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MOBILE SATELLITE CDMA SYSTEM

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CONTENTS

Abstract: In this paper, the basic aspects of the CDMA mobile satellite system including channel and receiver model, performance analysis of such system, and related simulation results are presented. Different multiple accesses used in mobile satellites are introduced and comparison of CDMA systems to single-channel-per-carrier FDMA systems including simulation results are also carried out which show that CDMA approach provides greater capacity in mobile satellite systems. The performance results together with capacity comparison results show that the spread spectrum CDMA approach is a feasible and appropriated candidate for mobile satellite communication.

1. INTRODUCTION

During last three decades satellite communications have become one of the most important carries especially in long distance realm of communications. Since the launch of first commercial satellite in 1965, the satellite industry has grown until it handles most international telephone traffic, all international and almost all domestic long-distance television program distribution, and rapidly growing proportion of new domestic voice and data channels. Satellites have significantly improved the reliability and the accuracy of aviation and maritime communications and navigation, removing theses functions from the high-frequency portion of the spectrum[1]. These changes have occurred because the technology is now available to put large spacecraft into synchronous orbit where, to an observer on the ground, they remain permanently at the same place in the sky.

This paper is organized as follows: In section 2, some general aspects of mobile satellite communication are reviewed. In section 3, the mobile satellite CDMA model is introduced and the performance of such system is analyzed. In section 4, capacity aspects of CDMA mobile satellite system is discussed, and in section 5, the final conclusion about the application of the CDMA approach in mobile satellite communication is made.

2. MOBILE SATELLITE COMMUNICATION SYSTEMS

Communication satellites that could provide PCS are considered "mobile satellites" because the object they communicate with on the Earth is capable of moving [4].

A satellite network consists of a geosynchronous or Low Earth Orbit satellite and a number of Earth stations that communicate with each other. In a single-beam satellite there is a transponder that operates as a repeater. It receives uplink signals, amplifies, and translates to a downlink frequency band. In a multibeam satellite there are multiple transponders that point to different regions on the Earth. Terminals within the same beam will use the same uplink and downlink frequency bands. A transmission between two terminals in different regions will therefore involve two roundtrips to the satellite, unless on-board switching between beams is provided on the satellite. It may be advantageous to do on-board processing for multibeam satellites or in a network consisting of several single-beam satellites. Then the transponder has to make certain routing decisions for each message [5].

There are several kinds of mobile satellite network solutions and proposals. The main infrastructure for most of them, however, is very similar to each other. Fig. 1 shows one example solution in which the network elements are; satellite, earth station, portable terminals, PSTN.

The ground communications segment is the critical link in the overall satellite network. Due to its complexity, the ground infrastructure component should be thought of at the same time

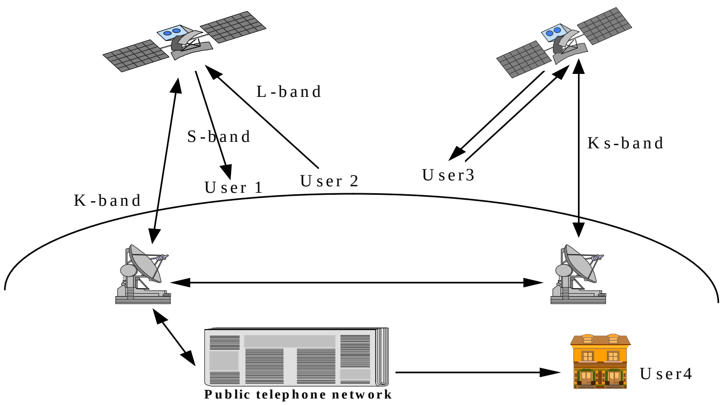

Figure 1. Mobile Satellite Network Solution [7].

as choosing a satellite to launch into orbit. It is most important from revenue generation standpoint since it handles all calls, billing, fraud detection and customer management.
The system architecture consists of a number of interconnected elements: the network operations center, the network communications controller, the remote monitor station, the system test station, an portions of the feederlink earth station, mobile terminal, and operational data hub [6]. Table 1 shows the most important mobile satellite system planing and their basic characteristics.

Table 1. Satellite Personal Communications Planing [1, 2, 3].

Satellite Personal Communications	Altitude (Km)	Multiple Access	Occupied Spectrum (MHz)	Services	Start of Services
GLOBALSTAR	1389	CDMA	16.5	Global roaming, extension to terrestrial cellular networks	By 1999
IRIDIUM	765	TDMA	10.5	Voice, data and paging to hand-held terminals	By 1998
ODYSSEY	10355 (MEO)	CDMA	16.5	Voice, data, paging to hand-held terminals	By 1997
CONSTELLATION	1020	CDMA	16.5	Wireless services to customers worldwide where no viable alternative exist	By 1997
ELLIPSO	429/2903	CDMA	16.5	Complements and expands existing cellular systems	By 1996
CALLING	700	TDMA	2 x 198 (fixed terminals) 2 x 12.4 (mobiles)	Rural telephony, remote parts (hand-held terminal)	By 1996

2.1 MOBILE SATELLITE SERVICES

The commercial availability of mobile satellite communications services began earnest in 1976 with the introduction of standard-A system, which evolved into the Inmarsat- A system of the International Maritime Satellite Organization (Inmarsat). Originally, voice communications services were offered to the commercial maritime community, with data services and land portable terminals being introduced later. While by today's standards the Inmarsat-A terminals are neither small nor cheap, there are over 10000 of them in service through out the world. Clearly, there exist major communications requirements that can be best be filled by mobile satellite communications systems.

