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ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 7 (2): 344-349, 2008
ISSN 1812-5638

Determining Rate of Handoff for Irregularly Bounded Cellular Environments in Future Mobile Networks

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Abstract: In this study, we have presented and tested a method to calculate rate of handoff accurately by accounting for irregularities in cellular coverage area in next generation wireless and cellular communication networks. Traditionally, rate of handoff calculations are based on the assumption that cell boundaries can be represented by uniform geometrical shapes such as circle, square and hexagon. However, in real situations cell boundaries are irregular due to various signal-degradation factors and hence cannot be precisely represented by definite geometrical structures. The difference in calculated and measured values of rate of handoff introduces compounding error in probabilistic analysis of Next Generation Networks and hence, requires the multiplication of an appropriate correction factor with calculated rate of handoff to minimize the error. Extensive experimentation reveal that actual rate of handoff for a cellular environment is greater than the calculated rate by as much as 20% and is proportional to the degree of irregularity in the cell boundary.

Key words: Quality of service, rate of handoff, irregular cell boundaries, fluid flow model, probability of handoff

INTRODUCTION

Mobility is the most important service offered by next generation wireless cellular communication networks and has been a consistent part of wireless hierarchy and design. With the evolution of cellular communication systems and saturation of usable frequency spectrum, service providers are switching to higher frequencies and consequently, a smaller cell size. Quality of Service (QoS) in IEEE 802.11 networks demands that a mobile terminal should be connected to its Host Base Station (HBS) at all times (Zhu *et al.*, 2004). As Mobile Terminals (MTs) crossover cell boundaries frequently during the course of an active call, wireless resources must be provided for them to continue; otherwise active calls would be forced to terminate and overall efficiency of the system would depreciate. This process of wireless resource reservation and transfer of a mobile user to the next visited cell is called Hand Off (HO). However, HO can also be initiated by the network to reallocate its wireless resources and to improve network efficiency. In the present study, we are mainly concerned with HOs associated with mobility of a MT that is; a MT crosses over a cell boundary and requires channel in the new cell in order to maintain its ongoing call.

Traditionally, HO decisions have been associated with the Received Signal Strength (RSS) that is measured by individual MTs (Global System for Mobile communication) and/or by network in different architectures (AMPS). Figure 1 shows a common scenario when a mobile terminal moves from its HBS or current attachment point toward Base Station (BS) B. While the MT is near BS A its RSS is fairly strong but as it moves near the edge of service area, RSS from A depreciates and that from B becomes stronger. As long as RSS is above a certain HO threshold value, MT can continue its normal operation shown in Fig. 1. When MT reaches the end of overlapped region between the two base stations, HO from BS A to B must be completed. It is clear that if HO process is not completed within the HO completion window, any active voice or data sessions would be forcefully terminated due to poor signal reception and HO would be unsuccessful. HO can also be unsuccessful if wireless resources are not available in the Future Base Station (FBS). Several techniques have been proposed in literature for alleviation of HO blocking and dropping, these include queuing HO requests, prioritizing HO requests and utilizing additional parameters besides RSS measurements etc. (Louvros *et al.*, 2007; Beaubrun *et al.*, 2007; Pandey *et al.*, 2007; Ebersman and Tonguz, 1999)

Theoretically, cell boundaries have been considered as regular geometric shapes such as circle, hexagon and square for the sake of simplicity in calculation (Rappaport, 2001). However, in practice cell-boundaries are always irregular due to propagation losses, reflections from structures and buildings and other environmental

