DYNAMIC PRIORITY QUEUEING OF HANDOVER CALLS IN WIRELESS NETWORKS: AN ANALYTICAL FRAMEWORK

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ABSTRACT. This term paper address the issue of queueing of handover calls in Mobile Networks. There are two priority class for handover calls. The priority of the calls is decided based upon the Received Signal Strength (RSS) and the rate of change of RSS due to mobile velocity. If mobile velocity is large, handover call will be dropped quickly due to degradation in RSS so needs to be put in higher priority class. The facility of priority transition is also provided whereby a second priority handover call can become first order priority call if situation demands. Also, the situation that the call ends in the queue is taken into account.

With moinor adjustments, the framework can be modified to analyze First-in-First-Out queueing of handover calls, the schemes that use guard channels to manage handover calls and even networks which handle integrated voice/data transmission.

1. Introduction

This term paper summarizes the work in [1] which analyzes the call blocking probability of handover calls in wireless networks by making use of an analytic framework which employ M/M/C/K queues.

It is a well known fact that smaller cell size increse the capacity of cellular networks but the cost required to be paid is increased number of handoffs. Blocking a call in progress is less desirable than new calls. Many reseachers have tried to study the blocking probability of these calls. One of the common approaches is to reserve some channels exclusively for handoff calls (guard channels). While other approach is to queue the handoff calls in FIFO queues (while dropping the new originating calls). Better models propose queueing of both handover and new calls in different FIFO queues, later having low priority. It has been found that due to varying speed of different mobile units, the received signal strength (RSS) at the base station changes at different rates, so FIFO queues are unsuitable for managing handoff calls.

Some authors have studied dynamic queueing of handover calls based on measurement based priority schemes [2] and signal prediction priority queueing [3] [4] using simulations but the analytical analysis is largely lacking. [1] is first serious effort in this regard (as claimed by authors) and eleminates the need of time consuming simulations even for first hand approximations.

