correlation (Case 3) well represents a possible operational scenario. In many sampling intervals, the latter overlaps with the bottom curve and this happens more frequently with low fade margins; this can be explained considering that in

some cases only two satellites are optically visible to the receive terminal. If for one of them, this depending upon the elevation angle, the available margin is not enough then Case 2 and 3 present the same availability figures. A direct comparison with a geostationary system has been attempted considering the same locations and a satellite at 10E. The results are plotted in the figures 6, 7 and 8.

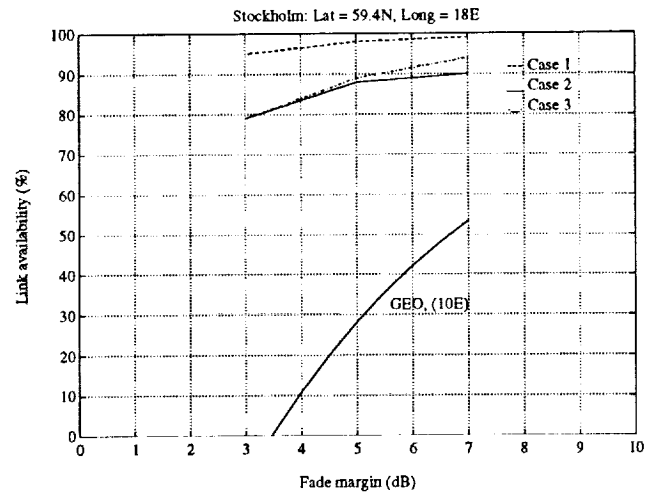


Fig. 6 Link availability (MAGSS-14 vs. GEO)

The results reported in the last three figures must be carefully interpreted. For the locations under investigation given a fixed margin on the satellite-mobile link, a multisatellite LMS system provides in general a much better link availability than a conventional geostationary. This improvement varies with the location considered and the available fade margin; the higher the latitude of the place the hand-held or mobile terminal dwells in, the higher the benefit introduced by a multisatellite constella-

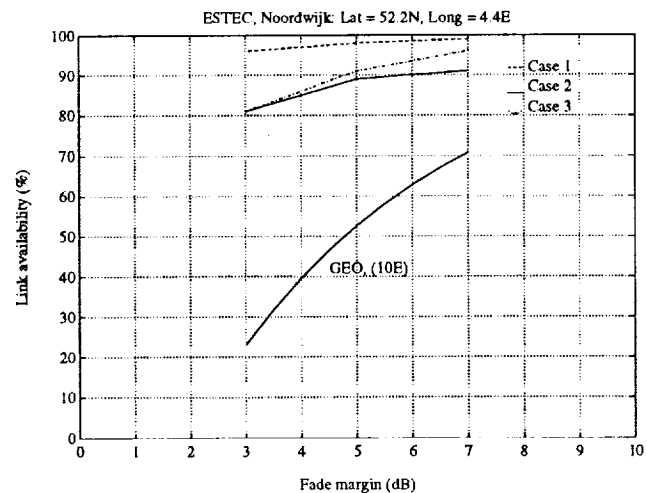


Fig. 7 Link availability (MAGSS-14 vs. GEO)

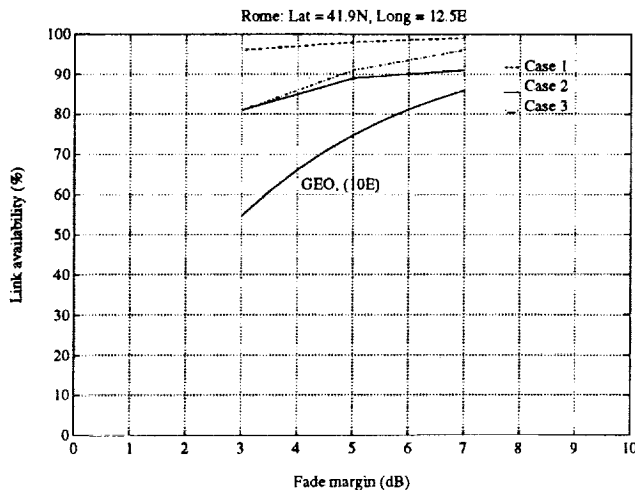


Fig. 8 Link availability (MAGSS-14 vs. GEO)

tion (in Stockholm we move from a 53% figure up to a minimum of 90% at 7 dB in multivisibility conditions). On the other hand, the higher the fade margin made available on the link, the lower the gap between multivisibility and geostationary systems.

It is instead debatable whether we can trade-off link availability with maximum allocated fade margin, that is RF power. Unless specific hypotheses on the system frequency plan and on the diversity technique implemented at receiver level are made, multivisibility in general deteriorates the interference environment in that it lowers the average C/M. Under this sort of considerations, we can not straightforwardly conclude from the previous curves that we can save power, having fixed a minimum goal for the link availability.

## 5 Conclusions

In this paper we have estimated, under certain assumptions on the channel statistics, that a non negligible improvement in the link availability can be expected for a multisatellite LMS constellation with respect to a conventional geostationary system. This improvement depends on the available fade margin and varies with the geographical location. The higher the latitude and the lower the available system fade margin, the higher the benefit coming from the use of a multisatellite constellation. It must be finally reminded that we have only considered geometrical not true multivisibility

hence these results should be interpreted in terms of probabilistic boundary conditions.

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