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Power Attenuation Characteristics As Switch-Over Criterion In Personal Satellite Mobile Communications

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ABSTRACT

A third generation mobile system intends to support communications in all environments (i.e., outdoors, indoors at home or office and when moving). This system will integrate services that are now available in architectures such as cellular, cordless, mobile data networks, paging, including satellite services to rural areas. One way through which service integration will be made possible is by supporting a hierarchical cellular structure based on umbrella cells, macro cells, micro and pico cells. In this type of structure, satellites are part of the giant umbrella cells allowing continuous global coverage, the other cells belong to cities, neighborhoods, and buildings respectively. This does not necessarily imply that network operation of terrestrial and satellite segments interconnect to enable roaming and spectrum sharing. However, the cell concept does imply hand-off between different cell types, which may involve change of frequency. Within this prospective, the present work uses power attenuation characteristics to determine a dynamic criterion that allows smooth transition from space to terrestrial networks. The analysis includes a hybrid channel that combines Rician, Raleigh and Log Normal fading characteristics.

INTRODUCTION

Presently, when hand-off between terrestrial and space networks is intended, the satellite network must be part of the overall network. This means that the satellite ground infrastructure has to be interconnected with the mobile station centers and the public land mobile networks. Such interconnection would be rather complex and perhaps difficult to coordinate due to limits of national boundaries. Thus, an ideal alternative to combined coverage is an automatic scheme selection and re-selection of cells and beams while the mobile terminal is idle. The criterion is based on the fact that a mobile equipment performs initial measurements of the radio environment, then selects a network according to a programmed list of allowed networks before it indicates service availability. An important limit used to classify the network list is the power level at the receiver, which in part depends on the transmission effects influenced by shadowing and fading.

Signalization

The signal of the active link from or to the mobile terminal (MT) in a land mobile satellite system (LMSS) is continuously monitored. Thus, whenever signal degradation occurs a handover procedure is initiated towards a stronger alternative link. For integrated mobile systems, handover support would imply that the fixed network has access to both the terrestrial and satellite ground infrastructure (i.e., the satellite fixed earth stations (FES) must be directly linked to the terrestrial mobile services switching center (MSC). Considering the GSM[1] as an example, it implies that the FESs and MSCs are connected at the same level under the GSM Mobile application Part of the CCITT Signaling System No. 7. This type of connection requires close adaptation of the FES to the GSM standard to behave like the terrestrial MSC when performing handover. Furthermore, if satellite infrastructures with numerous FESs, are distributed around many countries, the interconnection of FESs with terrestrial MSCs will overlap with some Public Land Mobile Networks (PLMN) and introduce additional complications. Thus, we believe that the close internetworking of many different mobile networks into a single system, will not only be difficult to implement but will also be hard to

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[1] Group Space Mobil, European Terrestrial mobile system.

administrate due to its complexity [1]. The question is then, how do we offer universal mobile communications without passing through a complicated design and complex system management. The following sections attempt to bring into consideration some alternatives.

POWER CHARACTERIZATION

Received power in experimental channel recordings was already illustrated in [2], nonetheless for completeness we outline a summary below. Signal attenuation in old cities with narrow streets like Munich [3], has high-frequency fading process superimposed on a low-frequency shadowing process, where relatively good and bad channel periods with an approximated mean of 15 dB are clearly distinguished. Similar observations could be made from recordings [4] in Australia. Open areas such as intercity highways, farm lands or spread suburban areas with open fields, essentially do not have obstacles on the direct line-of-sight path. Hence the received signal power has only small level variations due to multipath fading. However, there may still be total shadowing caused by bridges, trees or sporadic high mountains. In regions with vast open fields attenuation will depend primarily on the type of frequency transmission, more than on the shadowing obstacles. If transmission frequency is high (> 10 GHz), the received power level will have degradation due to atmospheric effects (i.e., rain). Nonetheless, the attenuation will not exceed 30 dB, and the mean (approximately 12 dB) remains close to the values in urban areas.

