An Analytical Model for Intersystem Handover

Brahmjit Singh*, K.K. Aggarwal**, and Shakti Kumar#
*ECE Department, National Institute of Technology, Kurukshetra-136119
** Vice-Chancellor, GGS Indraprastha University, Delhi-06
ECE Department, Haryana Engineering College, Jagadhri
pranjal_bjs@rediffmail.com

Abstract—Universal Mobile Telecommunication Systems (UMTS) shall be developed in such a way that it will support compatibility with an evolved Global System for Mobile Communications (GSM). In this paper, we investigate intersystem handover between GSM and UMTS based on Wideband Code Division Multiple Access (WCDMA) air-interface. A mathematical model is proposed to evaluate the handover performance. The handover initiation algorithm is based on the absolute value of averaged signal strength thresholds. Average number of handovers and handover initiation delay are used as performance measures. Based on numerical results, it is observed that handover initiation algorithm based on absolute thresholds induces large number of handovers near the cell boundary. Finally, threshold levels are optimized for given system parameters.

1. INTRODUCTION

The second generation digital cellular networks e.g., GSM, have been primarily focused on providing better voice services. Due to enormous demand for mobile wireless services, we are now faced with the challenges of incorporating data and multimedia services into these networks that were originally designed for voice communications. These requirements can be met by developing advanced air-interface technology. In 1999, the International Telecommunications Union (ITU) approved UMTS as a front-runner technology for delivering third generation mobile services. UMTS uses spread spectrum technique and is based on WCDMA radio air-interface [1]. It works at different frequencies (around 2.1GHz) from GSM and spreads the data over 5 MHz carriers and supports packet switched services. GSM, on the other hand, is a Time Division Multiple Access (TDMA) system and time slot is used as a phone channel. As the GSM standard is the most widely spread second-generation standard in the world today, the UMTS radio interface has to be capable of coexisting with GSM. An interesting future scenario could be the handover between these two networks providing seamless service connectivity to the user [2][3]. Since GSM and WCDMA networks operate on different standards, the handover between these two is termed as intersystem handover.

The algorithms for intersystem/intersegment handovers have been reported for geostationary satellite systems interworking with terrestrial systems [4]. For intersystem handover, mobile user equipment should be capable to operate in dual mode [5]. It has to regularly monitor on signals coming from various networks operating on different standards. For example, CDMA and GSM use different frame structures. Gianluca et al. in [6] have reported a scheme to monitor signal measurements from different networks simultaneously. A fuzzy logic based handover scheme has been reported in [7] to evaluate the intersystem handover performance amongst three segments; General packet Radio Access (GPRS), UMTS and a geostationary satellite systems. Recently, simulation results are reported in [8] for determining the various measurement quantities, which may be used to make UMTS to GSM handover decision.

In this paper, we study the intersystem handover between GSM and WCDMA networks using signal strength measurements. An analytical model is developed to evaluate the handover performance, which is measured in terms of the average number of handovers experienced by the Mobile Station (MS) while moving from one Base Station (BS) to another involving cell boundary crossing, and the handover initiation delay.

The rest of the paper is structured as follows: section 2 describes the system model under consideration. Criterion and algorithm for handover initiation are also stated in this section. Section 3 gives the analytical model for performance evaluation of the handover initiation algorithm. It also covers the performance measures used in the evaluation. Numerical results are presented in section 4. Finally, conclusions are drawn in section 5.

2. SYSTEM MODEL

We assume a simple two-cell model consisting of one GSM cell supported with BS_g and another WCDMA cell with

0-7803-7651-X/03/$17.00©2003 IEEE

BS_w as shown in fig. 1 for the development of analytical model and subsequent performance evaluation. BS_g and BS_w are D meters apart. MS moves from BS_g to BS_w along a straight line at constant speed.

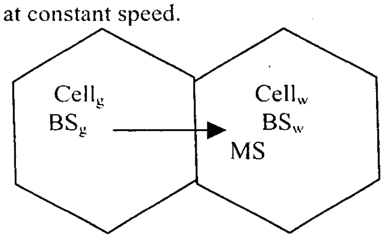

Fig. 1. Cellular network configuration.

