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An Analytical Approach for Mobility Load Balancing in Wireless Networks

Sarhan M. Musa[1] and Nader F. Mir[2]

[1] Roy G. Perry College of Engineering, Prairie View A&M University, Prairie View, Texas, USA
[2] Department of Electrical Engineering, San Jose State University, California, USA

Management of mobility especially balancing the load of handoff for wireless networks is an essential parameter for wireless network design and traffic study. In this paper, we present analytical mobility management in high speed wireless mobile networks focusing on factors such as the number of channel slots and offered load. We demonstrate the performance of handoffs with mobility consideration using several metrics including the alteration of states prior to reaching a cell boundary, the speed of mobile terminal, and the distance between a mobile terminal and a cell boundary. We mainly focus on the performance evaluation for the factor of mobility with taking into account the high speed status of a user.

Keywords: wireless mobile networks, handoff, mobility management

1. Introduction

With substantial growth in system development for mobile analog and digital cellular telephony, radio paging, and microwave satellite broadcasting, next generation wireless communications systems will require supporting the seamless delivery of multiple class of traffic. These systems have varying traffic characteristics, end-to-end performance requirement and bandwidth needs. Types of traffic include voice, data, and video in the forms of constants bit rate, available bit rate, variable bit rate, and unspecified bit rate with high quality. Handoff management wireless mobile communications guaranteed within networks have become a key factor in the development of mobile networks. While a user moves to a new cell, a wireless terminal requests a handoff for new channel in the new cell. Due to that movement, some of the challenging issues are developed such as the increase in traffic volumes and demand for high speed wireless mobile communications call for fast, seamless and high performance handoff in wireless mobile networks. When a wireless terminal moves from one base station cell to another, handoff protocols reroute the existing active connections in the new cell. The future challenges in the next generation of high speed wireless mobile networks are to minimize the packet loss and to provide efficient use of the network resources while maintaining quality of service assurances. Therefore, the performance of efficient management and a successful handoff operation in mobile wireless networks become an important issue.

High performance handoff in wireless systems and successful handoff operation requirements for certain criteria to be achieved was discussed in [1-3]. Issues of quality of service (QoS) provisioning for adaptive multimedia in mobile communication networks consider handoff dropping probability constrain and average allocated bandwidth constrain [4]. The gain that can be achieved by incorporating movement prediction information in the session admission control process in mobile cellular networks was determined. The gain was obtained by evaluating the performance of optimal policies achieved with and without the predictive information, while taking into account possible prediction errors [5]. Prioritization method for combining bandwidth borrowing and reservation with mentoring the rate-adaptiveness of ongoing calls in cell [6] and an efficient channel allocation scheme for mobile cellular networks can be performed [7-8]. Stochastic vehicle mobility with environmental condition adaption capability analysis in [9], and dynamic optimizing the QoS of high speed moving terminals and handoff calls in cellular networks was discussed in [10]. The effect of different mobility patterns on the handoff probability was studied in [11].The purpose of this paper is to present evaluation of handoff probabilities of traffic in next generation of high speed wireless mobile networks.

2. Performance Model and Evaluations

When a wireless terminal moves to a new cell, a handoff request for a new channel is needed. When all of the channels are used or none of them are available for any other reasons, the handoff call has to be terminated or blocked in telecommunication terms. Obviously, blocking probability of a handoff call has become one of the important issues in wireless networks and depends on various factors, such as the availability of channels, the call arrival rate, the holding time for exchange of channels, etc. However, we use stochastic modeling to analyse the handoff process. In the handoff in non-mobilized situation we categorize all types of traffic into i types. There is a considerable area where a call can be handled by base stations in any of the adjacent cells [12]. We consider only calls within the handoff area. The handoff process can be modeled by considering the random inter-arrival call time, exponential service time (or holding time of a channel), c channels and a number of handoff calls and non-handoff calls. Within the base-station, no queuing was considered in the sense that any arrival packets have either to be serviced or to be turned away.

The current manuscript extends our previously published work [13]. In this paper, we develop equations to further demonstrate the performance of handoffs with mobility consideration using several metrics and different realistic mobile speeds including the alteration of states prior to reaching a cell boundary, the speed of mobile terminal, and the distance between a mobile terminal and a cell boundary.

