Proceedings of ICCT2003

Performance Analysis of Voice Message Service in CDMA Cellular Systems

Song Liu, Zhisheng Niu
State Key Lab on Microwave and Digital Communications
Department of Electronic Engineering, Tsinghua University
Beijing, P. R. China
lius@atm.mdc.tsinghua.edu.cn, niuzhs@tsinghua.edu.cn

Dawei Huang
Bell Labs Research China
Lucent Technologies
Beijing, P. R. China
dhuang4@lucent.com

Abstract—**In this paper, we propose and analyze a preemption based admission control policy for an integrated voice and Voice Message Service (VMS) CDMA system. Granted with the priority, the performance of voice calls is not affected by VMS. A multicode scheme is used for VMS traffic to transmit on multiple spreading codes in parallel. The SIR constraints of voice and VMS calls are taken into account to identify the system capacity. By using a two-dimensional Markov model, the performance of the integrated system is evaluated. Under different system traffic loads, QoS-based system capacities are obtained and optimal coding schemes for VMS are specified. Finally, the effect of the VMS buffer size is discussed.**

Keywords–Voice Message Service (VMS); CDMA; Markov model; soft handoff

I. INTRODUCTION

As the rapid growth of the wireless market and the technological innovation, the 3G communication services have begun to be commercially operational and more efforts have focused on the content provisioning. One of the most attractive features of 3G systems is the capability of accommodating heterogeneous traffics with different QoS requirements. Due to the limited radio spectrum, however, a practical 3G system can hardly afford enough capacity considering the increasing hunger for multimedia services. In order to provide alternative solution to users, Voice Message Service (VMS), a novel voice-like application has been proposed [1]. For the sake of low tariff and delay sensitivity, VMS is designed to be a one-way and non-real time service. From such point of view, it can be considered as data traffic.

In order to provide more multimedia applications and accommodate more users in the scarce radio spectrum, there has been extensive study on the call admission control (CAC) for integrated voice and data wireless CDMA networks. In [2], a complete sharing policy is proposed. The admission and rejection of a new user is based on the signal-to-interference ratio (SIR) constraints. Two threshold-based admission control policies are developed in [3] and [4]. All voice and data users are accepted within the predefined thresholds, which are optimized empirically to achieve desired maximum blocking probabilities. In [5], the optimal admission policy is constructed with constraints both on the blocking probabilities and on SIR requirements.

In this paper, we propose and analyze an admission control policy for integrated voice and VMS (data) traffic in a multicode (MC) CDMA system, where a VMS stream can be split into several sub-streams with an equal basic rate and multiple orthogonal codes. Considering SIR constraints, an outage based system capacity is defined. It ensures that the accepted call can enjoy its specified QoS without degrading that of existing calls. The calls are divided into three different classes, namely handoff voice, new voice (originating in current cells), and VMS calls (new and handoff VMS calls). Queue method is used for handoff voice calls because the soft handoff in CDMA systems allows a real-time call to keep communicating with the old base station until the mobile terminal leaves out soft handoff region. With a buffer set for VMS requests, priority is given to voice calls. An arriving voice call finding no idle resources will preempt those serving VMS calls. It ensures that the voice service will not be affected by adding the VMS into the system. The performance of the integrated system is analyzed using a Quasi-Birth-and-Death process model.

The remainder of the paper is organized as follows. In Section II, we define the system model and describe the proposed admission control policy. In Section III, a two-dimensional Markov model is developed to evaluate the system performance. Numerical examples are presented in Section IV. Finally, conclusions are drawn in Section V.

II. SYSTEM MODEL AND CAC POLICY

The system under study is a cellular network consisting of homogeneous cells, where each cell behaves identically from stochastic point of view. Without loss of generality, the stochastic behavior of the whole network is taken into account by modeling an arbitrary cell.

A. System Capacity

Previous work has confirmed that the capacity of CDMA systems is limited by the uplink [6]. In our model, therefore, the SIR constraints in the uplink are used to account for the system capacity.

We consider a MC-CDMA system with total spreading bandwidth W. Voice users have a fixed symbol rate R_v.

