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Handoff Management in Priority Based Feedback Cellular Networks with Catastrophes and Impatient Customers

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ABSTRACT: Cellular service providers are increasing day by day. They compete themselves for market positioning and future direction in the market for wireless and mobile network infrastructure. To achieve this they need an effective cellular system for maintaining their Quality of Service [QoS]. Queueing handoff is another way to improve the system performance. We have modeled a 2D Markov chain where the handoff calls are allowed to form a queue. Feedback of calls has been incorporated in the model. In addition the event of impatient calls getting terminated while waiting in queue and a catastrophe resulting in loss of all calls are taken into account. An analytical solution is obtained by using backward continued fraction technique.

KEYWORDS: Backward continued fraction, Catastrophes, Cellular Network, Feedback calls, Impatience, M/M/C queue.

I. INTRODUCTION

The challenges and opportunities of various service providers increase the need to develop and new handoff schemes. The channel is a limited resource for any cellular network. But the demand for service is increasing day by day. A common measure of Quality of Service [QoS] is the unavailability of free channels for ongoing calls and protecting the network from disasters which result in loss of all calls. Thus the major challenge for service providers is proper allocation of channels to prevent the termination of ongoing calls.

Cellular network with handoff queues are the practical queuing models and thus they are not reliable. Disaster (virus infection, system breakdown or natural disaster disconnecting the satellite connections) seem to be appropriate in cellular networks as they depend on satellites. Disaster leads to loss of several or all calls in cellular network. Also the concept of customer impatience is well suited for cellular networks because a handoff call in queue that does not get service before its waiting time is over leaves the queue. Thus incorporating disaster, impatience and feedback of calls in handoff queues will gain significant attention.

Prioritization scheme for handover calls are discussed in [6,7,8]. Analysis of cellular networks is found in [10, 11]. The features of reneging are included in the analysis of a cellular network in [3]. Comparative study of various traffic models with handoff is done by Biswajit Bhowmik[2]. Backward continued fraction definition and an explicit formulae to find the inverse of a matrix using it are discussed in EmrahKilic[4]. Importance of queuing concepts like Impatient customers, catastrophes, feedback of customers are stressed in [1,9].

The rest of the paper is organized as follows. Section 2 explains about how the handoff call transition is done in the network. Section 3 describes the mathematical model of the problem. The steady state probabilities are derived in section 4 using backward continued fraction. Numerical example is given in section 5 to discuss about the system performance measures and validity of the model. Finally conclusion and references are given.

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II. HANDOFF CALLS IN QUEUE

Assume that there is C channels per cell in a cellular network. The new and handoff calls get the service if any of the C channels are free. If all the channels are busy then the new calls are blocked and handoff calls are queued according to priority. We consider a finite storage in the queue say H calls only. Once a call is queued then service is provided to only the handoff calls in the queue until it becomes empty. Moreover a handover call in the queue that does not get service until its waiting time is over leaves the queue. The described queue model is shown in Fig.2.1