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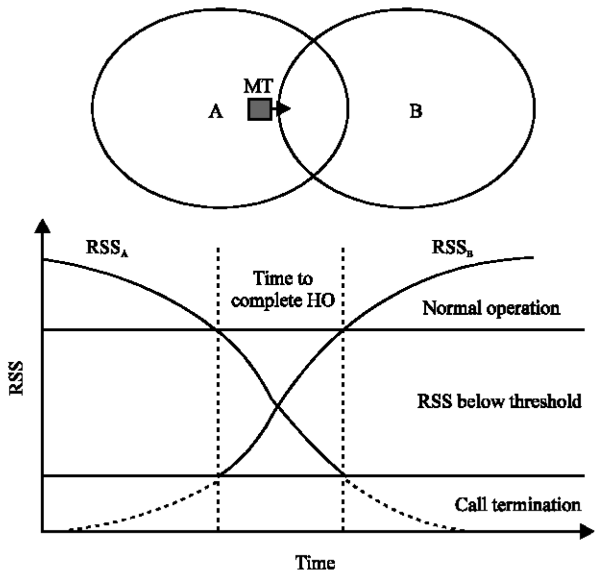

Fig. 1: Movement of mobile terminal from one attachment node to another and corresponding change in received signal strength from its current and future attachment node (Fig. Not to scale)

variables. There had been extensive research on signal propagation through air and consequently many models have been proposed to accurately account for propagation losses in urban and rural environments at different transmit frequency levels. Some of these models are given in (Okumura *et al.*, 1968; Hata, 1980). To determine important QoS parameters like probabilities of call blocking and HO, network capacity, throughput, transmitted and received power levels and percentage of errors (Hong and Rappaport, 1999), we need to establish the actual rate of HO in a cell. Jabbari (1996) presented a numerical calculation for rate of HO by considering fluid flow model for MT generation and mobility. However, this model also assumes that cell shapes are fixed geometrical structures and hence does not account for irregularities in cellular coverage areas.

With the advent of third generation and beyond wireless cellular networks (B3G), localization and mobility information has an escalating role to play in improving network efficiency. HO algorithms and resource reservation schemes are incorporating additional information parameters such as, location information, accurate measurement of speed and direction of MT's motion, cell dwell time and other network parameters (Chang and Leu, 2004; Liu *et al.*, 1998; Khan and Sha, 2006) but the amount of traffic and rate of HO have the greatest impact on overall system efficiency. Also, the role and capacity of MT to perform some tasks for host network has been fully established as in the case of Code Division Multiple Access (CDMA) and Mobile Assisted Handoffs (MAHO) in Global System for Mobile Communication (GSM). CDMA involves MTs in the HO decision process and provides better resource utilization with the help of soft HO technique which involves the provision of service from two or more base stations at the same time (Ma *et al.*, 2006) while GSM uses MTs in the measurement of RSS values from neighboring BSs to estimate necessity of HO (IEEE 802.1AB, 2005; IEEE 802.11, 2007).

RESEARCH MOTIVATION

For accurate and detailed simulation of future wireless cellular networks, we need to incorporate almost all of the real-world scenarios including micro and pico cellular structures which result in an increase in number of HOs. Also, the divergence of actual rate at which MTs enter or leave a given area under consideration from the theoretical value cannot be ignored as insignificant. Further investigation into rate of HO and other QoS variables dependent on its accurate calculation is required, especially for irregular cell boundaries.

In the following sections we would present basis and simulation setup for accurate calculation of rate of HO and its detailed analysis with a discussion of obtained results and conclusions.

FLUID FLOW MODEL AND RATE OF HANDOFF

Fluid flow model had been very effective in explaining traffic behavior in cellular networks with a large subscriber base (Xu *et al.*, 2005). The common assumptions used for incorporating fluid flow model in cellular networks are:

- Network under consideration has a dense population of randomly distributed MTs just like molecules in a liquid
- MTs can move in any direction with a constant speed and direction
- MTs exiting the network are re-injected into it so there is no loss of traffic
- The BS under observation is a very small part of whole network so the total traffic flow in and out of it is balanced

Following from Jabbari (1996) and using the above stated assumptions, it is assumed that mobile terminals are uniformly distributed across a cell of area (S) and perimeter (L), exhibit a mean velocity (V) and have a definite direction uniformly distributed over (0 to 2π). The resulting cell cross-over rate (η) is given as:

$$\eta = \frac{VL}{\pi S} \tag{1}$$

For a circle of radius (r), (1) takes the form,

$$\eta = \frac{2V}{\pi r} \tag{2}$$

With Average Call Holding Time (T_n) as $1/\mu$ and Dwell time (T_h), defined as the time interval between handoffs, having average equal to $1/\eta$. Both T_n and T_h are random quantities with exponential distribution.

