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Evaluation of Delay of Voice End User in
Cellular Mobile Networks with 2D Traffic System

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Abstract: In this study, a simple scheme to improve the performance of mobile cellular networks is presented by incorporating delay of voice end user to the new originating calls over handoff calls in a two-dimensional traffic model. Expressions for probability of forced termination of handoff calls and the blocking probability of new originating calls have been derived. It has been found from this study that the probability of forced termination of handoff calls is drastically reduced due to the incorporation of the delay of voice end user compared to the case when no delay of voice end user is used in the system. The results obtained from this study for performance improvement have been compared with the existing method of channel reservation scheme for handoff calls and have been found that the obtained results provide much better performance improvement by reducing the probability of forced termination and the blocking probability.

Key words: DOVE, handoff calls, newly originated calls, probability of forced termination

INTRODUCTION

The grade of service (GoS) of a wireless network can be defined in terms of blocking and dropping probabilities. The first refers to a situation in which a user cannot initiate a call because no network resources are available. Dropping or forced termination occurs when an established call initiates a handoff procedure and is forced to terminate because there are no channels available in the new cell. From a handoff perspective, it is important that a free channel is available in a new cell whenever handoff occurs, so that undisrupted service is continued. It is well known that if an originated call is unsuccessful due to blocking, this is not as disastrous as a handoff call being dropped. Therefore, it is important to provide a higher priority to an existing call that goes through the handoff process so that ongoing calls can be continued.

The interruption of a call in progress is highly unsatisfactory for the user, and we must avoid this situation whenever possible. A common strategy consists of giving priority to handoff call requests over new call requests. One of the established strategies is to use guard channels or priority reservation scheme (Lin and Chlamtac, 2000; Ramjee *et al.*, 1996; Wang *et al.*, 2003). The use of guard channels in cellular communications systems as a way of ensuring a certain GoS is widely accepted and implemented. This technique consists of having a fixed number of channels in each cell, reserved exclusively for handoff requests. These extra channels reduce the negative effect caused by dropping a call in progress, thus providing the overall GoS of the network. However, the drawback for using reserved channels for handoff calls is that the channels that are reserved may be unoccupied for a long duration and the service provider may loose huge revenue. Another strategy employed is the queuing

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to improve the GoS (Tekinay and Jabbari, 1992; Hong and Rappaport, 1986). Some schemes propose the insertion of a queue to deal with new originating calls, given the less restrictive delay constraint of this type of calls in comparison with handoff calls. Some studies also propose queuing the handoff requests, in an attempt to reduce the call dropping probability. Mixed schemes with guard channels and buffering techniques have also been proposed by Guerin (1998), Zeng *et al.* (1994), Rappaport (1991) and Purzynski and Rappaport (1995).

Oliver and Joan (1999) have recently proposed a variable reservation scheme for mobile cellular networks, based on prioritization of handoff calls over new originating calls. They have claimed that a noticeable improvement in blocking and call dropping probabilities have been achieved using adaptive channel reservation mechanism. However, such improvement is achieved at the expense of signaling protocol overhead.

Voice calls are assigned preemptive priority over data calls (Pavlidou, 1994). These schemes, however, do not differentiate handoff calls from new originating calls, thus the strict requirement of handoff dropping probability cannot be met. A preemptive handoff scheme is proposed by Li *et al.* (1998), where handoff voice calls have the right to preempt data calls. Since handoff voice calls and new originating calls use the same set of channels, voice handoff dropping probability is still high when there are too many new originating voice calls. A dual trunk reservation with queuing scheme has been studied by Wu *et al.* (2002), in which two thresholds are used, one to reserve bandwidth for handoff voice calls and the other for managing the data traffic.

Recently, two handoff schemes with and without preemptive priority procedures were proposed by Zeng and Agrawal (2002), where both real-time and nonreal-time handoff requests are allowed to be queued. These schemes are based on the complete sharing strategy with an objective of maximizing channel utilization. However, since the different types of traffic share the same set of channels, QoS of one type of traffic is affected by the other. Consequently, QoS of each service cannot be easily controlled (Wang *et al.*, 2003). In addition, these schemes reserve guard channels for handoff calls in order to minimize handoff dropping probability (Epstein and Schwartz, 1995). The limitation of the guard channel schemes, as has been discussed earlier, is that some of reserved channels for handoff requests may be idle when new calls are blocked if handoff requests are not very often.

