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Improvement of QoS of Land Mobile Satellite Systems Using Diversity Techniques

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Abstract

In order to enhance the availability and the offered Quality of Service (QoS), Land Mobile Satellite Systems (LMSS) will have the option to use simultaneous transmission via two or more satellite as diversity. In this paper the performance of a TDMA and CDMA single user return link employing such a diversity reception is investigated by means of computer simulation using a multi state mobile satellite channel model. System capacity and availability have been theoretically evaluated under different operating conditions. The obtained results have shown that by using signal combining techniques improvement of the balance between service availability and system capacity is feasible.

Keywords: *LMSS, QoS, Diversity, Capacity*

1. Introduction

To enhance services available by the terrestrial Universal Mobile Telecommunication Systems (UMTS) global Land Mobile Satellite (LMS) Systems for multimedia telecommunication have been proposed and developed in recent years [1]. Service availability, Quality of Service (QoS) and capacity are perhaps the most important characteristics when evaluating the satisfaction of users employing LMS telecommunication systems. The majority of these systems are operated in L and S bands with their satellite installed in low and medium earth orbits (LEO/MEO). On the physical layer, the performance of LMS systems is strongly affected by their channel environment and the elevation angle that governs the fading condition due to the shadowing and blockage. Multiple reflections of the radio signal cause the signal to arrive at the mobile station via multiple paths, which differ in amplitude, phase and delay time. The multipath reception in combination with the low link margins and low elevation angles is the main cause for signal outages, reduced communication quality and system capacity. A well-known method to combat the effects of multipath fading is to obtain not just one, but several versions of a signal at the receiver. This principle is known as diversity. There are several ways of obtaining more than one version of a signal at the receiver. In the case of LMS systems the signals from different satellites are uncorrelated and thus, once several versions of a signal are obtained, they could be combined in various ways to improve the received signal quality. This technique is especially suited for LEO/MEO LMS systems since for the user usually there exist at least two visible satellites at any given time instant. Under this assumption the probability of space path shadowing or blockage to both satellites is significantly less than the probability of blockage to a single satellite. Furthermore, in order for the system designer to accurately determine the fade margins, reliable information about the channel conditions is required. To achieve this a satellite diversity scheme that adaptively selects the best line of sight satellite seems promising for LEO/MEO satellites systems. The satellite diversity effect assuming that the area is illuminated simultaneously by at least two satellites moving in LEO for urban and suburban environment [2]. In the past, many studies have been carried out employing LMS system propagation channel models suitable for assessing the diversity effect in various propagation environments [3],[4]. Although results obtained so far have given significant insights into system designing, an LMS system propagation channel model sufficient for assessing the satellite diversity effect has not yet been established because of complex and diversified LMS system propagation environments. With the present paper, the performance of a TDMA and a wideband CDMA single-user return link with the diversity reception is investigated using a multi-state mobile satellite channel model. The novelty of this paper is to accurately estimate the capacity and QoS improvements offered by the reception of signals from LEO satellites at different elevation angles.

2. Diversity scenario and assumptions

For satellite systems, quality of service and service availability depend very much upon the line-of-sight satellite availability. The satellite visibility is one of the major factors which influences satellite link availability, since the satellite channel behavior is depended on the link conditions between satellite and land user. Because of this, the LMS systems are using satellite constellation in low elevation orbits, which can provide multiple satellite visibility . As illustrated in Fig. 1, from the geometry of the satellite constellation in LEO systems, it is well known that the probability at least two satellites, one with high and one with low elevation angle, to be linked with the land user is very high. The proposed diversity scenario is discerning in the following assumptions:

- The simultaneous transmission of the data from two satellites,
- The use of multiple beams or scan beam antennas in satellite station, and
- The use of a combining technique in the land receiver as pre-detection diversity scheme.

For a LEO satellite system, the minimum beam width together with the satellite altitude determines the number of cells in a satellite coverage area. The coverage angle of the satellite is necessary in order to determine the number of antenna beams of a satellite. Because of the existing symmetry in the geometry of satellite footprint, if the coverage angle is θ , then θ can be calculated by [5]:

$$\theta = \sin^{-1}\left(\frac{R_E}{R_E + h}\sin\varphi\right) \quad (1)$$

Where R_E denotes the radius of the earth, h is the satellite altitude and φ equals π/2 plus the minimum elevation angle. The number obtained in this way is the number of antenna beams that can fit across the diameter of the satellite coverage area.