Data sequences at a basic rate R_m are used to transmit VMS traffic. VMS user can use multiple data sequences in parallel to achieve a higher transmission rate. Under the assumption of perfect power control, the SIR requirements of voice and VMS at a base station is given by

$$SIR_v = \frac{W}{R_v} \frac{P_v}{\sum_{i=1}^{Nv-1} x_i P_v + \sum_{i=1}^{Nm} P_m + I_0 + \eta} \tag{1}$$

and

$$SIR_m = \frac{W}{R_m} \frac{P_m}{\sum_{i=1}^{Nv} x_i P_v + \sum_{i=1}^{Nm-1} P_m + I_0 + \eta}, \tag{2}$$

where N_v and N_m are the number of voice users and VMS data sequences in the system, respectively. P_v and P_m are the received power of voice and VMS at the base station, respectively. I_0 is the total interference from the other cells and η is the background noise. The random variable x_i denotes the voice activity factor, which is given by

$$\begin{cases} P(x_i = 1) = \alpha_v \\ P(x_i = 0) = 1 - \alpha_v \end{cases}. \tag{3}$$

Since VMS can be viewed as a data application, we assume that VMS users are always active during transmission.

As the assumption in [6], the interference I_0 can be approximated by a Gaussian distribution with mean and variance,

$$E\left[\frac{I_0}{P_v}\right] \approx 0.247\left(N_v + N_d\left(\frac{P_d}{P_v}\right)\right)$$

and

$$Var\left[\frac{I_0}{P_v}\right] \approx 0.078\left(N_v + N_d\left(\frac{P_d}{P_v}\right)^2\right). \tag{4}$$

By simply modifying the results in [7], the outage probability of voice and data users, which is defined as the probability that the SIR requirements cannot be satisfied during the call, is then derived as follows:

$$\Pr_v(N_v, N_m) = \sum_{n=0}^{Nv-1} \binom{N_v - 1}{n} \alpha_v^n (1-\alpha_v)^{(Nv-1-n)} \times Q\left(\frac{\delta_v - n - N_m \frac{P_m}{P_v} - E\left[\frac{I_0}{P_v}\right]}{\sqrt{Var\left[\frac{I_0}{P_v}\right]}}\right), \tag{5}$$

$$\Pr_m(N_v, N_m) = \sum_{n=0}^{Nv} \binom{N_v}{n} \alpha_v^n (1-\alpha_v)^{(Nv-n)} \times Q\left(\frac{\delta_m - n - (N_m - 1)\frac{P_m}{P_v} - E\left[\frac{I_0}{P_v}\right]}{\sqrt{Var\left[\frac{I_0}{P_v}\right]}}\right), \tag{6}$$

where $\delta_v = \frac{W}{R_v}\frac{1}{SIR_v} - \frac{\eta}{P_v}$, $\delta_d = \frac{P_d}{P_v}\frac{W}{R_d}\frac{1}{SIR_d} - \frac{\eta}{P_v}$, and $Q(x) = \int_x^\infty \frac{1}{\sqrt{2\pi}} e^{-y^2/2} dy$.

Since a new user accommodated by the system should not deteriorate the quality of existing users, the system capacity is defined as

$$S = \{(N_v, N_m) \mid \Pr_v(N_v, N_m) \le \beta_v, \Pr_m(N_v, N_m) \le \beta_m\}, \tag{7}$$

where β_v and β_m can be specified according to different QoS requirements of traffic.

B. Traffic Model

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 μ_{vd}^{-1} and μ_{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 μ_{dwell}^{-1} will depend on the speed of the terminals and the size of the cell [8]. In this paper, the average dwell times of voice and VMS terminals are denoted by μ_{vw}^{-1} and μ_{mw}^{-1}, respectively. Assuming that T_{cd} and T_{dwell} are independent of each other and using the memoryless property of the exponential distribution, the channel holding time of a call T_{ch} is exponentially distributed. For voice and VMS calls, the mean of T_{ch} is μ_v^{-1} and μ_m^{-1}, respectively, where $\mu_v = \mu_{vd} + \mu_{vw}$ and $\mu_m = \mu_{md} + \mu_{mw}$.

