An Analytical Framework of Handoff in Wireless Mobile Network with Catastrophes

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Abstract *— The demand for wireless mobile networks led to an increase in handoff calls. Optimum utilization of the channel should be planned as it is the limited resource for any mobile network. Poorly designed handoff schemes lead to a drastic decrease in quality of service. The study gives an analytical framework of handoff procedure when some channels are purely reserved for handoff calls. In addition to that the loss of customers due to disaster in communication network is incorporated in the model. Steady state probabilities, blocking probability of new calls and probability of forced termination of ongoing calls are found.*

Keywords — *Multi server queue, Handoff calls, Reserved channels, Catastrophes, Matrix Differential Equation.*

I. INTRODUCTION

Mass market for mobile networks has been increasing. The service covers all generations of mobile network infrastructure like 2G, 3G and 4G. Most of these users are mobile while availing these services. Mobility is the most important feature of these networks. User's perspective is that their service should be uninterrupted once a service provider starts providing service to them. There are two types of calls in a mobile network; new calls and handoff calls. New calls are the calls that start in that station only if a channel is free. Handoff calls are the ongoing calls that are transferred from one station to another in order to prevent termination of those calls. Thus handoff procedure has a significant impact on the performance of the system undersigned. Continuous service can be achieved by supporting handoff (handover) from one cell to the next adjacent cell as mobile users' moves through the coverage area of the underlying base station.

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) may occur in them leading to loss of several or all customers. Thus incorporating disaster in handoff queues is the need of the hour.

To develop wireless cellular system that provides best quality of service many studies has been done. Handoff calls are the main factor in evaluating the performance of a mobile network. Introduction of guard channels [3,4] for handoff calls has decreased the handoff blocking probability. Some models have used queues to delay the handoff calls until a channel is available as in [2,5]. Though there is a reduction in the handoff blocking probability it in turn increased the blocking probability of new calls. In [1] a comparative study of handoff management in wireless mobile networks is done. None of the previous studies treated reserved channel model as a 2D Markov chain. Inclusion of disaster in the model is the highlight of our work.

The rest of the paper is organized as follows. The next section gives the flow chart of channel sharing. Section 3 describes the mathematical model of the problem. The steady state probabilities are derived in section 4. Numerical example is given in section 5 to discuss about the system performance measures and validation of the model. Finally conclusion and references are given.

II. HANDOFF IN MOBILE NETWORK

Let there be C channels in a wireless mobile network. A priority is set to handoff requests by assigning exclusively C_2 channels out of available C channels. Thus both new calls and handoff calls share the remaining $C_1 = C - C_2$ channels in the band. The flow chart of the channels sharing process are shown in Fig. 1

III. MATHEMATICAL MODEL

Assume a wireless mobile network with FIFO queue. The arrival rates of new calls and handoff calls be λ_1 and λ_2 respectively. Let $\frac{1}{\mu}$ be the mean average holding time for both new calls and handoff calls. The arrival rates are assumed to follow Poisson process and mean holding time is assumed to be exponentially distributed. The Channel sharing is shown in Fig. 2

