N94-22761

HANDOVER PROCEDURES IN INTEGRATED SATELLITE AND TERRESTRIAL MOBILE SYSTEMS

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ABSTRACT

The integration of satellite and terrestrial mobile systems is investigated in terms of the strategies for handover across the integrated cellular coverage. The handover procedure is subdivided into an inizialization phase, where the need for issuing a handover request must be identified, and an execution phase, where the request must be satisfied, if possible, according to a certain channel assignment strategy. A modeling approach that allows the design of the parameters that influence the performance of the overall handover procedure is presented, along with a few numerical results.

1. INTRODUCTION

Future mobile telecommunication networks should provide the user with the highest possible degree of mobility and service quality. This objective implies, in particular, the development of a seamless coverage achieved through the combination of different systems fully transparent to the user. In fact, no single system can be the optimal solution to a global coverage.

A promising configuration for future mobile network architectures is the integration of terrestrial cellular with satellite multispot systems [1-3]. The satellite system provides an overlay of large cells on the terrestrial cellular layout, and would be mostly utilized when users are in open areas (rural or suburban), while the terrestrial system would serve most of the large traffic generated in urban areas. In order for this architecture to be attractive from the user point of view, a single terminal with dual-mode capability is needed for a transparent connection to either system.

The peculiarity of an integrated system is the need to efficiently select the access medium (terrestrial or satellite) offering the best performance at any instant for every user. Therefore, an increase in network intelligence is the price paid for the agility provided to the user. In particular, a procedure for active user handling (*handover*) during the transition between cells belonging to the two systems must be added to the ones required in conventional cellular systems. In terrestrial cellular systems, in fact, handovers are needed when the channel quality belonging to a mobile user active call becomes unacceptably low, and the active call should be entrusted to a new base station (*intercell* handover) or simply to a new channel (*intracell* handover) [4-8]. In satellite cellular systems, intercell handover may happen between two spots belonging to the same satellite, or even to different satellites in the case of a multi-satellite system. In addition, in an integrated satellite and terrestrial mobile system the necessity for *inter-system* handover arises, for example, when the active user approaches the borders of the area serviced by the terrestrial system.

Reliability of handover procedures impacts heavily on the successful exploitation of an integrated system. A crucial point in the assessment of the procedure is the role played by the user terminal in handover decisions. In *Network Controlled HandOver* strategies (*NCHO*), for instance, the choice of the handover starting time and the target Base Station (BS) is performed by the Mobile Switching Center (MSC). When the decisions are taken at BS/MSC level, but the user terminal cooperates in the research of alternative base stations to the present one, it is a *Mobile Assisted HandOver* (*MAHO*). The maximum decentralization degree is reached when the mobile terminal itself takes the handover decision (*Mobile Controlled HandOver, MCHO*) [5]. The mentioned strategies result in different handover duration and features. Some key characteristics related to the above strategies are summarized in Table 1.

Given a handover strategy, the procedure for handing over the active call from one server to the other can be subdivided into two distinct steps:

- handover *initialization*: channel monitoring and recognition of handover necessity;
- handover *execution*: new resource assignment, if available.

HANDOVER STRATEGY	INTER-SYSTEM HANDOVER	INTERCELL HANDOVER	INTRACELL HANDOVER	TERMINAL COMPLEXITY	NETWORK SIGNALING
NCHO	critical	allowed	critical	low	usual
MAHO	allowed	allowed	allowed	fair	usual
MCHO	allowed	allowed	allowed	high	heavier

Table 1

The initialization phase must prevent an unnecessary request from being flagged, while, at the same time, be prompt in issuing the necessary ones. The time spent in trying to take the proper decision has a fundamental impact on the probability of successful handover. The handover execution phase depends on channel assignment strategies and on techniques aimed at reducing the probability of forced termination. In the present study, a procedure for inter-system handover inizialization and execution is analyzed.