The initial strength of mobile satellite communications is its ability to provide services to vast regions where such services could not be possibly be reliably provided by purely terrestrial systems due to geographical location (such as oceanic areas) or lack of a reliable terrestrial infrastructure (such as in many sparsely populated and developing countries).

Mobile satellite systems are capable of delivering a range of services to a wide variety of terminal types. Example of mobile satellite terminal platforms include land vehicles, aircraft, marine vessels, and remote data collection and control sites. Additionally, services can be provided to portable terminals, which are currently about the size of a briefcase, but maybe reduced to "handheld" size for future systems. Many services include position reporting e.g. Global Position System (GPS) to determine the location of the mobile satellite communication system. The type of communication channels available to the user can be subdivided into three categories [9]:

- Store-and-forward packet data channels
- Interactive packet data channels
- Circuit-switched channels

Store-and-forward packet channels, which are the easiest to implement, allow the transmission of small quantities of user data with delivery times that can be several minutes or more. This channel type is usually acceptable for services such as vehicle position reports (e.g., when tracking truck trailers, rail cars, or special cargos), paging, vehicle routing message, telexes, and for some emergency and distress signaling. However, for many emergency and distress applications, as well as for interactive messaging (such as inquiry-based services), a delay of up to several minutes is unacceptable. For these applications the second channel type, interactive packet data channel, is required. Finally, for applications involving real-time voice communications or the transmission of large amount of data (e.g. facsimile and file transfers), circuit-switched channels are needed.

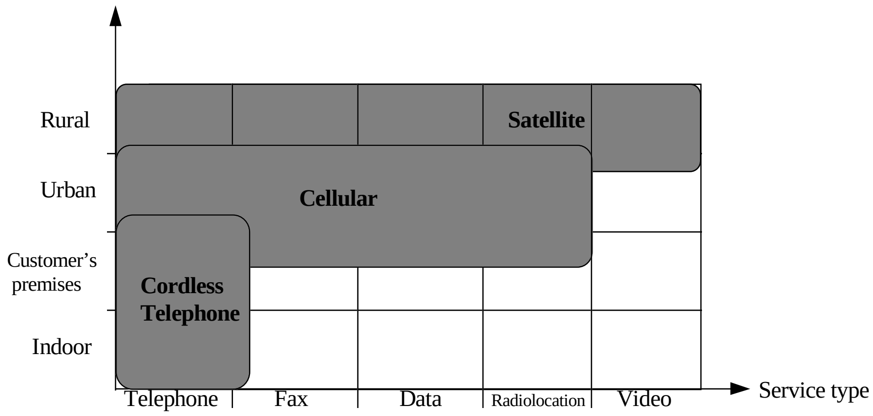

Figure 2. Complementary between terrestrial and satellite PCS Services [9].

In many cases, voice services provide a mobile telephone capability similar to those offered by cellular telephone, but offering much broader coverage,. In these cases a gateway station, which provides an interface with the public switched telephone network (PSTN), communicates with the mobile via the satellite (Fig. 1). In other cases mobile radio voice services can be offered to a closed user group (such as a government or large company), with the satellite communications being provided between the mobiles and a base station [8].

2.2 MULTIPLE ACCESS ALTERNATIVES IN MOBILE SATELLITE SYSTEMS

Because of large number of users, channel interference, fading shadowing etc. multiple access techniques are essential for mobile satellite systems. The most commonly used multiple access in mobile satellite systems are FDMA, TDMA, and CDMA.

In FDMA, the frequency spectrum is divided and the segments are apportioned to different users. In TDMA on the other hand, each user is apportioned the entire transmission resource periodically for a fraction of time. FDMA is the only one of the three access methods that can be used with analog as well as digital transmission.

In the narrowly focused application of digital communication through isolated orbit geostationary satellites and large earth terminals, the 1966 study found TDMA to be advantageous for a technical reason. In such applications, the most valuable commodity is the satellite transponder's transmitted power since this is proportional to payload weight. To utilize the power of transmitters most efficiently, they must be driven into saturation, where the amplifier operates as a nonlinear device. As a consequence, if multiple uplink user signals are simultaneously received by the satellite, the nonlinear amplifier generates undesired intermodulation products, which both interfere with the desired signals and rob them of downlink transmitted power. TDMA avoids this by having only one user access the satellite transponder at any given time interval. This advantage, however, is offset by a number of disadvantages, chief among them that the intermittent nature of the signal transmitted by the earth stations requires a high peak-to-average power ratio proportional to the number of users, which reduces the efficiency of the earth transmitters. With large antennas and expensive high-power amplifiers on the ground, this trade-off is acceptable.

CDMA relies on a particular signature sequence which is assigned to each user to ensure signal separability[10]. With the arrival of very small aperture terminals (VSATs) in 1980s, CDMA has become one of the most recent candidates for establishing multiple access in satellite systems. many mobile satellite systems have considered employing CDMA schemes for their land-mobile links. While there does not appear to be a single multiple access technique that is superior to others in all situations, there are characteristics of spread spectrum waveforms that give CDMA certain distinct advantages. The two basic problems with which the mobile radio system designer is faced are multipath fading of radio link and interference from other systems. Spread spectrum signals are effective in mitigating multipath because their wide bandwidth introduces frequency diversity. They are also useful in mitigating interference, again because of their wide bandwidth. The result of these effects is a higher capacity potential, by employing voice activity and frequency reuse, than that of nonspread access methods. Moreover, in CDMA in (in contrast to FDMA and TDMA), integration of circuit-mode and packet-mode traffic requires no special protocol, making an integrated voice/data system easy to realize [9]. The CDMA satellite system model is discussed in next chapter.