Let (λ_i) be the handoff request rate for traffic type $i \in \{0, 1 \ldots, n\}$ which follows a Poisson process, and $1/\mu_i$ be the mean holding time of a channel or mean channel exchange time for traffic type i within an exponential distribution. When (j) channels are busy, handoff calls depart at rate $j\mu_i$. When the number of requested channels reaches the total number of channels available (s_i), i.e., $j = s_i$, then (s_i) all channels are in use and the channel exchange rate is $s_i\mu_i$. In this situation, any new arriving handoff call is blocked since there is no room in the wireless system.

Assume P_j is the probability that j channel exchanges are requested for traffic type i.

Therefore, P_0 is the probability that no channel exchange is requested for traffic type i, and P_1 is the probability that one channel exchange is requested for traffic type i.

Now, the global balance equations can be: $\lambda_i P_0 = \mu_i P_i$ for $j = 0$ and $\lambda_i P_{j-1} = j\mu_i P_j$ for $0 < j < s_i$. It then follows that: $P_1 = \rho_i P_0$ and $P_j = \frac{\rho_i P_{j-1}}{j} = \frac{\rho_i^j P_0}{j!}$, where $\rho_i = \frac{\lambda_i}{\mu_i}$ is the offer load of the system. Knowing that the sum of the probabilities must be one, then, $P_0 = \frac{1}{\sum_{j=0}^{s_i} \frac{\rho_i^j}{j!}}$. Now, by combining P_0 and P_j we can get: $P_j = \frac{\rho_i^j}{j! \sum_{j=0}^{s_i} \frac{\rho_i^j}{j!}}$, so when $j = s_i$, all the channels are busy and any handoff call gets blocked. Thus, the handoff blocking probability, P_{c_i}, is expressed by:

$$P_{s_i} = \frac{\rho_i^{s_i}}{s_i! \sum_{j=0}^{s_i} \frac{\rho_i^{s_i}}{j!}}. \tag{1}$$

From equation 1, it is evident that the handoff blocking probability, P_{s_i}, is directly proportional to the mean channel exchange time. As the mean holding time increases, the performance reaches its ideal value. Also, the handoff blocking probability, P_{s_i}, can be dropped when the number of available channels increases. This means that the more bandwidth is available in a cell, the less chance a handoff call is blocked. Suppose that a base-station switch in a wireless mobile network supports multiple-class traffic i in which each traffic type (i) may belong to cluster $\{0, 1, \ldots, n\}$. To handle different QoS requests for any type of traffic, assuming the network reserves bandwidths in the form of a frame. Each slot denoted by (s_i) in a frame represents the reserved bandwidth for traffic type (i). Let parameter (k) be the number of active calls in class (i) in (a) independent Bernoulli calls, then the probabilities of k are given by the binomial probability:

$$\psi_i(l) = \binom{a}{l} \rho_i^l (1-\rho_i)^{a-l},\ l = 0, ..., a, \quad (2)$$

where $\psi_i(l)$ is the probability of (k) calls being active in (a) independent calls for class-i traffic and $\rho_i = \dfrac{\lambda_i}{\mu_i}$ is the offered load of the system in which (λ_i) and (μ_i) are the arrival rate and the service rate for a call respectively. Since our system is a finite source system, a parameter known as *time congestion* is introduced. Time congestion is defined as the probability that all the channels in a system are busy [14]. The time congestion or the probability when (l) channels are in use, $P_i(l)$, is the ratio of the probability of (l) calls of class (i) being active to all the possible probabilities that the number of slot (s_i) are in use. It can be presented as:

$$\begin{aligned} P_i(l) &= \frac{\binom{a}{l} \rho_i^l (1-\rho_i)^{a-l}}{\sum_{m=0}^{s_i} \binom{a}{m} \rho_i^m (1-\rho_i)^{a-m}} \\ &= \frac{\binom{a}{l} \left(\frac{\rho_i}{1-\rho_i}\right)^l (1-\rho_i)^a}{\sum_{m=0}^{s_i} \binom{a}{m} \left(\frac{\rho_i}{1-\rho_i}\right)^m (1-\rho_i)^a} \\ &= \frac{\binom{a}{k} \left(\frac{\rho_i}{1-\rho_i}\right)^l}{\sum_{m=0}^{s_i} \binom{a}{m} \left(\frac{\rho_i}{1-\rho_i}\right)^m}, \end{aligned} \quad (3)$$

where $P_i(l)$, is the probability that k channels in class-i traffic are busy.