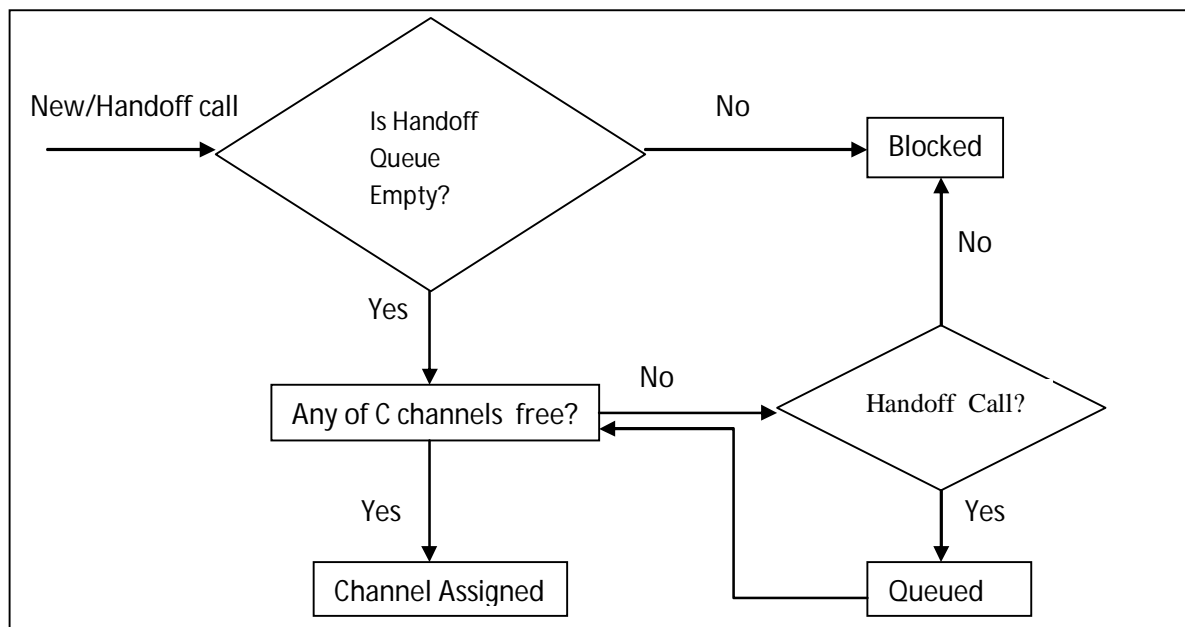


Fig. 2.1

III. MATHEMATICAL MODEL

Assume a cellular network with FIFO queue. The arrival rates of new calls and handoff calls are assumed to follow Poisson distribution. Let the mean average holding time for both new calls and handoff calls follow exponentially distribution. Queues with feedback are very appropriate for computer networks and telecommunication systems. After completion of service the customer goes out of the system with probability q or again comeback to use the service of the channels with probability p . However there is no difference between the regular arrival and feedback arrival.

Impatience is another feature of queue which perfectly fits in for the cellular network. When handoff calls are queued some calls gets terminated in the queue itself before getting their service for their waiting time in the queue in over. This can be treated as the impatience of the waiting calls. Catastrophes may occur at the system. All the available customers are terminated immediately, the channels get inactivated momentarily and the channel is ready for service only when an arrival occurs. The parameters of the model are listed in TABLE 3.1

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Table 3.1

λ_{new}	Arrival rate of new calls
λ_h	Arrival rate of handoff calls
λ	Arrival rate of either new or handoff call. Hence $\lambda = \lambda_{new} + \lambda_h$
$\frac{1}{\mu}$	Average holding time for either a new call or a handoff call
p	Probability with which the calls that finish the service again come back
q	Probability with which the calls that finish the service leaves the system
η	Rate at which calls are terminated in queue before getting the service
γ	Rate at which catastrophes occur to the cell

Define $S_{m,n}$ as the state of the cell where m represents the total number of calls in the cell and n denote the number of handoff calls in queue (i.e) $m = 0, 1, 2 \dots C$ and $n = 0, 1, 2 \dots H$. Here handoff calls are allowed to join a queue of finite size H . Let $p_{i,j}(t)$ denote the probability that there are i calls in the cell and j handoff calls in the queue. Then the system of differential difference equations is as follows [5].

$$\begin{aligned}
 p'_{00}(t) &= -\lambda p_{00}(t) + \mu q p_{10}(t) + \gamma \sum_{n=0}^C p_{n,0}(t) + \gamma \sum_{k=0}^H p_{C,k}(t) \\
 p'_{n0}(t) &= -(\lambda + \gamma + n\mu q)p_{n0}(t) + \lambda p_{n-1,0}(t) + (n+1)\mu q p_{n+1,0}(t) && n = 1, 2, 3 \dots C-1 \\
 p'_{C0}(t) &= -(\lambda_h + \gamma + C\mu q)p_{C0}(t) + \lambda p_{C-1,0}(t) + (C\mu q + \eta) p_{C,1}(t) \\
 p'_{ck}(t) &= -(\lambda_h + \gamma + \eta + C\mu q)p_{C,k-1}(t) + \lambda_h p_{C,k-1}(t) + (C\mu q + \eta) p_{C,k+1}(t) && k = 1, 2, 3 \dots H-1 \\
 p'_{CH}(t) &= -(\gamma + \eta + C\mu q)p_{CH}(t) + \lambda_h p_{C,H-1}(t)
 \end{aligned}$$