A channel borrowing scheme for handoff management, Li *et al.* (2005) has been proposed recently to provide a good balance between the efficiency and the fairness. Channel partitioning is used to prevent one type of service from excessively using resources while the other suffering starvation at the time of congestion. In order to increase the bandwidth utilization, one type of service is allowed to borrow unused channels from the other, provided that the QoS of the latter is not significantly affected. However, to our understanding, the scheme resembles to a complete partitioning of traffic like channel reservation scheme. The concept of channel borrowing used here is widely prevalent but the study only deals with the case of multidimensional traffic.

In the present study, a very simple scheme is proposed to improve the performance of mobile cellular networks by adopting some delay to the last user of the new originating calls over the handoff calls. A two-dimensional (2D) traffic model is studied here for the delay of voice end user (DOVE) (Mahdavi *et al.*, 2001) on the performance evaluation, particularly the probability of forced termination of the handoff calls and the blocking probability of the new originating calls. It has been found in this study that the probability of forced termination of handoff calls is drastically reduced compared to the existing method of channel reservation scheme of handoff calls.

THE MODEL

It has been mentioned in the introduction that a very common strategy to avoid dropping handoff calls is to use guard or reserved channels for the handoff calls. In this study, it is shown that the performance of wireless mobile networks can be highly improved if we apply DOVE in the system

over the existing method of channel reservation scheme. This is done by comparing the proposed method with the method of channel reservation scheme for handoff calls.

For the smooth presentation of the idea of using DOVE for performance improvement, the usual 2D Erlang theory and the Erlang theory with channel reservation scheme is reviewed. The Erlang theory with DOVE and extended DOVE (E-DOVE) in a 2D traffic model is then described.

For simplicity, a mobile cellular system with homogeneous cells and a fixed number of channels which are permanently allocated to each cell is considered. In such a system, attention is focused on a single cell; let this cell be called as the reference cell. Newly generated calls in the reference cell are called originating calls. When a moving real-time service (voice call, called handoff call) user holding a channel approaches from a neighboring cell toward the reference cell and the received signal strength goes below the handoff threshold of the neighboring cell, a handoff request is generated in the reference cell.

2D Usual Erlang Model

To review the 2D Erlang theory for such a situation, the Markovian M/M/m/m model is assumed, where, m is the total number of channels allocated to the reference cell. Both the originating calls and handoff calls are treated equally by m channels in the cell, the calls are served as they arrive if there are channels available and both kinds of requests are blocked if all m channels are busy. For modeling the system of the cell, the corresponding 2D Markov chain is shown in Fig. 1. All mobile stations (MSs) are assumed to be uniformly distributed through the cell; the average arrival rate of originating calls (new calls) is denoted by λ_O and the average arrival rate of handoff calls is denoted by λ_H; the average service termination rates of originating calls and handoff calls are denoted, respectively, by μ_O and μ_H.

If a whole column is considered at the x-th position of a row, then the stationary probability states are given by the following equations:

$$\lambda_O P_{x,0} = \mu_O P_{x,1} \tag{1}$$

$$(\lambda_O + \mu_O) P_{x,1} = \lambda_O P_{x,0} + 2\mu_O P_{x,2} \tag{2}$$
$$\vdots$$
$$\vdots$$

$$(\lambda_O + y\mu_O) P_{x,y} = \lambda_O P_{x,y-1} + (y+1)\mu_O P_{x,y+1} \tag{3}$$

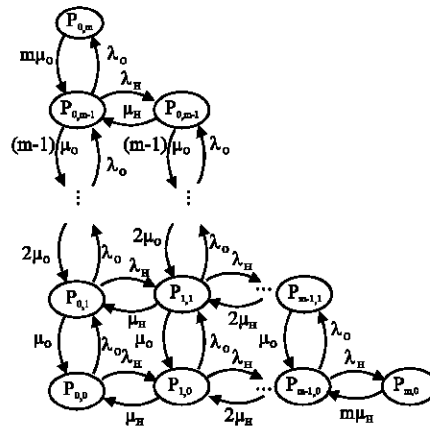Fig. 1: 2D Markov chain for the Erlang model

where, $0 \le x+y \le m$. Solving Eq. 1-3, we obtain:

$$P_{x,y} = \frac{a_O^y}{y!} P_{x,0}, \quad 0 \le x + y \le m \tag{4}$$

where, $a_O = \lambda_H / \mu_O$ is the offered traffic of the new originating calls.

Similarly, if a whole row at the y-th position of a column is considered, then it can easily be shown that:

$$P_{x,y} = \frac{a_H^x}{x!} P_{0,y}, \quad 0 \le x + y \le m \tag{5}$$

where, $a_H = \lambda_H / \mu_H$ is the offered traffic of the handoff calls.