$$f_n(t) = \mu \times e^{-\eta \times t},\ f_h(t) = \eta \times e^{-\eta \times t},\ t \text{ is in sec} \tag{3a}$$

And corresponding distribution functions are:

$$F_n(t) = 1 - e^{-\mu \times t},\ F_h(t) = 1 - e^{-\eta \times t}, \tag{3b}$$

Probability of HO is found as:

$$P_h = \int_0^\infty f_h(T_h)\left[\int_0^\infty f_n(t \mid T_h)dt\right]dT_h = \frac{\eta}{\eta + \mu} \tag{4}$$

Let λ_n be the new traffic intensity in calls per sec generated in every cell and P_b be the probability that a new call is blocked. As shown in Fig. 2, the net new traffic intensity is $\lambda_n(1-P_b)$. Assuming homogeneity, the sum of rates of handoff calls leaving all neighboring cells would be equal to λ_h. Let P_{hf} be the probability that a handoff call is dropped in the new cell due to unavailability of channels. So rate of handoff traffic entering a cell would be $\lambda_h(1-P_{hf})$. From simple balance of flow conditions, average rate of calls leaving the cell would be equal to average rate of calls requiring handoff, that includes new calls and handoff calls in to the cell. Solving flow equation yields average handoff intensity as:

$$\lambda_h = \frac{P_h(1-P_b)}{\left[1 - P_h(1-P_{hf})\right]}\lambda_n \tag{5a}$$

For exponential statistics, considering new call blocking and handoff dropping probabilities to be very small P_b, $P_{hf} << 1$,

$$\lambda_h \approx \frac{\eta}{\mu}\lambda_n,\ (P_b,\ P_{hf} << 1) \tag{5b}$$

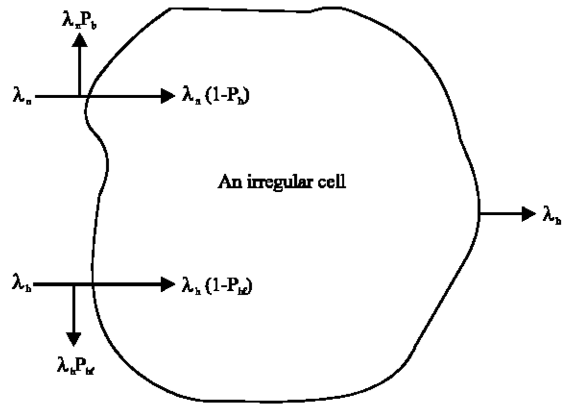

Fig. 2: Traffic entering and leaving a cell

From Eq. 5a and b, it is clear that if rate of cell cross-over is undervalued due to inaccurate approximation of cell boundaries as regular; rate of handoff and all other variables dependent on its value carry certain amount of error and must be multiplied with a correction factor to account for irregularities in cell boundaries. Also, irregular signal propagation increases the surface area and consequently provides more entry and exit points for considered cells. That causes the actual handoff traffic in and out of considered cell to be higher than calculated values. In cellular system simulations, probability of new call and HO call blocking, probability of HO and other performance metrics are measured using an iterative process, in which probabilities of next level are dependent on measured values of previously executed stage through Monte Carlo simulation procedures (Louvros *et al*., 2007; Beaubrun *et al*., 2007). If the rate of HO is consistently higher as shown by above analysis, it can have drastic effects on overall system performance metrics and can cause considerable error in steady state measurements. This effect can be alleviated by using appropriate HO management scheme to reduce the number of false HO requests (Khan and Sha, 2006).

