Abstract

This paper presents the performance analysis of both non-preemptive and preemptive policies proposed for the access control of VMS. By applying queuing theory, the stochastic behavior of an arbitrary cell in the network is discussed for each access control policy. The system is modeled by a two-dimensional Markov chain. Two dimensions represent the number of voice calls and that of VMS calls in a cell, respectively. The stationary distribution probabilities are obtained through the method of matrix analysis. Based on the stationary distribution, call blocking and dropping probabilities of voice and VMS calls are given for both policies. In addition, the average transmission delay of VMS calls and the average queue length of VMS requests are obtained for the preemptive policy. The numerical analysis shows that both policies can increase the channel utilities while keeping the blocking and dropping probabilities of regular voice service under control. Moreover, the system with the preemptive control policy is able to support about 9 times VMS users over the system with the non-preemptive policy while its performance is more sensitive to the proportion of VMS traffic load added to the system when approaching the maximum capacity of the VMS buffer.

Introduction

There has been a rapid development in wireless mobile networks that are designed to support a wide range of traffic, including both real-time service and non real-time service. Meanwhile, the demand of data service in wireless mobile networks has been increasing drastically. While the next generation mobile system can support a true multimedia service, the existing second-generation networks such as GSM will still accommodate most of the mobile users in a few years. Therefore, Voice Message Service (VMS), a novel voice application has been proposed to satisfy the various requirements of message services in existing mobile systems [1]. In order to keep its tariff inexpensive and acceptable by subscribers, VMS is designed to be a one-way and non-real time service. From such point of view, VMS can be considered as data traffic. Due to the precious bandwidth in wireless networks, some forms of access control policy should be used to keep the system working efficiently. Considering Quality of Service (QoS) requirements of wireless traffic, one of the essential issues characterizing the performance is the handover procedure. From the user’s point of view, the forced termination of an ongoing call caused by the blocking of handover request is more undesirable than the blocking of a new call. On the other hand, the transmission delay of non real-time traffic should be kept in a tolerable range and the channel utilization should be maximized. Generally, a satisfying access control policy has to make a trade-off between those requirements. In [2] and [3], prediction based admission control policies are proposed with regard to the multiclass traffic in cellular networks. In [4], handover voice calls can borrow a specified number of channels assigned to data service if they are idle. To decrease the forced termination probability and improve the channel utilization further, priority is given to voice handover requests over data calls in [5], where voice handover calls can preempt the service of data if there is no idle channel.

In this paper, we proposed two access control policies for existing circuit-switching cellular networks (such as GSM) and multimedia systems (such as GPRS and 3G), respectively. Calls are divided into three different classes, namely handover voice calls, new voice calls (originating in current cells), and VMS calls (new and handover VMS calls). For circuit-switching networks, VMS calls are acting as voice calls except that they are one-way traffic. No buffer is provided for VMS requests, namely VMS calls are a type of real-time traffic. Therefore, a number of channels should be reserved to keep the QoS of voice calls from being affected by bursty VMS traffic. For multimedia systems, VMS calls are treated as data traffic. With a buffer set for VMS requests, priority is given to voice calls, including both handover and new calls. If the buffer is not full, a voice call finding no idle channels will preempt a channel serving a VMS call. In both policies, a fix number of channels are reserved for handover voice calls to improve the handover performance. In the preemptive policy, however, VMS calls can use these channels if they
Access control policies and queuing models are idle due to the low priority of VMS traffic. For both policies, a two-dimensional Markov queuing model is established to give a theoretical performance analysis. In the next section, we describe the access control policies and their queuing models. Analysis of the policies is given in Section III. Numerical results are presented in Section IV. Finally, Section V concludes the paper.

**Access control policies and queuing models**

In this paper, a cellular network consisting of homogeneous cells is considered, where each cell behaves identically from stochastic point of view. Therefore, we consider the stochastic behavior of the whole network by taking into account an arbitrary cell without loss of generality. For simplicity, there is no handover area for both voice and VMS mobile users, but there is a cell boundary between two neighboring cells where the received signal strength of the two neighboring cells is equal. When a mobile user holding a channel approaches a neighboring cell and the received signal strength of the current base station goes below that of the base station in the neighboring cell, a handover request is generated to the neighboring cell.

