Effect of User Mobility on the QoS Parameters for the Guard Channel Policy

Mohamed M. Abdallah
mabdalah@idsc.gov.eg

Khaled M. El-Sayed
kelsayed@alpha1-eng.cairo.eun.eg

Mahmoud T. El-Hadidi
hadidi@frcu.eun.eg

Department of Electronics & Electrical Communication
Faculty of Engineering
Cairo University
Giza, Egypt 12613

Abstract

In this paper, we studied the effect of the user mobility parameters on the quality of service parameters of guard channel policy; namely: new call blocking probability and handoff call blocking probability. The high-way mobility model was utilized to define the traffic parameters of the user in terms of its mobility parameters, namely; average velocity of the user and the radius of the cell. The mathematical equations of the new call blocking probability and handoff call blocking probability were derived and solved iteratively. The results show that the value of the new call blocking probability is lower and that of the handoff call blocking probability is higher when compared with the case of non-mobile users. In addition, there exists a critical value; defined by the user mobility parameters ; where the behavior of the new and handoff call blocking probabilities differs in a distinct way.

1. Introduction

The main function that controls the acceptance of th calls is the call admission control (CAC). The function of CAC in wireless multimedia networks (WMN) is to minimize the new call blocking probability and the handoff call blocking probability for a generic call. However, since the disconnection in the middle of a call is highly undesirable with respect to the user, so it is one of the goal of the network designer to keep the handoff blocking probability as low as possible. An efficient method is threshold-based guard channel policy [1][2]. This guard channel policy uses a threshold to decide whether to accept new call request or not, whereas handoff requests ar always accepted if the required channels are available. In the literature, the threshold-based guard channel policy was studied under static traffic conditions. In this paper, we study the effect of user mobility on the QoS parameters ;namely: new call blocking probability and handoff call blocking probability. In the literature, many types of mobility models have been proposed which try to characterize the random motion of the user as a function of its velocity, directions of its motion and the area of the cell in cellular networks [3][5][4][6]. In our analysis, we choose the high-way user mobility model [3][5] which will be explained later. Using the high-way user mobility model, we define each traffic parameter as a function of the user mobility parameters, number of users in neighboring cell and the value of new call blocking probability and handoff call blocking probability. Consequently, we update the relation of the new call blocking probability and handoff call blocking probability using the new values of traffic parameters which depends on user mobility. Analytical results are deduced which show the effect of varying the user mobility parameters on the new call blocking probability and handoff call blocking probability.

2. Threshold-based guard channel call admission control policy

For a cellular network with certain number of channels (C), a number of guard channels is reserved for handoff calls. The threshold (Th) can be defined as the number of channels if exceeded by the number of busy channels, the new calls would be blocked. Therefore, the number of guard channels equals (C – Th).

It is clear that the guard channel policy provides priorit for handoff calls over new calls since all channels are available for handoff calls while only a portion of the channels is available for new calls. Also, the value of the threshold is considered as a control parameter for solving the off trade between maximizing utilization through minimization of new call blocking probability and increasing the probability of call completion by decreasing handoff call blocking probability. As the threshold valu increases, the new call blocking probability decreases and the handoff call blocking probability increases and the opposite occurs when the threshold value decreases.

3. High-way mobility system model

A high-way mobility system model is considered in which the users move along a cellular network composed of identical circular cells of radius 'r' [3][5]. The users are assumed to move in one direction with average velocity 'v'. Furthermore, it is assumed that all the cells have identical

0-7803-5668-3/99/$10.00 © 1999 IEEE.

values of new call blocking probability and handoff call blocking probability. Therefore, we can isolate a single cell in which the following traffic parameters are considered:

λ_N ≡ Average new call arrival rate.

λ_H ≡ Average handoff arrival rate.

$1/\eta$ ≡ Average call residence time in a cell.

$1/\mu$ ≡ Average call duration time in the system.