2. INTER-SYSTEM HO INIZIALIZATION

Suppose the chosen strategy for handover is MAHO. The most appropriate quantity to be measured should be identified. The Bit Error Rate (BER) experienced in the demodulation of the received digital signals is the most reliable measure of quality, particularly in the presence of interference, when power level measurements may lead to misleading results. Therefore, it would be desirable that the Mobile Station (MS) periodically monitored the BER's pertaining to the signals coming from the serving Base Station (BS) and from all other adjacent or overlaying BS's. Unfortunately, BER measurements are not always feasible: due to the statistical nature of errors, a sufficient number of them must be detected before an estimate of reasonable accuracy can be made. This fact may introduce a significant delay in the measurement, especially in the case of low bit rates.

An istantaneous estimate of quality can be extracted by measuring the received signal-to-(interference plus noise) power ratio, SINR. However, in deciding in favor of an inter-system HO, the measured SINR's in the two channels cannot be directly compared unless both systems employ identical modulation and coding formats (which is often unreasonable due to the extremely different channel characteristics). A possible solution would be to set a minimum acceptable value for SINR in the two systems, and then compare the relative difference of the measured values to the respective minimum values. The comparison is meaningful only when the slopes of the BER vs. E_b/N_0 curves in the two systems are, at least, similar.

The simplest approach is to rely solely on power level measurements performed by the MS periodically, even though it should be evident that the lack of important information may lead to incorrect handover requests. As before, the comparison between the measured levels in the two systems should be carried out on the basis of the distance from a minimum acceptable level, assuming similar performance curves slopes.

2.1 The Modeling Approach

The model for an inter-system HO can be formalized as follows: suppose, for simplicity, that the MS sees only one BS in the terrestrial system, TBS (Terrestrial Base Station), and one in the satellite system, SBS (Satellite Base Station). If the MS is logged onto the terrestrial system, assume it is moving out of the serving cell following a straight line at a constant velocity. The terrestrial cell is overlaid by a cell in the satellite system controlled by the SBS. If the MS is logged onto the satellite system, assume it is moving toward a cell in the terrestrial system following a straight line at a constant velocity. Let $y_T(i)$ and $y_S(i)$ be the current estimate at $t = t_i$ of measured levels of the signals received from TBS and from SBS, respectively. Ignoring any co-channel interference, these estimates can be written as:

$$(1) \quad y_x(i) = P_x - L_x(i) - A_x(i), \quad x = T, S \quad ,$$

where P_T is the power transmitted from TBS, $L_T(i)$ and $A_T(i)$ are the free-space loss and shadowing contribution in the terrestrial path at $t = t_i$, P_S is the power transmitted from the satellite, $L_S(i)$ and $A_S(i)$ are the free-space loss and shadowing contribution in the down-link path at $t = t_i$. All quantities are expressed in dB. A_T(dB) and A_S(dB) are supposed to be quasi-stationary zero-mean Gaussian random processes. The stationarity is maintained as long as the environment in which the MS is moving does not change significantly. In (1) the effects of Rayleigh and Rice fading are neglected, assuming that the level estimates are obtained through proper filtering. However, the same filtering is not able to eliminate the effects of A_T and A_S, due to the much lower pitch of shadow fading. Therefore it is advisable not to compare instantaneous quantities but rather averaged quantities:

$$(2)\quad \bar{y}_T(i) = \frac{1}{N}\sum_{n=0}^{N-1} y_T(i-n) \quad ,$$

$$(3)\quad \bar{y}_S(i) = \frac{1}{M}\sum_{m=0}^{M-1} y_S(i-m) \quad .$$

The number of averaging intervals can be different in the two systems since channel propagation conditions are usually different. Let ξ_T and ξ_S be the minimum acceptable levels for the power received from TBS and SBS respectively. Assuming the BER vs. E_b/N_0 curves in the two systems have similar slopes, the decision statistics can be based on the relative average levels:

$$(4)\quad \delta_x(i) = \bar{y}_x(i) - \xi_x \quad , \qquad x = T, S$$

The autocorrelation function of the two shadowing processes is supposed to be exponentially distributed [4]:

$$(5)\quad E\{A_x(i)A_x(i+n)\} = \sigma^2_{A_x}\,\gamma_x^{|n|} \,, \quad x = T, S \quad ,$$