IV. STEADY STATE ANALYSIS

A. DIFFERENTIAL DIFFERENCE EQUATION

Using the steady state conditions $p'_{ij}(t) \rightarrow 0$ & $p_{i,j}(t) \rightarrow p_{i,j}$ and the initial condition that sum of all steady state probabilities is 1, the above equations become:

$$\begin{aligned}
 \lambda p_{00} &= \mu q p_{10} + \gamma(1 - p_{00}) && \text{-----(1)} \\
 (\lambda + \gamma + n\mu q)p_{n0} &= \lambda p_{n-1,0} + (n+1)\mu q p_{n+1,0} && \text{-----(2)} \\
 &&& n = 1, 2, 3 \dots C-1 \\
 (\lambda_h + \gamma + C\mu q)p_{C0} &= \lambda p_{C-1,0} + (C\mu q + \eta) p_{C,1} && \text{-----(3)} \\
 (\lambda_h + \gamma + \eta + C\mu q)p_{C,k-1} &= \lambda_h p_{C,k-1} + (C\mu q + \eta) p_{C,k+1} && \text{-----(4)} \\
 &&& k = 1, 2, 3 \dots H-1 \\
 (\gamma + \eta + C\mu q)p_{CH} &= \lambda_h p_{C,H-1} && \text{-----(5)}
 \end{aligned}$$

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B. STEADY STATE PROBABILITIES BY BACKWARD CONTINUED FRACTION

Equations 3.1 and 3.5 can be expressed as a matrix differential equation in the form $AX = B$.

Here A is the Coefficient matrix of all stationary probabilities and X the column vector of stationary probabilities and B the column vector $(-\gamma, 0, 0 \dots 0)$.

Thus the steady state probabilities are given by $X = A^{-1}B$.

For smaller order matrices A^{-1} can be found by the usual procedure. For higher order matrices, we can follow the procedure given by EmrahKilicin [4] and Yamamoto, T, Ikebe, Y [12].

Define

$$\begin{aligned} G_{-1} &= -1 \\ G_0 &= -(\lambda + \gamma) \\ G_n &= -(\lambda + \gamma + n\mu q)G_{n-1} - n\mu q \lambda G_{n-2} \quad n = 1, 2, 3 \dots C - 1 \\ G_C &= -(\lambda_h + \gamma + C\mu q)G_{C-1} - C\mu q \lambda G_{C-2} \\ G_k &= -(\lambda_h + \gamma + \eta + C\mu q)G_{k-1} - (C\mu q + \eta) \lambda_h G_{k-2} \\ k &= C + 1, C + 2, C + 3 \dots C + H - 1 \\ G_{C+H} &= -(\gamma + \eta + C\mu q)G_{C+H-1} - \lambda_h (C\mu q + \eta) \lambda G_{C+H-2} \end{aligned}$$

Then the backward continued fractions are defined as

$$C_i^b = \frac{G_{i-1}}{G_{i-2}} \quad i = 1, 2, 3 \dots (C + H + 1)$$

Also define

$$\begin{aligned} w_{ii} &= \frac{1}{C_i^b} + \sum_{k=i+1}^n \left(\frac{1}{C_k^b} \right) \prod_{t=i}^{k-1} \frac{y_t z_t}{(C_t^b)^2} & i = 1, 2, 3 \dots C + H \\ w_{k1} &= (-1)^{k+1} w_{kk} \prod_{t=1}^{k-1} \frac{z_t}{C_t^b} & k = 2, 3 \dots C + H + 1 \end{aligned}$$

where

$$y_t = \begin{cases} \lambda & t = 1, 2, 3 \dots C \\ \lambda_h & t = C + 1, C + 2, C + 3 \dots C + H \end{cases}$$

$$z_t = \begin{cases} t\mu q & t = 1, 2, 3 \dots C \\ C\mu q + \eta & t = C + 1, C + 2, C + 3 \dots C + H \end{cases}$$