By substituting $y = 0$ in Eq. 5 and the resulting $P_{x,0}$ so obtained, if substituted in Eq. 4, results in the following expression for the stationary probability states $P_{x,y}$:

$$P_{x,y} = \frac{a_H^x}{x!} \frac{a_O^y}{y!} P_{0,0}, \quad 0 \le x + y \le m \tag{6}$$

where, $P_{0,0}$ is obtained from the normalization condition that the sum of all the stationary probability states $P_{x,y}$ is unity. The expression for $P_{0,0}$ is thus given by the following equation:

$$P_{0,0} = \left(\sum_{y=0}^{m} \sum_{x=0}^{m-y} \frac{a_H^x}{x!} \frac{a_O^y}{y!} \right)^{-1} \tag{7}$$

In this usual case of the usual Erlang model, the probability of forced termination of handoff calls is the same as the blocking probability of the new originating calls and is given by the following expression:

$$P_{FT0} = P_{B0} = \sum_{x=0}^{m} P_{m-x,x} = \sum_{x=0}^{m} \frac{a_H^{m-x}}{(m-x)!} \frac{a_O^x}{x!} P_{0,0} \tag{8}$$

2D Erlang Model of Channel Reservation Scheme for Handoff Requests

As has been already mentioned in the introduction that it is important for a system to provide a higher priority to an existing call that goes through the handoff process so that ongoing calls can be continued. One way of assigning priority to handoff requests is by reserving a number of channels, say r, exclusively for handoff calls among the m channels in a cell. The remaining m-r channels are shared by both originating and handoff calls. An originating call is blocked if channels have been allocated. A handoff request is blocked if no channel is available in the cell. The system model must be modified to reflect priorities. Here, the theory of the channel reservation scheme in a 2D Erlang model is reviewed. The corresponding Markov chain is similar to Fig. 1, except that along the vertical axis, the axis along the originating calls, the last channel will be m-r instead of m. In this case, after solving the 2D Markov chain, not shown here, the possible stationary probability states can be easily derived to be:

$$P_{x,y} = \frac{a_H^x}{x!} \frac{a_O^y}{y!} P_{0,0R}, \quad 0 \le x \le r, 0 \le y \le m-r \tag{9}$$

and

$$P_{x,y} = \frac{a_H^x}{x!} \frac{a_O^y}{y!} P_{0,0R}, \quad r+1 \le x \le m-y \tag{10}$$

where, $P_{0,0R}$ is obtained by normalization of the probability of the stationary states and is shown to be:

$$P_{0,0R} = \left(\sum_{x=0}^{r-1} \sum_{y=0}^{m-r-1} \frac{a_H^x}{x!} \frac{a_O^y}{y!} + \sum_{x=r}^{m} \sum_{y=0}^{m-x} \frac{a_H^x}{x!} \frac{a_O^y}{y!} \right)^{-1} \tag{11}$$

The probability of forced termination for the handoff requests in this case is given by:

$$\begin{aligned}P_{FTR} &= \sum_{x=0}^{m-r} P_{m-x,x} \\ &= \sum_{x=0}^{m-r} \frac{a_H^{m-x}}{(m-x)!} \frac{a_O^x}{x!} P_{0,0R}\end{aligned} \tag{12}$$

and the blocking probability of the new originating calls is obtained as:

$$\begin{aligned}P_{BR} &= \sum_{x=0}^{r-1} P_{x,m-r} + \sum_{x=0}^{m-r} P_{m-x,x} \\ &= \sum_{x=0}^{r-1} \frac{a_H^x}{x!} \frac{a_O^{m-r}}{(m-r)!} P_{0,0R} + \sum_{x=0}^{m-r} \frac{a_H^{m-x}}{(m-x)!} \frac{a_O^x}{x!} P_{0,0R}\end{aligned} \tag{13}$$

2D Erlang Model for Finite Delay to the Voice End User (DOVE) of the Originating Calls
Here, the proposed model is developed by including the DOVE (Mahdavi *et al.*, 2001) in the system for the performance improvement of mobile cellular networks. No channel is reserved for the handoff calls here. The originating and handoff calls are given equal priority but for the end user of the originating calls is given a delay $d_1 = 1/\delta_1$. In this situation all assumptions are equally applicable to all cells in the system. The resulting 2D Markov chain in this case is shown in Fig. 2.