Using the fact that when all slots of reserved bandwidth (s_i) are occupied, any new call is blocked, we can determine the blocking probability of a class-i call by setting $k = s_i$ as follows:

$$P_i(s_i) = \frac{\binom{a}{s_i} \left(\frac{\rho_i}{1-\rho_i}\right)^{s_i}}{\sum_{m=0}^{s_i} \binom{a}{m} \left(\frac{\rho_i}{1-\rho_i}\right)^m}, \quad (4)$$

which $P_i(s_i)$ is known as the blocking probability of class-i calls.

Figure 1 shows the blocking probability of class-i calls in terms of available number of slots in a frame. We assume the number of calls (a) in traffic type (i) to be 100 and the number of slots (s_i) varies from 0 to 100. We observe that the blocking probabilities can be improved by increasing the number of reserved bandwidth. Also, we know that the effect of decreasing blocking probability can be improved by reducing the offered load as the number of occupied channels can be reduced this way.

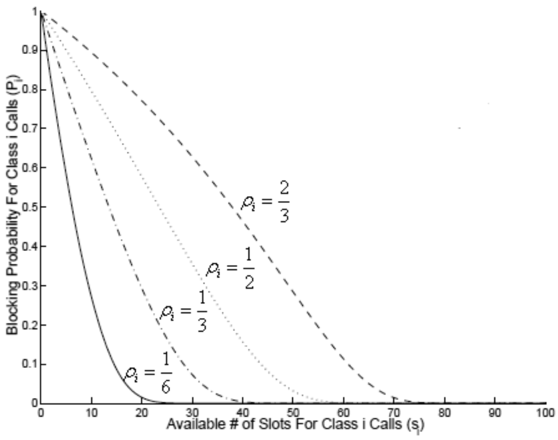

Figure 1. Channel blocking probability $P_i(s_i)$, versus the available number of slots s_i

The blocking probability as a function of system offered load is shown in Figure 2. Different pairs of numbers of calls (a) and number

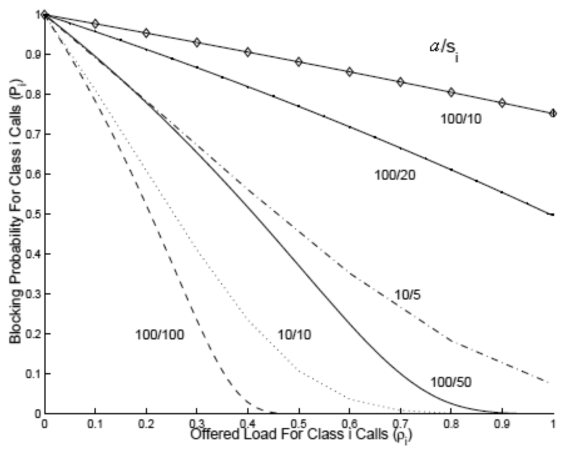

Figure 2. Channel blocking probability $P_i(s_i)$, versus the offered load ρ_i

of reserved bandwidths (s_i) are selected. The results show obviously that large group sizes can greatly reduce the blocking probabilities for class-i call.

Now, we can consider handoff with mobility situation. Analytical results confirm that the chance of requirement for handoff is dependent on the speed of the mobile terminals and the distance between a mobile user and its cell boundaries [15-16]. Besides, the fluctuation of states for a mobile unit, whether it is still or moving while carrying a call in progress, has to be considered for handoff analysis.

In this work, we assume that our handoff model is free of signal strength difficulties and when the vehicle prior to reaching a cell boundary, a vehicle that has a call in progress alternates between periods of being still (at rest or Stop-state) and periods of moving (Go-state). Now, let us define the following:

- State $0 = a$ vehicle is at rest, but has a call in progress.
- State $1 = a$ vehicle moves with an average speed of k mph (m/h) and has a call in progress.
- β_x^y = the rate at which a system with x states moves from state x to state y, where $x, y \in \{0, 1\}$ follows an exponential random process.
- β_x^x = the rate at which the system leaves state x and remains in state x.
- $P_x(t)$ = the probability that a vehicle having a call in progress is in state x at time t, where $x \in \{0, 1\}$.
- $P_x(0)$ = the initial probability of the vehicle at time $t = 0$.
- $P_x^x(\tau)$ = the probability that the system remains in state x during a very short period of time τ.
- $P_x^y(\tau)$ = the probability that the system leaves state x, and then the system enters state y and remains in state y during τ.
- v = the average speed of the vehicle ($v = 0$ in state 0 and $v = k$ in state 1).
- d_b = the distance a vehicle takes to reach a cell boundary, ranging from -15 miles to 15 miles.
- $o(t)$ = the vehicle's position at time t, where $o(0) = 0$.
- $P_x(t, d_b)$ = the probability that a vehicle in state x with a call in progress is at the cell boundary at time t, where $x \in \{0, 1\}$.
- $P\left(o(t) \geq d_b\right)$ = the probability that a vehicle reaches a cell boundary with speed v undergoing state 0 and state 1.

