spectrum system performance only in a limited way.

Coherent receiver

With the channel phase of the first path assumed as perfectly recovered, the principal impairments are the combination of the Rice first useful path amplitude fluctuation and the delayed multipath contributions, which adds asynchronous crosscorrelation components to the synchronous multiple access interference.

GOOD channel

The symbol error probability for different operating conditions is illustrated in Fig.5. In addition, the curve relative to a linear AWGN channel is also shown for comparison.

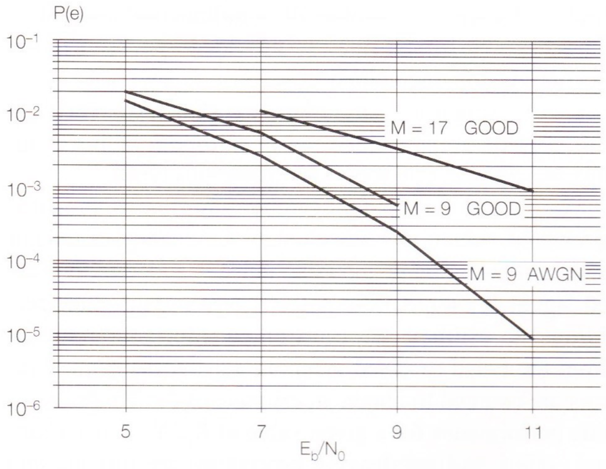

Fig. 5 - Probability of symbol error vs. E_b/N_0 for land-mobile satellite channel GOOD, coherent receiver.

As the extremely long computation time was not conducive to numerous simulation tests, we limited testing to two system load conditions. As can be observed, even with the maximum number of users ($M = 16$) simultaneously present in the channel, system performance degradation is not too large. Hence, we may conclude that, if the mobile terminals are localized in open areas such as highways, railways, and waterways, the considerations expressed in [2] about greater capacity of the CDMA scheme with respect to FDMA are fully justified.

MEDIUM channel

The MEDIUM channel is shown in Fig. 6, together with the BAD channel condition and a curve of the GOOD channel condition for comparison. A net performance degradation with respect to the GOOD channel and an error floor for high E_b/N_0 values clearly emerge The use of an interleaver to break up burst errors longer than one symbol (noted in the error configuration) is recommended to allow successful operation of the decoder for the associated channel coding procedure.

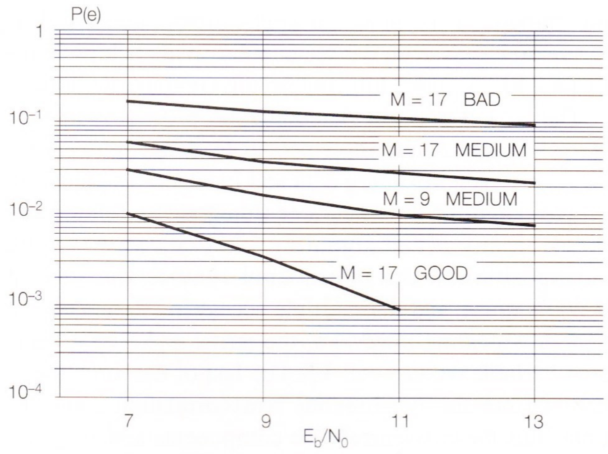

Fig. 6 - Probability of symbol error vs. E_b/N_0 for land-mobile satellite channel MEDIUM, coherent receiver.

Hence, when the mobile user operates in a more complex environment (in rural or suburban areas with roads surrounded by trees, houses, or small buildings), CDMA is still advantageous if a powerful combination of channel coding and interleaving procedure is achieved.

BAD channel

A BAD channel results when the mobile unit is embedded in a very hostile environment where all communication systems have notable operating problems. The direct path is completely obscured and the receiver is obliged to work with the weak *multipath* components that reach it.

The situation is illustrated in Fig. 6 where an irreducible high error probability is shown. Presumably, a lower load condition would not be able to improve error performance, because the primary causes of system failure are: 1) the receiver's locking on the first multipath component subject to wide and fast Rayleigh amplitude fluctuations and 2) the presence of asynchronous multipath components with a power level comparable to the first useful path one. The only remedy appears to be system diversity.