It is assumed that new and handoff traffic generated b mobile stations are modeled by a Poisson process with mea λ_N and λ_H, respectively. The call residence time is defined as the length of time a mobile resides in the cell independent of being engaged in a call before crossing the cell boundary. It is assumed the call residence time is a random variable which has a negative exponential distribution of mean $1/\eta$. The call duration time is the amount of time that the call would remain in progress if it would continue to completion without forced termination. Also, it is assumed that the call duration time has a negative exponential distribution of mean $1/\mu$.

According to the above definitions, the channel holding time, that is the time spent in a cell by a mobile station being involved in a call, is a random variable which equal to the minimum of the two random variables representing the call residence time and call duration time, respectively. Thus, the channel holding time will follow negative exponential distribution of mean $1/\gamma$ which is given by the relation [2]:

$$1/\gamma = 1/(\eta + \mu) \tag{1}$$

Consequently, the service rate - which equals the reciprocal of channel holding time - is equal to γ.

Finally, according to the high-way mobility model, th call residence time can be expressed in terms of the user mobility parameters; namely: average velocity of the user, v, and the radius of the cell, r. The call residence time is th reciprocal of the cell boundary crossing rate, i.e. the number of cell boundaries crossed by the moving user per unit time. In the literature the cell boundary crossings was calculated using fluid flow model and the following relation has been deduced [3] [5]:

$$\eta = \frac{2}{\pi} * \left(\frac{v}{r}\right) \tag{2}$$

The parameter (v/r) indicates whether the mobility of the user is slow or high. As (v/r) increases, this indicates higher boundary crossing rate, i.e. faster user mobility.

4. Definition of traffic parameters in terms of user mobility parameters

In this section, we define the system traffic parameters which depend on the user mobility parameters; namely: average velocity of the user and cell radius. These traffic parameters are handoff traffic represented by handoff arrival rate and service rate. Firstly, the service rate as a function of user mobility parameters can be deduced from Eqs. (1) & (2) resulting in the following relation:

$$\gamma = \frac{2}{\pi} * \left(\frac{v}{r}\right) + \mu \tag{3}$$

Secondly, the handoff arrival rate depends upon the following parameters:

- Average velocity of the user [v]; it is expected that as v increases handoff traffic also increases.
- Radius of the cell [r]; it is expected that as r increases, the handoff traffic decreases.
- New call blocking probability and handoff call blocking probability [P_N, P_H]; it is evident that as both of these values increase, handoff arrival rate decreases and vice versa.
- Average call duration time [$1/\mu$]; as the call duration time decreases relative to the cell residence time, the handoff traffic increases.

As mentioned above, the average velocity and radius of the cell can be integrated in a single parameter; namely: (v/r) since all the previous and successive relations does not depend on either of average velocity of the user or cell radius but depend on their division (v/r). The unit of the parameter of (v/r) is number of crossings per hour if the velocity is given in Km/hr and radius is given in Km.

In order to deduce the relation of handoff arrival rate λ_H and the above parameters, we firstly need to define the following parameter:

- Probability of handoff [P_r]; it is the probability that a mobile user moves from one cell to its neighboring cell. It is clear that P_r depends on both the cell residence time and call duration time; i.e. as the call residence time increases relative to call duration time, P_r increases and vice versa. Therefore, P_r can be given by the following relation:

$$P_r = \frac{\eta}{\eta + \mu} \tag{4}$$

Thus, we can calculate λ_H as follow [7]:

Assume that for identical cells of radius r as shown in Fig. (3):

- The average carried traffic of new calls for each cell i $\lambda_N(1 - P_N)$.
- Probability that an accepted call will attempt one handoff is P_r.
- Probability that an accepted call will attempt second handoff = $P_r(1-P_H)P_r = P_r^2(1-P_H)$.
- Probability that an accepted call will attempt k^{th} handoff = $P_r^k(1-P_H)^{k-1}$.