After solving the node equations of the 2D Markov chain of Fig. 2, the following stationary probability distributions are obtained:

$$P_{x,y} = \frac{a_H^x}{x!} \frac{a_O^y}{y!} P_{0,0D1}, \quad 0 \le x+y \le m-1 \tag{14}$$

where, the normalization constant $P_{0,0D1}$ will be defined shortly.

In addition to (14), the following node equations are derived for finding the remaining states $P_{x,D1}$ and $P_{x,m-x}$:

$$\begin{aligned}(\lambda_O + (m-x-1)\mu_O) P_{x,m-x-1} &= \lambda_O P_{x,m-x-2} \\ + (m-x-1)\mu_O P_{x,D1} + (m-x)\mu_O P_{x,m-x}\end{aligned} \tag{15}$$

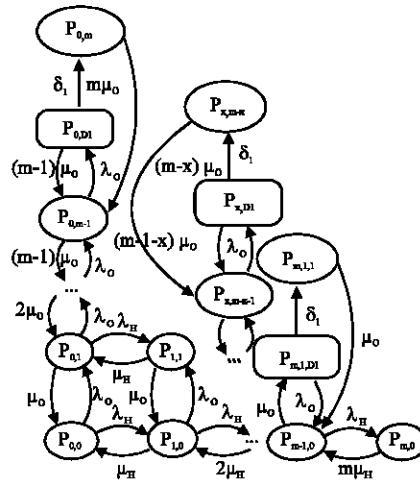Fig. 2: 2D Markov chain for the Erlang model with DOVE

$$\left(\delta_1 + (m - x - 1)\mu_O\right)P_{x,D1} = \lambda_O P_{x,m-x-1} \tag{16}$$

and

$$(m - x)\mu_O P_{x,m-x} = \delta_1 P_{x,D1} \tag{17}$$

After solving the above equations, the following relations, the expressions for $P_{x,D1}$ and $P_{x,m-x}$ are obtained as:

$$P_{x,D1} = \frac{\lambda_O}{\delta_1 + (m - x - 1)\mu_O}\frac{a_H^x}{x!}\frac{a_O^{m-x-1}}{(m-x-1)!}P_{0,0D1} \tag{18}$$

and

$$P_{x,m-x} = \frac{\delta_1}{\delta_1 + (m - x - 1)\mu_O}\frac{a_H^x}{x!}\frac{a_O^{m-x}}{(m-x)!}P_{0,0D1} \tag{19}$$

The constant $P_{0,0D1}$ is given by, after normalization of the stationary states:

$$P_{0,0D1} = \left(\sum_{x=0}^{m-1}\sum_{y=0}^{m-x-1}\frac{a_H^x}{x!}\frac{a_O^y}{y!} + X_1\right)^{-1} \tag{20}$$

Where:

$$X_1 = \sum_{x=0}^{m-1}a_O f_x \frac{a_H^x}{x!}\frac{a_O^{m-x-1}}{(m-x-1)!} + \sum_{x=0}^{m-1}\frac{\delta_1}{\mu_O}f_x\frac{a_H^x}{x!}\frac{a_O^{m-x}}{(m-x)!}$$

and

$$f_x = \frac{\mu_O}{\delta_1 + (m - x - 1)\mu_O}$$

The probability of forced termination of handoff requests in this case is:

$$
\begin{aligned}
P_{FT1} &= \sum_{x=0}^{m} P_{x,m-x} \\
&= \sum_{x=0}^{m} \frac{\delta_1}{\mu_O} f_x \frac{a_H^x}{x!} \frac{a_O^{m-x}}{(m-x)!} P_{0,0D1}
\end{aligned}
\tag{21}
$$

and the blocking probability is obtained as:

$$
\begin{aligned}
P_{B1} &= \sum_{x=0}^{m-1} P_{x,D1} + \sum_{x=0}^{m} P_{x,m-x} \\
&= \sum_{x=0}^{m-1} a_O f_x \frac{a_H^x}{x!} \frac{a_O^{m-x-1}}{(m-x-1)!} P_{0,0D1} + \sum_{x=0}^{m} \frac{\delta_1}{\mu_O} \frac{a_H^x}{x!} \frac{a_O^{m-x}}{(m-x)!} P_{0,0D1}
\end{aligned}
\tag{22}
$$

2D Erlang Model with Finite Delay to the Last Two Voice End Users (E-DOVE)

Similar to the above case, if the delays $d_1 = 1/\delta_1$ and $d_2 = 1/\delta_2$ are now provided to the last two end users (d_1 for the last m-th user and d_2 for the (m-1)-th user) of the new originating calls, known as the extended delay of voice end user (E-DOVE) scheme (Okuda *et al.*, 2002), the corresponding 2D Markov chain then takes the form of Fig. 3.