where $\sigma^2_{A_T}$ and $\sigma^2_{A_S}$ are the variances of the shadowing processes in the terrestrial and satellite links, while $\gamma_T < 1$, and $\gamma_S < 1$, are the parameters which determine the decaying rate of the correlation. The variance of the estimated relative level from TBS is:

$$(6)\quad \sigma_T^2 = \mathrm{Var}\{\delta_T\} = \frac{\sigma^2_{A_T}}{N}\left[1 + 2\sum_{n=1}^{N-1}\left(1 - \frac{n}{N}\right)\gamma_T^n\right] \quad ,$$

and a similar expression for $\sigma_S^2 = \mathrm{Var}\{\delta_S\}$. The variance in the estimates is usually large enough for an unnecessary handover to occur, that is a handover followed by a handover back to the former system. In order to decrease the probability of unnecessary handovers, P_U, a hysteresis cycle is introduced in the handover inizialization procedure. Letting $\Delta(i) = \delta_T(i) - \delta_S(i)$, the rules for issuing a handover request can be expressed as:

$$(7)\quad HO(i)\ \{TBS \to SBS\} : \Delta(i) < -H_T \quad ,$$

$$(8)\quad HO(i)\ \{SBS \to TBS\} : \Delta(i) > H_S \quad .$$

where H_T and H_S are the hysteresis margins. The decision statistics is given by the distribution of the variable $\Delta(i) \sim N\,[\mu(i), \sigma^2]$, where $\mu(i) = E\{\delta_T(i)\} - E\{\delta_S(i)\}$ and $\sigma^2 = \sigma_T^2 + \sigma_S^2$.

An approximate evaluation of the probability of unnecessary HO can be obtained as:

$$(9)\quad \begin{aligned} P_U(TBS \to SBS) &= \mathrm{Prob}\{\Delta(i) < -H_T\,,\ \Delta(i+k) > H_S\} \\ &\cong Q\left(\frac{H_T + \mu(i)}{\sigma}\right)\cdot Q\left(\frac{H_S - \mu(i+k)}{\sigma}\right) \quad , \end{aligned}$$

$$\text{where } Q(x) \overset{\Delta}{=} \frac{1}{\sqrt{2\pi}}\int_x^{\infty} \exp\left(-\frac{t^2}{2}\right) dt \quad .$$

An expression similar to (9) holds for $P_U(SBS \to TBS)$. The larger the values for H_T and H_S, the longer will be the delay in issuing a handover request, D, which is comprised of two contributions [8]: the first is due to the averaging of measured levels, while the second is the effect of the hysteresis cycle. For a given MS speed, evaluation of D depends on the slope of $E\{\delta_T(i)\}$ and $E\{\delta_S(i)\}$ as a function of i. As far as the terrestrial link is concerned, the slope can be derived from [9]. In the case of the satellite link, a distinction must be made between systems employing geostationary (GEO) satellites and those with constellation of small satellites on low-Earth orbits (LEO). In the first case, for all practical purposes the path loss slope can be assumed to be almost zero. The situation changes drastically when the satellite is on a LEO: the relative angular velocity of the spacecraft w.r.t. Earth renders the slope much steeper. Only the case of a GEO orbit is considered here. The delay in issuing the handover request TBS -> SBS can be estimated through the following equation:

$$(10)\quad D_T = \frac{T_{av}}{2} + \frac{R}{v}\left(10^{H_T/K} - 1\right) \quad ,$$

where T_{av} is the averaging time, v is the MS velocity, R is the distance of the MS from the TBS at the overlay borderline, K = 45 - 6.6 log (h_B), h_B is the TBS antenna height. A similar expression holds for SBS -> TBS handover.

3. INTER-SYSTEM HO EXECUTION

In order to analyze inter-system handover execution, some assumptions are needed about network architecture. The satellite system is supposed to be integrated with a GSM-like (or DCS-like) terrestrial system [10]. The satellite system shares the fixed facilities of the terrestrial network. Since the switching facilities are located on ground, transparent satellites are considered. The Home Location Register (HLR) can be unique for both systems in the service area. The home of a user is located in the satellite system if and only if it belongs to an area not covered by the terrestrial system. On the other hand, a dedicated Visitor Location Register (VLR) is assumed for each system.