Thus, assuming an infinite number of cells, λ_H considered for a certain cell can be approximated by the following relation:

$$\lambda_H = \lambda_N(1-P_N)\sum_{k=1}^{\infty} P_r^k (1-P_H)^{k-1} = \lambda_N \frac{P_r(1-P_N)}{1-P_r(1-P_H)}. \quad (5)$$

Substituting from equations (2) and (4) into equation (5), λ_H can be rewritten as follows:

$$\lambda_H = \lambda_N(1-P_N)\frac{\frac{2}{\pi\mu}\left(\frac{v}{r}\right)}{1+\frac{2P_H}{\pi\mu}\left(\frac{v}{r}\right)} \quad (6)$$

In order to investigate the effect of mobility parameter (v/r) and blocking probabilities on the handoff traffic, equation (6) can be rewritten as follows:

It is clear that for low values of (v/r), blocking probabilities are small and therefore can be neglected. As indicated b Eq. (7), the handoff traffic will be mainl affected by the mobility parameter (v/r). However, as

$$\lambda_H = \frac{\lambda_N(1-P_N)}{\frac{1}{\frac{2}{\pi\mu}\left(\frac{v}{r}\right)} + P_H} \quad (7)$$

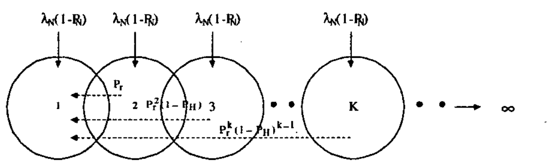

Fig. (1) Illustration of the handoff probabilities from neighboring cells and the input traffic parameters

(v/r) increases, the values of P_N and P_H increase and are no longer negligible. Finally, for higher values of (v/r), the first term in the denominator of Eq. (7) can be neglected compared to P_H and the handoff traffic becomes mainl affected by P_N and P_H as can be seen from Eq. (8):

$$\lambda_H \cong \frac{\lambda_N(1-P_N)}{P_H} \quad (8)$$

The following remarks can be deduced easily from Eqs. (7) and (8):

- The value of handoff traffic increases a (v/r) increases. However, this will occur until a certain value fo (v/r) is reached. Then the effect of (v/r) can be neglected in comparison to the effect of P_N and P_H as shown in Eq. (8). Therefore, we can deduce that there exists a critical value for (v/r), namely; $(v/r)^*$ where the behaviour of the blocking probabilities varies since handoff arrival rate values changes before and beyond this critical value.
- As the average call duration time $1/\mu$ increases, the value at which the effect of (v/r) becomes negligible compared to P_N and P_H decreases.

Therefore we can divide the values of (v/r) into two regions based on the effect of (v/r) on handoff arrival rate, λ_H, and channel holding time, $1/\gamma$ as follows:

- Region 1: It defines the values of (v/r) before the critical value $(v/r)^*$. In this region, handoff arrival rate increases as (v/r) increases as seen in Eq. (7) while channel holding time decreases as (v/r) increases as seen in Eq. (3).
- Region 2: It defines the values of (v/r) beyond the critical value $(v/r)^*$. In this region, the handoff arrival rate does not depend on (v/r) as seen in Eq. (8) and it will become constant while the channel holding time decreases as (v/r) increases.

These remarks will be confirmed by a numerical example later in this paper.

Finally, equations (3) and (6) define the service rate and the handoff arrival rate which will be utilized to study the effect of user mobility on the QoS parameters; namely: ne call blocking probability and handoff call blocking probability.