After solving the node equations of the 2D Markov chain of Fig. 3, the probability of the stationary states are obtained as:
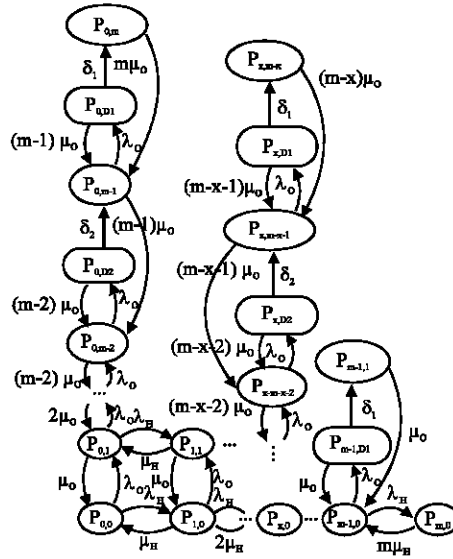

Fig. 3: 2D Markov chain for the Erlang model with E-DOVE

$$P_{x,y} = \frac{a_H^x}{x!} \frac{a_O^y}{y!} P_{0,0D2}, \quad 0 \le x + y \le m - 2 \tag{23}$$

where, the constant $P_{0,0D2}$ will be defined in Eq. 23:

In addition to Eq. 23, the following node equations for finding the remaining states $P_{x,D2}$, $P_{x,m-x-1}$, $P_{x,D1}$ and $P_{x,m-x}$ are to be considered:

$$\begin{aligned}(\lambda_O + (m - x - 2)\mu_O)P_{x,m-x-2} &= \lambda_O P_{x,m-x-3} \\ &+ (m - x - 2)\mu_O P_{x,D2} + (m - x - 1)\mu_O P_{x,m-x-1}\end{aligned} \tag{24}$$

$$(\delta_2 + (m - x - 1)\mu_O)P_{x,D2} = \lambda_O P_{x,m-x-2} \tag{25}$$

$$\begin{aligned}(\lambda_O + (m - x - 1)\mu_O)P_{x,m-x-1} &= \delta_2 P_{x,D2} \\ &+ (m - x - 1)\mu_O P_{x,D1} + (m - x)\mu_O P_{x,m-x}\end{aligned} \tag{26}$$

$$(\delta_1 + (m - x - 1)\mu_O)P_{x,D1} = \lambda_O P_{x,m-x-1} \tag{27}$$

and

$$(m - x)\mu_O P_{x,m-x} = \delta_1 P_{x,D1} \tag{28}$$

After solving the above equations, the expressions for $P_{x,D2}$, $P_{x,m-x-1}$ and $P_{x,m-x}$ are obtained as:

$$P_{x,D2} = \frac{\lambda_O}{\delta_2 + (m - x - 2)\mu_O} \frac{a_H^x}{x!} \times \frac{a_O^{m-x-2}}{(m - x - 2)!} P_{0,0D2} \tag{29}$$

$$P_{x,m-x-1} = \frac{\delta_2}{\delta_2 + (m - x - 2)\mu_O} \frac{a_H^x}{x!} \times \frac{a_O^{m-x-1}}{(m - x - 1)!} P_{0,0D2} \tag{30}$$

$$P_{x,D1} = \frac{\lambda_O}{\delta_1 + (m - x - 1)\mu_O} \frac{\delta_2}{\delta_2 + (m - x - 2)\mu_O} \times \frac{a_H^x}{x!} \frac{a_O^{m-x-1}}{(m - x - 1)!} P_{0,0D2} \tag{31}$$

and

$$P_{x,m-x} = \frac{\delta_1}{\delta_1 + (m - x - 1)\mu_O} \frac{\delta_2}{\delta_2 + (m - x - 2)\mu_O} \times \frac{a_H^x}{x!} \frac{a_O^{m-x}}{(m - x)!} P_{0,0D2} \tag{32}$$

The constant $P_{0,0D2}$ is given by, after normalization of the stationary states, as:

$$P_{0,0D2} = \left(\sum_{x=0}^{m-2} \sum_{y=0}^{m-x-2} \frac{a_H^x}{x!} \frac{a_O^y}{y!} + X_2 \right)^{-1} \tag{33}$$