The average number of active antenna beams per satellite, A, is given by [5]:

$$A = B_{max} \cdot \frac{A_E}{A_S \cdot N} \quad (2)$$

Where B_{max} is the number of antennas beams per satellite, A_E is the area of the earth, N is the number of satellites in the constellation and A_S is the satellite coverage area given by the equation:

$$A_S = 4R_E \int_0^{\pi/2}\int_0^{r} \frac{\rho d\rho d\theta}{\sqrt{R_E^2 - \rho^2}} = 2\pi R_E^2(1-\cos\psi) \quad (3)$$

Where,

$$r = R_E \sin\psi \text{ and } \psi = \pi - \varphi - \theta$$

3. Channnel model

In order to determine fade margin or to compensate for the fades using modulation and coding techniques, it is important for the system designers to have the most reliable information about the statistics of fade duration. Because the channel characteristics are depended on propagation effect through the channel, the proposed channel model is based on the state oriented modeling approach and for the implementation a multi state Markov chain model has been used. The land mobile satellite channel model, proposed for analysis is shown in fig. 1. The prediction of the received signal is a function of :

- Elevation angle,
- User velocity, and
- Type of environment the mobile traverses.

The three states, which are considered in the present paper, are given in table 1.

Table 1: State satellite channel conditions

State	Description
I	Line of sight condition
II	Slightly – moderate shadow condition
III	Fully blocked condition

The statistical signal level characteristics are considered in terms of the probability density function (pdf). Analytically, the state I is expressed by the Rician model, which is a phasor sum of constant and Rayleigh phasor. In state II the receive signal is the sum of a log normally

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distributed signal and a Rayleigh distributed signal. The signal in state III shows ully blocked condition and can be expressed only by the Rayleigh distribution.

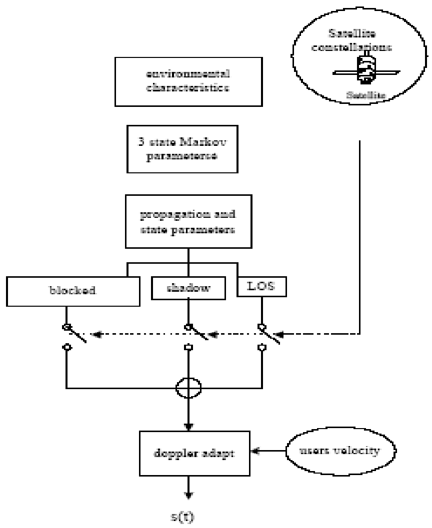


Fig1.Land Mobile satellite(LMS) channel model.

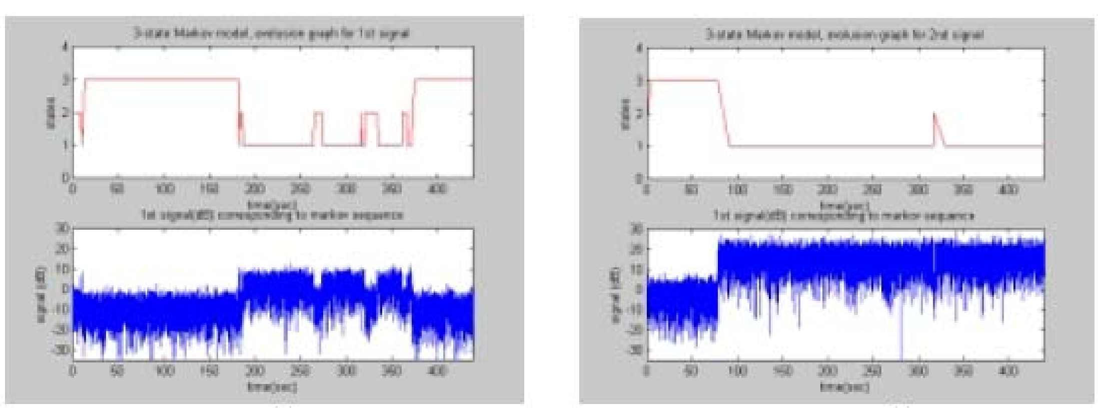
4. Diversity simulation and capacity results

In order to examine the performance of the transmission diversity, is important the knowledge of the envelopes of the received signals. Fig.4 shows the corresponding signal envelopes of the satellite with low and high elevation angle using the input parameter of the satellite channel simulator as shown in table 2.