Differential receiver

The aim of this section is to evaluate the feasibility of a differential demodulation of QPSK signals for a synchronous CDMA multiple access scheme in a time-variant *multipath* fading channel and compare its efficiency to the ideal coherent receiver considered in the previous section. The environmental conditions and simulation parameters are the same as those for coherent demodulation. The condition that the channel-introduced random phase be constant over the duration of two adjacent symbols is due to the stochastic-process temporal variation rates in accordance with the planned *coherence time* [17] or maximum Doppler frequency. This can be verified by a simple look at the channel simulator output.

GOOD channel

The system behavior is illustrated in Fig. 7. By adding 3 dB to the E_b/N_0 value, it is possible to achieve the same performance as the coherent receiver. Therefore, even with a simplified receiver, synchronous CDMA is a reliable and efficient multiple access scheme in open areas link.

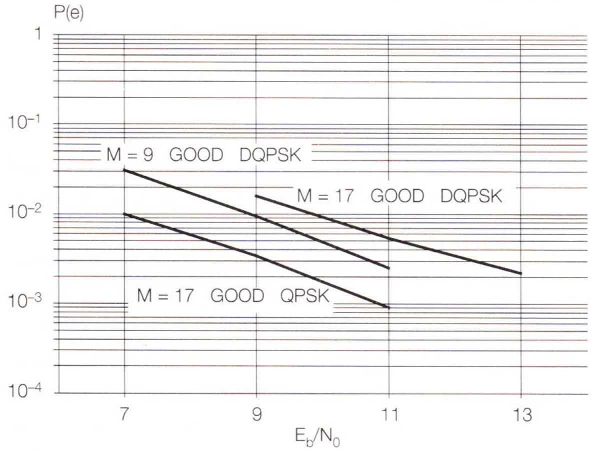

Fig. 7 - Probability of symbol error vs. E_b/N_0 for land-mobile satellite channel GOOD, differential receiver.

MEDIUM channel

As shown in Fig. 8, the full-loaded system with a heavier *multipath* is unable to operate correctly. However, it is unlikely that channel coding and interleaving techniques could improve system performance at such conditions. Presumably, the asynchronous interference deriving from *multipath* delayed contributions "saturates" the more sensitive to noise differential demodulation system. Hence, we can deduce that, under more "difficult" propagation conditions, a synchronous DQPSK-CDMA scheme can operate correctly only for a low traffic flow.

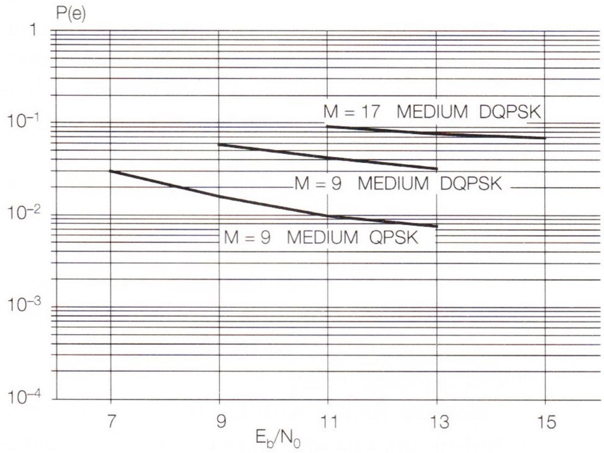

Fig. 8 - Probability of symbol error vs. E_b/N_0 for land-mobile satellite channel MEDIUM, differential receiver.

BAD channel

No analysis was performed for the BAD channel, since negative behavior was foreseen.

Land mobile channel

As described in section 2, the land mobile channel simulator architecture is the same as the land mobile satellite channel architecture. The parameters are now in accordance with the guidelines in [23]. We chose Urban Area and Rural Area from among the propagation conditions proposed in [23] with a common maximum Doppler frequency f_D = 100 Hz and used a spreading sequence set of 127 *preferentially phased Gold codes* operating at a rate of 4 Mchip/s. It should again be pointed out that at this transmission rate, all the paths planned in the channel model are resolved. The larger number of chips in an information symbol translate into an increased system complexity and also increase simulation computation time.

The results are summarized in Fig. 9. Even with a low traffic flow (**M** = 9 users of 64 possible) the coherent receiver does not perform well in the Urban Area, while an acceptable symbol error probability **$P(e)$** = 10^{-2} is achieved in the Rural Area. A differential receiver was also tested, but performance did not prove fully satisfactory.