Where:

$$X_2 = \sum_{x=0}^{m-2} \frac{\lambda_O h_x k_x}{\delta_2} \frac{a_H^x}{x!} \frac{a_O^{m-x-2}}{(m-x-2)!} + \sum_{x=0}^{m-1}\left(1 + \frac{\delta_O g_x}{\delta_1}\right)k_x \frac{a_H^x}{x!} \frac{a_O^{m-x-1}}{(m-x-1)!} + \sum_{x=0}^{m} g_x h_x \frac{a_H^x}{x!} \frac{a_O^{m-x}}{(m-x)!}$$

$$g_x = \frac{\delta_1}{\delta_1 + (m-x-1)\mu_O}, \; h_x = \frac{\delta_2}{\delta_2 + (m-x-2)\mu_O}$$

The probability of forced termination of handoff requests in this case of E-DOVE is:

$$P_{FT2} = \sum_{x=0}^{m} P_{x,m-x}$$

$$= \sum_{x=0}^{m} g_x h_x \frac{a_H^x}{x!} \frac{a_O^{m-x}}{(m-x)!} P_{0,0D2} \qquad (34)$$

and the blocking probability is obtained as:

$$P_{B2} = \sum_{x=0}^{m-2} P_{x,D2} + \sum_{x=0}^{m-1} P_{x,D1} + \sum_{x=0}^{m} P_{x,m-x}$$

$$= \sum_{x=0}^{m-2} \frac{\lambda_O h_x}{\delta_2} \frac{a_H^x}{x!} \frac{a_O^{m-x-2}}{(m-x-2)!} P_{0,0D2} + \sum_{x=0}^{m-1} \frac{\lambda_O g_x h_x}{\delta_1} \frac{a_H^x}{x!} \frac{a_O^{m-x-1}}{(m-x-1)!} P_{0,0D2} + \sum_{x=0}^{m} g_x h_x \frac{a_H^x}{x!} \frac{a_O^{m-x}}{(m-x)!} P_{0,0D2} \qquad (35)$$

RESULTS AND DISCUSSION

For the numerical appreciation of the obtained results, the following parameters are assumed for a cell of a mobile cellular system: number of channels in the cell, $m = 14$, reserved channels, $r = 3$-5 in the case of channel reservation scheme, offered traffic of new originating calls $a_O = 2.0$-12.0 Erls, offered traffic of handoff calls $a_H = 2.0$-6.0 Erls, service termination rates for new originating calls and handoff calls are respectively as $\mu_O = 0.67$ min^{-1} and $\mu_H = 0.83$ min^{-1}, delay of the voice end user for DOVE, $d_1 = 0.05$-0.26 min; delays of the voice end user in the case of E-DOVE are $d_1 = 0.05$-0.26 min and $d_2 = 0.2$ min.

The probability of forced termination of the handoff calls, P_{FT0}, P_{FTR} P_{FT1} and P_{FT2} from Eq. 8, 12, 21 and 34 and the blocking probability P_{B0}, P_{BR}, P_{B1} and P_{B2} from Eq. 8, 13, 22 and 35 are plotted against the offered traffic of new originating calls, handoff calls and delay to the voice end user of the originating calls d_1 in Fig. 4-9.

In Fig. 4, the probability of forced termination for the handoff calls is drawn against the offered traffic of new originating calls in the 2D Erlang traffic model for the DOVE (where, last end user of voice originating calls is delayed) and E-DOVE (where last two users of the new originating calls are delayed). The curves for the usual 2D Erlang model and the Erlang model for the channel reservation scheme are also drawn for comparison purpose. It is observed from the Fig. 4 that the probability of forced termination in the case of DOVE and E-DOVE is drastically reduced as the offered traffic of new originating calls increases beyond $a_O = 4.0$ Erls compared to the case when there is no delay to the voice end user is considered and also to the case of channel reservation scheme for handoff requests. It is also seen that the probability of forced termination in the case of usual Erlang model and the Erlang model with reserved channel are almost same. The number of reserved channels r is considered as $r = 3$ out of the total 14 channels in the cell in this investigation.