The alternation of stop (state 0) and go (state 1) states can be modeled, using a simple state machine with continuous-time Markov chain.

For our analysis, we use $\beta_0^0 = -\beta_0^1$ and $\beta_1^1 = -\beta_1^0$. The time in state 0 is an exponential random variable with mean, $1/\beta_0^1$. Also, the time in state 1 is an exponential random variable, with mean, $1/\beta_1^0$.

In a continuous-time Markov chain based on a random process, $O(t)$, the transition probabilities occur in a very short period of time, (τ).

$$\begin{aligned} P_x^x(\tau) &= P(T_x > \tau) = e^{\beta_x^x \tau} \\ &= 1 - \frac{\beta_x^x \tau}{1!} + \frac{(\beta_x^x \tau)^2}{2!} - \cdots \approx 1 - \beta_x^x \tau. \end{aligned} \tag{5}$$

When the vehicle leaves state (x), the system enters state (y) with probability φ_x^y. Thus, the probability that the system remains in state (y) during (τ) is:

$$P_x^y(\tau) = \left(1 - P_x^x(\tau)\right) \varphi_x^y. \tag{6}$$

Combining equations (5) and (6), we derive:

$$P_x^y(\tau) = \beta_x^x \tau \varphi_x^y = \beta_x^y \tau. \tag{7}$$

If we divide equations (5) and (7) by (τ) and take the limit, we get

$$\begin{aligned} &\lim_{\tau \to 0} \left(\frac{P_x^x(\tau) - 1}{\tau} \right) = -\beta_x^x, \\ \text{and} \quad &\lim_{\tau \to 0} \left(\frac{P_x^y(\tau)}{\tau} \right) = \beta_x^y. \end{aligned} \tag{8}$$

Now, if $P_y(t)$ is the state (y) probability of the process at a given time t, $P_y(t) = P[O(t) = y]$, then

$$\begin{aligned} P_y(t + \tau) &= P[O(t + \tau) = y] = \sum_x P[O(t + \tau) \\ &= y | O(t) = x] P[O(t) = x] = \sum_x P_x^y P_x(t). \end{aligned} \tag{9}$$

By subtracting $P_y(t)$ from both sides of equation (9), dividing them by (τ), taking limit of $\tau \to \infty$, and applying the equations in (8), we can derive the Chapman-Kolmogorov equation on continuous-time Markov chain as:

$$\frac{dP_y(t)}{dt} = \sum_{x \neq y} \beta_x^y P_x(t), \tag{10}$$

where $\frac{dP_y(t)}{dt}$ is the time differential of relative state (y) probability. The Chapman-Kolmogorov equation for continuous-time Markov chain states that when an exponential random process moves from state (x) to state (y) at a rate β_x^y and moves from state (y) to state (x) at rate β_y^x, then it will be given as in equation (10). Now, by applying equation (10) for a system with two states, 0 and 1, we have

$$\frac{dP_0(t)}{dt} = -\beta_0^1 P_0(t) + \beta_1^0 P_1(t), \tag{11}$$

$$\frac{dP_1(t)}{dt} = \beta_0^1 P_0(t) - \beta_1^0 P_1(t), \tag{12}$$

where $P_0(t)$ and $P_1(t)$ are the probability that a vehicle having a call in progress is in state 0 and state 1, respectively, at time t. Knowing the $P_0(t) + P_1(t) = 1$, equation (11) can be combined as

$$\frac{dP_0(t)}{dt} + (\beta_0^1 + \beta_1^0)P_0(t) = \beta_1^0, P_0(0) = P_0. \tag{13}$$

By knowing that the total solution to the differential equation consists of a homogenous solution, $P_{0h}(t)$, and a particular solution, $P_{0p}(t)$. Also, $\frac{dP_{0h}(t)}{dt} + (\beta_0^1 + \beta_1^0)P_{0h}(t) = 0$, where $P_{0h}(0) = P_0(0)$, we can form the general solution of equation (13) by:

$$\begin{aligned} P_0(t) &= P_{0p}(t) + P_{0h}(t) \\ &= \frac{\beta_1^0}{\beta_0^1 + \beta_1^0} + \left(P_0(0) - \frac{\beta_1^0}{\beta_0^1 + \beta_1^0} \right) e^{-(\beta_0^1 + \beta_1^0)t}, \end{aligned} \tag{14}$$

where $P_0(t)$ is the probability that the vehicle with a call in progress is in state 0 at time t.

