Code Division Multiple Access Schemes for Terrestrial and Satellite Mobile Communication Networks: Modeling and Performance Evaluation (1)

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Abstract. This paper deals with the modeling and performance evaluation of different Code Division Multiple Access schemes suitable for applications in terrestrial and satellite mobile communication networks. The use of particular propagation channel models and the relative sensitivity of different demodulation schemes to their parameters are the subject the paper is focused on. In particular, an extension to the case of wideband communications of Lutz's satellite channel model is presented. The main goal is to analyze how the increased interference level, typical of a multipath environment, can influence different demodulator architectures in different propagation conditions. Perfectly coherent and differential modulation methods are employed with conventional and RAKE receivers to derive the error rate performance by computer simulations. Some issues concerning the characterization of the propagation channel models in the case of the RAKE receiver are also investigated and discussed.

1. INTRODUCTION

Mobile communications is one of the fastest growing sector of the telecommunications industry. A clear measure of its vitality is the huge effort currently underway to develop the second-generation of digital mobile radio systems on the heels of the stunning success of their first-generation analog counterparts.

Part of the development effort is aimed at enhancing the efficiency of wireless networks to serve increasing numbers of users and broader coverage areas, while providing reliable links whatever the channel propagation conditions. Needless to say, this arduous task can only be accomplished by combining extremely sophisticated technologies and architectures. A recent architectural proposal (termed "mixed cell architecture" [1]), possibly interconnected to a satellite network covering vast areas of land, sea, and air, seem to be a valid solution to flexibly cope with extremely complex and variable traffic flows. The communication system to meet these requirements affords perfect integration of the various hierarchy layers, while providing enhanced user capacity and call quality regardless of the hostility of the environment.

Code Division Multiple Access (CDMA) is a prime candidate for a future multiple access scheme in a global wireless network. It can be shown that, taking advantage of the interference reduction induced by some techniques such as *multibeamed* or *multisectored* antennas and *voice activation*, CDMA is able to increase capacity with respect to FDMA and TDMA [2 - 5]. However, these considerations contrast sharply with those of Turin who investigated the effects of the mobile radio propagation channel on an asynchronous CDMA system [6]. According to Turin, the environmental characteristics where the mobile link is established have a "multiplying" effect on multiple access interference, thereby sometimes resulting in an unacceptable quality degradation of the received signal. Such a disagreement shows that further results are needed to really consider CDMA a competitive technique in a global mobile radio network environment.

Discussions of CDMA performance in the *frequency-selective* fading channels typical of mobile links have regularly appeared in the literature [7-10]; unfortunately, however, they all share the drawback of involving sophisticated, and sometimes approximate, mathematical approaches that are unwieldy when nonlinearities and imperfect filtering or timing must be considered. Therefore, in order to evaluate true effectiveness, computer-aided modeling is the only practical approach to carry out in deriving the performance of CDMA communication systems in a simple and quick way.

This paper is concerned on the performance evaluation of different CDMA schemes in satellite and terrestrial mobile fading channels on the basis of simulation results obtained using the Comdisco system SPW soft-

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ware on a UNIX platform. Of note is the special care taken with modeling of the propagation channels in order to simulate actual operating conditions as closely as possible. In evaluating the symbol error probability at the mobile unit of a synchronous CDMA system [11], different types of propagation channel, and different alternatives for the mobile demodulator implementation, such as perfectly coherent, differential and RAKE demodulation, have been considered.

The paper is divided into the following sections: After the Introduction (section 1), section 2 provides an expression for the transmitted signal, relating it to the structure of the transmitters and the CDMA system parameters. Section 3 illustrates the channel models for mobile satellite and land communications. Section 4 describes the receiver model in coherent and differential forms. Section 5 provides the performance analysis. Section 6 evaluates the effectiveness of a simple RAKE demodulation algorithm and deals with the problems concerning the computer simulation of such a system. Section 7 presents the conclusions.

2. TRANSMITTER MODEL

In this section, the transmitter model in the case of a quaternary (QPSK and differential QPSK) spread spectrum direct sequence system is defined. Let us consider the situation of $\boldsymbol{M}$ active transmitters at the base station. Focusing on a particular mobile receiver, only one of the $\boldsymbol{M}$ active radios transmits information intended for the receiver, while the other $\boldsymbol{M-1}$ active radios produce undesirable interference.