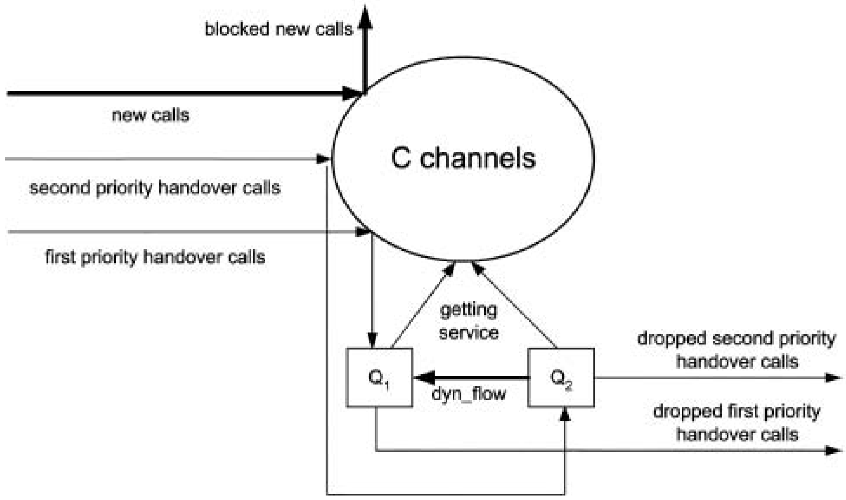


FIGURE 1. Queueing Model

2. Salient features of the Model

(1) It is assumed that a call arrivals (both new and handoff) follow a Poisson process. While new call arrivals indeed follow a Poisson process, the handover traffic is non-Poisson due to the blocking phenomenon in neighboring cells. However, studies have shown that the Poisson approximation for handover traffic is a reasonable approximation.
(2) The proposed queueing model is shown in fig. 1. The cell is assumed to have C channels (servers). If channels (servers) are free, both new calls (originating in the cell) and the handoff calls (arriving from adjacent cells) are served in identical way. If all the channels are busy, new calls are dropped while handoff calls are queued according to their priority.
(3) Two classes of priority is considered for handover calls. Priority is decided by estimating the time it will take for the mobile unit to go out of the range of the current base station. It depends on the RSS and the rate of change of RSS (which varies with the speed of mobile unit).
(4) There is a facility of priority transition from second to first prioriy structure. Thus transition time between the priority class (the time after which second priority class handoff call switches to first priority class) needs to be taken into account. For analytical tractability this is assumed to have exponential distribution with rate μ_t.
(5) A queues are assumed to have finite storages H_1, H_2, for first and second priority respectively . If a handover request belonging to the first (second) priority queue finds H_1 (H_2) requests in the queue, this call is blocked; otherwise, it joins the queue which it belongs to.
(6) A handover call in the queue that does not get service before a specified time, leaves the queue (i.e., the call is dropped). This time is approximated by an exponential random variable with rate μ_{q1} and μ_{q2} respectively for the two priority queues.
(7) Channel holding time is the time a mobile unit remains in the same cell during a call. Channel holding time for handoff calls is less than generic channel holding time because the mobile unit travels more than one cell as handover take place and thus relinquishes the channel. For simplicity of analysis channel holding time is assumed to have exponential distribution with rate λ_{Hn} and λ_{Hh} respectively for new and handoff calls.
(8) Due to consideration of channel holding time of new and handover calls separately, the event that the handoff call ends while waiting in the queue is taken into account. Ignoring it may lead to overestimation of call blocking probability.
(9) Call duration time is assumed to follow exponential distribution with rate μ_M.
(10) Inter-arrival time between new calls is exponential with rate λ_n and that between first and second priority handover calls is exponential with rate λ_{h1} and λ_{h2} respectively. $\lambda_h = \lambda_{h1} + \lambda_{h2}$ is handoff call arrival rate and $\lambda = \lambda_n + \lambda_h$ is call arrival rate.

3. Analysis of the Model

It has been found that the handover performance of a cell that is surrounded by a cluster of cells and having non-Poisson traffic is nearly identical to the handover performance of a single isolated cell when one assumes that the cells are identical, have the same statistical behavior and the traffic in the cells is Poisson. Also as stated earlier channel holding time is approximated by an exponential distribution. The affect of these two assumptions is that one has to deal with $M/M/C/K$ system.

If $\lambda_{h_{in}}$ and $\lambda_{h_{out}}$ denote out-of-cell and into-cell handover rates and P_H,P_B denote handover and new call blocking probabilities then handover arrival rate can be calculated by solving following equation for $\lambda_{h_{out}} = \lambda_{h_{in}}$

$$\lambda_{h_{out}} = P_h(1 - P_b)\lambda_n + P_h(1 - P_H)\lambda_{h_{in}} \tag{1}$$