2.1. The Mobile radio signal model

The mobile received signal consists of a distance dependent attenuation component and a shadow-fading component. Fast fading is neglected as it assumed to be averaged out at the time scale under consideration. In this paper, we adopt a discrete time formulation. The signal levels from BS_g and BS_w are sampled every kd_s distance, where k is an integer and d_s, the sampling distance. The signal levels S_i (k), i = g, w, the MS receives from BSs at the k^{th} instant {k ∈ (1, D/d_s)} at a distance of kd_s from BS_g in dB are given by [9]

$$S_g(k) = K_{1g} - K_{2g} \log_{10}(kd_s) + u(kd_s) \quad \ldots(1)$$

$$S_w(k) = K_{1w} - K_{2w} \log_{10}(D - kd_s) + v(kd_s) \quad \ldots(2)$$

where K_{1i} and K_{2i} are the path loss parameters and γ_i (i = g, w) are the path loss exponents. $K_{2i} = 10.\gamma_i$. For GSM and WCDMA networks, we assume propagation environments with different path loss exponents. {u (kd_s)} and {v (kd_s)} are zero mean stationary Gaussian random processes that model lognormal shadowing. As a result, the signal received by MS could be assumed as a random variable with lognormal distribution [10].

$$P(s) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left\{-\frac{(s-\mu)^2}{2\sigma^2}\right\} \quad \ldots(3)$$

where P(s) is the probability density function of the signal strength received by MS from GSM and WCDMA BSs. σ denotes the standard deviation of shadow fading. μ is the signal strength due to path loss only, which could be calculated from path loss models [11].

The fading process is assumed to have the exponential correlation function proposed by Gudmundson [12] on the basis of experimental results, as given below:

$$\rho(d) = \sigma^2 \exp(-d/d_0) \quad \ldots(4)$$

where d_0 is the correlation distance and σ is the standard deviation of lognormal shadow fading. d_0 and σ both characterize the propagation environment.

Averaging of Received Signal Strength (RSS) at MS is used to smooth out the random signal fluctuations. It makes the handover decision to be based on underlying trends and not instantaneous changes. It is accomplished according to the following rectangular window [13]

$$\hat{S}_i(k) = \frac{1}{N_w} \sum_{n=0}^{N-1} S_i(k-n) W_n , \quad \ldots(5)$$

where $\hat{S}_i$ is the averaged RSS (i = g ,w). N denotes the number of samples used for averaging the signal strength measurements. W_n is the weight assigned to the sample taken at t = k − n, and $N_w = \sum_{n=0}^{N-1} W_n$. For a rectangular window, $W_n = 1$ for all n.

2.2. Handover Initiation criterion

WCDMA systems are interference-limited meaning that their capacities are closely related to the amount of interference the system can tolerate. Handover may be initiated when the Carrier to Interference Ratio (CIR) falls below a certain threshold. But for the problem under consideration the two systems i.e., GSM and WCDMA are supposedly operating in different spectrums. CIR, therefore, may not be the suitable criterion. Bit Error Rate (BER) may be another parameter for handover initiation. However, BER measurement is not always feasible as sufficient number of bits should be collected and this may introduce a significant and intolerable delay in handover initiation. Signal to Noise Ratio (SNR) can also make an instantaneous estimate of BER. But direct comparison of SNR of two systems, which exploit different modulation and coding, may not be a reliable criterion for handover initiation. As a result of the above argument, the signal strength received by a dual mode mobile terminal can be a suitable criterion. However, measured signal levels cannot be directly compared since the signal variations (path loss exponents) in the two systems may be totally different. Hysteresis margin approach, therefore, cannot be utilized for intercell handovers in this case [14]. As a result, absolute value of received signal strength may the possible criterion for the problem of intersystem handovers between GSM and WCDMA networks. The handover initiation criterion used in the present work is based on absolute thresholds of received signal strength measurements.

2.3. Handover Initiation algorithm

A handover is performed if the following conditions are simultaneously fulfilled:

1). The averaged signal strength form the serving BS falls below a threshold value.
And

2). The averaged signal strength from the target BS becomes greater than a preset threshold.