3. MOBILE SATELLITE CDMA SYSTEM MODEL

In this chapter a CDMA satellite system model based on main results of [11] are reviewed. In the mobile satellite systems shadowing and multipath fading are the most important aspect which should be taken into consideration in system modeling. As a result, the basic assumptions in system model described in this chapter are:

- The Line Of Sight (LOS) component under shadowing is log-normally distributed.
- The multipath effect is Rayleigh distributed.
- These two random process are assumed to be correlated.

3.1 THE CHANNEL AND RECEIVER MODEL

The system consideration consists of a satellite transceiver serving as base station and a number of mobile terminals on the earth surface communication with satellite transceiver (Fig. 3).

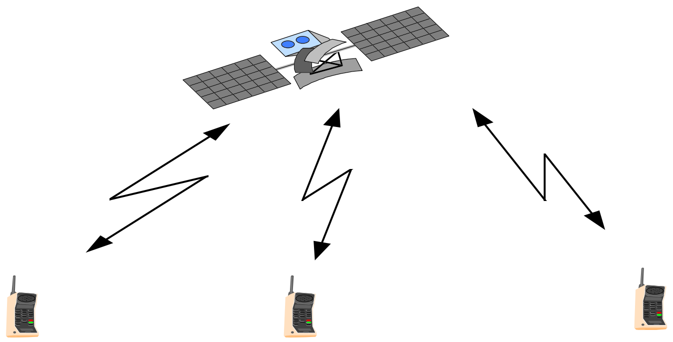

Figure 3. Satellite system model [11].

In this system model the received signal is assumed to be the sum of a multipath signal with Rayleigh distributed envelope and a shadowed LOS signal with a log-normal envelope distribution. The basic signal path in receiver is illustrated in (Fig. 4).

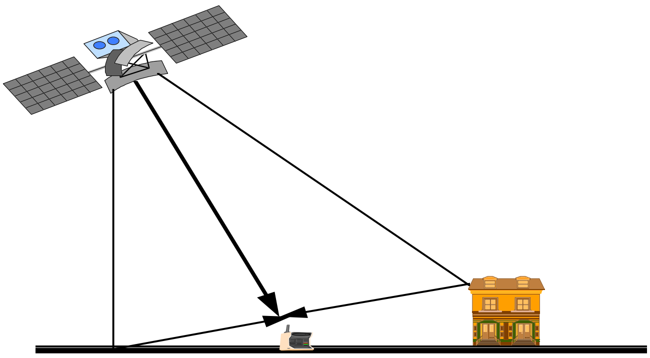

Figure 4. Radio Channel with strong LOS and sum of multipath signals [11].

The resulting probability distribution of the received signal envelope r can be given by [11]:

$$P_{\beta}(r) = \int_0^{\infty} \frac{r}{\sigma^2} \exp\left[-\frac{r^2+z^2}{2\sigma^2}\right] I_0\left[\frac{rz}{\sigma^2}\right] \frac{1}{\sqrt{2\pi\sigma_s z}} \exp\left[-\frac{(\ln(z)-m_s)^2}{2\sigma_s^2}\right] dz \qquad (1)$$

Where:

$I_0\,(.)$ = the modified Bessel function of the first kind and the zeroth order

σ^2 = the average scattered power due to maltipath

m_s = the mean value due to shadowing

σ_s^2 = the variance due to shadowing

The probability density function (PDF) of the received signal phase ϕ was found to be approximately Gaussian and so can be given as:

$$P_{\phi}(\phi) = \frac{1}{\sqrt{2\pi\sigma_{\phi}^2}} \exp\left[\frac{(\phi-m_{\phi})}{2\sigma_{\phi}^2}\right] \qquad (2)$$

Where:

m_ϕ = the mean value of the received signal phase
σ_ϕ^2 = the variance of the received signal phase

The above model is valid for a narrow band system. If spread spectrum modulation is used with chip duration of less than delay spread of the channel, the envelope and the phase distribution functions remain the same, but the values of σ^2 and σ_ϕ are reduced. Due to the correlation operation, the multipath power σ^2 is reduced. For path l it can be approximated as

$$\sigma_l^2 = \sigma^2\left[1-\exp\left(-\frac{T_c}{T_m}\right)\right]\exp\left[-(l-1)\frac{T_c}{T_m}\right] \tag{3}$$

Where T_c is the chip duration and T_m is the delay spread.
The phase variance in the case of spread spectrum modulation is given by [11]:

$$\sigma_\phi^2 = \int_{-\pi}^{\pi}\phi^2 P(\phi)d\phi \tag{4}$$

Where the phase distribution function $P(\phi)$ of a log-normally shadowed Rician signal is given as:

$$P(\phi) = \frac{1}{\sqrt{8\pi^3\sigma_s^2}}\int_0^\infty \exp\left[\frac{-z^2}{2\sigma^2} - \frac{(\ln(z)-m_s)^2}{2\sigma_s^2}\right]\frac{\left[1+G\sqrt{\pi}\exp(G^2)[1+erf(G)]\right]}{z}dz \text{ and}$$

$G = \dfrac{z\cos(\phi)}{\sqrt{2}\sigma}$, and erf(.) is the error function: $erf(G) = \dfrac{2}{\sqrt{\pi}}\int_0^G \exp\left(-t^2\right)dt$

(5)