**A. Non-preemptive priority control policy**

In this policy, VMS calls are considered a real-time traffic. Each cell has \( S \) channels. To keep voice calls from being impacted by bursty VMS traffic, \( n+k \) channels are reserved for voice calls, \( n \) of which are dedicated to voice handover calls. The remaining \( S-n-k \) channels are shared by voice calls and VMS calls, as shown in Fig. 1.

![Fig. 1. System model with non-preemptive priority policy.](image)

For both voice and VMS traffic, calls that are being served (occupying channels) in a cell will release their channels in two conditions: the calls are finished in current cell and the mobile terminals move into a neighboring cell with the calls unfinished. The total serving time required for a call without being forced into termination is defined as the call duration time \( T_{cd} \). We assume that the call duration time of both voice and VMS calls are exponentially distributed, with mean \( \mu_{vd}^{-1} \) and \( \mu_{md}^{-1} \), respectively. For terminals leaving current cell, the serving time of their calls is equal to their dwell time \( T_{dwell} \) in the cell. If the dwell time is assumed to be exponentially distributed, its mean \( \mu_{dwell}^{-1} \) will depend on the speed of the terminals and the size of the cell. Assuming a uniform density of terminals throughout the area and an arbitrary direction of movements with respect to the cell boundary, \( \mu_{dwell}^{-1} \) is given by [6]

\[
\mu_{dwell} = \frac{E[v]L}{\pi A} \tag{1}
\]

where \( E[v] \) is the average speed of terminals in the cell, \( L \) is the length of the perimeter of the cell, \( A \) is the area of the cell. In this paper, the average dwell time of voice and VMS terminals are denoted by \( \mu_{v_d}^{-1} \) and \( \mu_{m_d}^{-1} \), respectively. Therefore, the channel holding time of a call \( T_{ch} \) is equal to the smaller one between \( T_{cd} \) and \( T_{dwell} \). Assuming that \( T_{cd} \) and \( T_{dwell} \) are independent of each other and using the memoryless property of the exponential distribution, \( T_{ch} \) is exponentially distributed. For voice and VMS calls, the means of \( T_{ch} \) are \( \mu_{v}^{-1} \) and \( \mu_{m}^{-1} \), respectively, where \( \mu_{v} = \mu_{vd} + \mu_{vw} \) and \( \mu_{m} = \mu_{md} + \mu_{mw} \).

For both voice and VMS traffic, we assume that the arrival processes of new calls are Poisson, with rates \( \lambda_{vn} \) and \( \lambda_{mn} \), respectively. Since we assume an equilibrium homogeneous mobility pattern, the mean number of incoming users into a cell is equal to that of outgoing ones from the cell. Therefore, the arrival rate of handover requests at a cell is equal to the departure rate of handover calls from the cell. Let \( \lambda_{vh} \) and \( \lambda_{mh} \) denote the arrival rate of handover voice calls and handover VMS calls respectively, which are given by [5]

\[
\lambda_{vh} = E[N_v]\mu_{vw} \tag{2}
\]
\[
\lambda_{mh} = E[N_m]\mu_{mw} \tag{3}
\]

where \( E[N_v] \) and \( E[N_m] \) are the average number of voice and VMS calls being served in the cell respectively. We assumed that the arrival processes of both kinds of handover requests are Poisson processes with above rates. Therefore, the arrival processes of voice and VMS traffic are both Poisson, with rates \( \lambda_{v} \) and \( \lambda_{m} \), where \( \lambda_{v} = \lambda_{vn} + \lambda_{vh} \) and \( \lambda_{m} = \lambda_{mn} + \lambda_{mh} \).
B. Preemptive priority control policy