3. Analytical Model

The handover initiation analytical model introduced below will be used in this paper for handover performance evaluation. This distance D between BS_g and BS_w is divided into sampling interval of length d_s. $d_k = kd_s$, ($k = 1,2,\ldots D/d_s$). Handover will occur in two cases:

1. MS is with GSM at d_{k-1} but at d_k,

$$\hat{S}_g < T_g \text{ and } \hat{S}_w \geq T_w \qquad \ldots(6)$$

OR

2. MS is with WCDMA at d_{k-1} but at d_k,

$$\hat{S}_w < T_w \text{ and } \hat{S}_g \geq T_g \qquad \ldots(7)$$

where $\hat{S}_g$ and $\hat{S}_w$ are the averaged signal strengths received from BS_g and BS_w respectively. T_g and T_w denote the respective absolute threshold settings to initiate the handover for GSM and WCDMA networks. Assuming that G(k-1) and W(k-1) denote the events that at d_{k-1}, the serving BSs are GSM and WCDMA respectively, the probability of handover from GSM to WCDMA and vice-versa are given by

$$P_{wg}(k) = P\{W(k) / G(k-1)\} \qquad \ldots(8)$$

$$P_{gw}(k) = P\{G(k) / W(k-1)\} \qquad \ldots(9)$$

respectively. Where P_{wg} (k) denotes the probability of handover from GSM to WCDMA and P_{gw} (k), denotes the probability of handover from WCDMA to GSM. Using the handover initiation criterion as stated by (6) and (7), P_{wg} and P_{gw} can be computed as follows

$$P_{wg}(k) = P\{\hat{S}_w(k) \geq T_w, \hat{S}_g(k) < T_g / G(k-1)\} \qquad \ldots(10)$$

$$P_{gw}(k) = P\{\hat{S}_g(k) \geq T_g, \hat{S}_w(k) < T_w / W(k-1)\} \qquad \ldots(11)$$

The probability of being associated with GSM network is given by

$$P_g(k) = P_g(k-1)\times(1-P_{wg}(k)) + P_w(k-1)\times P_{gw}(k) \qquad \ldots(12)$$

Similarly, the probability of being associated with WCDMA network is given by

$$P_w(k) = P_w(k-1)\times(1-P_{gw}(k)) + P_g(k-1)\times P_{wg}(k) \qquad \ldots(13)$$

Eqns. (12) and (13) can be computed recursively in k with initialization $P_g(1) = 1$ and $P_w(1) = 0$.

Finally, the probability that there is a handover in the k^{th} interval will be given by

$$P_{ho}(k) = P_g(k-1)\times P_{wg}(k) + P_w(k-1)\times P_{gw}(k) \qquad \ldots(14)$$

The probability that the received signal from GSM BS is greater than the signal strength threshold T_g at the interval k, is given by

$$P\left\{\hat{S}_g(k) > T_g\right\} = \int_{T_g}^{\infty} \frac{1}{\sigma_g\sqrt{2\pi}} \exp\left\{\frac{\hat{S}_g(k) - \mu_g(k)}{2\sigma^2_g}\right\} dx \qquad \ldots(15)$$

where μ_g and σ_g respectively denote the mean signal strength due to path loss only and standard deviation of lognormal shadow fading from BS_g. Also

$$Q(s) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} e^{-t^2/2} dt \qquad \ldots(16)$$

Similarly, other probabilities can be determined.

3.1 The performance metrics

Handover algorithm performance can be evaluated in terms of the average number of handovers and the handover initiation delay. The aim of a handover scheme is to maximize the average received quality while minimizing the number of handover per call, and handover initiation delay. The number of handovers experienced by the MS during the trip from BS_g to BS_w should be minimized, since unnecessary handovers affect the call quality and can increase the switching and signaling load. From the switching and signaling point of view, ideally only one handover should be performed when a MS crosses a cell boundary. Handover decision should not be delayed too much, since the communication link with BS_g deteriorates as the MS moves farther away from it. Hence the number of handovers has to be traded off against the handover initiation delay when choosing the optimum parameters for the algorithm.

4. Performance Results

In this section, we present the numerical results. The following set of parameters given in table I is assumed for numerical computation:

Table I: System parameters.

D = 1500 m	Distance between the two BSs. Radii of GSM and WCDMA cells are 1000 m and 500 m respectively
$\gamma_g = 3$; $\gamma_w = 3.4$	Path loss exponents for GSM and WCDMA cells respectively
$\sigma = 6$ dB	Standard deviation of shadow fading
$N_{w\_gsm} = 30$; $N_{w\_wcdma} = 10$	Number of samples used in the averaging window for GSM and WCDMA networks respectively
$d_s = 1$m	Sampling distance