Substituting λ_h for both $\lambda_{h_{out}}$ and $\lambda_{h_{out}}$ we get

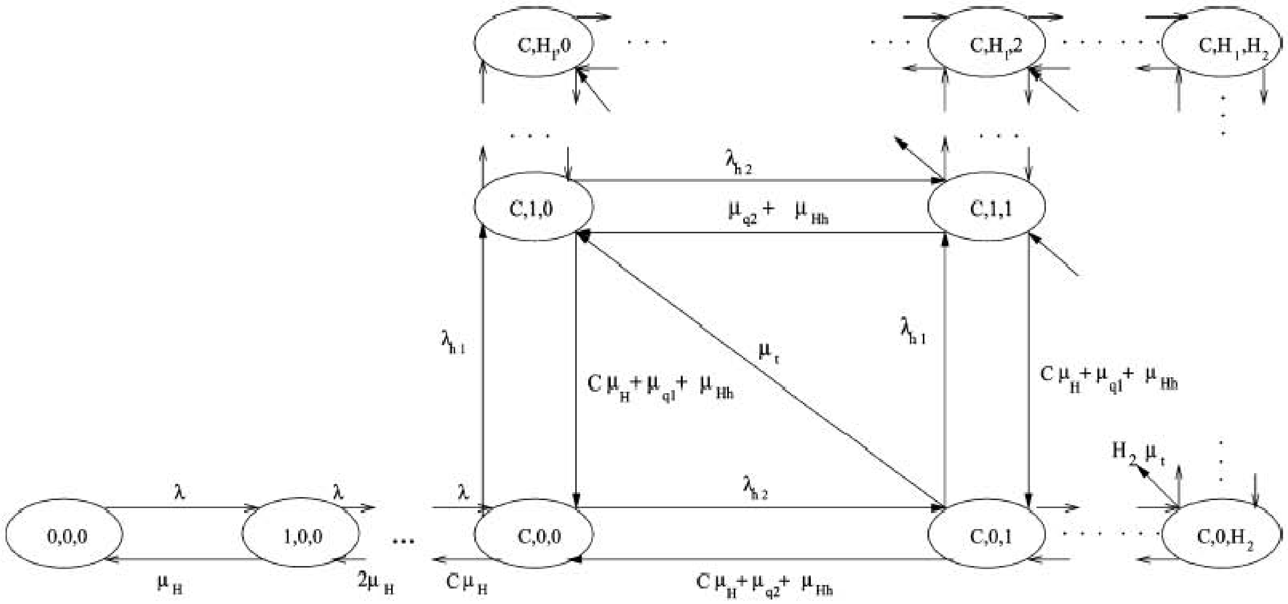
$$\lambda_h = \frac{P_h(1 - P_B)}{1 - P_h(1 - P_H)}\lambda_n \tag{2}$$

The channel holding time T_H is approximated by an exponential distribution with mean $1/\mu_H$, μ_H can be solved using

$$\int_0^\infty e^{-\mu_H t}\, dt = \int_0^\infty (1 - \frac{\lambda_n}{\lambda} F_{TH_n}(t) - \frac{\lambda_n}{\lambda} F_{TH_h}(t))dt \tag{3}$$

where $F_{TH_n}(t)$ and $F_{TH_h}(t)$ are actual distribution of channel holding time for new and handoff calls.

At this moment all the parametres used in the resulting Markov chain representing the process is known to us.



$$
\begin{aligned}
(\lambda_n + \lambda_h)P_{k,m,n} &= (k+1)\mu_H P_{k+1,m,n} && \text{for } 0 \le k < C, m=0, \quad n=0 \\
(\lambda_h + C\mu_H)P_{C,m,n} &= (C\mu_H + (m+1)(\mu_{q1} + \mu_{Hh}))P_{C,m+1,n} + (\lambda_h + \lambda_n)P_{C-1,m,n} \\
&\quad + (C\mu_H + (n+1)(\mu_{q2} + \mu_{Hh}))P_{C,m,n+1} && \text{for } m=0, \quad n=0
\end{aligned}
$$

$$
\begin{aligned}
(\lambda_h + C\mu_H + m(\mu_{q1} + \mu_{Hh}))P_{C,m,n} &= (C\mu_H + (m+1)(\mu_{q1} + \mu_{Hh}))P_{C,m+1,n} \\
&\quad + (n+1)\mu_t P_{C,m-1,n+1} + (n+1)(\mu_{q2} + \mu_{Hh})P_{C,m,n+1} + \lambda_{h1}P_{C,m-1,n} \\
&&& \text{for } 0 < m < H_1, \quad n=0
\end{aligned}
$$

$$
\begin{aligned}
(C\mu_H + m(\mu_{q1} + \mu_{Hh}) + \lambda_{h2})P_{C,m,n} &= \lambda_{h1}P_{C,m-1,n} + (n+1)\mu_t P_{C,m-1,n+1} \\
&\quad + (n+1)(\mu_{q2} + \mu_{Hh})P_{C,m,n+1} && \text{for } m = H_1, \quad n=0
\end{aligned}
$$

$$
\begin{aligned}
(C\mu_H + \lambda_h + n(\mu_t + \mu_{q2} + \mu_{Hh}))P_{C,m,n} &= (C\mu_H + (n+1)(\mu_{q2} + \mu_{Hh}))P_{C,m,n+1} \\
&\quad + (C\mu_H + (m+1)(\mu_{q1} + \mu_{Hh}))P_{C,m+1,n} + \lambda_{h2}P_{C,m,n-1} \\
&&& \text{for } m=0, \quad 0 < n < H_2
\end{aligned}
$$