5. Calculation of new and handoff call blocking probabilities

In this section, we study the effect of high-way user mobility parameters on new call blocking probability (P_N) and handoff call blocking probability (P_H). Based on threshold-based guard channel CAC policy, P_N and P_H were given as follows:

$$P_N = \left(\sum_{i=Th}^{C}\frac{1}{i!}\left(\frac{\lambda_N+\lambda_H}{\gamma}\right)^{Th}\left(\frac{\lambda_H}{\gamma}\right)^{i-Th} P_0\right) * \left(\frac{\lambda_N}{\lambda_N+\lambda_H}\right) \quad (9)$$

$$P_H = \left(\frac{1}{C!}\left(\frac{\lambda_N+\lambda_H}{\gamma}\right)^{Th}\left(\frac{\lambda_H}{\gamma}\right)^{C-Th} P_0\right) * \left(\frac{\lambda_H}{\lambda_N+\lambda_H}\right) \quad (10)$$

where P_0 equals:

$$P_0 = \frac{1}{\sum_{i=0}^{Th}\frac{1}{i!}\left(\frac{\lambda_N+\lambda_H}{\gamma}\right)^{i} + \sum_{i=Th+1}^{C}\frac{1}{i!}\left(\frac{\lambda_N+\lambda_H}{\gamma}\right)^{Th}\left(\frac{\lambda_H}{\gamma}\right)^{i-Th}} \quad (11)$$

and C is the total number of channels and Th is the threshold after which new calls are rejected and onl handoff calls are accepted.

Substituting from equations (3) and (6), equations (9), (10) and (11), two non-linear equations in terms of P_N and P_H are obtained. In order to deduce P_N and P_H, the two non-linear equations are solved. The initial values of P_N and P_H used for the successive substitution method can be easil obtained if we consider equation (5) which defines λ_H. If we assumed that P_N and P_H is much smaller than 1, then equation (5) can be rewritten and the initial value fo handoff arrival rate is given by :

$$\lambda_{Hi} = \lambda_N \frac{P_r}{1-P_r} \qquad (12)$$

Substituting from equations (2) and (4), equation (15) can be rewritten as follows:

$$\lambda_{Hi} = \lambda_N \frac{2}{\pi\mu}\left(\frac{v}{r}\right) \qquad (13)$$

Substituting from equation (13) into equations (9), (10) & (11), the initial values for P_N and P_H are obtained.

6. Effect of varying the mobility parameters on new and handoff call blocking probabilities

In this section, we study the effect of user mobilit parameter (v/r) on the QoS parameters of the threshold-based guard channel policy; namely: new call blocking probability (P_N) and handoff call blocking probability (P_H).

In order to study this effect on the new call blocking probability, P_N, Eq. (9) can be rewritten as follows:

$$P_N = A_N * B_N \qquad (14)$$

where A_N and B_N are given as follows:

$$A_N = \left(\sum_{i=Th}^{C} \frac{1}{i!} \left(\frac{\lambda_N + \lambda_H}{\gamma}\right)^{Th} \left(\frac{\lambda_H}{\gamma}\right)^{i-Th} P_0 \right) \qquad (15)$$

$$B_N = \left(\frac{\lambda_N}{\lambda_N + \lambda_H}\right) \qquad (16)$$

Similarly, in order to study the effect of (v/r) on the handoff call blocking probability, P_H, we rewrite Eq. (10) as follows:

$$P_H = A_H * B_H \qquad (17)$$

where A_H and B_H are given by:

$$A_H = \left(\frac{1}{C!} \left(\frac{\lambda_N + \lambda_H}{\gamma}\right)^{Th} \left(\frac{\lambda_H}{\gamma}\right)^{C-Th} P_0 \right) \qquad (18)$$

$$B_H = \left(\frac{\lambda_H}{\lambda_N + \lambda_H}\right) \qquad (19)$$

•We applied the expressions of P_N, P_H and λ_H defined by Eqs. (9), (10), (11) and (6) to a numerical example for which the following values for the policy and mobilit parameters were selected ; C = 25, λ_N = 0.1 call/sec, Th = 20, r = 500 m, v = [5 Km/hr : 100 Km/hr], $1/\mu$ = 5 min .

One concludes from Figs. (2) and (3) that P_N is lower when user mobility is taken into account, while P_H is higher.