Under these assumptions, referring to Fig. 1, the complex envelope of the signal transmitted by the base station (satellite or terrestrial) can be defined as [11]:

$$S(t)=\sum_{k=1}^{M}\sum_{i=-\infty}^{\infty}\left(c^k_{p,|i|_N}\, d^k_{p,\{i\}_N} + j c^k_{q,|i|_N}\, d^k_{q,\{i\}_N}\right)\cdot g_T\left(t-iT_c\right) \qquad (1)$$

where:

$$|\cdot|_N \triangleq \cdot \text{ modulus } N$$

$$\{\cdot\}_N \triangleq \text{int}\left\{\frac{\cdot}{N}\right\}$$

- $d^k_{p,n}$ sign of the k-th user n-th in-phase transmitted symbol
- $d^k_{q,n}$ sign of the k-th user n-th quadrature transmitted symbol
- $d^k_{p,h}$ sign of the k-th chip for the k-th user in-phase spreading sequence
- $c^k_{p,h}$ sign of the k-th chip for the k-th user quadrature spreading sequence
- $c^k_{q,h}$ sign of the k-th chip for the k-th user quadrature spreading sequence
- T_c chip duration
- $g_T(t)$ transmit filter impulse response
- $d^k_{p,n}$ and $d^k_{q,n}$ are information sequences in the case of coherent QPSK, whereas for differential QPSK they are differentially encoded version of information sequences [12].

The spreading sequences belong to the *preferentially phased Gold codes* having quasi-orthogonal cross-correlation properties in synchronous systems (i.e., systems having a synchronization of the spreading sequences at chip level) [11]. We assume that the spreading sequences in each data pulse are formed by $\boldsymbol{N}$ pulses and the period of the spreading sequences is $\boldsymbol{NT_c}$. The use of different spreading sequences for in-phase and quadrature signals is needed to cope with the problems arising from the presence of amplifier nonlinearities, imperfect carrier phase recovery, and of any other phenomenon carrying a part of the in-phase component into the quadrature and vice versa.

All frequency and timing inaccuracies at the transmitter and receiver have been neglected, since an analysis of their effects would be beyond the scope of this paper.

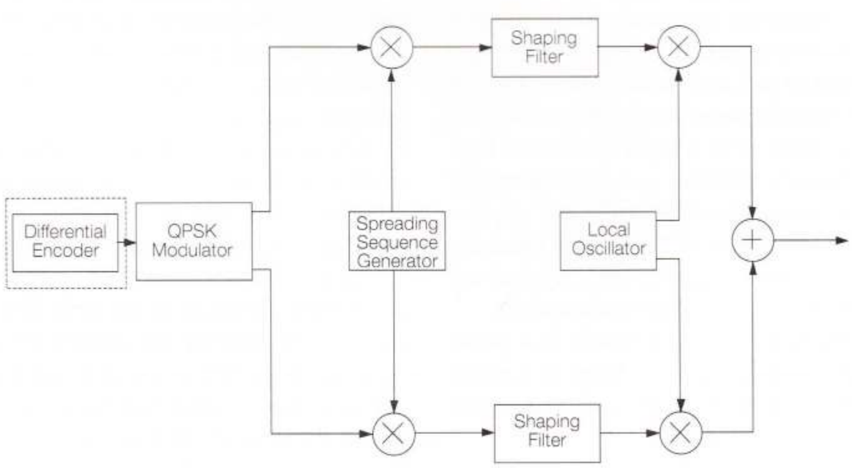

Fig. 1 - Modulator principle block diagram.

3. CHANNEL MODEL

Land-mobile satellite channel

Satellite communications with land mobile terminals are plagued by severe degradation due to signal *shadowing* and *multipath* fading. *Shadowing* is the attenuation of the direct path, i.e. *line-of-sight* (LOS), over the total signal bandwidth caused by trees, buildings, hills, and mountains. The process, which may be explained in terms of absorption, diffraction, and scattering, is strongly dependent on the signal path length through the obstacle, the type of obstacle, the elevation angle of the satellite with respect to the position of the mobile unit, the direction of travel, and carrier frequency [13, 14].

Multipath fading is due to the so-called *signal diffuse component* defined in [14]. The signal, transmitted from a satellite, illuminates obstacles in the vicinity of the mobile unit, which results in reflected energy emanating from multiple scatterers. Waves from these scatterers vary randomly in polarization, amplitude, and phase according to the nature of the scatterer and different propagation distances. In addition, every wave shows a Doppler frequency shift proportional to the relative speed between any scatterer and the vehicle.