$$\begin{aligned} P_1(t) &= P_{1p}(t) + P_{1h}(t) \\ &= \frac{\beta_0^1}{\beta_0^1 + \beta_1^0} + \left(P_1(0) - \frac{\beta_0^1}{\beta_0^1 + \beta_1^0} \right) e^{-(\beta_0^1 + \beta_1^0)t}, \end{aligned} \tag{15}$$

where $P_1(t)$ is the probability that a vehicle with a call in progress is in state 1 at time (t). In the situation for the vehicle to change states between resting and moving, a vehicle moves and stops on a congested path until reaching a cell boundary so, $P_0(0) = 0$ and $P_1(0) = 1$.

Now, let us consider mobility and handoff in cellular networks to show the probability of a call to reach a cell boundary with an average speed k mph with vehicle at rest and a vehicle moves or the probability requiring a handoff. We assume the high speed mobility in miles per hour (mph) for the interval $65\,mph \leq k \leq 100\,mph$. Let us assume that time (t) is a random variable representing a channel holding time, or the time a vehicle takes to reach a cell boundary, $\frac{d_b}{v}$, and (d_b) be the distance a vehicle takes to reach a cell boundary, ranging from -15 miles to 15 miles. Therefore, the probability that a vehicle reaches a cell boundary with speed v undergoing Stop and Go states (states 0-and-1) is

$$\begin{aligned} P\left(o(t) \geq d_b\right) &= P_0\left(t, d_b; at\, t = \frac{d_b}{v}, v = 0\right) \\ &+ P_1\left(t, d_b; at\, t = \frac{d_b}{v}, v = k\right), \end{aligned} \tag{16}$$

where

$$P_0\left(t, d_b; at\, t = \frac{d_b}{v}, v = 0\right) = \frac{\beta_1^0}{\beta_0^1 + \beta_1^0}, \tag{17}$$

and

$$\begin{aligned} P_1\left(t, d_b; \quad \text{at} \quad t = \frac{d_b}{v}, v = k\right) &= \frac{\beta_0^1}{\beta_0^1 + \beta_1^0} \\ + \left(P_1(0) - \frac{\beta_0^1}{\beta_0^1 + \beta_1^0} \right) e^{-\frac{(\beta_0^1 + \beta_1^0) d_b}{k}}. \end{aligned} \tag{18}$$

Suppose that a vehicle initiates a call in a cell with 15 miles radius. The vehicle speed is chosen to be 65 mph and 100 mph. Figures 3 and 4 illustrate the probability curves for reaching a cell boundary in which a handoff is required with high speed 65 mph and 100 mph respectively.

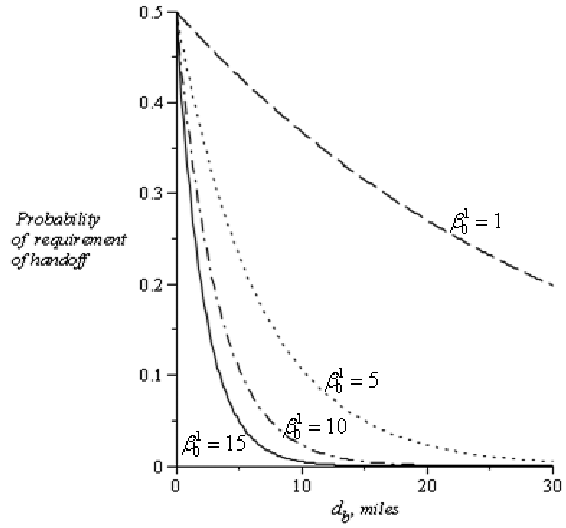

Figure 3. The probability of requiring handoff versus the speed of vehicle versus d_b when $k = 65$ mph