It is also evident from Fig. (4) that effect of (v/r) on the handoff arrival rate, λ_H , is as explained in section (4). A the mobility parameter (v/r) increases, the handoff traffic increases until (v/r) reaches a certain value where its effect becomes negligible compared to the effect of P_N and P_H and the handoff traffic becomes constant. Therefore, there exist two regions; namely, Region 1 and Region 2 where the behaviour of the handoff arrival rate, λ_H , changes. The regions are divided based on the critical value $(v/r)^*$, which is approximately equal to 90 as shown in Figs. (2), (3) and (4).

The behavior of the blocking probabilities shown in the above figures can be explained based on the simultaneous effects of A_N and B_N on the new call blocking probabilit and A_H and B_H on the handoff call blocking probability in the two regions. Firstly, we will study the behaviour in Region 2 then in Region 1 as follows:

- Region 2:

  New call blocking probability, P_N : It is clear in Fig. (2) that P_N is decreasing in that region. As mentioned before, A_N decreases due to the effect of channel holding time, and B_N is constant. Therefore, it can be concluded that the net effect of A_N and B_N is the decrease of P_N.

  - Handoff call blocking probability, P_H: It is clear in Fig. (3) that the P_H is decreasing in that region. As mentioned before, A_H is decreasing due also to the effect of channel holding time, and B_H is constant. Therefore, it can be concluded that the net effect of A_H and B_H that P_H is decreasing because the channel holding time is decreasing.
- Region 1:
  - New call blocking probability, P_N: It is clear in Fig. (2) that P_N is decreasing in that region. We notice that, while A_N still decreases due to the decrease of the channel holding time (at the same rate shown in Region 2). However, the effect of the increase in the handoff arrival rate, λ_H , leads to the increase of A_N and the decrease of $_N$. Since P_N is decreasing with a rate slower than that in Region 2 then the net of effect of handoff arrival rate on A_N and B_N will lead to the increase of P_N but still the rate of decrease of P_N due to the effect of channel holding time is higher
  - Handoff call blocking probability, P_H: It is clear in Fig. (3) the P_H is increasing in that region. A_H is still decreasing due to the decrease of the channel holding time with the same rate as in Region 2. However, th effect of increasing handoff arrival rate, λ_H , which appears in that region leads to the increase of A_H and B_H. Since P_H is increasing then the net of effect of handoff arrival rate on A_H and B_H will lead to the increase of P_H and is higher than the rate of decrease of P_H due to the effect of channel holding time.

It can be easily deduced that the value of $(v/r)^*$ depends on the value of average call duration time ($1/\mu$). This can be explained according to Eq. (7) where the denominator can be approximated to P_H for lower values of (v/r) as the average call duration time ($1/\mu$) increases. i.e. the critical value for the parameter (v/r), where the behavior of the blocking probabilities changes, decreases as the average call duration increases.

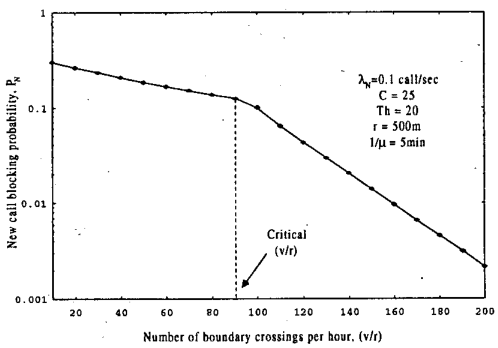

Fig. (2) New call blocking probability (P_N) versus number of boundary crossings per hou (v/r) for $1/\mu = 5\,\text{min}$