SIMULATION SETUP

In order to measure the correction factor in rate of cell-crossing and handoff, fluid flow model was implemented on 300×300 simulation grid. Base Station control and handoff procedure implemented in simulation are based on GSM architecture. However we can accommodate other technologies as well. As we are interested in the rate at which MTs cross a given cross-section, HBS is assumed to offer bandwidth (channels) for all the users requesting HO. Users are randomly generated

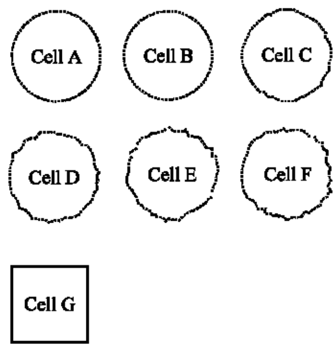

Fig. 3: Cells used for measuring rate of Handoffs in a 300×300 simulation grid. Different cell shapes were generated by using variance of 0 to 0.5 (Cells A, B, C, D, E and F). Cell G is a square with each side equal to diameter of circular cell

across homogeneous simulation environment with Poisson call arrivals with parameter λ (calls/s). As in the case of fluid flow model, the rate of entering a Region Of Interest (ROI) is equal to the rate of departure from ROI. Same is true for mobile users provided the generated traffic is much larger as compared to HO traffic (P_h<<1). Cells boundaries in the simulation network are represented by random variables (rv) having a specified mean (μ_{mean}) and variance (σ^2) following normal distribution. As cell boundaries are actually defined by signal degradation over distance and this loss of electromagnetic energy is known to have many factors that affect it independently and additively, normal distribution is used to model this phenomenon. Density of Normal distribution is given as:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu_{mean})^2}{2\sigma^2}}, (\sigma > 0) \quad (6)$$

Each sample cell consists of user-specified number of normally distributed points generated for angle (φ: 0→2π) with a specified variance (σ^2: 0→1) (Fig. 3). However, it is worth noticing that if a cell is generated using very small angular divisions, its irregularity does not appear natural and results in an unrealistic cell boundary. A tradeoff exists between the angular divisions used to constitute an irregular cell. In current simulation setup, each cell is constructed with linear interpolation of 200 equally spaced angular divisions around HBS. The area of irregular surfaces is kept within 0.1% of the area of corresponding circle of radius r as shown in Table 1.

Traffic is generated at user-defined rate in calls per sec with direction (0, 2π) and speed (V_{min}, V_{max}). Here, V_{min} is chosen to be 3.5 kmph equivalent to average walking speed of a human being. While V_{max} is taken as 55 kmph which is average speed of a vehicle in urban environment. Average call duration (in sec) is exponentially distributed with adjustable mean value. In current work, we have assumed that MTs follow a straight path with constant speed during connection life-time. Number of HOs in and out of every cell is recorded and relevant parameters are calculated at the end of simulation time (in min).

Table 1: Area and Perimeter of generated cells (r = 50 km)

Cell	Area	Perimeter
A	7845	314
B	7847	321
C	7858	330
D	7848	338
E	7844	350
F	7847	359
G	10000	400

RESULTS AND DISCUSSION

In order to study the effect of irregular cell boundaries on rate of HO, average call duration is fixed at 180 sec and traffic is generated at 200 calls per min, while time for simulation is varied to get the curves for different cell shapes as shown in Fig. 4. It is evident that as the irregularity of cell under consideration increases, its rate of cell cross-over increases too as compared to bottom-line condition (Cell A with σ^2). For a moderately irregular cell shape (Cells D, E), the measured rate of cell cross-over is 10 to 20% more than Cell A. Square cell with sides equal to diameter of circular polygons, gives the maximum error in calculations of about 30% due to its marked difference in shape as compared to other coverage areas under consideration. Analysis of results from cells A and G highlights the fallacy in the assumption of definite geometrical shape of wireless coverage area.