Suppose, as before, a simplified situation with only one TBS and one SBS in visibility. A flow diagram of the TBS->SBS handover procedure (including initialization and excecution) is shown in Fig.1, while the main signaling flow is shown in Fig.2. While it is connected to a TBS during an active call, the dual-mode MS monitors the Broadcast Control Channels (BCCH) coming from both TBS and SBS. If MAHO is adopted, the measurements results are sent to the TBS on the Slow Associated Control Channel (SACCH) to assist the handover decision process performed at TBS/MSC level. Monitoring continues until the necessity for a handover is recognized. The handover request is issued to the Satellite MSC (S-MSC), which grants one of its available channels. The handover execution message is forwarded, through a Fast Associated Control Channel (FACCH), to the MS, which starts transmitting on the assigned satellite channel. Handover indication to the T-MSC includes characteristics of the granted channel and the relative commands. It is evident that the delay introduced by the satellite hop must be properly taken into account, since it may generate a time interval during which no message blocks are received from both the MS and the fixed network side.

As pointed out in the introduction, the handover failure rate is affected by the delay in the handover inizialization process. However, it also depends on the availability of free channels to be assigned to handover requests which, in turn, is tightly related to the selected channel assignment strategy. *Fixed* and *dynamic* criteria refer to the free channel selection among a pre-assigned permanent channel set of each cell or among all the available channels, respectively. An intermediate solution (*flexible*) adds to the pre-assigned permanent channels a set of emergency channels, which are distributed to the cells on either a scheduled or a predictive basis. Further, borrowing strategies are possible where the free channel can be also searched in the neighbouring cells, provided it does not interfere with the active calls [6].

In the present study the channel assignment strategy is supposed to be basic fixed, as this choice seems reasonable in an integrated satellite and terrestrial environment. However, the fixed assignment could be effectively modified in the cells where inter-system handovers more often take place. In particular, a subset of the pre-assigned permanent channels of each satellite and terrestrial cell covering the border area could be permanently devoted to satisfying inter-system handover requests.

Guard channels or queueing of handover requests have been proposed to keep the probability of handover failure low [6,7]. In particular, queueing of handover requests seems an interesting method of giving priority to handover requests with respect to new call attempts. The MS, after recognizing the need for handover, is usually able to communicate on the old channel with acceptable quality for a certain time interval, waiting for the new channel. Note that in Fig.1 the queueing alternative is considered.