In CDMA systems, calls can simultaneously communicate with two or more base stations during handoff, which is characterized by the term *soft handoff.* To take into account this feature in our model, we divide a cell into two areas. One is called the *handoff region* and the other is the *normal region*. The dwell times in these two areas are also assumed to be exponentially distributed, with mean μ_{Hdwell}^{-1} and μ_{Ndwell}^{-1}, respectively. Their values can be specified according to μ_{dwell}^{-1} and a_h, where a_h is the ratio of areas between the handoff region and the whole cell [9]. In this paper, the average dwell times of voice in the handoff region and the normal region are denoted by μ_{vhw}^{-1} and μ_{vnw}^{-1}. According to our CAC policy, no handoff region needs to be considered for VMS calls, which will be explained as follows.

For both voice and VMS traffic, we assume that the arrival processes of new calls are Poisson, with rates λ_{vn} and λ_{mn}, respectively. In addition, let λ_{vh} and λ_{mh} denote the arrival rate of handoff voice calls and handoff VMS calls, respectively. Based on an equilibrium homogeneous mobility pattern, the average number of incoming users into a cell is equal to that of outgoing ones from the cell. Therefore, the following two homogeneous equations should be satisfied.

$$\lambda_{vh} = (1-a_h)E[N_v]\mu_{vnw}, \ \lambda_{mh} = E[N_m]\mu_{mw} \qquad (8)$$

where $E[N_v]$ and $E[N_m]$ are the average number of voice and VMS calls being served in the cell, respectively.

C. *Admission Control Policy*

The proposed CAC policy is based on a preemptive mechanism, as shown in Fig. 1. From the application point of view, we do not expect that the voice service be affected by adding VMS into current system. Hence, the right to preempt the resources of VMS calls is granted to voice calls, including both new and handoff calls that find on idle channel on arrival. A buffer with length L ($\geq N_{m\_\max}$, where $N_{m\_\max} = \max\limits_{(n,m)\in S}\{m\}$) is set in the base station. Any VMS call, either new or handoff one, will register its request for channels in the buffer on arrival, when the buffer is not full. Otherwise, the admission will be denied. The request cannot be deleted until the VMS call is finished or leaves the cell. Therefore, no preempted VMS call will be lost. In addition, a VMS request in the buffer can be transferred to a buffer of a neighboring cell into which the terminal moves. Since the information of handoff VMS calls can be kept in the buffer, a soft handoff region for VMS calls is not included in our Model. To keep a low dropping probability of voice calls, n ($< N_{v\_\max}$, where $N_{v\_\max} = \max\limits_{(n,m)\in S}\{n\}$) channels are reserved for handoff voice calls. New voice calls are allowed to use the remaining ($N_{v\_\max} - n$) channels only. However, VMS calls can use the reserved channels when they are idle, due to their low priority.

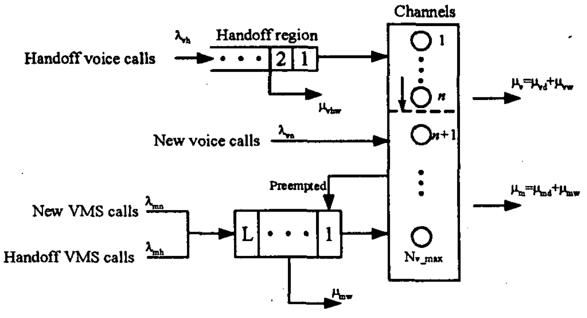

Fig. 1. System model with preemptive priority policy.

Due to the feature of soft handoff, queue method can be used for real-time traffic in CDMA systems. In our model, a virtual queue is considered for all handoff voice calls in the handoff region that find no idle channel. Being served by the old cells, the calls can be kept in the system until they move out of the handoff region. The length of the virtual queue can be infinite, however, it is not larger than $N_{v\_\max}$, generally.