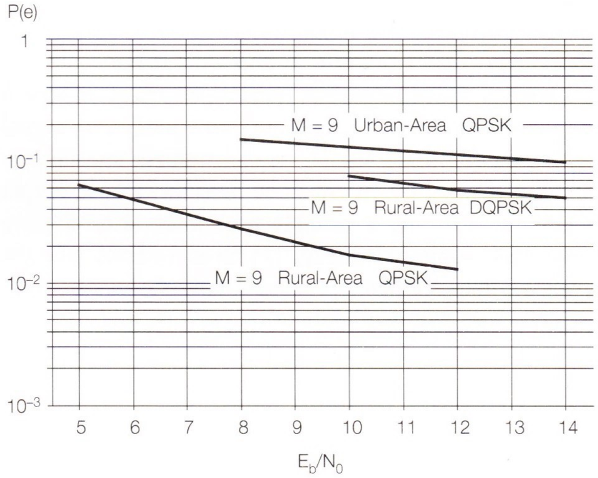

Fig. 9 - Probability of symbol error vs. E_b/N_0 for GSM channel models.

Hence, we can conclude that, with perfect coherent demodulation and with the reduction in interference induced by the techniques described in section 1, a terrestrial CDMA system is feasible in good propagation conditions. However, to make it support a sufficient traffic flow, which would thus make it competitive with the most recent digital multiple access schemes, some diversity procedure has to be used in order to solve the problem of the propagation channel which constitutes the main impairment of system performance.

6. RAKE RECEIVER

We have seen earlier that, apart from the total shadowed propagation condition, CDMA behaves well for a satellite mobile radio network. However, in a terrestrial application, problems arise due to the heavier multipath presence. As we have already suggested, there are basically two principal causes of system failure: the random amplitude fluctuation of the first path the receiver locks onto and the asynchronous interference deriving from the presence of delayed *multipath* signal components.

Unless all the codes assigned to the users are known, nothing can be done to solve the asynchronous interference problem, which is an intrinsic characteristic of the CDMA multiple access scheme in multipath channels.

A practical solution to reduce the performance degradations is to use diversity techniques [17].

The RAKE approach is a well known diversity technique which is based upon the time discriminability offered by a wideband spread spectrum system which resolves the *multipath* components and provides the receiver with several independently fading signal paths.

RAKE receiver scheme

A possible scheme for the RAKE receiver is depicted in Fig. 10. Every demodulator has one chip time-shifted despreading sequences with respect to the adjacent demodulators, so that all received signal components with delays falling into a window of about three chip times can be processed. We suppose that, at the start, the first demodulator locks onto the first strong signal multipath component. The other arms sound a portion of *multipath* profile, searching, in a temporal fixed window, for signal significant contributions. The signal strength in each portion is measured by an envelope detector, whose output is integrated during a variable time interval to achieve better noise suppression (Fig. 11). In accordance with the envelope measurements, a control unit chooses periodically the best two demodulator outputs to combine them according to an *equal gain combining* rule to form the decision variable. Such a contribution allows to discard the weakest contribution, which is very likely to be heavily conditioned by noise and interference.

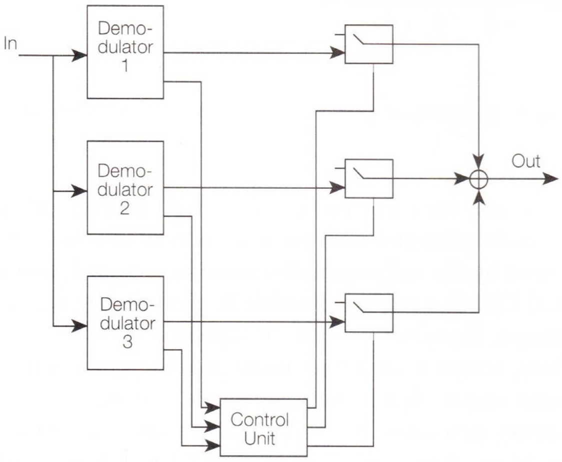

Fig. 10 - RAKE demodulator principle block diagram.

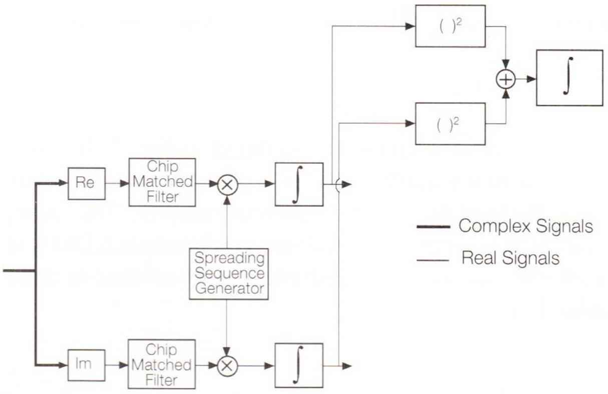

Fig. 11 - Power estimation principle block diagram.