In order to develop the receiver model for such system, the total signal for binary phase shift key (BPSK) modulation can be shown as:

$$r(t) = \sum_{k=1}^{K}\sum_{l=1}^{L} A\beta_{lk}\alpha_k(t-\tau_{lk})b_k(t-\tau_{lk})\cos[(\omega_c+\omega_{lk})t+\phi_{lk}] + n(t) \tag{6}$$

Where:
l = path number
k = user number
A = the transmitted signal amplitude, which is assumed to be constant and identical for all users.
For user k:
$\{a_k\}$ = the spread spectrum code
$\{b_k\}$ = the data sequence
$\omega_c + \omega_{lk}$ = the carrier plus Doppler angular frequency
ϕ_{lk} = the carrier phase
$n(t)$ = white Gaussian noise with two-side spectral density $N_0/2$
β = instantaneous path amplitude
The signal is supposed to be converted to baseband and correlated with a particular user code. By taking into account the approximated variance and the variance of the cross-correlation calculated for Gold codes as is given in [11], a closed-form expression for the *interference power* is obtained:

$$\sigma_{\text{int}}^2 = \frac{2KA^2T_b^2}{3N}\left(\sigma^2 + 1/2\exp\left[2m_s + 2\sigma_s^2\right]\right) \tag{7}$$

Where:
K = the total number of users
N = the length of the spreading code

$$\sigma^2 = \sum_{l=1}^{L} \sigma_l^2$$

In (7) it is assumed that all users have the same power and the same amplitude distribution function. This is valid for downlink, but it is an approximation for the uplink.

3.2 PERFORMANCE ANALYSIS

In order to analysis the performance for the system model the bit error probability (BEP) is considered to be a basic performance measure. This BEP has been derived in the following for the system with and without diversity. The derivations are made based on BPSK modulation but can be easily extended to other types of modulation.

It is assumed that data bits -1 and 1 are equiprobable, then the bit error probability P_e can be expressed as:

$$P_e = P\left(z < \left\langle 0 \middle| b_0^l \right\rangle = 1\right) \tag{8}$$

Where the decision variable z can be written as $z = Z_X + Z_Y$, where Z_X is the desired component with pdf by $P_X(X)$ and Z_Y is the total noise plus interference described by Gaussian pdf denoted by Z_Y with mean 0 and variance σ_t^2:

$\sigma_t^2 = N_0 T_b + \sigma_{int}^2$

Where:

$N_0 =$ the power density of the Gaussian noise

$T_b =$ the duration of a data bit

σ_{int}^2 = the interference power

By using (1) and (2) and the total distribution function given by [11], the expression for the pdf of Z_X can be written as [11]:

$$P_X(x) = \int_{|x|}^{\infty}\int_{0}^{\infty} \frac{r}{\sigma^2\sqrt{\pi^2\sigma_s^2\sigma_\phi^2}} \exp\left[-\frac{(\ln(z)-m_s)^2}{2\sigma_s^2} - \frac{(r^2+z^2)}{2\sigma^2} - \frac{\arccos^2(x/r)}{2\sigma_\phi^2}\right] \frac{I_0\left(\frac{rz}{\sigma^2}\right)}{z\sqrt{(r^2-x^2)}}\, dzdr \tag{9}$$

This equation is valid in the case for which the receiver locks on the LOS signal. This requires the bandwidth of the carrier tracking loop to be much smaller than the fading bandwidth of the received signal. If the bandwidth of the tracking loop is larger than the fading bandwidth, then the phase ϕ is approximately zero because the receiver will lock on the phase of the total signal. In this case, the distribution function $P_X(x)$ is equal to the shadowed Rician distribution $P_\beta(x)$. However, with a larger tracking bandwidth the loop noise increases, so there is always a certain phase error. Therefore, in the bit error probability calculations one gets an upper bound by using (9) and a lower bound by using $P_X(x) = P_\beta(x)$.

Finally for the bit error probability the following expression can be carried out [11]:

$$P_e = \int_{-\infty}^{\infty} \left(\left\langle p_e \middle| x \right\rangle\right) P_X(x)\,dx \tag{10}$$

Where:

$P_e|x = P(x + Z_Y < 0) = 1/2erfc\left(\frac{x}{\sigma_t\sqrt{2}}\right)$ and erfc (.) is complementary error function, given by

$$\left(\frac{2}{\sqrt{\pi}}\right)\int_{x}^{\infty} \exp\left(-t^2\right)dt$$

Corresponding simulation results are given in [11]. The related channel parameters are shown in table 2 for basic and modified channels for spread spectrum cases.

Table 2. Channel Parameters for simulation [11].

Channel parameters	Light	Average	Heavy
σ^2	0.158	0.126	0.0631
m_s	0.115	-0.115	-3.91
σ_s	0.115	0.161	0.806
Modified Channel Parameters			
σ_ϕ narrowband	0.40	0.47	1.55
σ_ϕ Spread Spectrum	0.14	0.16	1.42
σ_I^2 Spread Spectrum	0.023	0.018	0.009

Figure 5 and 6 show that spread spectrum modulation yields better performance than narrowband modulation for light and average shadowing.

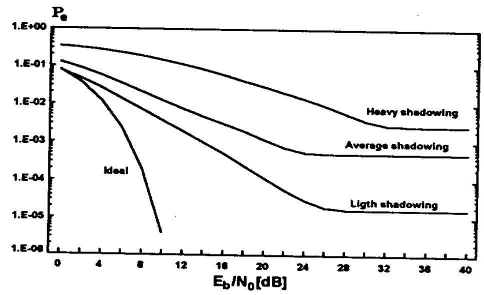

Figure 5. Bit error probability for ideal BPSK and for narrowband BPSK with light, average, and heavy shadowing [11].