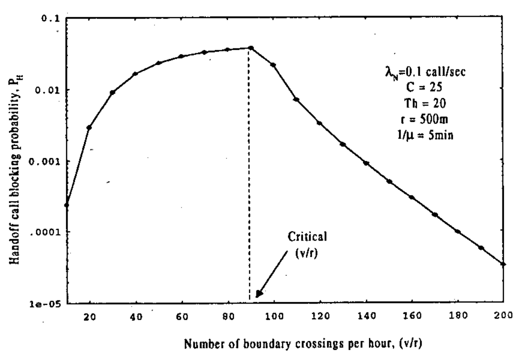

Fig. (3) Handoff call blocking probability (P_H) versus number of boundary crossings per hour (v/r) for $1/\mu = 5\,\text{min}$

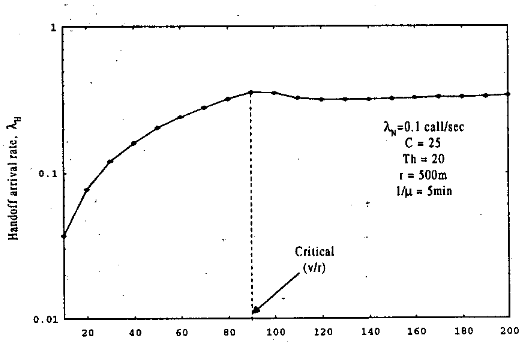

Fig. (4) Handoff arrival rate (λ_H) versus number of boundary crossings per hou (v/r) for $1/\mu = 5\,\text{min}$

8. Conclusion

In this paper, we studied the effect of the user mobilit parameters on the new call blocking probability and handoff call blocking probability. The high-way mobility model was utilized to define the traffic parameters of the user in terms of its mobility parameters, namely; average velocity of the user and the radius of the cell.

After obtaining and solving iteratively the mathematical equations of the new call blocking probability and handoff call blocking probability, the graphs of the new and handoff call blocking probabilities are drawn. The results show that the value of the new call blocking probability is lower and that of the handoff call blocking probability is higher when compared with the case of non-mobile users. In addition, there exists a critical value for the user mobility parameter where the behavior of the new and handoff call blocking probabilities differs in a distinct way. The results show that the new call blocking probability is always decreasing as the user mobility increases. However, for handoff call blocking probability, it first increases until the user mobilit reaches the critical value after which it decreases.

9. References

[1] D. Hong and S. Rappaport, "Traffic Model and Performance Analysis for Cellular Mobile Radio Telephone Systems with Prioritized and Non Prioritized Handoff Procedures," *IEEE Transactions on Vehicular Technology*, Vol. 35, No. 3, pp. 77-92, Aug. 1986.

[2] R. Gurien, "Channel Occupancy Time Distribution in a Cellular Radio System,"*IEEE Trans. Veh. Technol.*, Vol. VT-35, pp.89-99, Aug. 1987.

[3] G. Morales-Andreas and M. Villen-Altamirano, " An Approach to Modeling Subscriber Mobility in Cellular Radio Networks," *in 5th World Telecommun. Foru* , Geneva, Switzerland, pp. 185-189, Nov. 1987.

[4] E. Del Re, R. Fantacci, and G. Giambene, " Handover and Dynamic Channel Allocation Techniques in Mobile Cellular Networks," *IEEE Trans. Veh. Technol.*, Vol. 44, pp. 229-237, May 1995.

[5] R. Thomas, H. Gilbert, and G. Mazziotto, "Influence of the Movement Over the Mobile Station on the Performance of a Radio Cellular Networks," presented at *the 3rd Nordic Seminar*, Copenhagen, Denmark, paper 9.4, Sept. 1988.

[6] M. Zonoozi and P. Dassanayake, " User Mobilit Modeling and Characterization of Mobility Patterns," *IEEE Journal on Selected Areas in Communication*, Vol. 15, No. 7, pp.1239-1252, Sept. 1997.

[7] M. Sidi and D. Starobinski, "New Call Blocking Versus Handoff Blocking in Cellular Networks," *Journal on Wireless Networks*, Vol. 3, No. 1, 1997.