Averaging amount of signal strength measurements is different for GSM and WCDMA cells. GSM environment is expected to follow gentle path loss characteristics and hence smooth variation of received signal strength. It allows us to use larger averaging window. WCDMA environment, on the other hand, may have faster variation of received signal power with respect to distance. Large averaging window may, therefore, cause forced termination of the call due to poor signal level. Hence smaller window has been employed for averaging signal strength measurements from BS_w. For simplicity, we have assumed zero correlated shadow fading. Initially, to study the algorithm performance, GSM and WCDMA thresholds are set to the signal strengths available due to path loss only at the geographical boundary of the cells, i.e., $T_g = -90$ dB and $T_w = -91$ dB. From the numerical results obtained, the following observations are made:

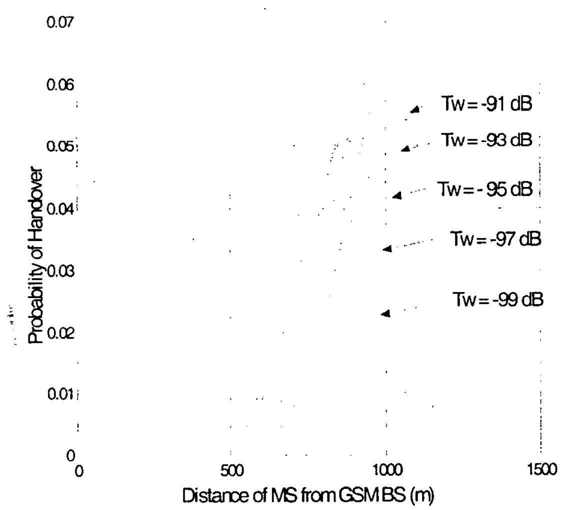

Fig.2: Probability of handover w.r.t. MS position when T_w is decreased.

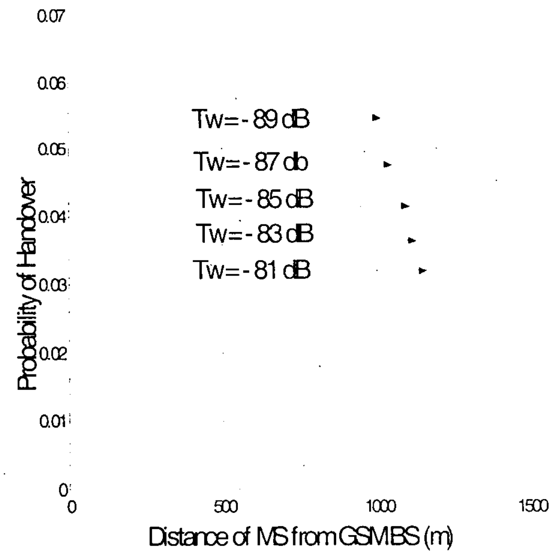

Fig. 3: Probability of handover w.r.t. MS position When T_w is increased..

1. As seen in fig. 2, the position of the maximum probability of handover from GSM to WCDMA network happens earlier as T_w is decreased from –91 dB onwards. For $T_w = -91$ dB, it occurs at 1020 m away from BS_g, almost at the boundary. But as T_w is decreased to –99 dB, the position of maximum probability of handover shifts to 833 m. This implies that the effect of decreasing T_w makes the handover of call to happen earlier.
2. On the other hand, when T_w is increased, handover process is delayed. As shown in fig. 3, typically for $T_w = -81$ dB, it occurs at 1244 m away from BS_g. This indicates the large penetration of MS into WCDMA network before handover takes place, which is not desirable.
3. Fig. 4 shows the handover rate as a function of T_w. When $T_w = -93$ dB, it gives the maximum number of handovers equal to 21.4. On either side of this reference value, handover rate is decreased. For $T_w = -81$ dB and –99 dB, handover rate was observed as 9.89 and 14.48 respectively.
4. Fig. 5 depicts the handover delay marked by the position of maximum probability of handover as a function of T_w. Increasing T_w delays the handover process.
5. For microcellular structures, handover process should be fast enough. It should occur at or near the cell boundary. To achieve this objective, T_w should be chosen in the range of –93 to –89 dB. This range corresponds to number of handovers varying from 21.4 to 19 and delay from 970 m to 1070 m respectively.

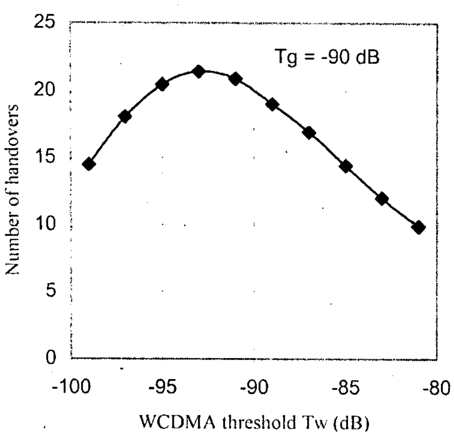

Fig. 4: Number of handovers v/s WCDMA threshold keeping T_g fixed.