If a very wide bandwidth is utilized, a time discrimination capability sufficient to resolve discrete paths is achieved even using fixed time spacing among demodulators sequences. The main drawback is the high number of demodulators necessary to sound a wide portion of multipath profile. To relax this constraint, only three arms are considered in our approach by taking into account that important signal contributions having small delays are generally more likely than those with larger delays.

Simulation results

Even if the above mentioned RAKE scheme is a feasible, simple and robust scheme, evaluating its effective behavior in the propagation channels saturated by multiple access interference, considered so far, is an arduous task also by computer simulation runs besides being almost impossible by analytical approaches without heavy assumptions.

Simulation results are strongly dependent on the propagation channel characterization. Usually, and as assumed in the previous sections, radio mobile propagation channels can be modeled as particular linear time varying tapped delay lines. Considering a conventional CDMA receiver, the delayed multipath components, whether fixed or not, represent only interference while in a RAKE receiver part of them are exploited as indipendent signal contributions.

Different configurations may be considered and evaluated:

a) An adaptive RAKE with indipendent arms able to follow the channel impulse response and a channel model characterized by time varying multipath components delays.
b) An adaptive RAKE with indipendent arms able to follow the channel impulse response and a channel model characterized by fixed multipath components delays.

c) A fixed time referenced arms RAKE (e.g. the scheme shown previously) and a channel model characterized by time varying multipath components delays.
d) A fixed time referenced arms RAKE and a channel model characterized by fixed multipath components delays.

Option a) corresponds to a "real" situation but its implementation would need accurate evaluation of feasibility of different path-tracking functions for arms time positioning. The results would depend on the technique used to track the time at which the main multipath components are received. Optimization procedures and comparison among different possibilities are currently ongoing activities for a further work.

Option b) has not the same validity as option a). Now the arms of the RAKE would periodically jump from one path to another, according to the power level measurements, instead of following a rapidly time varying propagation profile. Therefore it would have simulated a very complex system with little correspondence to the effective operating conditions.

Option c) would offer a pessimistic outlook as the multipath components would positively contribute to the demodulation process only when synchronized with the RAKE arms. In a real situation a "continuum" of multipath components making the propagation profile is more likely to appear; therefore the fixed time delay referenced RAKE arms would probably have something useful, even if weak and noisy, to demodulate all the time (see the classical approach outlined in [17, chapt. 7.5]).

Option d) has no sense if the fixed multipath time delays are different from the fixed time references of the RAKE arms, and someway predictable results if the delay coincides. However this last statement needs a more detailed discussion.

In our simulation approach we have considered the GSM channel model suggested by [23]. In this model, the time delays associated to each multipath component are fixed. Under this assumption, the most reasonable choice was recognized to be option d) with coincident delays. At first sight the situation could simulate the case of an equivalent adaptive RAKE receiver with a perfect multipath intensity profile estimation, i.e. a perfect time positioning of the RAKE arms with respect to the multipath components; this way, the scheme offers an upper bound to the performance of a very efficient adaptive RAKE receiver in a multiuser CDMA environment. A deeper investigation of the structure used in our analysis tells us that the most important signal contributions are perfectly synchronized with the three fixed time spaced arms of the RAKE, that is, with a proper choice of the transmission bandwidth, or equivalently of the chip duration, and the sampling frequency of the computer simulation process, the demodulators are synchronized with the first, equally time spaced, multipath components. This case simulates the situation where a multipath intensity profile, or equivalently a continuum of multipath components, is sounded with a resolution of T_c, where a T_c is the duration of a chip. Therefore, our analysis can be considered as an extension of the results given in [17] to consider the case of a CDMA multiple access environment with well-established and standardized channel model parameters.

Coherent receiver

We suppose that in the two demodulators chosen by the control unit a perfect carrier recovery is performed. The results for the propagation condition Urban Area are illustrated in Fig. 12, where the symbol error rate for the conventional receiver considered in the previous sections is reported for comparison. The performance improvement is evident.