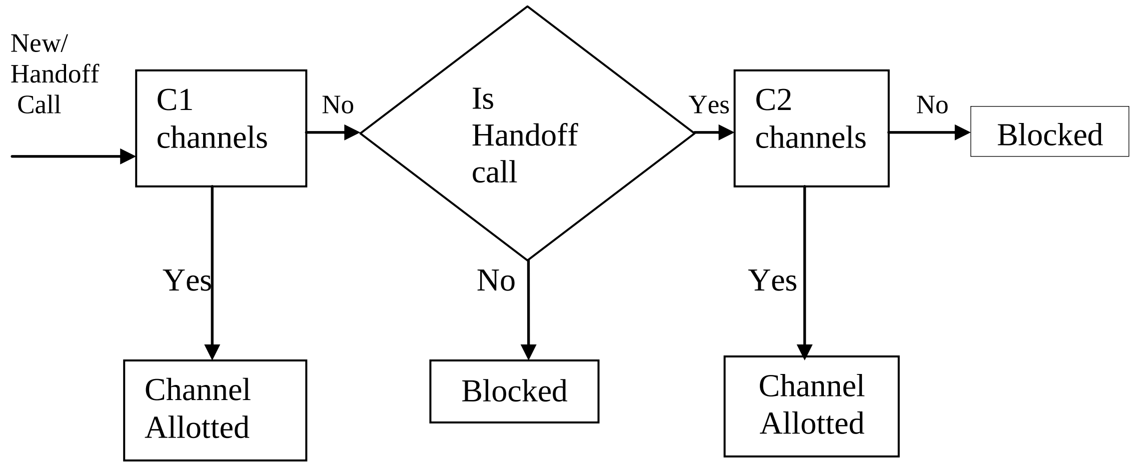

Fig 1: Handoff Sharing

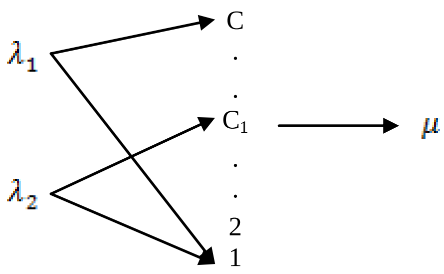

Fig :2

Catastrophes occur at the service facilities as a Poisson process with rate γ. Whenever a catastrophe occur at the system all the available customers are destroyed immediately, the channels get inactivated momentarily and the channel is ready for service only when an arrival occurs.

Let us define $S_{m,n}$ as the state of the cell where m represents the total number of handoff calls in the cell and n denote the number of new calls that is $m = 0, 1, 2 \ldots C$ and $n = 0, 1, 2 \ldots C_1$ such that

$m + n = C$. Hence no queue is allowed to form. Also when total number of calls is greater than or equal to C_1 new calls are blocked and handoff calls are sent to reserved channels. When total number of calls is C then handoff calls are also terminated.

Let $p_{i,j}(t)$ denote the probability that there are i handoff calls in the cell and j newcalls in the cell. Then the system of differential difference equations [6] which is subject to catastrophes follows.

$$p'_{00}(t) = -(\lambda_1 + \lambda_2 + \gamma)p_{00}(t) + \mu p_{10}(t) + \mu p_{01}(t) + \gamma$$

$$p'_{i0}(t) = -(\lambda_1 + \lambda_2 + \gamma + \mu)p_{i0}(t) + \lambda_1 p_{i-1,0}(t) + (i+1)\mu p_{i+1,0}(t) + \mu p_{1i}(t)$$
$$i = 1,2,3 \ldots C_1 - 1$$

$$p'_{i0}(t) = -(\lambda_1 + \gamma + \mu)p_{i0}(t) + \lambda_1 p_{i-1,0}(t) + (i+1)\mu p_{i+1,0}(t) + \mu p_{1i}(t)$$
$$i = C_1, C_1 + 1 \ldots C - 1$$

$$p^{i}_{c0}(t) = -(\gamma + c\mu)p_{c0}(t) + \lambda_1 p_{c-1,0}(t)$$

$$p'_{oj}(t) = -(\lambda_1 + \lambda_2 + \gamma + j\mu)p_{oj}(t) + \lambda_2 p_{0,j-1}(t) + \mu p_{1j}(t) + (j+1)\mu p_{0,j+1}(t)$$
$$j = 1,2,3 \ldots C_1$$

$$p'_{ij}(t) = -[(\lambda_1 + \lambda_2 + \gamma + (i+j)]\mu p_{ij}(t) + \lambda_2 p_{i,j-1}(t) + \lambda_1 p_{i-1,j}(t) + (i+1)\mu p_{i+1,k}(t) + (j+1)\mu p_{i,j+1}(t)$$
$$i = 1,2,3 \ldots (C_1 - j)$$
$$j = 1,2,3 \ldots C_1$$

$$p'_{ij}(t) = -(\lambda_1 + \gamma + (i+j)\mu)p_{i,j}(t) + \lambda_1 p_{i-1,j}(t) + (i+1)\mu p_{i+1,k}(t) + (j+1)\mu p_{i,j+1}(t)$$
$$i = C_1 - (j-1), (C_1 - j) \ldots C - (j+1)$$
$$j = 1,2,3 \ldots C_1$$

$$p'_{c-j,j}(t) = -(\gamma + c\mu)p_{c-j,j}(t) + \lambda_1 p_{c-j-1,j}(t)$$
$$j = 1,2,3...C_1$$

IV. STEADY STATE ANALYSIS

Using the steady state conditions $p'_{ij}(t) \to 0$ and $p_{i,j}(t) \to p_{i,j}$ the above equations become,

$$(\lambda_1 + \lambda_2 + \gamma)p_{00} = \mu p_{10} + \mu p_{01} + \gamma$$

$$(\lambda_1 + \lambda_2 + \gamma + \mu)p_{i0} = \lambda_1 p_{i-1,0} + (i+1)\mu p_{i+1,0} + \mu p_{1i}$$
$$i = 1,2,3...C_1 - 1$$

$$(\lambda_1 + \gamma + \mu)p_{i0} = \lambda_1 p_{i-1,0} + (i+1)\mu p_{i+1,0} + \mu p_{1i}$$
$$i = C_1, C_1 + 1...C - 1$$