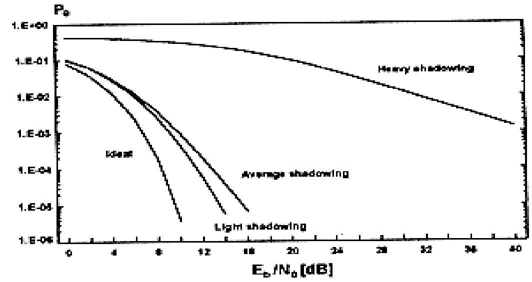

Figure 6. Bit error probability for spread spectrum modulation with $K=1$ user, chip length $T_c = 0.1\mu s$, Gold code length $N = 4095$, and bit rate $r_b = 2.4\ kbit/s$ [11].

For heavy shadowing, the performance is worse at signal-to-noise ratios (SNRs) below 36 dB. The reason for this is that for light and average shadowing most of the signal power is received via the LOS, so if the multipath power reduced by the use of spread spectrum modulation, a less perturbed signal will be obtained. In the case of heavy shadowing, however, the direct LOS power is much smaller than the multipath power, resulting in an approximately Rayleigh faded signal. The use of spread spectrum modulation now decreases the total signal power considerably, with the result that the bit error probability increases. In this case, diversity techniques can be used to improve the bit error probability. If the receiver is able to lock onto the total phase of the first path, then only the envelope fading has to be considered, which is investigated in Figure 7 and 8, where the bit error probability is compared to the narrowband and spread spectrum modulation.

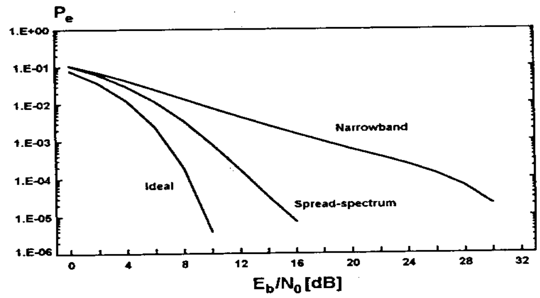

Figure 7. Comparison of the bit error probability with narrowband and spread spectrum modulation with light shadowing and envelope fading only for *K=1* user, chip length $T_c = 0.1\mu\, s$, Gold code length $N = 4095$, and bit rate $r_b = 2.4\ kbit/s$ [11].

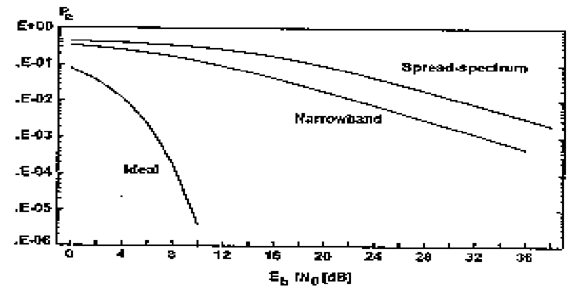

Figure 8. Comparison of the bit error probability with narrowband and spread spectrum modulation with heavy shadowing and envelope fading only for *K=1* user, chip length $T_c = 0.1\mu\, s$, Gold code length $N = 4095$, and bit rate $r_b = 2.4\ kbit/s$ [11].

The number of users can be used as a parameter for performance analyzing.

Figure 9 shows the results for spread spectrum modulation with average shadowing and the number users as a parameter. To maintain with a BEP of 10^{-3} the SNR has to be increased by about 0.5 dB for *K= 100*, 1 for *K=200*, and 2 dB for *K=400* as compared to the SNR for single user (*K=1*). It can be carried out that E_0 /N_0 is the average signal-to-noise ratio, which does not include interference power. So increasing E_0 /N_0 decreases the BEP, until the irreducible BEP caused by the interference power is reached. Figure 10 shows that as T_c decreases, the BEP decreases because of the decreased multipath power.

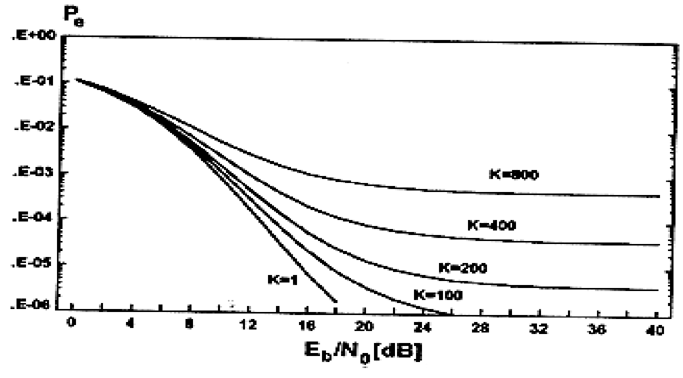

Figure 9. Bit error probability for spread spectrum modulation with average shadowing for chip length $T_c = 0.1\mu\, s$, Gold code length $N = 4095$, and bit rate $r_b = 2.4\ kbit/s$ and *K* as parameter [11].