In order to apply transmission diversity it is necessary for the land mobile user to employ a signal combining receiver unit. Two most of the most commonly used combining techniques are Equal Gain Combining (EGC) and the Maximum Ratio Combining (MRC). In Fig. 5 the computer simulation results of the signals received from two satellites using both of these diversity techniques are presented. Also in the same figure, the results of the second order characteristics of the received signals, i.e. the calculated Cumulative Fade Distribution (CDF), the Average Fade Duration (AFD) and the Level Crossing Rate (LCR) are shown as a function the signal level.

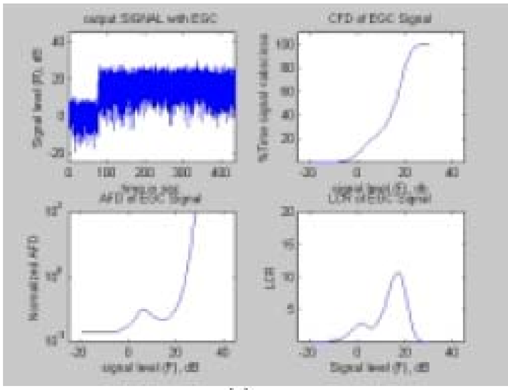
Table 2: Simulator input parameters

Parameter	Value - Unit
Environment type	1 for urban, or 2 for suburban environment
Velocity	Miles/h
Elevation angle of the 1st satellite (low elevation)	degree
Elevation angle of the 2nd satellite (high elevation)	degree
Rayleigh C/M mean-square-ratio of 1st signal	dB
Rayleigh C/M mean-square-ratio of 2nd signal	dB
Lognormal mean of 1st direct component	dB
Lognormal mean of 2nd direct component	dB
Constant L_1(m)	Average distance between obstacles in urban area
Constant L_2(m)	Average distance between obstacles in suburban area
Initial state	1-I, 2-II and 3-III
Operating frequency	MHz
Lognormal standard deviation of noise	dB

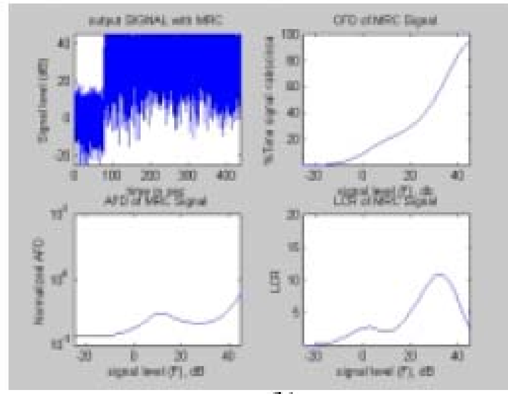


(a) (b)

Fig.4: Classification of propagation states and the corresponding signal envelope of the satellite with (a) low elevation angle and (b) high elevation angle



(a)



(b)

Fig. 5: The final received envelope and the 2[nd] order statistical channel characteristics after the application of (a) the EGC method and (b) the MRC method

Considering a system which uses the BPSK modulation format, using the approach suggested in [5] the results for the following main parameters are calculated: i) Signal-to-Noise Ratio (SNR); ii) Carrier-to-Noise Ratio (CNR);iii) Bit Error Rate (BER); iv) Percentage of time for which the relation BER< 10^{-3} is satisfied (T_A); v) minimum CNR for which the relation BER< 10^{-3} is satisfied (CNR_{min}), and vi) Percentage of time for which the CNR > CNR_{min} (T_o). These results, which are summarized in Table 3, are necessary for estimating the communication performance and the overall system availability and capacity.

The use of narrow satellite beams, not only allows the use of satellite power effectively, but also the capability to reuse the frequency band in case of Frequency Division Multiple Access – FDMA and to outgrow the self interference limit in Code Division Multiple Access – CDMA. There are two types of satellite beams, the fixed and the scanning. In order to calculate the capacity of a system using scanning satellite beams, it is necessary to determine the satellite altitude and the antenna beam opening. The evaluation of the channel capacity for FDMA link and CDMA link has been analytically studied in [5], which considers the various system parameters such as EIRP.The channel capacity for the FDMA return link is given by:

$$M_{FDMA} = \frac{\left[\frac{N_0}{E_b}\right]_T \frac{B_{ch}T}{XL_{fu}} - \left[\frac{L_u K T_s B_{ch}}{EIRP_u G_{sr}}\right]_L - \frac{(N/C)_1 \alpha}{B_0^{\gamma}} - (N/C)_{sl}}{\frac{b}{B}\left[\frac{L_d L_{fd} B_0 \alpha K T_e B_{ch}}{EIRP_{Bd} G_d}\right]} \quad (4)$$