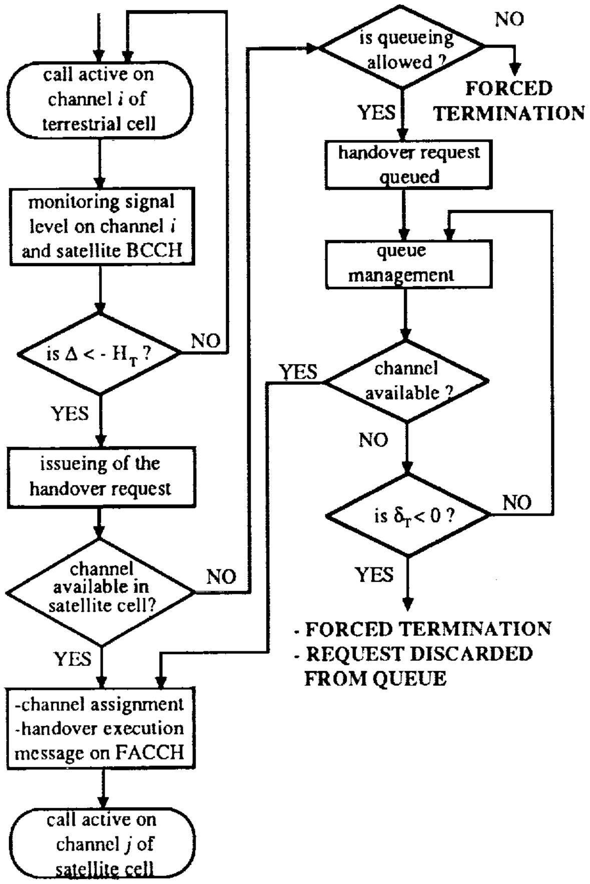

Fig. 1 - Terrestrial-to-satellite inter-system handover procedure flow-diagram

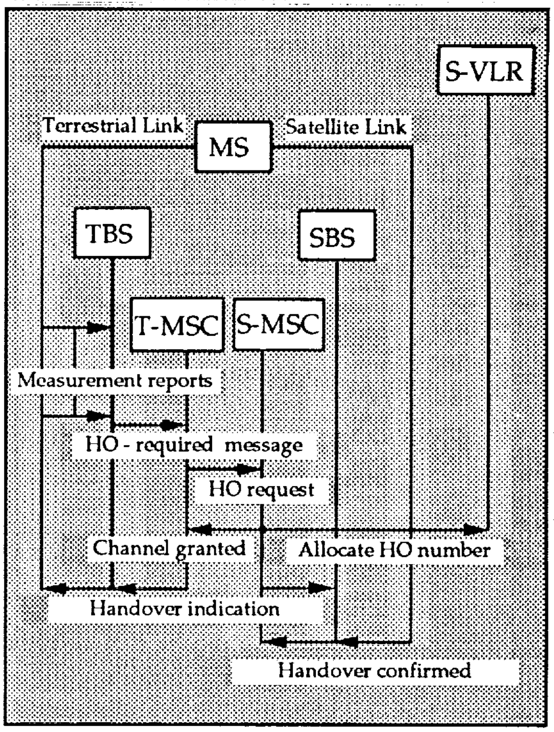

Fig. 2 - Handover signaling flow

4. NUMERICAL RESULTS

On the basis of the previously developed model, a numerical analysis is carried out. Fig.3 shows the standard deviations σ_T (continuous line) and σ_S (dotted line) as a function of the number of averaging intervals. The following values are assumed for the shadowing model parameters: $\sigma_{A_T} = 6.5$ dB, $\gamma_T = 0.8$, $\sigma_{A_S} = 5.5$ dB, $\gamma_S = 0.7$. Choosing N = 37 and M = 16, it turns out $\sigma_T \cong \sigma_S \cong 3$ dB. In this case, hysteresis margins can be equal.

The probability of unnecessary handover is plotted in Fig.4 versus the common value of hysteresis margin, assuming $\mu(i) \equiv \mu(i+k)$. The benefit of inserting the hysteresis cycle is evident.

The delay in issuing the handover request is shown as a function of the hysteresis margin in Fig.5, supposing the sampling interval is 250 msec, R = 3000 m, v = 13 m/s, and for two values of the number of averaging intervals in the terrestrial link measurement N (N = 40, continuous line; N = 200, dotted line).

As far as the execution of inter-system handover is concerned, a queueing algorithm based on FIFO (First In First Out) discipline has been simulated for a satellite cell provided with 200 channels (110 s mean occupancy time), for a 15% handover traffic over the total offered traffic. The simulation results are reported in Fig.6, in terms of probability of handover failure versus the *residual handover margin*, here defined as the difference between the signal level at the time instant when the handover request is issued and ξ_T. As the advantages of queueing increase with this margin, it clearly results that the optimization of the handover procedure must involve both the inizialization and the execution processes.

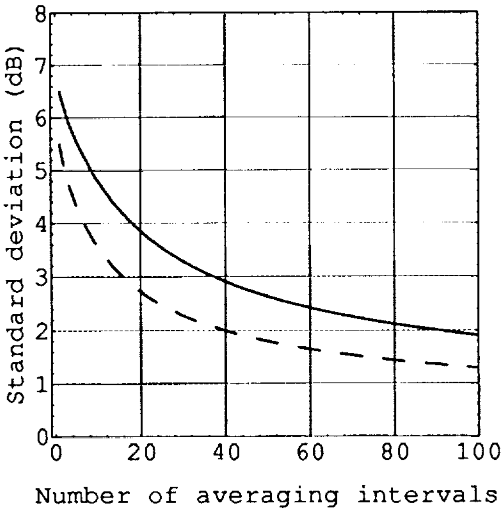

Fig.3 - Standard deviation in the power level measurement (continuous line: σ_T; dotted line: σ_S)