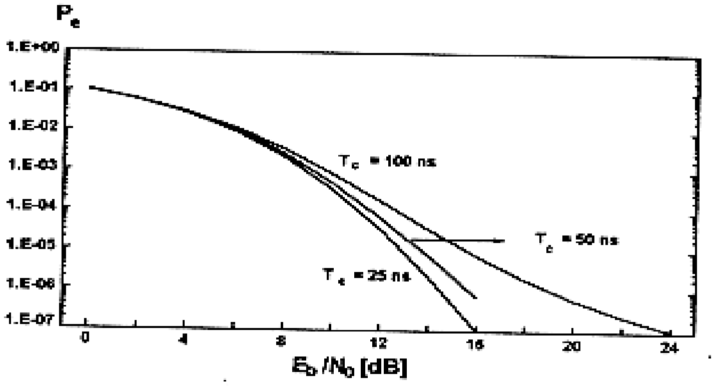

Figure 10. Bit error probability for spread spectrum modulation with average shadowing for $K=1$, Gold code length $N = 4095$, bit duration $T_b = N*T_c$, and chip duration T_c as parameter [11].

3.2.1 PERFORMANCE OF BEP BY USING DIVERSITY

Diversity techniques can be used to achieve better performance in spread spectrum satellite communications. When spread spectrum modulation is used with a chip time that is less than the delay spread of channel, a number of resolvable path L exist that can be used to improve the performance. The simulations results of two tapes of diversity, maximal ratio combining and selection diversity given by [11] are considered here. For simplicity it has been assumed that code and carrier phase tracking errors are negligible.

When maximal ratio combining is used, the received signal is coherently correlated with a particulars code for M different paths. Here M is the order of diversity. Each path is multiplied by the path β_{lk} and all correlation outputs are combined. The probability density function of the sum of the squared path β_{lk}^2 is the convolution of the M different squared path gain probability density functions. Figure 11 shows the bit error probability P_e for light shadowing, using maximal ratio combining. For the sake of comparison, P_e is also plotted for the ideal BPSK case, i.e., coherent BPSK without fading and interference.

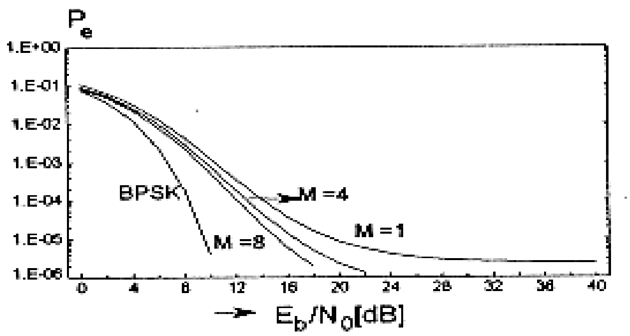

Figure 11. Bit error probability for light shadowing using maximal ratio combining [11].

As it showed in Fig. 11 with no diversity ($M=1$), the performance difference with the ideal BPSK plot is not much for small values of E_0 /N_0, about 3.8 dB for $P_e=10^{-3}$. As a result, the gain of maximal ratio combining is limited. For $P_e=10^{-3}$, about 1.3 dB less power is required if $M=8$.

In the case of heavy shadowing (Fig. 12), the irreducible bit error probability due to multi-user interference is very large. Diversity decreases this level from $5x10^{-2}$ to a minimum of $5x10^{-6}$ for MRC with $M=8$. The reason for the poor performance is that the multipath power is dominant, so the use of diversity decreases the total received power considerably and increases the bit error probability.

With light and heavy shadowing the performance of a system with selection diversity will be worse than with maximal ratio combining (MRC), since MRC is known to be a superior diversity technique as compared to selection diversity. For heavy shadowing, Fig. 15 shows that selection diversity gives an irreducible bit error probability that is 8 times greater than with MRC for $M=4$.

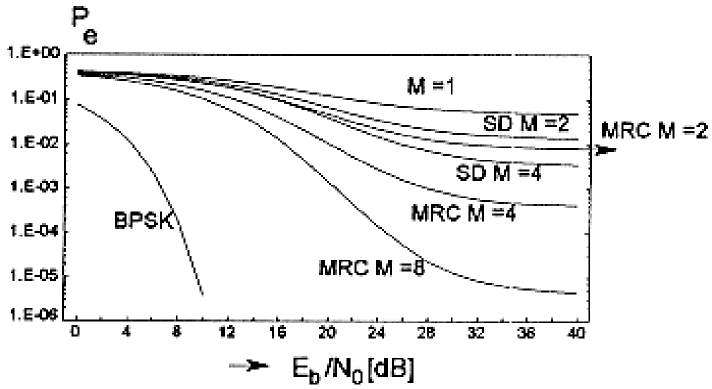

Figure 12. Bit error probability for heavy shadowing using selection diversity and maximal ratio combining [11].

Figure 13, 14, and 15 show on the other hand, the effect of changes in the parameters used in the previous results in the bit error probability for different values of K, T_c, and N, respectively. These figures are calculated for average shadowing. The use of maximal ratio combining is assumed with an order of diversity $M=4$. If the number of users K is increased (Fig. 13) the bit error probability increases because of the interference power, which is proportional to K. Decreasing the chip time T_c (Fig. 14) while keeping the number of chips per bit constant leads to a decrease of the bit error probability because of increased multipath rejection. A decrease of the code length N, while $T_c=T_b/N$ is fixed at 100 ns, causes an increase in the bit error probability (Fig. 15), because the interference power in inversely proportional to N.

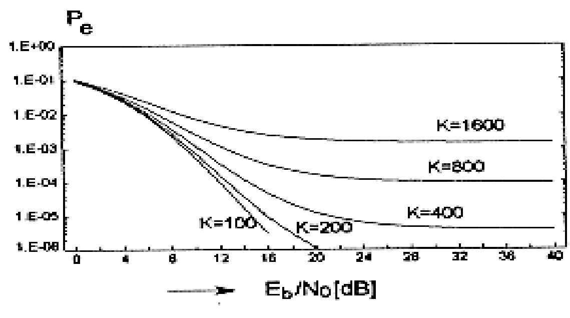

Figure 13. Bit error probability for average shadowing using maximal ratio combining $M=4$, $r_b = 2400$ *bit/s*, $N = 4095$, and K as parameter [11].