As the vehicle moves from one location to another, most of the propagation characteristics vary, resulting in different shadowing conditions and a nonstationary statistical character of the received signal. Due to their relative slowness, the environment characteristic variations may be considered constant within a small area. Hence, in modeling channel propagation effects, we can identify typical environment categories, build their relative models, test our communication systems separately, and thus draw conclusions about their adaptability to different operating conditions.

Other effects on the link such as *Faraday rotation*, *ionospheric scintillation*, and the presence of a signal component reflected from the ground in the direction of the satellite, vanish in relation to particular carrier frequencies (L band) or antenna radiation patterns [14].

Due to the time-varying behavior of the land mobile satellite link, the introduction of a fade margin into the link budget is often insufficient, meaning that an accurate carrier recovery, bit timing, and frame synchronization have to be adopted. All these conditions have been assumed as satisfied in our analysis.

A statistical propagation channel model for land mobile satellite communications, based on narrowband measurements at a single frequency, was developed by Lutz et al. [15]. Two distinct propagation link states are considered: *shadowing* and no *shadowing*.

When there is *no shadowing*, the mobile unit receives the superimposition of the direct wave and constant intensity (power) multipath echoes. The total received signal amplitude forms a Rice process and the probability density of the instantaneous received power $\boldsymbol{P}$ has the form:

$$f_{\text{RICE}}(P) = Ke^{-K(P+1)} \boldsymbol{I}_0\left(2K\sqrt{P}\right) \tag{2}$$

where $\boldsymbol{I}_0$ is the modified Bessel function of zero order and $\boldsymbol{K}$ is the ratio of LOS to average *multipath power*, assuming unitary LOS power, i.e. the power of the unfaded satellite link is normalized to unity.

With *shadowing*, a totally obscured LOS is assumed. The mobile unit receives only *multipath* components resulting in a Rayleigh statistics. The received power has the following distribution:

$$f_{\text{RAYLEIGH}}(P) = \frac{1}{S} e^{-\frac{P}{S}} \tag{3}$$

where $\boldsymbol{S}$ is the average *multipath* power lognormally distributed as follows:

$$f(S) = \frac{10}{\sqrt{2\pi}\,\sigma \ln 10} \frac{1}{S} e^{-\frac{(10\log S-\mu)^2}{2\sigma^2}} \tag{4}$$

where μ is the mean power level decrease (in decibels) and σ^2 is the variance of the power level due to shadowing. The process associated to the lognormally distributed average *multipath* power is usually slow time-varying. In our analysis, it is kept constant, since the resulting simulation time is too short to properly take into account the variations. As mentioned previously, every contribution from multiple scatterers to the *multipath* signal is shifted in frequency by an amount proportional to the relative speed between any particular scatterer and the mobile unit. Summing all the components, we observe a form of frequency spreading in addition to a frequency distortion. The maximum Doppler shift, termed *fade rate* [14], is closely related to the dynamics of fading. Typical values in L band and for the velocity of the mobile unit less than 100 km/h range between 100 and 200 Hz [15, 16].

The model proposed by Lutz et al. reproduces the probability density function of the received signal power as well as the dynamic behavior of the fading and shadowing processes, but its applications are limited to the analysis of systems where the bandwidth of the transmitted signal is small compared to the coherence bandwidth of the channel. Under these conditions, the concept of multiplying fading [17] can be applied, so the received signal is the transmitted signal multiplied by a complex (Rice or Rayleigh distributed) fading process. Lutz et al. show that the model may be used only for signal bandwidths up to several tens of kHz. This section deals with a suitable extension of the channel model given in [15] to the case of wider transmission bandwidths.

Let us assume that in the spread spectrum systems under consideration, a chip time small enough for the *delay spread* of the channel or, equivalently, a transmission bandwidth wide enough for the *coherence bandwidth* is used. Under these conditions, the channel becomes *frequency-selective* and a multipath time discrimination capability is possible at the receiver. By means of the properties of code crosscorrelation, *two multipath* signal components separated by at least one chip time, can be resolved, while distinct paths in the physical medium whose propagation time difference is smaller than one chip time cannot be distinguished, thereby merging into a single *frequency-nonselective* fading signal.