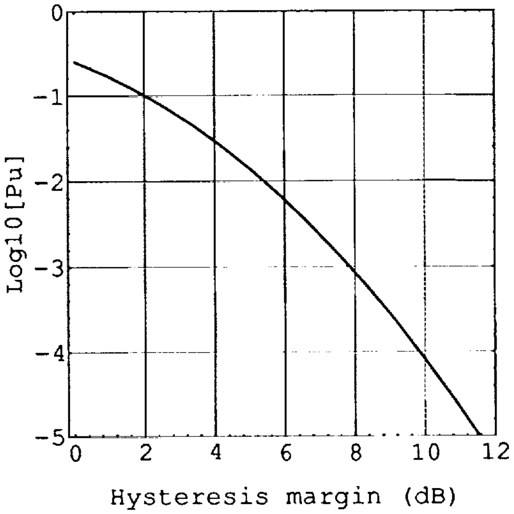

Fig.4 - Probability of unnecessary handover as a function of the common value of hysteresis margin $H_T = H_S$

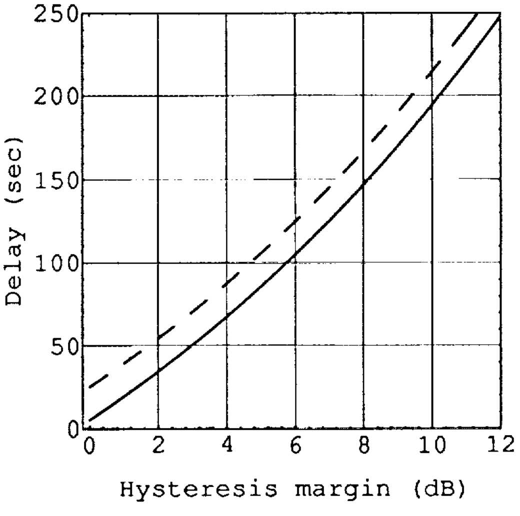

Fig.5 - Delay in the initialization phase of a TBS -> SBS handover (continuous line: N = 40; dotted line: N = 200)

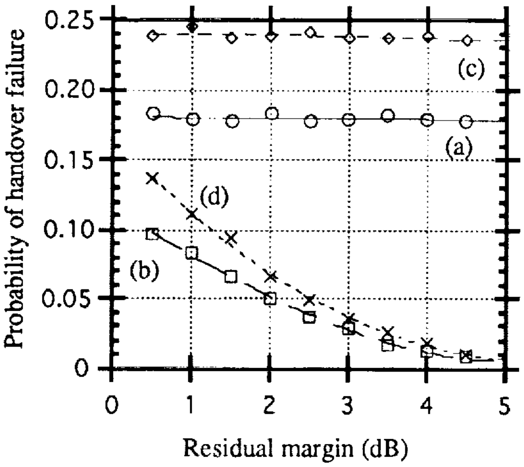

Fig.6 - Probability of handover failure offered traffic: (a),(b) 250 E; (c),(d) 300 E queue: (a),(c) unqueued ; (b),(d) FIFO

5. CONCLUSIONS

A key aspect in the integration of satellite and terrestrial mobile systems is the effectiveness and the reliability of inter-system handover procedures. Difficulty arises in trying to estimate the relative quality of two systems employing different modulation and coding formats. The criticity of the comparison and the user terminal complexity could be lowered if the satellite and the terrestrial systems were as similar as possible.

The optimum handover procedure should minimize the probability of unnecessary handover, on one side, and the probability of handover failure, on the other. The compromise between these two contrasting objectives must be carried out on the basis of a model that includes the overall handover procedure. The paper has proposed and analyzed a complete inter-system handover model, consisting of both the inizialization and execution phases.

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