$$
\begin{aligned}
(C\mu_H + \lambda_h + m(\mu_{q1} + \mu_{Hh}) + n(\mu_t + \mu_{q2} + \mu_{Hh}))P_{C,m,n} &= \lambda_{h1}P_{C,m-1,n} + (n+1)\mu_t P_{C,m-1,n+1} \\
&\quad + (C\mu_H + (m+1)(\mu_{q1} + \mu_{Hh}))P_{C,m+1,n} \\
&\quad + \lambda_{h2}P_{C,m,n-1} + (n+1)(\mu_{q2} + \mu_{Hh})P_{C,m,n+1} && \text{for } 1 \le m < H_1, \quad 0 < n < H_2
\end{aligned}
$$

$$
\begin{aligned}
(C\mu_H + m(\mu_{q1} + \mu_{Hh}) + n(\mu_{q2} + \mu_{Hh}) + \lambda_{h2})P_{C,m,n} &= \lambda_{h1}P_{C,m-1,n} + \lambda_{h2}P_{C,m,n-1} + (n+1)\mu_t P_{C,m-1,n+1} \\
&\quad + (n+1)(\mu_{q2} + \mu_{Hh})P_{C,m,n+1} && \text{for } m = H_1, \quad 0 < n < H_2
\end{aligned}
$$

$$
(C\mu_H + \lambda_{h1} + m(\mu_{q1} + \mu_{Hh}) + n(\mu_t + \mu_{q2} + \mu_{Hh}))P_{C,m,n} = (C\mu_H + (m+1)(\mu_{q1} + \mu_{Hh}))P_{C,m+1,n}
$$

FIGURE 2. 2-D Markov Chain representing the Model and the state equations

Let $S_{k,m,n}$ represent the state when k calls are in progress with m and n handoffs waiting in first and second priority queue respectively, and $P_{k,m,n}$ the steady state probability of system being in state $S_{k,m,n}$. Fig. 2. shows the Markov Chain representing the queueing model and the associated state equations. Diagonal lines representing the priority transition and the facility to end the call in the queue should be noted. Also use of μ_{Hh} instead of μ_H in estimating handover failure probabily should be noted.

The following points should be noted with respect to the markov chain:

(1) A transition from state $S_{k,0,0}$ to $S_{k+1,0,0}$ for $0 <= k < C$ occurs when a new call or handover call arrives, thus it occurs with rate λ.
(2) A transition from state $S_{k,0,0}$ to state $S_{k-1,0,0}$ for $0 < k <= C$ occurs if a call in progress finishes its service and releases the channel, thus occurs with rate $k\mu_H$.
(3) Transition from state $S_{C,m,n}$ to state $S_{C,m+1,n}$ occurs with rate λ_{h1}, while a transition from state $S_{C,m,n}$ to state $S_{C,m,n+1}$ occurs with rate λ_{h2}.
(4) A transition from state $S_{C,m,n}$ to state $S_{C,m-1,n}$ occurs if a channel is released and the first-priority handover call gets service or the first-priority handover call finishes its call while in the queue, or the waiting time in the queue for a handover call in first-priority is over before a channel is released, thus occurs with rate $C\mu_H + m(\mu_{Hh} + \mu_{q1})$.
(5) A transition from state $S_{C,m,n}$ to state $S_{C,m,n-1}$ occurs if the waiting time for a second-priority handover call is over before a channel is released or the second-priority handover call finishes its call while in the queue, or a channel is released and a second-priority handover call gets served provided there is no handover call waiting in first-priority handover queue, thus it occurs with rate $n(\mu_{Hh} + \mu_{q2})$ or with rate $C\mu_H + n(\mu_{Hh} + \mu_{q2})$.
(6) A transition from state $S_{C,m,n}$ to state $S_{C,m+1,n-1}$ occurs if a second-priority handover call becomes a first-priority handover call, thus it occurs with rate μ_t.