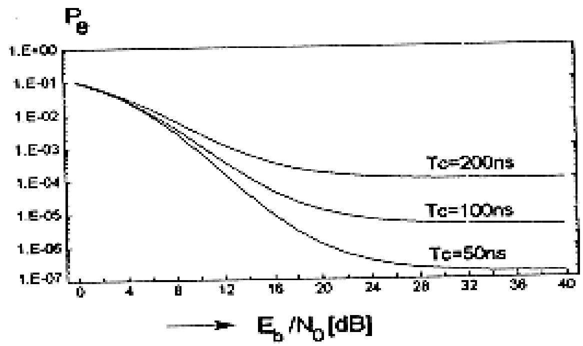

Figure 14. Bit error probability for average shadowing using maximal ratio combining *M=4*, r_b *= 2400 bit/s, N = 4095, K=400*, and T_c as parameter [11].

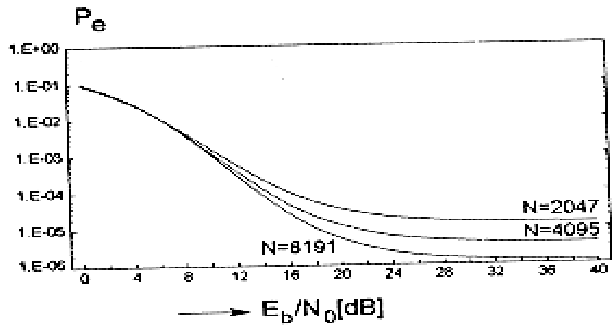

Figure 15. Bit error probability for average shadowing using maximal ratio combining *M=4, K=400*, T_c *=100 ns*, and *N* as parameter [11].

4. CAPACITY ASPECTS OF MOBILE SATELLITE CDMA SYSTEM

In chapter 2 different multiple accesses used in mobile satellite communications were discussed. We review here the considerable results of [12] which compares CDMA capacity versus FDMA multiple access in mobile satellite communication applications.

In comparing CDMA and FDMA in mobile satellite channel the four major factors that alter the result of the comparison are:

- Voice
- Spatial discrimination provided by satellite multiple beam antennas
- Cross-polarization frequency reuse
- Discrimination between multiple satellites providing co-coverage

Voice services will likely occupy the largest percentage of the mobile communication channel. The voice activity factor will greatly reduce the self-noise of the spread spectrum system and utilize the satellite downlink power more efficiently. CDMA voice services will use voice activated carrier transmission, so that when a user is listening or pausing during a conversation the carrier is turned off and thus does not contribute to the system self-noise. Conventional telephone practice for satellite circuits indicates that a given user will be talking approximately 35% of the time.

FDMA systems on the other hand are unable to exploit voice activity factor to improve the capacity of bandwidth limited mobile-to-hub links because of delays inherent with synchronous orbit satellites.

Moreover, the CDMA system can reuse the entire frequency band again by utilizing the two opposite senses of circular polarization. The frequency reuse is possible because the I_0 affecting a given channel is the sum of the I_0 generated by the users with the same polarization plus the I_0 generated by the users of opposite polarization attenuated by cross-polarization isolation. This will increase capacity by 60% even with cross-polarization attenuation of only 6 dB. On the other hand, polarization isolation usually can not be exploit by a FDMA system employing small mobile antennas because such antennas provide only limited cross-polarization isolation, usually less than the necessary cochannel C/I required by FDMA.

In a multiple access satellite system uplink from a number M of similar mobile user terminals, each assumed to provided equal incident power at the satellite, the total received carrier power at the satellite C is given as:

$$C = ME_bR_b \tag{11}$$

Where:

E_b= Energy per bit of information.

R_b = Each User’s information rate.

By dividing C by N_0W_s where N_0 is the single-side thermal noise spectral density and W_s is the total occupied system bandwidth we obtain

$$\frac{C}{N_0W_s} = M\frac{E_b}{N_0}\frac{R_b}{W_s} \tag{12}$$

Link performance is measured by the spectral efficiency η of the transponder or link as a function of C/N_0W_s, and is defined as

$$\eta \equiv M\frac{R_b}{W_s}\frac{\frac{C}{N_0W_s}}{\frac{E_b}{N_0}} \tag{13}$$

In a spread spectrum system the total noise is determined by the sum of the thermal noise N_0 and the mutual interference noise spectral density I_0. The desired bit error rate performance of the link is determined by $E_b/(N_0 + I_0)$ or the ratio of the bit energy to the single-side total noise power spectral density. The total noise N_0+I_0 is given by the following:

$$N_0 + I_0 = N_0 + \alpha\rho V(M-1)\left(\frac{E_bR_b}{W_s}\right) \tag{14}$$

Where:

a = 1/number of antenna beams

ρ = polarization isolation factor

V = voice activity factor.