$$(\gamma + c\mu)p_{c0} = \lambda_1 p_{c-1,0}$$

$$(\lambda_1 + \lambda_2 + \gamma + j\mu)p_{oj} = \lambda_2 p_{0,j-1} + \mu p_{1j} + (j+1)\mu p_{0,j+1}$$
$$j = 1,2,3...C_1$$

$$[(\lambda_1 + \lambda_2 + \gamma + (i+j)]\mu p_{ij} = \lambda_2 p_{i,j-1} + \lambda_1 p_{i-1,j} + (i+1)\mu p_{i+1,k} + (j+1)\mu p_{i,j+1}$$
$$i = 1,2,3...(C_1 - j)$$
$$j = 1,2,3...C_1$$

$$(\lambda_1 + \gamma + (i+j)\mu)p_{i,j} = \lambda_1 p_{i-1,j} + (i+1)\mu p_{i+1,k} + (j+1)\mu p_{i,j+1}$$
$$i = C_1 - (j-1), (C_1 - j)...C - (j+1)$$
$$j = 1,2,3...C_1$$

$$(\gamma + c\mu)p_{c-j,j} = \lambda_1 p_{c-j-1,j}$$
$$j = 1,2,3...C_1$$

The above equations can be written 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 $X = A^{-1}B$.
The blocking probability of new calls $= P(C_1)$ where P(i) denote the steady state probability at state i.

The blocking probability of handoff calls $= \sum_{i=c-c_1}^{c} p_{i,c-i}$

V. NUMERICAL ANALYSIS

A. *Validity of the model*

For the above numerical example, we find that the blocking probability for handoff calls is

$$P(3) = \frac{\lambda_1}{3\mu+\gamma}\frac{(\lambda_1+\lambda_2+\gamma)^2}{(2\mu)(\mu)}P(0) + \frac{\lambda_1}{3\mu+\gamma}\frac{\gamma}{2\mu}P(0) + \frac{\lambda_1}{3\mu+\gamma}\frac{\gamma(\lambda_1+\lambda_2+\gamma)}{(2\mu)(\mu)} - \frac{\lambda_1}{3\mu+\gamma}\frac{\gamma}{2\mu}$$

When $\gamma \to 0$, $P(3) = \frac{\lambda_1}{3\mu}\frac{(\lambda_1+\lambda_2)^2}{(2\mu)(\mu)}P(0)$

which coincides with the results in [2].

B. *Evaluation of Blocking Probability*

Assume there are 3 servers in a mobile network out of which 1 is reserved for the handoff calls. Let the arrival rate of new calls be 7 and handoff calls be 2 and follow Poisson process. The average holding time of each call be $1/10$. Also assume the rate at which disaster occurs be 0.1 resulting in loss of all customers.

The various states of the system are (0,0), (1,0), (2,0), (3,0), (0,1), (1,1), (2,1), (0,2) and (1,2). The matrix differential equation is $AX = B$ where

$B = [-0.1 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]^T$

$X = [p_{00}\, p_{01}\, p_{02}\ \ p_{03}\ p_{01}\ \ p_{11}\ \ p_{21}\ \ p_{02}\ p_{12}]$

$= [\,0.447\ \ 0.29\ \ 0.097\ \ 0.022\ \ 0.078\ \ 0.047\ \ 0.01\ \ 0.006\ \ 0.001]$

The blocking probability of new calls =P(2) = 0.15
The blocking probability of handoff calls = P(3)
= 0.033

VI. CONCLUSION

In this paper, we have considered a 2D Markov model of reserved channels for handoff calls. Also the concept of disaster resulting in loss of all customers is incorporated. The steady state probabilities were calculated to determine the performance of this model. In most of the handoff queuing models developed only simulation results are found. Hence the future research on these queue models can be in finding the analytical solution of various models. Thus control of queues, decision on number of channels required to reduce the blocks can be effectively studied.

$$A=\begin{bmatrix} -9.1 & 10 & 0 & 0 & 10 & 0 & 0 & 0 & 0 \\ 7 & -19.1 & 20 & 0 & 0 & 10 & 0 & 0 & 0 \\ 0 & 7 & -29.1 & 30 & 0 & 0 & 10 & 0 & 0 \\ 0 & 0 & 7 & -30.1 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & -19.1 & 10 & 0 & 20 & 0 \\ 0 & 2 & 0 & 0 & 7 & -29.1 & 20 & 0 & 20 \\ 0 & 0 & 0 & 0 & 0 & 7 & -30.1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2 & 0 & 0 & -27.1 & 10 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 7 & -30.1 \end{bmatrix}$$

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