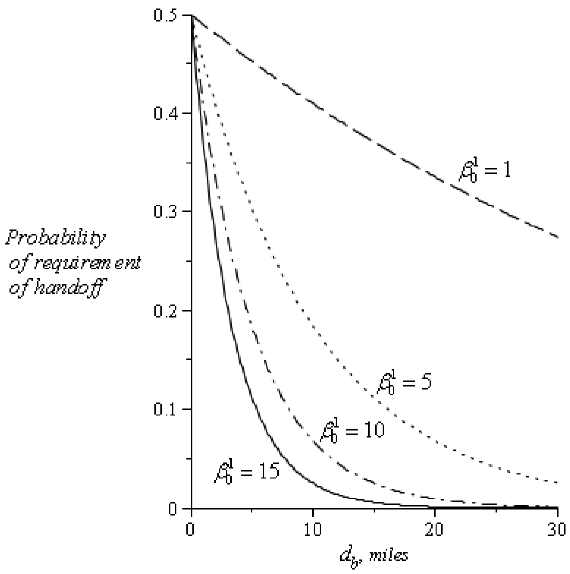

Figure 4. The probability of requiring handoff versus the speed of vehicle versus d_b when $k = 100$ mph

It is clear from Figures 3 and 4, that, as the cell size increases, the probability of reaching a boundary decreases in an exponential approach. Figures 5 through 8 show the probabilities of requiring handoff versus the speed of vehicle when $d_b = 1$, 5, 10, and 15 miles respectively.

The probability of reaching a cell boundary is proportional to the vehicle's speed. This is true since the increase in vehicle's speed increases the chance of reaching a cell boundary. Also, from the figures, we observe that as the distance

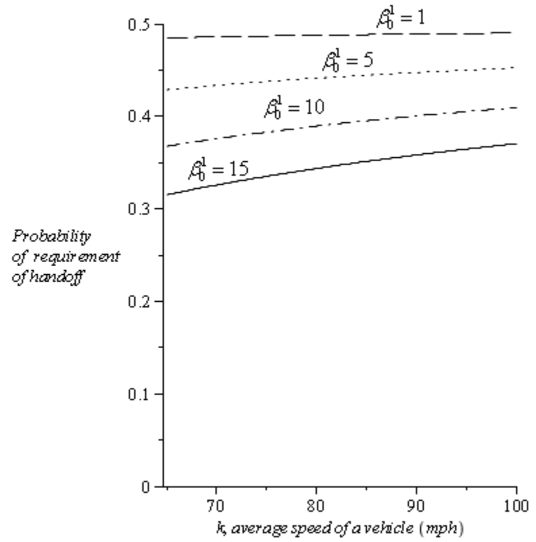

Figure 5. The probability of requiring handoff versus the speed of vehicle when $d_b = 1$ miles

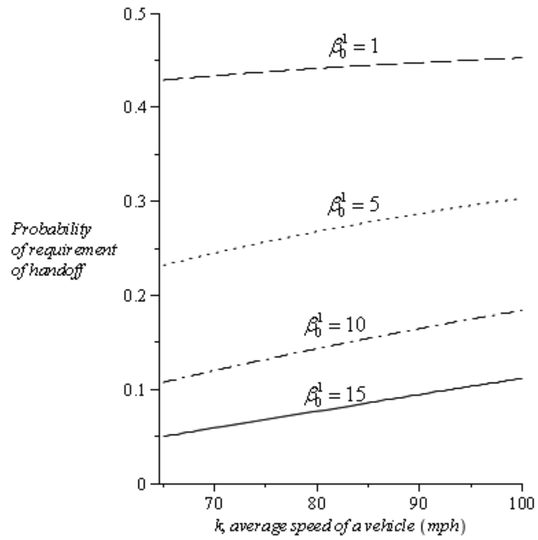

Figure 6. The probability of requiring handoff versus the speed of vehicle when $d_b = 5$ miles

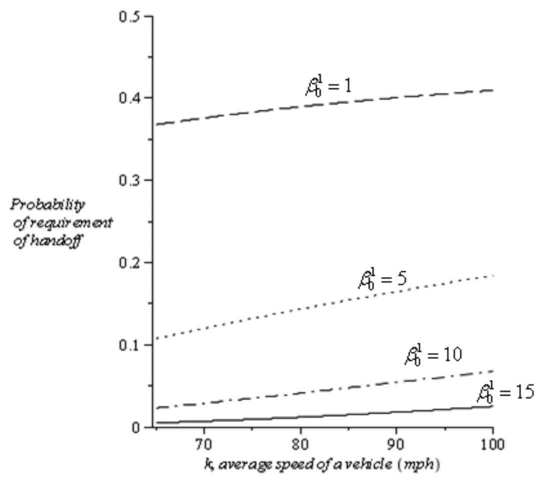

Figure 7. The probability of requiring handoff versus the speed of vehicle when $d_b = 10$ miles