III. PERFORMANCE ANALYSIS

We first define the state of the system by (i,j), where i is the number of voice calls (being served and waiting in the handoff region) in the cell and j is the number of VMS requests registered in the VMS buffer. Upon the above assumptions, (i,j) is a two-dimensional Markov chain. The state space V of the cell is

$$V = \{(i,j) \mid \ 0 \leq i < \infty, \ 0 \leq j \leq L \ \}, \qquad (9)$$

The detailed state transitions are given by

$$\begin{cases} (i,j) \xrightarrow{\lambda_v} (i+1,j), & i < N_{v\_\max} - n \\ (i,j) \xrightarrow{\lambda_{vh}} (i+1,j), & i \geq N_{v\_\max} - n \\ (i,j) \xrightarrow{\lambda_m} (i,j+1), & 0 \leq j < L \\ (i,j) \xrightarrow{i\mu_v} (i-1,j), & 0 < i \leq N_{v\_\max} \\ (i,j) \xrightarrow{N_{v\_\max}\mu_v + (i-N_{v\_\max})\mu_{vh}} (i-1,j), & i > N_{v\_\max} \\ (i,j) \xrightarrow{k\mu_{md} + j\mu_{mw}} (i,j-1), & 0 < i \leq N_{v\_\max}, 0 < j \leq L \\ (i,j) \xrightarrow{j\mu_{mw}} (i,j-1), & i > N_{v\_\max}, 0 < j \leq L \end{cases} \qquad (10)$$

where $\lambda_v = \lambda_{vn} + \lambda_{vh}$, $\lambda_m = \lambda_{mn} + \lambda_{mh}$, $\mu_{vh} = \mu_{vd} + \mu_{vhw}$, and $k = \max\limits_{(i,m)\in S}\{m\}$. For a MC-CDMA system, we assume that the available data sequences are equally shared among VMS calls and each VMS call can use as many data sequence as possible, when $j \leq k$.

Through partition the state space V, the two-dimensional Markov process leads to a standard Quasi-Birth-and-Death (QBD) process. Matrix-analytic

TABLE I. SYSTEM PARAMETERS

Parameters	**Value**
Total spread bandwidth W	3840 KHz
Symbol rate of voice R_v	16 Kbps
The received SNR P_v/η	-1 dB
SIR criterion of voice SIR_v	5 dB
SIR criterion of VMS SIR_d	8 dB
Outage criterion of voice β_v	0.1
Outage criterion of VMS β_m	0.01
Average speed of terminals $E[v]$	25 km/h
Radius of a cell R	1 km
Average call duration of voice μ_{vd}^{-1}	120 s
Average call duration of VMS μ_{md}^{-1}	15 s
Area ratio of handoff region a_h	0.2

method is then used to solve the stationary probabilities $p(i,j)$ [10, 11]. By using the equilibrium equations and the normalizing condition equation

$$\sum_{(i,j)\in S} p(i,j) = 1, \qquad (11)$$

$p(i,j)$ is obtained. It is worth noting that to satisfy the equilibrium equations (8), the iteration method in [9] is used. Based on the $p(i,j)$, various performance measures including blocking and dropping probabilities are readily calculated.

IV. NUMERICAL EXAMPLES

We assume that the shape of the cell is circular. The parameters are set as shown in Table I.

In our system, voice users have priority over VMS users. In this way, the performance of voice is not affected by VMS traffic. Therefore, the blocking and dropping probabilities of the voice service is plotted in Fig. 2, with different number of reserved channels n, where $a_v = \lambda_{vn}/\mu_{vd}$. The solid lines in the figure indicate the blocking probabilities and the dotted lines indicate the dropping probabilities. If a connection-level QoS requirements that $P_{bvn} < 10^{-2}$ and $P_{dv} < 10^{-3}$ are specified, the maximum system capacity is obtained when $n = 2$. This value is used in the following results.

Considering the same QoS requirements (i.e. $P_{bm} < 10^{-2}$ and $P_{dm} < 10^{-3}$) to VMS calls, the maximum VMS traffic load that the system can support is given in Table II and the corresponding transmission delay is given in Table III. The offered voice traffic loads of 10, 30, and 50 Erlangs represent the light, medium, and heavy load of the system, respectively. Three options of the basic rate R_m of data sequences are investigated, corresponding to three VMS coding schemes with different classes of quality. The average call duration of VMS calls is fixed at 15s and the length of VMS buffer $L = 50$. Under all of three system loads, we see that R_m at 8 Kbps yields the best performance. If R_m is used as a measurement of QoS, however, we obtain different optimal coding schemes according to different criteria, as shown in Table IV.