The impulse response of the channel, as also illustrated in [18], is given by:

$$h(t) = \sum_{k=1}^{L} \alpha_k \, e^{j\theta_k} \, \delta(t - \tau_k) \tag{5}$$

where $\alpha_k, \tau_k, \theta_k$ are the gain, time delay, phase of the $\boldsymbol{k}$-th path respectively and $\delta(\cdot)$ the Dirac function.

Assuming an unshadowed situation, the first received path is described by (2).

The superimposed *multipath* is due to the components coming to the receiver within a chip time after the arrival of the direct path. The other paths resulting from *multipath* contributions with propagation delays, with respect to the direct path arrival time, greater than one chip time, are accurately described by a Rayleigh path gain distribution and uniformly distributed phase.

The parameters of the various paths can be found if the *power delay profile* [17] is known. In [9] the *power delay profile* is considered:

$$P(\tau) = \frac{1}{\Delta} b e^{-\frac{\tau}{\Delta}} \tag{6}$$

where Δ is the *delay spread*, $\boldsymbol{b}$ the total *multipath* power and τ the time variable. The power of path $\boldsymbol{k}$ can be approximated as:

$$b_k = b\left(1 - e^{-\frac{T_c}{\Delta}}\right) e^{-\frac{(k-1)T_c}{\Delta}} \tag{7}$$

The *multipath* power superimposed on the direct path is reduced with respect to the case of conventional narrowband transmission. The rest of *multipath* power is distributed, according to (7), among a number of resolvable paths approximately equal to:

$$L = \left\lfloor \frac{\Delta}{T_c} \right\rfloor \tag{8}$$

where $\lfloor \boldsymbol{x} \rfloor$ is the integer part of x.

Simulator architecture

We shall start by describing the structure of the land mobile satellite channel model used in our test. Taking into account typical values of *delay spread* (measured in land mobile channels) [18] and the system transmission bandwidth, a three paths model seems a reasonable choice; in section 5 numerical values of the system under consideration will justify the choice.

In the unshadowed condition, the first path gain has a Rice distribution, while the others are Rayleigh distributed. In the case of a completely obstructed LOS, energy propagation is largely by way of scattering, and all three path gains are Rayleigh distributed.

Referring to the results in [15] for the statistics of the recordings made for different satellite elevations, types of environments, and antennas, we set three typical propagation cases:

Good	$\boldsymbol{K = 14}$ **dB**	corresponding to a propagation link in an open area, free from large obstacles able to obscure the direct path, and with a relatively small number of scatterers responsible for the multipath.
Medium	$\boldsymbol{K = 5.5}$ **dB**	corresponding to a propagation link in weakly shadowed areas or in dense scatterer areas.
Bad	$K \rightarrow -\infty$	totally shadowed direct path, typical of densely populated urban areas.

The heart of the channel model is the Rayleigh *multipath* fading simulator. Each path has a proper simulator independent of the others (Fig. 2). In addition to a proper frequency nonselective *multipath* simulator, the paths are characterized by a propagation delay and attenuation.To

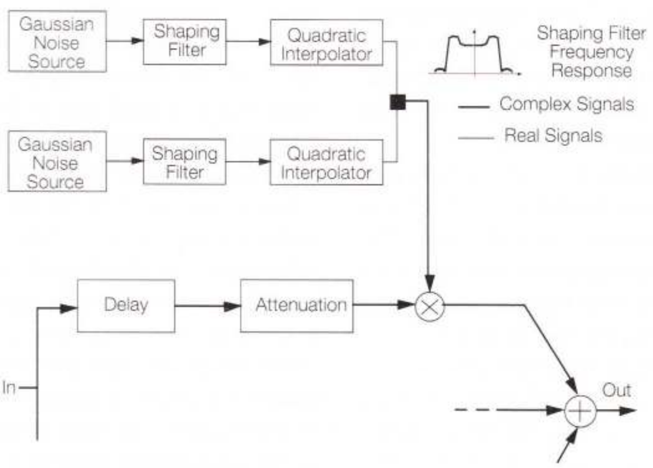

Fig. 2 - Multipath channel simulator block diagram.

represent the propagation environment associated to unshadowed conditions, the direct path between the satellite and the mobile antenna must also be considered.