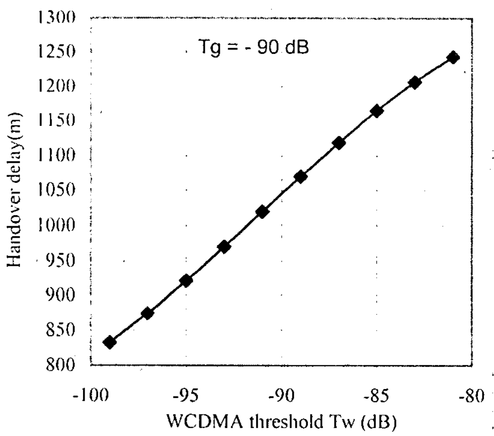

Fig. 5: Handover initiation delay v/s WCDMA threshold keeping T_g fixed.

6. CONCLUSION

In this paper, we have evaluated the performance of inter system handovers between GSM and WCDMA networks using a mathematical model. The effect of various threshold settings was analyzed. From the performance results obtained, it is observed that the handover initiation algorithm based on absolute value of signal strength thresholds results in a large number of handovers near the cell boundary causing heavy signaling and switching load. For the given system parameters, threshold settings were determined to minimize both the handover delay and average number of handovers. However, employing more averaging of signal strength measurements can further reduce the handover rate. But simultaneously, more averaging reduces the detection probability of handover at right place and at right time, particularly in microcellular networks. We are further working in this direction and the incorporation of other link quality parameters in the handover initiation criterion.

REFERENCES

[1] E. Dahlman, B. Gudmundson, M. Nilsson, J. Skold, " UMTS /IMT-2000 Based on Wideband CDMA," *IEEE Communications Magazine, pp. 70 – 80,* September 1998.

[2] France Telecom," Handover from a UMTS FDD Cell to a GSM Cell," *tdoc SMG2 UMTS-L1 69/98*, April 1998.

[3] France Telecom, "Introduction of FDD to GSM Handover Scenarios," *tdoc UMTS-L1. 177/98*, June 1998.

[4] Marco Leo and Michele Luglio, "Intersegment Handover between Terrestrial and Satellite Segments: Analysis and Performance Evaluation Through Simulation." IEEE Transactions on Vehicular Technology, Vol.50, No. 3, pp. 750 – 760, 2001.

[5] NEC Techn, "Handover Procedures for Dual-Mode WCDMA/GSM Terminals," tdoc. SMG2 A38/97. November 1997.

[6] Gianluca Durastaute, Alberto Zanella, "An Efficient Monitoring Strategy for Intersystem Handover from TD – SCDMA to GSM Networks," Proceedings of PIMRC, pp. 1555 – 1560, 2002.

[7] P.M.L. Chan, R.E. Sheriff, Y. F. Hu, "An Intelligent Handover Strategy for a Multi-Segment Broadband Network," IEEE Vehicular Technology Conference, pp. 55-59, 2001.

[8] M. Benson, H.J. Thomas, "Investigation of the UMTS to GSM Handover Procedure," IEEE Vehicular Technology Conference, pp. 1829 – 1833, 2002.

[9] Rajiv Vijayan, "A Model for Analyzing Handoff Algorithms," IEEE Transactions on Vehicular Technology, Vol. 42, No. 3, 351-356, 1993.

[10] Vijay K. Garg and Joseph E. Wilkes, "Principles and Applications of GSM," Prentice Hall, 1999.

[11] Theodore S. Rappaport ,"Wireless Communications; Principles and Practice," Prentice Hall, New Jersey, 1996.

[12] M. Gudmundson, "Correlation models for Shadow fading in Mobile Radio Systems," *Electronics Letters* Vol. 27, No. 23. November 1991.

[13] G.E. Corazza, D. Giancristofaro, and F. Santucci, "Characterization of Handover Initialization in Cellular Mobile Radio Networks," Vehicular Technology Conference, pp. 1869 – 1872, June 1994.

[14] Gregory P. Pollini, " Trends in Handover Design," IEEE Communications Magazine, pp. 82-90, March 1996.