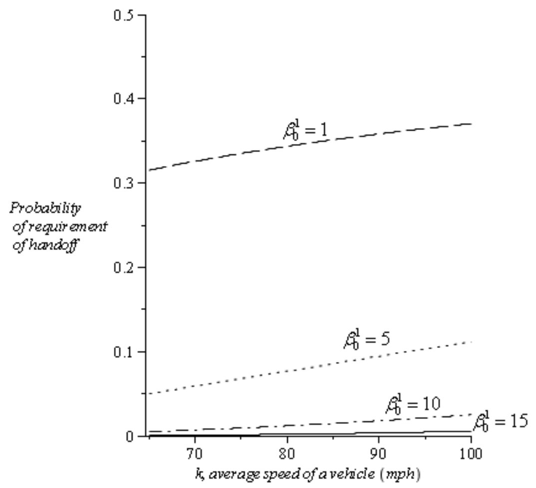

Figure 8. The probability of requiring handoff versus the speed of vehicle when $d_b = 15$ miles

a vehicle takes to reach a cell boundary, d_b increases, the probability of requiring a handoff decreases. In addition, from the figures, as β_0^1 increases, the probability of requiring a handoff decreases.

3. Conclusion

We presented analytical mobility management and load balancing model of handoff in high speed wireless mobile networks focusing on factors such as the number of channel slots and offered load. The performance results in terms of state probabilities and the probability that a mobile terminal reached a cell boundary were investigated. The mobilized analysis involved a number of issues such as the alternation of states before a mobile unit reached a cell boundary, the distance between the mobile terminal and a cell boundary and the speed of the vehicle. The blocking probabilities can be improved by increasing the number of reserved bandwidth. The effect of decreasing blocking probability can be improved by reducing the offered load. Performance results were also analyzed showing that for a vehicle that experienced the change of states, the outcome chance of reaching a cell boundary was proportional to the distance in between the mobile terminal and a cell boundary and inversely proportional to the speed of the vehicle. Our other observation was that the probability of handoff blocking reduced with increased number of available channels.

References

[1] J. NAYLON, D. GILMURRAY, J. PORTER, A. HOPPER. Low-latency handover in a wireless ATM LAN. *IEEE Journal on Selected Areas in Communication*, 16 (1998), pp. 909–921.

[2] A. ACHARYA, S. BISWAS, L. FRENCH, J. LI, D. RAYCHAUDHURI. Handoff and location management in mobile ATM networks. *Proceedings of the 3rd International Conference on Mobile Multimedia Communication,* September (1996).

[3] A. ACHARYA, J. LI, B. RAJAGOPALOAN, D. RAYCHAUDHURI. Mobility management in wireless ATM networks. *IEEE Communications Magazine*, (1997), pp. 100–109.

[4] Y. FEI, V. W. WONG, V. C. LEUNG.Efficient QoS provisioning for adaptive multimedia in mobile communication networks by learning. *Mobile Networks and Applications,* 11 (2006), pp. 101–110.

[5] J. G. GUZMAN, J. M. BAUSET, V. PLA. Performance bounds for mobile cellular networks with handover prediction, Management of Multimedia Networks and Services, Springer Berlin / Heidelberg, (2005), pp. 35–46.

[6] R. ZANDER, J. M. KALSSON. Combining bandwidth borrowing and reservation in cellular networks. *International Journal of Wireless Information Networks,* 12 (2005), pp. 187–201.

[7] G. H. MA, A. Y. ZOMAYA. An efficient channel allocation scheme for cellular network using maximum channel packing. *Wireless Communications and Mobile Computing*, 4 (2004), pp. 683–692.

[8] K. Q. TIAN, D. C. COX. Mobility management in wireless networks: data replication strategies and applications, Kluwer Academic Publishers, New York, (2004).

[9] A. R. MOMEN, P. AZMI. Stochastic vehicle mobility with environmental condition adaption capability. *Wireless Communications and Mobile Computing*, 9 (2008), pp. 1070–1080.

[10] K. IOANNOU, S. KOTSOPOULO, P. STAVROULAKIS. Optimizing the QoS of high speed moving terminals in cellular networks. *International Journal of Communications systems,* 16 (2003), pp. 851–863.

[11] D. BANSAL, A. CHANDRA, R. SHOREY, A. KULSHRESHTHA, M. GUPTA. Mobility models for cellular systems: cell topography and handoff probability. *Proceedings of IEEE 49thConference on Vehicle Technology,* (1999), pp. 1794–1798.