It is also noticed from Fig. 5 that the blocking probability of originating calls are almost same for the usual Erlang model, DOVE and E-DOVE, whereas it suddenly starts increasing at the offered traffic $a_O = 7.0$ in the case of channel reservation scheme.
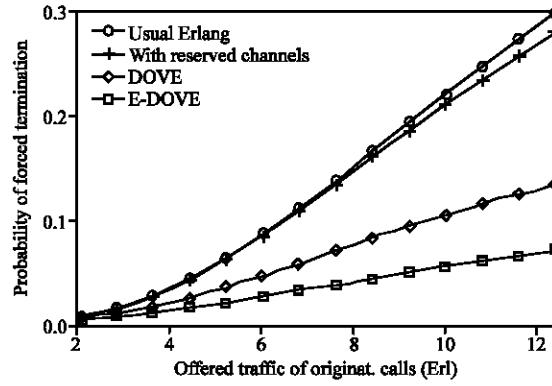
Fig. 4: Variation of the probability of forced termination against offered traffic of new originating calls (m = 14, r = 3, μ_O = 0.67 min^{-1}, μ_H = 0.83 min^{-1}, a_H = 5.0 Erls, d_1 = 0.2 min, d_2 = 0.2 min)

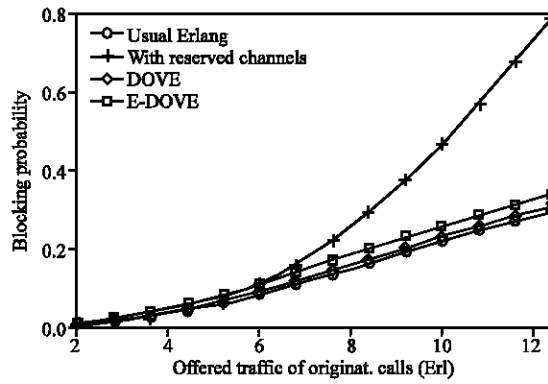
Fig. 5: Variation of the blocking probability of new originating calls against offered traffic of new originating calls (m = 14, r = 3, μ_O = 0.67 min^{-1}, μ_H = 0.83 min^{-1}, a_H = 5.0 Erls, d_1 = 0.2 min, d_2 = 0.2 min)
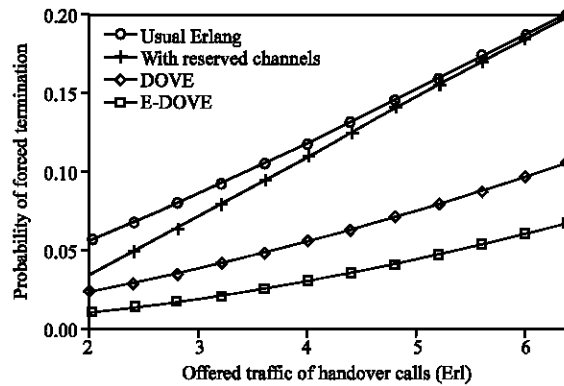

Fig. 6: Variation of the probability of forced termination of handoff calls against offered traffic of handoff calls (m = 14, r = 3, μ_O = 0.67 min^{-1}, μ_H = 0.83 min^{-1}, a_O = 8.0 Erls, d_1 = 0.2 min, d_2 = 0.2 min)
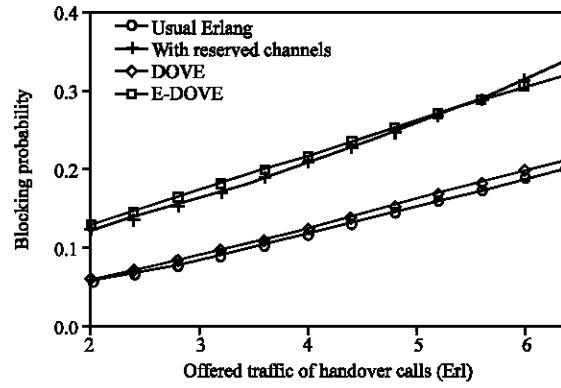
Fig. 7: Variation of the blocking probability of new originating calls against offered traffic of handoff calls (m = 14, r = 3, μ_O = 0.67 min^{-1}, μ_H = 0.83 min^{-1}, a_O = 8.0 Erls, d_1 = 0.2 min, d_2 = 0.2 min)
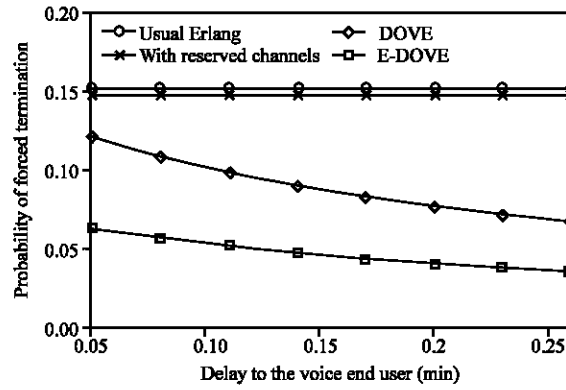