When checked for different values of average call duration (1 to 4 min), the values of rate of HO depict insignificantly small variations confirming the established theory of fluid flow motion that flow in and out of a given small area under homogeneous conditions is equal and hence, an increase in the net inward traffic would be balanced by a raised outward traffic. Here, traffic is generated at 200 calls per min and time for simulation is 500 min. Several sets of test cells were tested and the average of 100 test runs is shown in Fig. 5. The curves show some variations at smaller times for simulation but this transitional period is over if simulation is performed for more than 200 min indicating a state of equilibrium in traffic entering or leaving a cell.

Through extensive experimentation we find that the calculated values of rate of HO are acceptable only for the case of simulations that do not account for irregularities

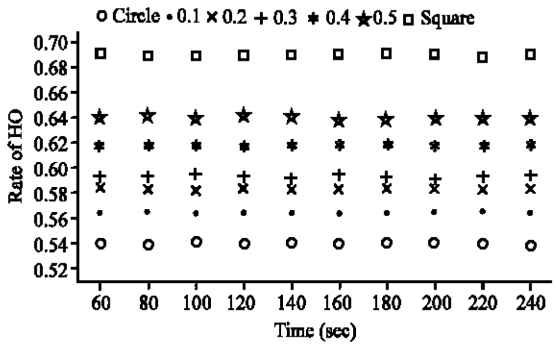

Fig. 4: Rate of handoff against variation in average call duration (1-4 min)

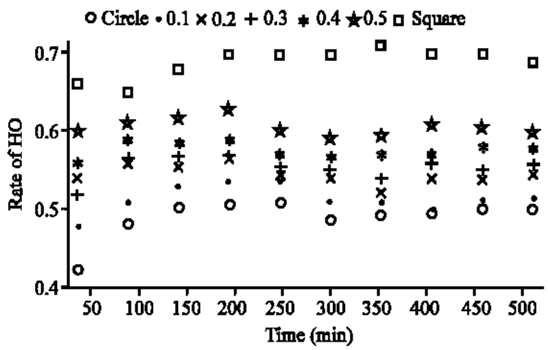

Fig. 5: Effect of simulation duration time on rate of HO

Table 2: Proposed correction factor for different cell boundary conditions

Cell boundary conditions	Variance (σ)	Correction factor for rate of handoff (η)
Perfect circle	0.0	1.0
Mildly irregular	0.1 to 0.3	1.1
Moderately irregular	0.3 to 0.5	1.3
Highly irregular	0.5 to 1.0	1.5

in cell coverage areas. Irregular cell boundaries effect the dwell time of MTs in a given BS and consequently increase or decrease the actual rate of HO. Based on these results, we present our proposed correction factor values in Table 2. These values are obtained by averaging the observed rate of HO with increase in variance used for generating test cell boundaries. Correction factor should be multiplied with calculated rate of handoff values to account for the error introduced by irregularity in cellular structure. For cells in urban areas, we suggest a correction factor of 1.5 as they provide a large number of entry and exit points and the cell coverage areas are highly irregular.

CONCLUSIONS

In this study, we have analyzed the effect of irregular cell boundary on average cell cross-over rate and rate of handoff which are important QoS parameters and are fundamental for complete analytical synthesis of next generation wireless cellular networks. A simulation setup is explained and results confirm that irregularity in cell boundary increases rate of handoff by 10% to more than 20% and its multiplication with appropriate improvement factor becomes inevitable for the removal of error in probabilistic calculations. Fluid flow model for traffic flow in and out of given simulation environment is also established to be independent of call duration parameter. Probabilistic variables related to handoff are measured through Monte Carlo simulations, hence, the error in calculation is accumulated in every iterative step and can introduce significant difference in measured and calculated average values, deeming it necessary to propose a correction factor for rate of handoff metric.

Further investigation is required for mobile terminals with direction and speed variation during passage through a cell with road topology information as well. Also, generation of cell boundaries in simulation environments with random variables governed by distributions other than Normal distribution is also desired.

ACKNOWLEDGMENTS

This research is supported by Program for New Century Excellent Talents in University, China (NCET-04-0332). Mr. Ali Nawaz Khan is grateful to COMSATS Institute of Information Technology, Pakistan for doctoral scholarship and funding.

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