Fig. 2 shows that, in the *multipath* fading simulator, the technique used is that of [19] with two independent Gaussian low-pass noise sources with identical spectra as real and imaginary parts of the complex fading process. The simulation of the fading spectrum appropriate to mobile radios is obtained by properly shaping the spectrum of the noise sources. For an omnidirectional antenna and for urban and suburban land communication channels, the theoretical spectral density of the complex envelope of the received signal is given by [20]:

$$S(f)=\begin{cases}\dfrac{E^2}{2\pi f_D}\dfrac{1}{\sqrt{1-\left(\dfrac{f}{f_D}\right)^2}} & |f|\le f_D\\ 0 & \text{otherwise}\end{cases} \tag{9}$$

where $\boldsymbol{E}$ is the *root mean square* (rms) value of the signal envelope and $f_d = V/\lambda$ is the Doppler shift corresponding to a vehicle speed $\boldsymbol{V}$ and a carrier wavelength λ .

Even though (9) has been obtained in [20] for land mobile radio environments, Vucetic et al. and Lutz et al. agree in defining the shape of the fading spectrum as a sharply bandlimited with maximum power at the edges. Field measurements [16] have shown that the effect on an unmodulated carrier, whose power density is an impulse, is spreading and a distortion of the spectrum, which results in a frequency shaping that is accurately represented by the action of the Rayleigh multipath fading simulator with shaping filters suggested by Arredondo in [19]. At this point, the similarities between a propagation model for satellite and land mobile radio channel start to show up.

In our model the shaping filter is a 13-th order IIR filter. In Fig 2, the shaping filter is followed by a quadratic interpolator that has the task of making compatible the sampling frequency of the transmission system with that of the complex fading process.

The fading rate, or temporal variation rate of the stochastic process in the complex fading process generation, is regulated by the interaction between the filter and the interpolator according to the maximum Doppler frequency and the transmission rate of the communication system, by interpolating three adjacent samples with a parabolic curve. Such a simple approach has been found to be, for our aims and considering the large interpolation rates, a good compromise between accurate interpolation and simulation time saving.

Land mobile channel

Radio propagation in the land mobile radio environment is described by a highly dispersive *multipath* caused by reflection and scattering. Similarly to what happens in satellite systems, the reflection, refraction and scattering of radio waves by obstacles of different natures cause the transmitted signal to reach the mobile unit by more than one path. All the contributions combine at the receiver to produce a distorted version of the transmitted signal.

If we consider the receiver motion and the Doppler effect associated to each wave, the channel must necessarily be described as time variant. The effects observable on the received signal may be expressed in terms of superposition on two different phenomena [21]:

- A slow fading component, mainly due to local topographic conditions, antenna height, and other environmental conditions, whose statistics can be assumed to be of the log-normal type. As the time variations of this fading component are relatively slow, we harenot taken them into consideration in the realization of our land mobile channel model.
- A fast fading component (*multipath* fading) due to reflections from obstacles and mobile receiver movement. While for narrow-band transmission, the multipath medium causes fluctuations in the received signal amplitude and phase (modeled by a multiplying complex gaussian fading process as explained in [17]), if wideband signaling is used, not all the frequency components of the transmitted signal are influenced by the channel in the same manner and consequently a series of delayed and attenuated echoes can be observed at channel output [22]. Being replicas of the same information signal over independently fading channels, the transmission paths produce a diversity effect because not all of them tend to fade together.

In addition to these effects, another characteristic of the land mobile propagation is power decadence with distance as the inverse of the fourth power [4]. However, since this is irrelevant for our aims, it is not contemplated in the channel model.

As readily observed, the situation is in every aspect similar to that of the satellite mobile channel model described in the previous section. Consequently, on the one hand, the theoretical assumption about the extension of Lutz's narrowband model to the case of wideband transmission may be considered substantially correct, while, on the other, we may have a unique simulator architecture for the two propagation channel models.

The model parameters used in our test are taken from [23], where different propagation environment and the simulation solutions are proposed for testing communication systems to be used in GSM mobile radio network. Even if the model is normally used with GSM transmission parameters, a properly chosen transmission bandwidth of our spread spectrum system can make the model frequency selective. As suggested in [24], we set our transmission bandwidth to 4 MHz to have a sufficient temporal discrimination of the channel response. In this way, all the paths prescribed by [23] are resolved, and we can again express the channel impulse response by (5). Hence, with the structure of Fig. 2 and using parameters such as number of paths, delays, attenuations, fading spectra given in [23], we have a land mobile channel software model which is realistic, standardized, extremely adaptable to the evaluation of the performance of different spread spectrum solutions and consistent with those used in the analytic approaches of [25, 26].