In this policy, VMS calls are treated as data traffic. Each cell has $S$ channels. A buffer with length $L$ is set in a base station for VMS requests. As in the non-preemptive policy, $n$ channels are reserved for handover voice calls. However, VMS calls can use these channels when they are idle, due to the low priority of VMS calls. New voice calls are allowed to use the remaining $S-n$ channels only, sharing with VMS calls, as shown in Fig. 2. If the buffer is not full, the right to preempt the service of VMS calls is granted to voice calls, including both new and handover calls that cannot find idle channels on arrival. Otherwise, those voice requests will be denied. The requests of interrupted VMS calls return to the queue and wait for available channels. A new VMS request is queued in the buffer when there is no idle channel on arrival. If the buffer is full, the VMS call is blocked. In addition, a VMS request in the buffer can be transferred to the queue of the neighboring cell into which the terminal moves.

The traffic models are set the same as those in the non-preemptive policy, except that (3) should be changed into

$$\lambda_{mh} = (E[N_m] + L_q)\mu_{new}$$  \hspace{1cm} (4)

where $L_q$ is the number of VMS requests queuing in the buffer.

**PERFORMANCE ANALYSIS**

Due to the limited length of the paper, we only introduce the performance analysis in the non-preemptive priority system here.

A. Stationary probabilities

In order to analyze the performance of the network, we first define the state of the system by $(i,j)$, where $i$ is the number of voice calls in the cell and $j$ is the number of VMS calls in the cell. It is apparent from the above assumptions that $(i,j)$ is a two-dimensional Markov chain. The state space $V$ of the cell is given by

$$V = \{(i,j); \ 0 \leq i + j \leq S \cup 0 \leq j \leq S-n-k\}$$  \hspace{1cm} (5)

In Fig. 3, we show its state-transition-rate diagram. Through partition the state space $V$, the two-dimensional Markov process leads to a standard Quasi-Birth-and-Death (QBD) process. We use Matrix-analytic method [7] to solve the stationary probabilities, which are given by

$$P = (p_0, p_1, \cdots, p_S)$$  \hspace{1cm} (6)

$$p_i = \left\{ \begin{array}{ll}
(p(i,0), p(i,1), \cdots, p(i,S-n-k)), & (0 \leq i \leq n+k) \\
(p(i,0), p(i,1), \cdots, p(i,S-i)), & (n+k < i \leq S)
\end{array} \right.$$  \hspace{1cm} (7)

where $p(i,j)$ denotes the stationary probability of the system in the state $(i,j)$. Therefore, the infinitesimal generator $Q$ of the QBD process is given by

$$Q = \begin{bmatrix}
A_0 & B_0 \\
D_1 & A_1 & B_1 \\
& \ddots & \ddots & \ddots \\
& & D_{S-1} & A_{S-1} & B_{S-1} \\
& & & D_S & A_S
\end{bmatrix}$$  \hspace{1cm} (8)

where for $S \leq 2n + k$,

$$B_i = \begin{bmatrix}
\lambda_v & \cdots & 0 \\
\vdots & \ddots & \vdots \\
\lambda_v & \cdots & 0 \\
0 & \cdots & \lambda_v
\end{bmatrix}, (0 \leq i < k)$$  \hspace{1cm} (9)

$$B_i = \begin{bmatrix}
\lambda_v & \cdots & 0 \\
\vdots & \ddots & \vdots \\
\lambda_v & \cdots & 0 \\
0 & \cdots & \lambda_v
\end{bmatrix}, (k \leq i < S-n)$$  \hspace{1cm} (10)

$$B_i = \begin{bmatrix}
\lambda_{vh} & \cdots & 0 \\
\vdots & \ddots & \vdots \\
\lambda_{vh} & \cdots & 0 \\
0 & \cdots & \lambda_{vh}
\end{bmatrix}, (S-n \leq i < n+k)$$  \hspace{1cm} (11)