The steady-state probabilities $P_{k,m,n}$ that the cell is in state $S_{k,m,n}$ can be found by solving the system of linear equations consisting of the flow-equilibrium equations given in fig. 2. and the normalization condition $\sum_{k=0}^{C}\sum_{m=0}^{H_1}\sum_{n=0}^{H_2} P_{k,m,n} = 1$. New call blocking probability is given by

$$P_B = \sum_{m=0}^{H_1}\sum_{n=0}^{H_2} P_{C,m,n} \tag{4}$$

Handover failure occurs if a handover call arrival finds all channels occupied and its respective queue full or the handover call arrival is queued in its respective queue; however, it is dropped before getting service because its waiting time in the queue is over before the handover call gets served. The steady-state handover failure probability P_H is given as the sum of the handover failure probability for each class weighed by the probability that this call is a first or a second-priority handover call. Hence

$$P_H = \frac{\lambda_{h1}}{\lambda_h} P_{H/1} - \frac{\lambda_{h2}}{\lambda_h} P_{H/2} \tag{5}$$

where $P_{H/1}$ and $P_{H/2}$ are the conditional probabilities of the event that a first-priority and a second-priority handover call are dropped. Precisely:

$$P_{H/1} = \sum_{n=0}^{H_2} P_{C,H_1,n} + \sum_{m=0}^{H_1-1}\sum_{n=0}^{H_2} P_{H_1;m,n} P_{C,m,n} \tag{6}$$

where,

$$P_{H_1;m,n} = \frac{(m+1)\mu_{q1}}{C_{\mu_H} + m(\mu_{q1} + \mu_{Hh})} \tag{7}$$

A similar experession hold for $P_{H/2}$ details of which can be found in Appendix II of [1]

The algorithm used in calculating new call blocking and handover dropping probabilities [1] can be written as follows:

(1) Input parametres: $C, \lambda_n, \mu_{Hn}, \mu_{Hh}, P_h, \mu_{q1}$ and μ_{q2}
(2) Calculate μ_H and μ_t
(3) Assume a value of λ_h
(4) Write down equation of Markov chain and solve for $P_{C,m,n}$
(5) Calculate P_B and P_H using equation (4) and (5)
(6) Calculate new λ_h using equation (2) and compare it with previous value of λ_h, if it does not converge go to step 4 and use new value of λ_h computed

Fig.3. at the bottom of this page shows the comparison between the simulation results and analytical approach. It is assumed that the average channel holding time is 1 min, the average channel holding time for handover calls is 0.5 min, the average waiting times in the queue are 2 and 12 s for first and second-priority handover calls, respectively, probability of a call in progress experiencing a handover is 50%, and the cell has 30 channels. Comparing the blocking and handover failure probabilities, one can see that the agreement between the simulations and analytical results is very good.

References

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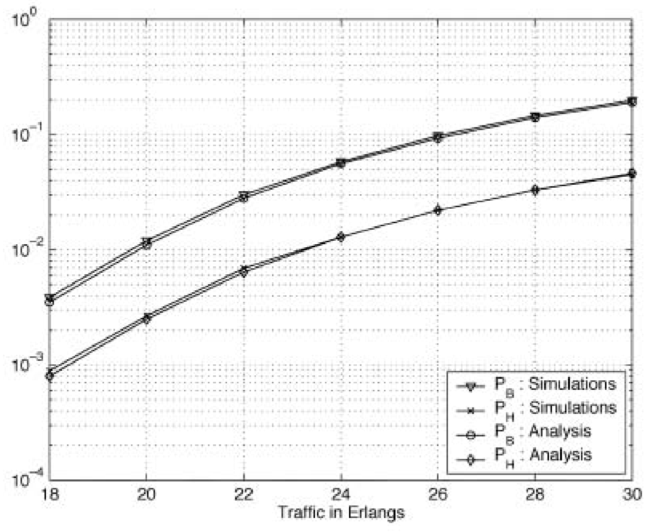

Figure 3. Comparison of new call blocking and handover failure probabilities between the analytical approach and simulation results