4. RECEIVER MODEL

Direct sequence spread spectrum receivers are traditionally based on correlation receiver techniques, which are optimal for the reception of spread spectrum signals in the presence of AWGN noise. Overlaid multiple access interference deteriorates system performance in terms of bit error probability: if a synchronous CDMA is employed, multiple access interference may be modeled as a slight increase in AWGN noise level, with the quality of the received signal still quite satisfactory [11]. Under these conditions, CDMA is very competitive with respect to other multiple access schemes. However, considering a propagation link from among the ones described in the previous section, the *multipath* effect on multiple access interference could deteriorate the bit error probability to the point of making CDMA totally inefficient.

We examined two receiver models: a conventional receiver and a RAKE receiver. The latter, considered only for cases where conventional receiver performance is very poor, is illustrated in section 6.

Referring to (1) and (5), the complex envelope of the received signal can be expressed as:

$$S_R(t) = \sum_{k=1}^{L} \alpha_k \, e^{j\theta_k} \, S(t - \tau_k) + \tilde{n}(t) \qquad (10)$$

where $\tilde{n}(t)$ is a complex AWGN process with one-sided spectral noise density N_0.

The assumptions we used to establish systems performance in terms of symbol error probability at the mobile unit operating upon the received signal (10), are:

- The composite signal received from the mobile unit comes from a single base station (satellite or terrestrial). Hence, as is evident from (1), all the multiple access interference signals have the same power level as the intended signal.
- A dedicated service channel provides the mobile unit with the spreading codes.
- A perfect chip synchronization of the incoming signal is achieved by suitable acquisition and tracking procedures on an unmodulated master code [11] or directly on the information stream with or without known training sequences. In all cases, we assumed locking on the first path of the various channel model configurations.
- No provision was made for channel coding or interleaving procedures, since we focused on evaluating the system intrinsic feasibility. Obviously, the use of such techniques is strongly desirable and an accurate assessment of an optimum interaction between them and the CDMA system structure is recommended. Again our model is optimally suited to the investigation of such an interaction.

Coherent receiver

The mobile unit is supposed to be able to adjust its timing clock and carrier frequency to provide a perfect phase, bit, and chip synchronization with the first signal *multipath* component endowed with a significant power level.

As shown in Fig. 3 (where the thick lines represent complex signals), the first step in the demodulation process after baseband conversion is chip matched filtering. The transmit filter of section 2 is defined as a square-root-raised cosine frequency-shaped. The same kind of filter shaping should be used in the demodulator. Theoretically, no detection losses are observed if ideal filters are employed, since the Nyquist criterion is satisfied:

$$\begin{cases} g(0) = 1 \\ g(kT_c) = 0 \quad \text{for any integer } k \end{cases} \qquad (11)$$

where $g(t) = g_T(t) \otimes g_R(t)$ is the resulting channel impulse response (linear AWGN propagation channel case) with $g_R(t)$ receiver filter impulse response and $\otimes$ is the time domain convolution operator.

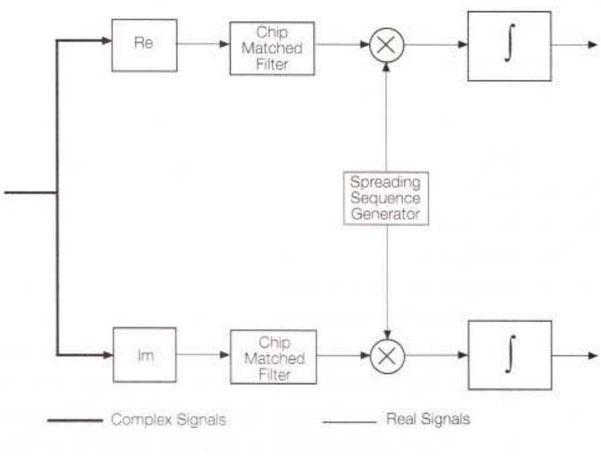

Fig. 3 - Coherent demodulator principle block diagram.

The performance of the CDMA system under consideration has been derived in the case of a linear AWGN propagation channel case with real square-root raised-cosine shaping filters with a roll-off factor $\beta = 0.5$. In comparing the symbol error probability with that of the rectangular-shaped chip, no substantial differences have been highlighted. This means that even if filtering is recommended for practical applications, we may deal throughout only with the rectangular shaped chip, thereby simplifying modeling and saving computation time.