Network Selection

The MT selects a PLMN while it is idle. Hence real-time for fixed inter network interaction is not critical. Once on, the MT measures its ratio environment and indicates the available service automatically from a programmed list of allowed networks, (i.e., the Home PLMN and the ones under roaming agreements). As the MT operates over large and mixed areas, the environmental properties change and the received signal has varying statistical character. This means that the received power level cannot be represented by a model with uniform or constant parameters. Furthermore, this implies that the channel is non stationary. Although statistical channel characteristics vary significantly over extended regions, propagation experiments show that they remain constant when areas have invariable environmental attributes. Hence, an all purpose land mobile satellite channel can be modeled as a non stationary system represented by M stationary channel models. A finite-state Markov model [4], [6] can integrate the Rician, Rayleigh and Log normal models.

Transmission Scenarios

In the context of universal personal communications, a MT will cross different environmental areas in random sequence but with probable characterization as summarized earlier. The signal propagation scenarios during a transmission event could be then classified in four independent states with the following received signal distributions:

S1	Sky-Path	High Rician dist.
S2	Clear-Path	Low " "
S3	Shadowed Path	Log normal dist.
S4	Diffused Path	Rayleigh dist.

Realistically, from the usage side, S1 corresponds to conditions when the user is traveling through the airspace, while S2 refers to transmissions in flat rural or desert areas and seas with almost uniform surfaces. S3 relates to suburban or semitropical regions with scattered high-ways and spread trees. Finally, S4 indicates communications in urban areas. It should be realized that S1 does not necessary imply 100 % signal reception, since the propagation phenomenon is subject to atmospheric effect.

State Analysis

Mathematically, the four states follow a discrete Markov chain [5], where the process has state transitions at times t_n, n = 1,2,3. . (possible into the same state). The discrete time $\{X_n\}$ (i.e., x_n for x(t)) starts in a initial state, say i when $t = t_1$ ($x_1 = i$), and makes a state transition at the next time step which is $t = t_2$ ($x_2 = j$, etc). The one-step transition probabilities are assumed to be independent of n, thus P_{ij} is the set of events for the transition probabilities. The transition probabilities of P_{ij} for the 4 states is then expressed by a square matrix P,

$$P = \begin{bmatrix} 1-3P_1 & P_1 & P_1 & P_1 \\ P_2 & 1-3P_2 & P_2 & P_2 \\ P_3 & P_3 & 1-3P_3 & P_3 \\ P_4 & P_4 & P_4 & 1-3P_4 \end{bmatrix} \quad (1)$$

where

$$P_1 = P_{12} = P_{13} = P_{14}; \quad P_2 = P_{21} = P_{23} = P_{24}$$
$$P_3 = P_{31} = P_{32} = P_{34}; \quad P_4 = P_{41} = P_{42} = P_{43}$$

$$\text{and} \quad E[i] = \frac{1}{3P_j} \qquad i = j = 1,2,3,4. \quad (2)$$

To calculate the four steady state conditions, we define the probability that the Markov chain $\{X_n\}$ is in the state j at the nth step by

$$\pi_j^{(n)} = P[X_n = j], \quad (3)$$

then assume that the chain has stationary probability distribution $\pi = (\pi_1, \pi_2, ..)$ satisfying the matrix equation $\pi = \pi P$, where each $\pi_j \geq 0$ and $\sum_i \pi_i = 1$. The matrix equation $\pi = \pi P$ can then be expressed as the set of equations by