Fig. 2. System model with preemptive priority policy.
Fig. 3. State-transition-diagram of the non-preemptive system.
where

\[
A_i(j) = -\lambda_i + \mu_i - j\mu_m, \quad (0 \leq j < S - n - i)
\]

\[
A_i(j) = -\lambda_i + \mu_i - j\mu_m, \quad (S - n - i \leq j \leq S - n - k)
\]

\[
a_{i,j} = -\lambda_i + \mu_i - j\mu_m, \quad (0 \leq j < S - n - i)
\]

\[
a_{i,j} = -\lambda_i + \mu_i - j\mu_m, \quad (S - n - i \leq j \leq S - n - k)
\]

\[
A_i = \begin{bmatrix}
a_{i,0} & a_{i,1} & 0 & 0 & \cdots & 0 \\
\mu_m & a_{i,1} & 0 & 0 & \cdots & 0 \\
0 & \mu_m & a_{i,1} & 0 & \cdots & 0 \\
0 & 0 & \mu_m & a_{i,1} & \cdots & 0 \\
\vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\
0 & 0 & 0 & 0 & \cdots & \mu_m
\end{bmatrix}, \quad (S - n - k < i < S - n - k)
\]

where

\[
a_{i,0} = 0
\]

\[
a_{i,1} = \begin{bmatrix}
\mu_m & a_{i,1} & 0 & 0 & \cdots & 0 \\
0 & \mu_m & a_{i,1} & 0 & \cdots & 0 \\
0 & 0 & \mu_m & a_{i,1} & \cdots & 0 \\
\vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\
0 & 0 & 0 & 0 & \cdots & \mu_m
\end{bmatrix}, \quad (S - n - k < i < S - n - k)
\]

For \( S > 2n + k \), the sub matrices in \( Q \) can be derived from the state-transition-rate diagram in a similar way. By using the equilibrium equations \( pQ = 0 \) and the normalizing condition equation

\[
\sum_{i=0}^{S} p_i e = 1
\]

we solve the stationary probabilities of the system \( p \). It is worth noting that to satisfy the equilibrium equations (2) and (3), we use the iteration method [8].

For the preemptive policy, the state-transition-rate diagram is shown in Fig. 4. In this policy, \( i \) is the sum of numbers of VMS calls being served and VMS requests queuing in the buffer in the cell and \( j \) is the number of voice calls in the cell.

**B. Performance measures**

Based on the \( p(i, j) \), various performance characteristics can then be readily calculated. For the non-preemptive policy, the call blocking probability of new voice calls is

\[
P_{n \to m} = \sum_{i=n+1}^{S} \sum_{j=1}^{S-n-1} p(i, j) + \sum_{i=0}^{S} \sum_{j=0}^{S-n-1} p(i, j) + \sum_{i=0}^{S} \sum_{j=0}^{S-n-1} p(i, j), \quad (S > 2n + k)
\]

The blocking probability of handover voice calls is

\[
P_{h \to m} = \sum_{i=0}^{S} p(i, S - i)
\]

The call blocking probability of new and handover VMS calls is
The handover probability of a call being served is given by

\[ P_h = P(T_{cd} > T_{dwell}) \]  

(28)

If \( T_{cd} \) and \( T_{dwell} \) are independent of each other and are exponentially distributed with mean \( \mu_{cd}^{-1} \) and \( \mu_{dwell}^{-1} \) respectively, we can get

\[ P_h = \frac{\mu_{dwell}}{\mu_{cd} + \mu_{dwell}} \]  

(29)

The call dropping probability, that an ongoing call is
forced into termination during the handover, is obtained by
\[ P_d = \frac{P_{bh} P_h}{1 - P_h (1 - P_{bh})} \]  (30)
where \( P_{bh} \) is the blocking probability of handover calls.

For voice and VMS traffic, \( P_{bh} \) is equal to \( P_{bhv} \) and \( P_{bm} \), respectively.

The average number of voice and VMS calls in the system is given by
\[ E[N_v] = \sum_{i=0}^{S} \sum_{j=0}^{S} \text{i}p(i, j) + \sum_{i=n+1}^{S} \sum_{j=0}^{S-i} \text{i}p(i, j) \]  (31)
\[ E[N_m] = \sum_{i=0}^{S-n-k} \sum_{j=0}^{S-i} \text{i}p(i, j) \]  (32)

The channel utilization is defined as
\[ \rho_{ch} = \frac{E[N_v]}{S} \]  (33)

Numerical results and discussions

In this section, some characteristics of the systems with both policies are numerically studied. Moreover, the two groups of results are compared to give a whole view on our control policies.