Fig. 8: Variation of the probability of forced termination against the delay to the voice end user of the new originating calls (m = 14, r = 3, μ_O = 0.67 min^{-1}, μ_H = 0.83 min^{-1}, a_O = 8.0 Erls, a_H = 5.0 Erls, d_2 = 0.2 min)
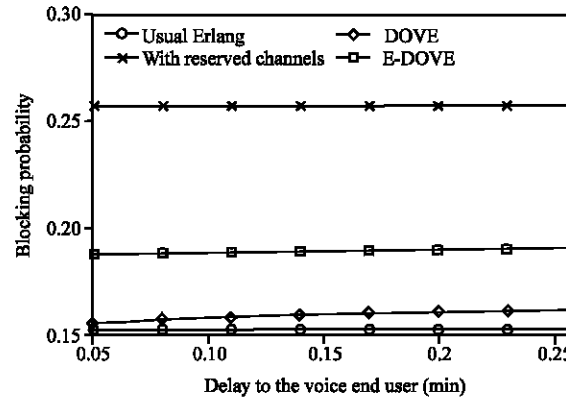

Fig. 9: Variation of the blocking probability of the new originating calls against the delay to the voice end user of the new originating calls (m = 14, r = 3, μ_O = 0.67 min^{-1}, μ_H = 0.83 min^{-1}, a_O = 8.0 Erls, a_H = 5.0 Erls, d_2 = 0.2 min)

Figure 6 shows the variation of the probability of forced termination with respect to the offered traffic of the handoff calls. It is observed from Fig. 6 that the probability of forced termination in the case of DOVE and E-DOVE falls drastically with the offered traffic of handoff calls in comparison with the usual Erlang model and Erlang model with reserved channels.

Figure 7 shows the variation of the blocking probability of the new originating calls with respect to the offered traffic of the handoff calls a_H. It is seen from Fig. 7 that the blocking probability in the case of usual Erlang model and DOVE are almost the same though in the case of DOVE it is slightly higher, whereas the blocking probability in the case of E-DOVE has been increased as in the case of channel reservation scheme.

Figure 8 and 9 show, respectively the variation of the probability of forced termination of handoff requests and the blocking probability of the new originating calls with respect to the delay d_1 to the voice end user of the originating calls. It is seen that a very small delay is needed to be applied, for example, 6 sec to the voice end user of the originating calls to reduce the probability of forced termination by an amount more than 33% in the case of DOVE and by an amount more than 53% in the case of E-DOVE. However, it is noticed that the blocking probability is somewhat slightly increased by 6% in the case of DOVE and by 20% in the case of E-DOVE. It is important to notice from Fig. 9 that the blocking probability is very much lower than the blocking probability for the case of channel reservation scheme.

It is observed from Fig. 4, 6 and 8 for the probability of forced termination that a drastic improvement of performance in the case of DOVE and E-DOVE occurs compared to the case of the channel reservation scheme. This is the new finding of the present study. Thus by introducing a very small delay to the voice end user, the model provides a tremendous performance improvement over the existing channel reservation scheme. It should be mentioned here that the blocking probability of new originating calls is somewhat increased (negligibly) (Fig. 9) when we DOVE and E-DOVE are included for the new originating calls in the system. From the user's point of view, as to handle a handoff request is more important than the blocking of new originating calls, this negligible increase in the blocking probability has no effect on the Erlang capacity for the users of the new originating calls.

CONCLUSIONS

A novel scheme of reducing the probability of forced termination of handoff calls is presented in this study. The effects of delay of voice end user of the new originating calls have been studied using a 2D traffic model both for DOVE, with delay to the last end user and E-DOVE, with delay to the last two end users of the new originating calls. It has been found from the study that the probability of forced termination of handoff calls is reduced drastically compared to the case when no delay to the voice end user is used in the system. The present obtained results are also compared with the Erlang model with reserved channels used exclusively to handle handoff calls. It has been found in both the cases of DOVE and E-DOVE that the model works much better than the existing method of channel reservation scheme for handoff calls.

It is stressed that the concept of DOVE discussed in this study can easily be implemented in mobile cellular networks to improve the GoS without any resource constraint. Although only a 2D case is considered for the presentation of the results in this paper, the concept of DOVE and E-DOVE can easily be extended to multidimensional traffic where both voice and data traffic can be accommodated.

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