The next step in the demodulation process is the despreading operation, implemented by means of a correlation between incoming data and local Gold sequences. At the output of the integrator (integrate and dump device), in any given signaling interval, we have the superposition of the information symbol, the filtered AWGN noise, and the multiple access interference. In a generic signaling interval s, the terms make up a decision variable we can call V_s^c. The last of the three terms comes from the synchronous crosscorrelation contributions plus the crosscorrelation components added by delayed *multipath*.

Noncoherent receiver

In the case of a rapidly time-varying *multipath* fading channel, carrier phase recovery may be a difficult task. Efficient acquisition and tracking procedures, capable of following the fast-changing channel complex impulse response phase, are feasible but of extremely complex realization. In order to reduce the cost of the mobile receiver, noncoherent data demodulation may be performed.

If a QPSK modulation scheme and a direct sequence spread spectrum technique are used, the choice inevitably falls on the differential demodulation.

The differential QPSK receiver requires only that the phase of the signal component it locks onto does not change over the duration of two adjacent symbols. Fig. 4 highlights that the differential demodulation process is similar to the coherent one. Obviously, the baseband conversion is achieved noncoherently.

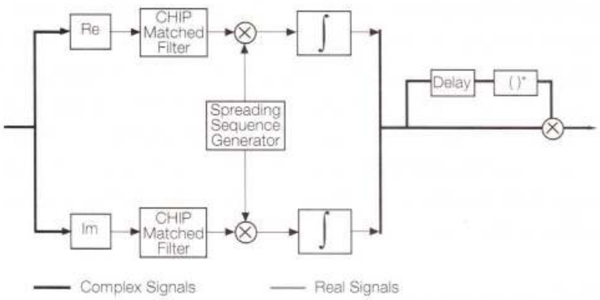

Fig. 4 - Differential demodulator principle block diagram.

At the output of the despreading process, the received signal in any given signaling interval is compared to the received signal in the previous signaling interval. The decision variable is now the phase difference between these two complex numbers, that is the phase of:

$$\Lambda_s = V_s \, V_{s-1}^* \qquad (12)$$

where V_s is the despreader output at signaling interval s, V_{s-1} is the despreader output at the signaling interval $s-1$, and * is the complex conjugate operator.

The results in [17] for DPSK modulation in the light of the conclusions regarding synchronous multiple access interference in [11] may be adapted to provide a theoretical analysis of symbol error probability of a synchronous DQPSK-CDMA system in a linear AWGN propagation channel. Even though a degradation in system performance is to be expected, we can assume that, under ideal conditions and for a linear AWGN propagation channel, a synchronous DQPSK-CDMA system is still able to guarantee high performance.

5. SIMULATION RESULTS AND CONSIDERATIONS

It is well known that CDMA is an exceedingly competitive multiple access scheme capable of reaching the highest theoretical number of simultaneous users with an acceptable signal quality, provided synchronization at chip level is maintained.

Using computer simulation, we shall now verify if this consideration is still valid in *multipath* fading propagation channel environments of various types.

For each test, a random symbol information stream is generated, which thereafter enters the channel simulator and zero mean, white gaussian noise is added to the faded signal at output. The detection process is then performed to estimate the transmitted information stream from the faded received symbols. Lastly, the symbol errors are counted to obtain an estimate of the symbol error rate performance for a given value of E_b/N_0. Since channel coding and interleaving procedures are missing and since voice communication is the system's primary application, a symbol error probability between $10^{-2} - 10^{-3}$ can be considered acceptable.

Land-mobile satellite channel

The propagation channel model architecture and a set of parameters have been described in section 2. The simulation test is based on a spreading sequence set of 31 chip *preferentially-phased Gold codes*, working at a chip-rate of 750 kchip/s, which approximately corresponds to a source bit rate of 50 kbit/s. The channel Doppler frequency is set at f_D = 150 Hz, while the *power delay profile* [17] is maintained on significant levels for approximately 4 μs. For the last two parameters, a better approach would have been to assign different values for different environmental conditions in the model, but, owing to the lack of standard measurements, any theoretical position about precise values appears questionable; therefore we set them to average, i.e., plausible fixed values, preferring to differentiate the various propagation conditions only by the parameter K as explained in section 2. However, we feel that, parameters K being equal, small variations in channel Doppler frequency or *multipath delay spread* would affect spread