$$\pi_j = \sum_i \pi_i P_{ij} \qquad j = 1,2,\ldots \quad (4)$$

From equation (2) πj is defined by

$$\pi_j = \frac{E_i}{\sum_{i=1}^{n} E_i} \qquad j = i = n = 1,2,3,4. \quad (5)$$

The steady state probability vector is thus

$$\pi_j = [\pi_1, \pi_2, \pi_3, \pi_4]. \quad (6)$$

State Probability boundaries

The environmental states identified previously by the probability density functions, p.d.f (i.e., Rician, Log normal, and Rayleigh) depend very much on the propagation conditions defined by a parameter k, which is the ratio of power in the direct component and power in the diffuse component. k assumes that the propagation medium can be characterized by the combination of a direct path and a number of fading weak paths. The parameter k is referred to as the Rice parameter. As k --> ∞ all power is in the direct component, implying that reception is via a direct carrier line-of-sight (l.o.s) transmission from the satellite, and that the diffuse component is negligible. This condition would correspond to S1 in our model. As k --> 0, the received power is all diffuse and the received signal distribution has a Rayleigh density. Therefore, as the parameter k increases, the mobile channel passes from Rayleigh channel to a Rice channel and vice versa. This means it goes from S1 to S4.

Practically, the values for the Rice parameter depend on the reflective terrain in the vicinity of the MT, which is strongly influenced by the elevation angle of the MT-satellite l.o.s. Generally k increases significantly as the satellite is observed at higher angles, where more of the horizontal multipath is rejected. In like manner a dense collection of reflectors, as in metropolitan areas tends to produce lower values of k. Rural environment is more benign, while maritime areas involve primarily long-range sea reflections whose severity is strongly dependent on the ocean wave structure. During periods of shadowing due to trees, foliage, and terrain the Rice parameter is reduced by 3 to 10 decibels from average values and the channel state passes to S3.

NETWORK SELECTION

The selection criterion, as discussed in the introduction, is based on the power level of the received signal. Such a faded signal at any given time instant t is

$$R(t) = m(t) * \{R_{dir}(t) + R_{spec}(t)\} + R_{diff}(t), \quad (7)$$

where m(t) is the long-term signal fading with Log normal distribution. For S1 and S2 the received power is

$$R_{S1}(t) \equiv R_{S2}(t) = R_{dir}(t), \tag{8}$$

assuming m(t) = 1 and neglecting the specular reflection $R_{spec}(t)$ since it is taken care by the antenna. The signal power for S3 is expressed as

$$R_{S3}(t) = m(t) * R_{dir}(t) + R_{diff}(t). \tag{9}$$

Finally, for S4 the signal at the receiver comes mainly from the diffused power, thus

$$R_{S4}(t) = R_{diff}(t). \tag{10}$$

The complex characteristics of the different received signal patterns just described and the spectral analysis were already presented in detail in [3], [4], [7], therefore they will not be repeated here. The fluctuation of the power level signal over a given threshold is the level-crossing rate (LCR), which influences directly the performance of the overall system. Whenever a signal goes below a threshold, the transmission quality is not warranted because there is a presence of fading implying errors [7]. Thus, using the LCR of a received signal we may calculate the BER and compare it to an expected performance. If the BER does not match a required level indicating an preassigned region, network switching process occurs. During this process the MT selects a strong terrestrial signal, sends a log-in-request and awaits log-in confirmation based on roaming agreements. While under the terrestrial coverage the MT receives periodical acknowledge-requests, if the MT does not reply, the terrestrial system sends a log-out confirmation to logout the MT, which in turn begins to listen to the satellite signal again after leaving the terrestrial link.

Switching Process

The network switching occurrences is obtained from the performance of the received signal or the conditional bit error rate (BER) probability, P_i (i = S1, S2...) which in the case of a BPSK modulation is given by

$$P_i = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_o}}\right) \approx Q\left(\sqrt{\frac{E_b}{N_o}}\right) \tag{11}$$

where E_b is the signal energy per bit and N_0 is the noise energy density. If we express P_i in terms of signal-to-noise ratio, S may be defined as the average power, R as the bit rate, N as the product of N_0 and the signal bandwidth W; and the new P_i is

$$P_i = Q\left(\sqrt{\frac{2S}{N}\left(\frac{W}{R}\right)}\right). \tag{12}$$

To relate the LCR to the P_i probability we first obtain N_{ro} as the number of times the received signal crosses a given threshold over a determined time period. We then calculate the normalized LCR, which from [7] is defined as