Thus the steady state probabilities of the model are given by

$$\begin{aligned} p_{00} &= -\gamma w_{11} \\ p_{n0} &= -\gamma w_{n+1,1} & n = 1, 2, 3 \dots C \\ p_{CH} &= -\gamma w_{C+K+1,1} & k = 1, 2, 3 \dots H \end{aligned}$$

The blocking probability of new calls = p_{C0}

The blocking probability of handoff calls = p_{CH}

V. NUMERICAL EXAMPLE

A. VALIDITY OF THE RESULT

When $C = 3$ and $H = 2$, we easily derive that the blocking probability of new calls is

$$p_{30} = p_0 \left[\frac{(\lambda + \gamma)^3}{3!(\mu q)^3} + \frac{3\gamma(\gamma + \lambda)}{(2\mu q)(3\mu q)} + \frac{\gamma}{3\mu q} \right] - \frac{\gamma^2}{\mu q(3\mu q)} - \frac{\gamma(\gamma + \lambda)(\mu q + \lambda + \gamma)}{3!(\mu q)^3}$$

$$\text{The blocking probability of handoff calls} = p_{32} = \frac{\lambda_h^2}{(3\mu q + \eta + \gamma)^2 + \gamma \lambda_h} p_{30}$$

Taking $\gamma \rightarrow 0, \lambda_h = \lambda, \eta \rightarrow 0$ and $q = 1$

$$p_{30} = p_0 \left[\frac{(\lambda)^3}{3! (\mu)^3} \right]$$

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$$p_{32} = \frac{\lambda^2}{(3\mu)^2} p_{30} = \frac{\lambda^5}{3! 3^2 \mu^5} p_0$$

The above results coincide with the ordinary M/M/C:H/FIFO queue model.

B. PERFORMANCE MEASURES

Consider a queue model with C = 3 and H = 2. Let $\lambda_{new} = 5$, $\lambda_h = 5$, $\lambda = 7$, $q = 1$, $\mu = 10$, $\gamma = 0.1$, $\eta = 0$. Then

$G_{-1} = 1$	$C_1 = -7.1$	$w_{11} = -5.011$	$p_{00} = 0.5011$
$G_0 = -7.1$	$C_2 = -7.241$	$w_{22} = -3.5$	$p_{10} = 0.346$
$G_1 = 51.41$	$C_3 = -7.765$	$w_{33} = -0.561$	$p_{20} = 0.054$
$G_2 = -399.211$	$C_4 = -8.0564$	$w_{44} = -0.325$	$p_{30} = 0.028$
$G_3 = 3216.21$	$C_5 = -16.48$	$w_{55} = -0.0873$	$p_{31} = 0.0047$
$G_4 = -53007.321$	$C_6 = -21$	$w_{66} = -0.04762$	$p_{32} = 0.0008$

The blocking probability of new calls = $p_{30} = 0.028$

The blocking probability of handoff calls = $p_{32} = 0.0008$

VI. CONCLUSION

In this paper we modeled cellular network as a 2D Markov chain. Here handoff customers are allowed to wait in a finite queue and priority is given to them. Since real applications of queue models undergo catastrophes and contain feedback customers, all these features are incorporated in the model. Here handoff customers are allowed to wait in a finite queue and priority is given to them. The explicit formulae derived using backward continued fraction for finding inverse of the coefficient matrix is used. Using this method one can easily create software to calculate blocking probability of handoff models. Further if explicit formulae are derived for blocking probability of handoff calls the control of queue can be done.

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