[12] Y. LIN, S. MOHAN, A. NOERPEL. Queueing priority channel assignment strategies for PCS handoff and initial access. *IEEE Transactions on Vehicular Technology*, 43 (1994), pp. 704–712.

[13] M. Y. CHOY, N. F. MIR. Performance modeling of multimedia traffic in mobile wireless networks, 95–99 vol. 1, MILCOM 2000.

[14] J. BELLAMY. Digital Telephony, *John Wiley* & Sons, Inc., (1991), pp. 495–496.

[15] S. S. RAPPAPORT. The Multiple-call hand-off problem in high-capacity cellular communication System. *IEEE Transactions on Vehicular Technology*, 40 (1991), pp. 546–557.

[16] S. NANDA. Teletraffic models for urban and suburban microcells: cell sizes and handoff rates. *IEEE Transactions on Vehicular Technology*, 42 (1993), pp. 673–682.

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Contact addresses:
Sarhan M. Musa
Roy G. Perry College of Engineering
Prairie View A&M University
Prairie View
Texas
e-mail: smmusa@pvamu.edu

Nader F. Mir
Department of Electrical Engineering
San Jose State University
California
e-mail: nader.mir@sjsu.edu

SARHAN M. MUSA earned his Ph. D. degree in Electrical Engineering from City University of New York, NY. Dr. Musa is currently an associate professor in the Engineering Technology department of Prairie View A&M University, Texas. He has been director of Prairie View Networking Academy (PVNA), Texas since 2004. From 2009 to 2010, Dr. Musa was a visiting professor in the Department of Electrical and Computer Engineering at Rice University, Texas. His research interests include computational methods in nanotechnology, computer communication networks, and numerical modeling of electromagnetic systems. He currently serves on the Editorial Board of Journal of Modern Applied Science, and he is a senior member of the Institute of Electrical and Electronics Engineers (IEEE). He is also a 2010 Boeing Welliver Fellow.

NADER F. MIR is currently a Professor, and has served as the Associate Chairman, at the Electrical Engineering Department of San Jose State University, California. In the meantime, he serves as the Director of MSE Program in optical sensors and networks for Lockheed-Martin Space Systems Corporation for the University. He is also an expert in intellectual property development and a consultant for patent litigation cases in the areas of communications, telecommunications and computer networks at both the protocol and hardware levels.

Prior to his current position, he was an associate professor at his current school, and assistant professor at the University of Kentucky in Lexington. From 1994 to 1996, he was a research scientist at the Advanced Telecommunications Institute, Stevens Institute of Technology in New Jersey working on design of advanced communication systems and high-speed computer networks. From 1990 to 1994 he was with the Computer and Communications Research Center at Washington University in St. Louis and worked as a research assistant on design and analysis of high-speed switching systems project. From 1985 to 1988, he was with Telecommunication Research & Development Center (TRDC), Surrey, and as a telecommunications system research & development engineer, participated in the design of a high-speed digital telephone Private Branch Exchange" (PBX), and received the best “design/idea” award.

Professor Mir is internationally known through his research, scholarly work, and his books in the areas of: analysis of computer communication networks, internet applications of voice over IP and multimedia networks, design and analysis of networking devices and high-speed routers, wireless and mobile networks and wireless sensor networks, applications of integrated circuits in computer communications.

Dr. Mir has published two successful books, one of which is a worldwide adopted university text-book entitled “Computer & Communication Networks” published by Prentice Hall Publishing Co. He has also published numerous refereed technical journal and conference papers, all in the field of communications and networking.

He was granted a successful U.S. Patent in 2006, claiming an invention related to hardware/protocol for use in high-speed computer communication networks.

He has several journal editorial positions such as: the Editor of Journal of Computing and Information Technology, a Guest Editor for Computer Networking at CIT Journal (in 2008), the Editorial Board Member of the International Journal of Internet Technology and Secured Transactions (in 2005), and the technical Editor of IEEE Communication Magazine. He is a senior member of the IEEE and has also served as the member of technical program committee and steering committee for a number of major IEEE communications and networking conferences such as WCNC, GLOBECOM, and ICC.

Dr. Mir has received a number of prestigious national and university awards and research grants. He is also the recipient of a university teaching recognition award and a research excellence award. He is also the recipient of a number of outstanding presentation awards from leading international conferences.

He received the B. Sc. degree (with honors) in electrical engineering in 1985, and the M. Sc. and Ph. D. degrees, both in electrical engineering from Washington University in St. Louis, MO, in 1990 and 1995 respectively.