The average carrier-to-noise power received at the satellite is given as

$$\frac{C}{N_0W_s} = VM\frac{E_b}{N_0}\frac{R_b}{W_s} \tag{15}$$

resulting in spectral efficiency given by

$$\eta_{CDMA} = M\frac{R_b}{W_s}\frac{\frac{C}{N_0W_s}}{V\frac{E_b}{N_0}} = \frac{\frac{C}{N_0W_s}}{V\frac{E_b}{N_0+I_0}\left(1+\alpha\rho\frac{C}{N_0W_s}\left(\frac{M-1}{M}\right)\right)} \qquad (16)$$

$$\eta_{CDMA} = \frac{\frac{C}{N_0W_s}}{V\frac{E_b}{N_0+I_0}\left(1+\alpha\rho\frac{C}{N_0W_s}\right)} \qquad (17)$$

Asymptotically, for $C/N_0W_s \rightarrow \infty$, corresponding to the bandwidth limited situation, (17) becomes

$$MAX\eta_{CDMA} = \frac{1}{V\alpha\rho\frac{E_b}{N_0+I_0}} \qquad (18)$$

It is emphasized that the above result for CDMA spectral efficiency is critically dependent on the $E_b/(N_0+I_0)$ required by the modem in the actual fading environment.

The spectral efficiency of FDMA system on the other hand, in the power limited region is given [12] by:

$$\eta_{FDMA} = 2\frac{\frac{C}{N_0W_s}}{V\frac{E_b}{N_0}} \qquad (19)$$

Where the factor of two accounts for the frequency reuse. Asymptotically, in the bandwidth limited region the spectral efficiency of FDMA is given by

$$Max\eta_{FDMA} = 2r\log_2(m)G_{FDMA} \qquad (20)$$

Where G_{FDMA} = *FDMA* guardband factor, *r* = code rate, and *m* = signal constellation dimension (*m = 2 for BPSK)*

The spectral efficiencies calculated above are shown in Fig. 16. In this figure, the CDMA system uses an $E_b/(N_0+I_0)=2.5$ *dB* with added capacity margin (1.2dB). The FDMA system assumes *m=8, r=2/3*, providing $E_0/N_0 = 8.4$ *dB*. Attention should be focused on the region around $C/N_0W_s = 10$ *dB,* of the satellite-to-mobile link which is generally the most power limited link.

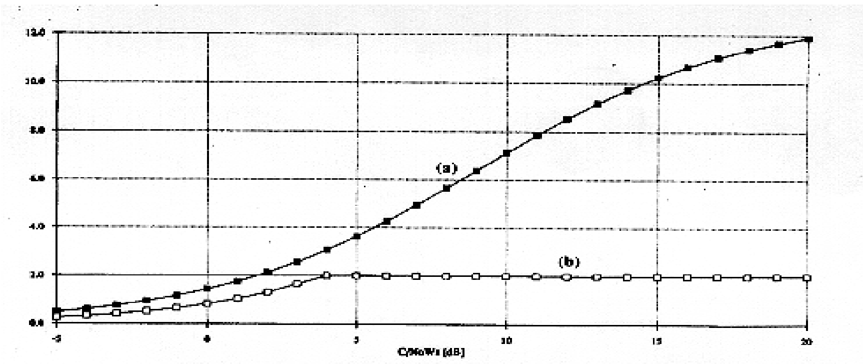

Figure 16. Spectral efficiency in bits/s/Hz as a function of C/N_0W_s, taking into account; voice activity factor, antenna discrimination factor, and polarization factor (a) CDMA with rate 1/3, $K=9$ code and $E_b/N_0=2.5\ dB$, (b) FDMA with trellis code, rate 2/3 $K=5$ *8-DPSK* and $E_0/N_0=8.4\ dB$ [12].

Multiple satellites provide another way of improving the CDMA capacity. First, note that in Fig 16, that if C/N_0W_s were increased by 3 dB by the addition of the second satellite, that the capacity would increase by about 33% with no additional processing required. A possibility for additional capacity increase is the coherent combining of signals transmitted between a terminal and all satellites in view. The coherent combining will result in a capacity gain approaching the increased number of satellites [12].

This technique is not available for FDMA because the nulls in the resulting interference patterns cannot, in general, be made to correspond to locations of cochannel interference signals. Furthermore, because the FDMA system is operating in bandwidth limited region, the increased available downlink power does not serve to increase capacity. Thus, an FDMA system operating in the bandwidth limited mode will not benefit from additional satellites as a way of increasing capacity unless every mobile terminal is equipped with a costly directive antenna capable of providing side lobe rejection to result in adequate C/I performance in the adjacent satellite.

5. CONCLUSION

As it has been shown in this paper, the CDMA approach has some considerable strengths to provide greater performance for the mobile satellite communication systems. The CDMA is an appropriate and flexible approach to be applied to the mobile satellite environment which has some specific aspects e.g. various environmental effects, bandwidth limitation, long signal path distances, a lot of interference etc. CDMA offers variable technical choices to settle the practical problems in developing of the mobile satellite systems . CDMA can provide a greater and more flexible performance enhancement for the mobile satellite system by exploiting diversity techniques, selection diversity and maximal combining as well as capacity increasing by utilizing speech factor as it has been discussed in this paper. It is further shown in this paper that CDMA approach is very flexible in providing system performance by using parameters like code length, chip time, beam antennas, frequency reuse, and etc.

The synergy of band-limiting, frequency reuse, coding, diversity, and advanced receiver design can make CDMA satellite systems suitable for high traffic applications, such as traditional mobile telephony.

The importance of CDMA in next generation Mobile Networks is another remarkable asset which should be keep in mind in the case of mobile satellite system development because it will definitely contribute to global mobile network solutions as a very flexible alternative. In addition to above mentioned facts, the additional techniques utilizing in spread spectrum

CDMA e.g. code acquisition, tracking, multi-user detection, as well as technology advances in HW prove that CDMA is a feasible and attractive candidate for mobile satellite communication as a part of integrated communication environment.

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