$$N_r(r_b) = \frac{v}{c} f_c \sqrt{\frac{\pi}{2(1+\rho)}} f_r(r), \tag{13}$$

where r_b is the fading threshold, v is the vehicle speed, c is the speed of light, f_c is the transmission frequency, ρ is the correlation coefficient and f_r is the p.d.f of the signal according to the environmental state. From the ratio of N_{ro} and N_r we determine the average signal strength, S, as

$$\frac{N_{ro}}{N_r} = S\exp^{(-S_o^2)}. \tag{14}$$

The channel bandwidth, W, required to pass a M-ary PSK signal is given by

$$W = \frac{2R}{\log_2 M}. \tag{15}$$

Thus, when the P_i probability of the received signal does not meet a service threshold quality level, the MT begins a network switching procedure (i.e., it will look a stronger signal in an alternative network).

A more dynamic way to begin the network switching process would be to measure the fading time. Because it is well understood that whenever long fading periods exist, the transmission quality will decrease due to high density of errors. originated by persisting shadowing or blocking. Thus from the normalized LCR on equation (13), The average duration of a fade $\bar{t}_f(r_b)$ relative to r_b, is equal to the probability that a transmitted signal remains below r_b divided by the number of times per unit time the signal is below r_b. That is

$$\bar{t}_f = \frac{1}{N_r(r_b)}\int_0^{r_b} f_r(r)dr = \frac{F_r(r_b)}{N_r(r_b)} \qquad (16)$$

where

$$F_r(r_b) = \int_0^{r_b} f_r(r)dr \qquad (17)$$

is the cumulative probability density function.

System Error Performance

The average bit error probability in the ith receiver state mainly due to fading attenuation as a result of shadowing or blockage is given [4] by

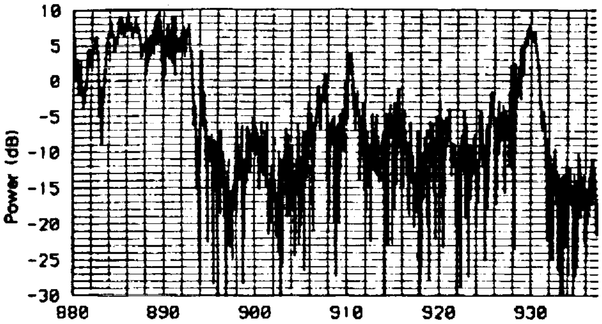
$$P_{si} = \int_0^{\infty} P_i f_r(r)dr, \qquad (18)$$

where $f_r(r)$ is the probability distribution of fading attenuation in each ith state. The average BER at the output of the demodulator for the M state Markov channel model is then

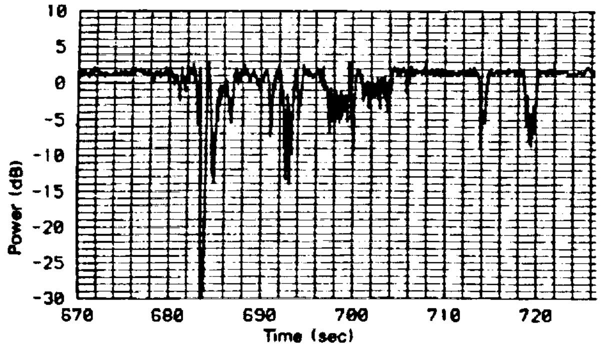
$$P_{BER} = \sum_{i=1}^{M} P_{si}\pi_i. \qquad (19)$$

EXPERIMENTAL OBSERVATIONS

The received signal power from a channel recording [3] in an area with narrow streets in the old city of Munich, shows on Figure. 4a relatively good and bad channel periods with a mean power level of 15 dB, however the bad periods are predominant for at least 34 s until a crossroad permits an obstructed view of the satellite from 928 - 932 s; but at 933 it falls again to a bad period. By contrast the received signal power from recordings on a highway, shows in Figure 4b. only small variations due to multipath fading. Although at 684 s there is total shadowing due to the blocking of a bridge, it does not last more than 2 s. All other shadowing events in this figure remain within acceptable fade margins. In the context of this study, the observation of Figure 4 indicates that the MT passes from state S3 to state S4 at point 894, and it will probably remain in this state until it changes of environment. This may imply for example that network switching would begin when the deep fade duration exceeds 2 seconds. Of course the fade duration time would no be the only criteria for network switching, nevertheless it appears to be the most visible and measurable factor.