We assume that the shape of the cell is circular with radius \( R \). The parameters are set as shown in Table I.

Table I. System Parameters

<table>
<thead>
<tr>
<th>Control policy</th>
<th>Non-preemptive</th>
<th>Preemptive</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S )</td>
<td>20</td>
<td>variable</td>
</tr>
<tr>
<td>( n )</td>
<td>0</td>
<td>500</td>
</tr>
<tr>
<td>( L )</td>
<td>120 sec</td>
<td>30 sec</td>
</tr>
<tr>
<td>( \mu^{-1}_\text{id} )</td>
<td>30 sec</td>
<td>15 sec</td>
</tr>
<tr>
<td>( \mu^{-1}_\text{md} )</td>
<td>25 km/h</td>
<td>10^{-8}</td>
</tr>
</tbody>
</table>

Table II. System Parameters

Fig. 5-7 show the performance of the system with the non-preemptive policy. The offered traffic load of new voice call is fixed to be 9 and the numbers of new VMS users in the system are 0%, 50%, 100%, 150% of the number of new voice users respectively. From the results, we see that the channel reservation for voice calls is not necessary in a light traffic load. When system load is heavy, the reservation will deteriorate the QoS of VMS calls much more than improve the QoS of voice calls. However, it keeps the voice service from being impacted by a large number of VMS users. A trade-off should be investigated here taking account of the cost of VMS service. Based on the parameters above, a system with the non-preemptive policy can accommodate as many VMS users as existing voice users (namely 1:1).

Fig. 8-12 show the performance of the system with the preemptive policy. The offered traffic load of new voice call is fixed to be 9. From the results, we see that the preemptive system can accommodate about 9 times VMS users over the non-preemptive one, with the same voice traffic load. However, the system has an evident critical condition. When the number of offered VMS users is below a critical value (such as 980%-990% of voice users), the performance of the system is satisfying and there is almost no impact of VMS traffic on the voice service. Moreover, the channel utilization can approach 100%. When the number of VMS users is above the critical value, the QoS of voice calls will be deteriorated rapidly. From the results of the channel utilization and queuing VMS requests, we obtain that this critical condition is associated with the stuffed state of the VMS buffer. Due to the preemptive priority of VMS users, the system is more sensitive to the change of VMS users when the buffer is nearly full. Since voice requests are denied only when no idle channel is available and no ongoing VMS call can return to the buffer, it is reasonable that a slight increase of VMS users in the critical condition will affect the performance of the system greatly. Therefore, a redundancy in the capacity of VMS users should be made in practical situation.

Conclusion

In this paper, we present the modeling and performance analysis for both non-preemptive and preemptive policies proposed for the access control of VMS. In each policy, the traffic is divided into three classes: new voice calls, handover voice calls, and VMS calls. A fixed number of channels are reserved for handover voice calls and remains are assigned according to the control policies. By applying queuing theory, the stochastic behavior of an arbitrary cell in the network is discussed for each access control policy. The system is modeled by a two-dimensional Markov chain. Two dimensions represent the number of voice calls that of VMS calls in a cell, respectively. The stationary distribution probabilities are obtained through the method of matrix analysis. Based on the stationary distribution, call blocking and dropping probabilities of voice and VMS calls are given for both policies. In addition, the average transmission delay of VMS calls and the average queue length of VMS requests are obtained for the preemptive policy. The numerical analysis shows that both policies can increase the channel utilities while keeping the blocking and dropping probabilities of regular voice service under
control. Moreover, the system with the preemptive control policy is able to support about 9 times VMS users over the system with the non-preemptive policy while its performance is more sensitive to the proportion of VMS traffic load added to the system when approaching the maximum capacity of the VMS buffer.

References
Fig. 11. Average number of queuing VMS requests.

Fig. 12. Average transmission delay of VMS calls.