where $[N_o/E_b]$ is the total noise to bit energy ratio, B_{ch} is the predetection channel bandwidth, X is the loss of detectability due to fading and enhances the required bit energy to noise density ratio for normal path condition, T is the information bit period, L_{fu}, L_u, L_d, L_{fd} are the path loss and fading loss of up and down link respectively. Furthermore in the same equation, K is the Boltzamann's constant, $EIRP_u$ is the uplink effective isotropic radiated power, G_{sr} is the satellite receive antenna gain, T_s is the satellite system noise temperature, α is the voice activation, B_o is the multicarrier backoff of satellite power amplifier, T_e is the earth station system noise temperature, $EIRP_{Bd}$ is the satellite edge of coverage *EIRP* into area B, G_d is the receiving earth station antenna gain, *B* is the total coverage area, *b* is the beam area, $(N/C)_{sl}$ is the noise to carrier ratio due to side lobe interference and $(N/C)_1$ is approximately 10 dB for v = 1.4 (traveling wave tube amplifier).

The channel capacity for the CDMA return link for fixed beam scheme is given by:

$$M_{CDMA} = \frac{\left[\frac{N_0}{E_b}\right]_T \frac{WT}{L_{fu}} - \left[\frac{L_u K T_s W}{EIRP_u G_{sr}}\right]_L \lambda + \lambda A_{sl}}{\frac{\alpha b \lambda}{B}\left[1 + (1/k)\right] A_{sl} + \alpha(\lambda - 1) - \left[\frac{L_d L_{fd} B_0 \alpha K T_e W}{EIRP_{Bd} G_d}\right]} \quad (5)$$

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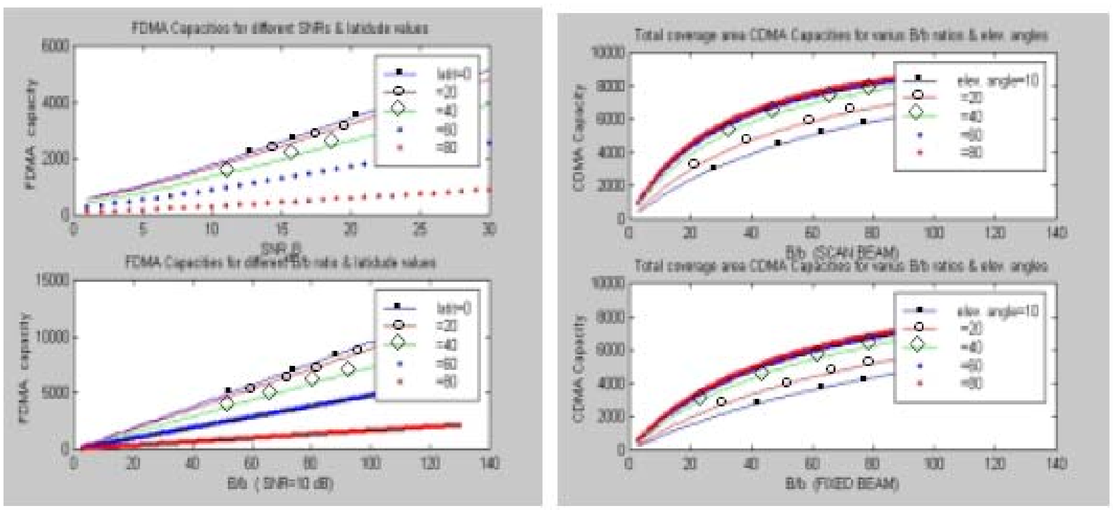
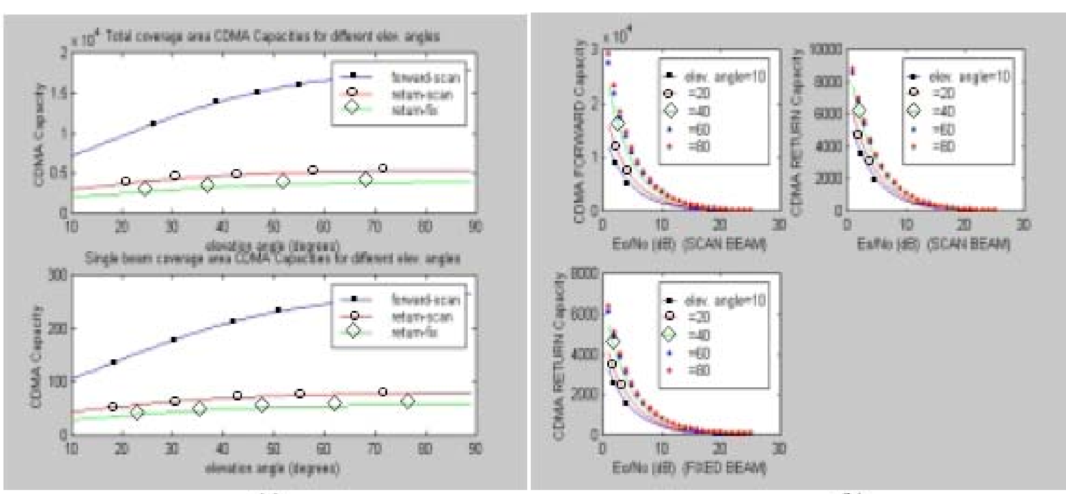
Table 3: Results about the availability and the channel performance