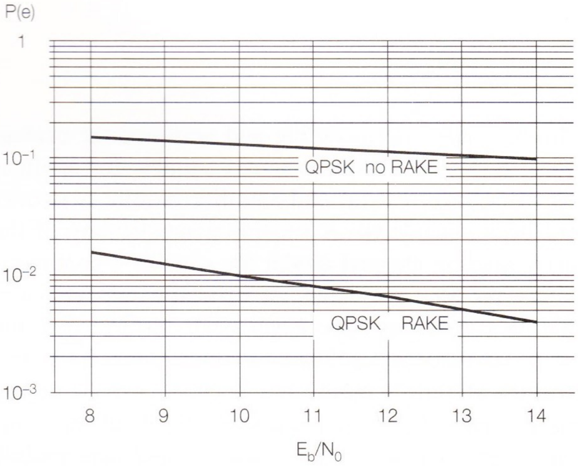

Fig. 12 - Probability of symbol error vs. E_b/N_0 for GSM channel Urban Area, RAKE receiver.

In the case of Rural Area as one can note in Fig. 13, the improvement is not so relevant, but still appreciable and an increase in capacity is possible at the expense of a little increase in system architecture complexity.

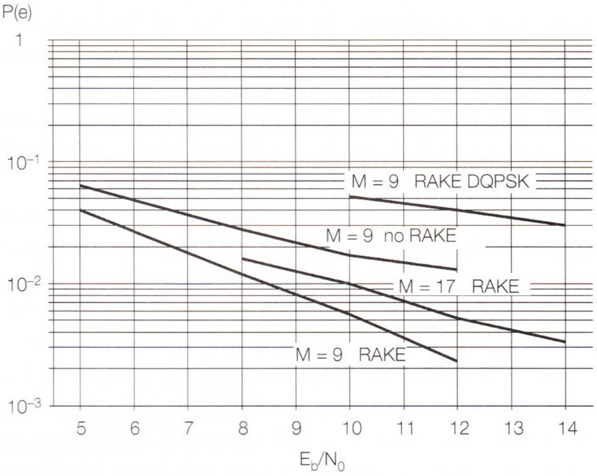

Fig. 13 - Probability of symbol error vs. E_b/N_0 for GSM channel Rural Area, RAKE receiver.

Differential receiver

Every chosen arm performs a differential demodulation before implementing the unity weighted combining. In the Urban Area the system has a very bad behavior, probably due to the presence, in every chosen arm, of strong aysnchronous interference that saturates the differential demodulation system. In Rural Area, as illustrated in Fig. 13, the RAKE improvement in performance is almost negligible with respect to the results shown in

Fig. 9. The last one is a quite interesting result; if we have to deal with a mobile communication links characterized by a Rice LOS propagation path, even in presence of strong delayed multipath components, a differential demodulation scheme and a CDMA multiple access, the real effectiveness of a simple RAKE receiver appears questionable.

7. CONCLUSIONS

In this paper the modeling and performance evaluation of different CDMA schemes suitable for application in both terrestrial and satellite mobile networks have been considered. A suitable generalization of the Lutz's satellite channel model for wideband communications has been presented. As official extensive wideband measurements have never been performed in the case of land mobile satellite communications, the generalization of Lutz's model has been developed taking into account qualitative considerations about the similarities between land mobile satellite and land mobile propagation environment.

The aim of the paper was to study the influence of multipath components interference on a synchronous CDMA multiple access scheme from the mobile user point of view. Extensive computer simulation runs of perfectly coherent QPSK-CDMA and DQPSK-CDMA have shown that if the mobile terminal is localized in open areas, system performance degradation caused by multipath interference is not too large even for very high load conditions. In particular DQPSK-CDMA seems a good choice for a simple, reliable and efficient with regard to multipath, multiple access scheme.

In more difficult, but not totally shadowed, propagation conditions, QPSK-CDMA is still good, whereas DQPSK-CDMA can operate correctly only for a low traffic.

As far as land mobile communications are concerned, the GSM channel models were used to study the impact of a multipath enviroment on a terrestrial CDMA system. Because of the heavy multipath presence, system performance is not so good as in the low shadowed satellite communications. The issues concerning a realistic and reliable computer simulation of a RAKE receiver have been discussed. After that, a RAKE algorithm taking into account the above mentioned issues, has been introduced and tested with the GSM channel models; the improvement in the system performance has been reported.

More realistic channel models and more realistic and sophisticated CDMA receivers, conventional or RAKE, are currently under study.

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