(a)



(b)

Figure 4. Received signal power level. 0 dB = mean received power. (a) City, cylindrical slot toroidal antenna with 6 dBi nominal gain, v = 10 km/h, 24 degree satellite elevation; (b) Highway, all conditions the same but v = 60 km/h [3].

Other statistical observations on the same recordings, show that in the city environments the received signal power is more than 10 dB below the unfaded satellite link at a 60 % probability , while it is only 8.5 % in the highways. This leads to deep fading periods longer than 0.1 s with 26 % probability in the city, and only 6 % in the highway [3]. Based on these type of percentages of the received power levels we can calculate the steady state probabilities of the four state model described in the preceding sections.

From preliminary simulations using the fade average technique, we can see in Figure

5a. that the average fading time in urban areas is logically higher than in rural or highway environments. The point to see in the plots is the magnitude of the difference between the fading periods once a link has lost the direct l.o.s with the MT, which is the case in the urban connection.

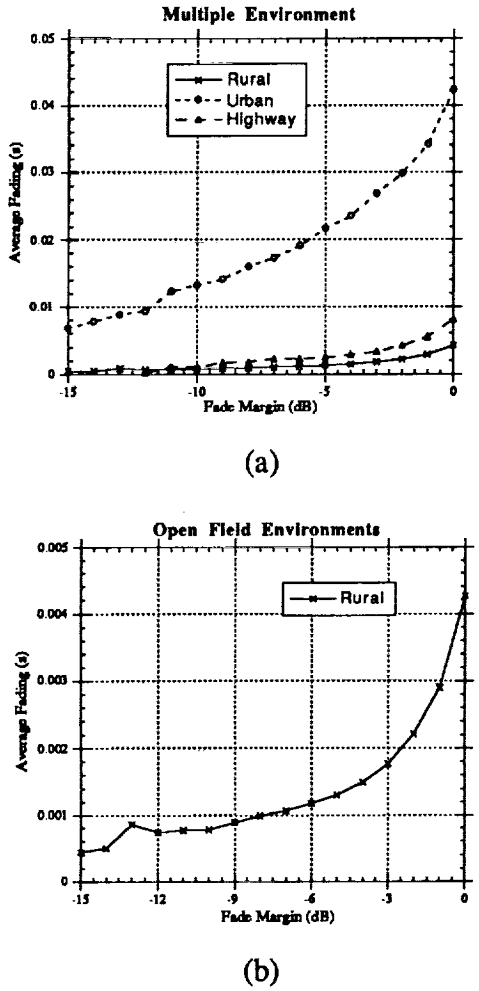


Figure 5. Average Fading. (a) Urban: v = 10 km/h, r_b = -15 dB, f_c = 1.6 GHz, k = 0 dB, Date rate = 4.5 kb/s, Highway: v = 60 km/h, k = 10 dB; (b) Rural: v = 120 km/h.

From the fading time illustrated in Figure 5b, we can observe thresholds that would lead to the initiation of the network switching mechanism. Yet again, this would not be the only factor to begin hand over; however it will be the predominant one.

CONCLUSIONS

In this paper we have discussed the complexity of an architectural level integration on mobile systems. Therefore, we have concluded that a service-level integration could be more practical, cost effective and more manageable if the MT selects a PLMN while it is idle where real-time for fixed inter network interaction is not critical. To support a universal MT that facilitates the selection and reselection of networks (i.e., the transition from satellite to terrestrial services or vice versa), we introduced a four state dual mode receiver along with the most probable mathematical analysis. In the study we also illustrated that fade duration would be a good dynamic alternative of network switching to that of calculating the BER probability. Future studies will include further characterization of experimental data and more simulation analysis to quantify state transition thresholds to adequately predict network switching.

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