	1st satellite signal	2nd satellite signal	EGC signal	MRC signal
SNR	3,96	25,45	27,21	39,11
CNR	7,88	22,11	20,31	22,24
BER	0.0379	0.0051	0.005	0.0012
T_A	19,6	84,8	94,4	95,8
CNR_{min}	9,7383	9,2951	6,7821	7,4339
T_Q	19,8	85,8	94,6	94



(a) (b)

Fig. 6: (a) Channel capacity versus SNR and the total coverage to beam size ratio for different latitude angle in TDMA link (b) Channel capacity versus the total coverage to beam size ratio for different latitude angle in CDMA link for scan and fixed beam



(a) (b)

Fig. 7: Channel capacity versus elevation angle (a) for total coverage area and single beam coverage area and (b) the channel capacity versus the noise to bit energy ratio for CDMA return fixed beam link, return scan beam link and forward scan beam.

Table 4: Comparison of channel capacity with different combining technique

	1st satellite signal	2nd satellite signal	EGC signal	MRC signal
FDMA	169	1136	1226	1771
CDMA scan_forward	1387	3723	4219	5235
CDMA scan_return	708	1250	1933	1732

where the new parameters in Eq. (5) as compared to Eq. (4) are: the W, where W is the spread bandwidth, λ is the loss of detectability of PN modulated signal in correlation receivers after it has passed a limit, *1/k* is the ratio of the reflected downlink power and A_{sf} is a side lobe beam array factor. The corresponding equation for scanning beam is almost the same, only a few parameters (the sidelobe array factor and the satellite antenna gain will be different). For the evaluation of capacity, the previous simulation results have been assumed, for the required E_b/N_0 for which the *BER* is 10^{-3}. Also the used link parameters are the same as in [7] except Ricean parameter *k* and 10 MHz bandwidth. Fig.6 illustrates the channel capacity versus SNR and the total coverage to beam size ratio for different latitude angle in FDMA link and the channel capacity versus the total coverage to beam size ratio for different latitude angle in CDMA link for scan and fixed beam. These results shows that the channel capacities are dependent on the elevation angle under a given satellite EIRP and the number of the used antenna beams. The results in Fig.6 and Fig.7 were derived for a system using 700 km as satellite altitude, 20 degree as antenna beam opening and 32 kbps as channel bit rate. Fig. 7 illustrates the channel capacity versus elevation angle for total coverage area and single beam coverage area. The capacity increases a lot using multibeam coverage. Fig.7(b) shows the same conclusion from the curves of the channel capacity versus the noise to bit energy ratio for CDMA return fixed beam link, return scan beam link and forward scan beam.

6. Conclusions

In this paper the performance of availability and the capacity of a LMS system has been presented. The proposed channel model for the evaluation of the system performance is a multi state Markov chain statistical modeling approach. From the results it is shown that using the transmission diversity with the combination of a combining technique, we can improve the availability to capacity ratio.The results shows that the channel capacities are dependent on the elevation angle under a given satellite EIRP and the number of the used antenna beams. A technical method for increasing the system's capacity, without the increase of available bandwidth, is the use of multiple beam coverage. It is worth noting that the EGC is recommended for application in LEO LMS systems because it introduces less complexity, less cost and better percentage of time for which the CNR > CNR_{min} than the MRC.

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