TABLE II
MAXIMUM AFFORDED VMS TRAFFIC LOAD $a_m = \lambda_{mn}/\mu_{md}$ (Erl)

R_m **(Kbps)**	a_v **(Erl)**		
	10	30	50
8	36.0	20.3	3.9
16	17.7	10.4	3.0
32	8.7	5.25	1.95

TABLE III. AVERAGE TRANSMISSION DELAY OF VMS CALLS T_D (sec)

R_m **(Kbps)**	a_v **(Erl)**		
	10	30	50
8	1.76	8.69	57.9
16	9.36	18.1	59.3
32	28.1	40.4	97.9

TABLE IV. OPTIMAL CODING SCHEMES R_m (Kbps)

QoS criteria	a_v **(Erl)**		
	10	30	50
$a_m R_m$	8	32	32
R_m / T_D	8	8	32
$a_m R_m / T_D$	8	8	16

The effect of the VMS buffer size on the performance of the system is displayed in Fig. 3 and 4. When the connection-level QoS requirements are satisfied, we see that the buffer size has little effect on the capacity of VMS traffic, while the transmission delay increases as the increase of the buffer size. In a practical system with above parameters, therefore, there is no need to set a very large buffer size (e.g. $L > 50$).

V. CONCLUSIONS

We have studied an integrated voice and VMS CDMA system with a preemption based admission control policy. With the priority over VMS calls, voice is not affected by occurrence of VMS. A multicode scheme was used for VMS users, where a VMS call can be assigned multiple spreading codes with a fixed rate. Based on the SIR constraints of voice and VMS calls, a two-dimensional Markov model was developed to give the performance analysis. In numerical examples, the QoS-based VMS capacities were obtained under different traffic loads of the system, which satisfy the requirements of outage, blocking, and dropping probabilities. The optimal coding schemes for VMS were specified according to different quality criteria, including the maximum VMS traffic loads, the average transmission delay of VMS calls, and the basic rate of data sequences. In our admission control policy, the VMS buffer size has little effect on the system capacity.

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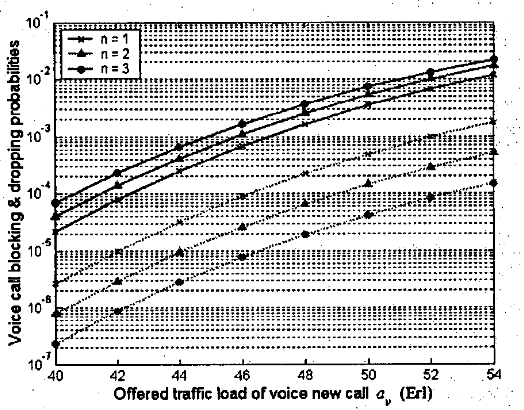

Fig. 2. The performance of voice calls vs. offered traffic load.

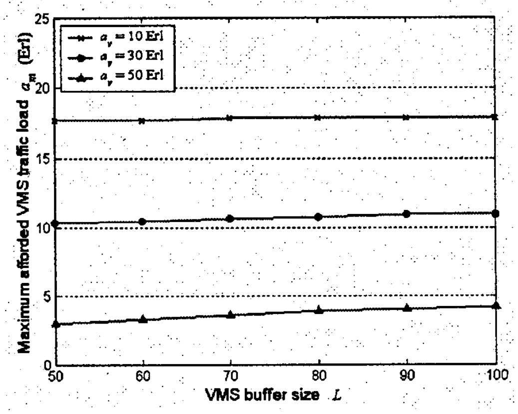

Fig. 3. The QoS-based capacity of VMS traffic vs. VMS buffer size.

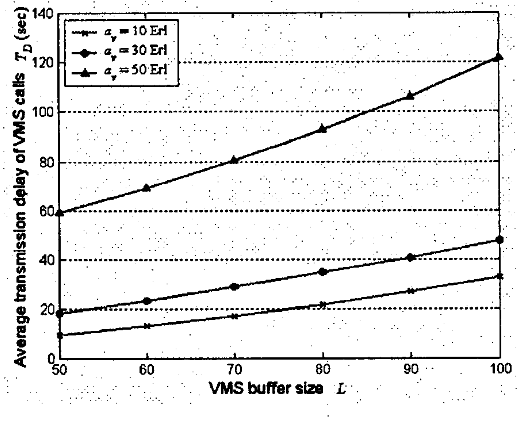

Fig. 4. Average transmission delay vs. VMS buffer size.