Outage Analysis for Multi-connection Multiclass Services in the Uplink of Wideband CDMA Cellular Mobile Networks

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Abstract. In this paper, we address the data link layer quality of service (QoS) issue by investigating the outage probabilities for multi-connection multiclass services in the uplink of a wideband CDMA cellular mobile network. Four Universal Mobile Telecommunications System (UMTS) QoS classes are served within each mobile user simultaneously. Each class has different QoS constraints. Assuming perfect power control, a power allocation scheme is designed to fulfill the desired received powers for all traffic classes. The outage probability is formulated for each mobile user with its traffic classes in terms of bit error rate (BER) and signal-to-interference-plus-noise ratio (SINR). In addition, an admission region, satisfying the outage probability requirements of all mobile users, is computed.

1 Introduction

In UMTS network, wideband CDMA technology enables multimedia services with different QoS specifications. In [1], four different QoS traffic classes, including conversational, streaming, interactive and background classes, are defined for 3G systems. The network is responsible for providing different QoS guarantees to all traffic classes. QoS attribute at the data link layer, such as outage probability, attracts a lot of research interest. In [2], Gilhousen et al. studied the outage probability issue for a single class on/off source in a CDMA network. Recently, Wong et al. extended the analysis of outage probability from a single class sources to on/off multiclass sources, variable bit rate (VBR) multiclass sources and video multiclass sources in [3], [4] and [5], respectively. However, each mobile user can only have a single connection in these papers. This paper differs from the existing published work [3-5] by dealing with QoS provisioning for each mobile user having multiple traffic classes. In this analytical work, each user can have multiple connections to serve more than one traffic class. According to [1,6], voice, video, web-browsing and data services are chosen as typical examples of conversational, streaming, interactive and background classes in the UMTS QoS architecture, respectively. From [6], voice, web-browsing

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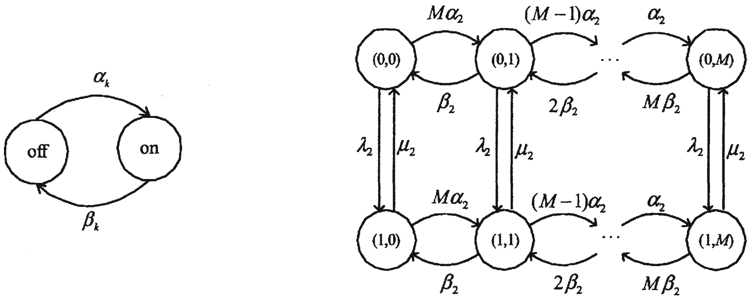
and data services are usually assumed to be on/off sources. Comparatively, video is usually modeled as a two-dimensional discrete-state, continuous-time Markov chain [7]. The main contribution of this paper is to analyze the outage probabilities for multi-connection multiclass services within all mobile users in the uplink of a wide-band CDMA cellular mobile network. In subsequent sections, the paper is organized as follows. The system model, power distribution, outage probability and feasible admission region will be investigated in sections 2, 3, 4 and 5, respectively.



(a) (b)

Fig. 1. Traffic Models with (a) a 2-state Markov chain for an on/off source and (b) a 2-dimensional Markov chain for a video source

2 System Model

As mentioned in section 1, voice, web-browsing and data services are usually modeled as on/off sources, which are shown as Markov chains in Fig. 1(a), $k \in \{1,3,4\}$, respectively. Thus, the activity factor, which is the probability that the process stays in the on state, for voice, web-browsing and data services, is given by

$$p_k = \alpha_k / (\alpha_k + \beta_k), \ k \in \{1,3,4\}. \tag{1}$$

On the other hand, a video service is usually referred to as Sen's model and its Markov chain is illustrated in Fig. 1(b) According to Sen's model [7], each video source can be decomposed into one high-bit-rate (HBR) and M low-bit-rate (LBR) mini-sources, which are identified by HBR and LBR spreading codes, respectively. Thus, the activity factors of LBR and HBR mini-source are given by

$$p_k = \alpha_2 / (\alpha_2 + \beta_2), \ k \in \{2l\}, \tag{2}$$

and

$$p_k = \lambda_2 / (\lambda_2 + \mu_2), \ k \in \{2h\}. \tag{3}$$

The followings are assumptions and system parameters used in this paper.

Assumptions

- All mobile users are uniformly located in each cell.
- An Additive White Guassian Noise (AWGN) channel is assumed.
- Perfect power control is assumed for each service.
- Convolutional coding is used for each traffic class, which is defined in [9].

System Parameter Definitions

- There exist N mobile users in each cell and the number of cells in the system is n.
- $n_{i,k}$ denotes the number of voice, video, web-browsing and data services within the ith ($1 \le i \le N$) mobile user, $k \in \{1,2,3,4\}$, respectively. p_k, G_k, γ_k^* and BER_k^*, denote the activity factors, spreading gains, SINR requirements and BER requirements for voice, video using LBR spreading codes, video using HBR spreading code, web-browsing and data services, $k \in \{1,2l,2h,3,4\}$, respectively.
- M denotes the maximum number of LBR spreading codes used by one video service.
- The convolutional coding rate is r_{coding}. The convolutional coding can result in a lower γ_k^*, $k \in \{1,2l,2h,3,4\}$, and will not appear in the mathematical formulation.
- $S_{i,k}$ and $l_{i,k}$, denote the received power and total number of active spreading codes used by voice, LBR video, HBR video, web-browsing and data services within the ith ($1 \le i \le N$) mobile user, $k \in \{1,2l,2h,3,4\}$, respectively.
- $I_{intercell}$ is the total intercell interference from neighbouring cells and η is the power of the AWGN noise. The area of a cell is A.

3 Power Distribution Algorithm

In the WCDMA network, the system capacity and QoS performance are directly associated with multiple access interference (MAI) which is contributed by interfering mobile users. Therefore, signal-to-interference-plus-noise ratio (SINR) is an important attribute at the data link layer. To attain good performance at the data link layer, it is necessary that the average SINR of each service should be maintained at a required level. Let us denote set V as $\{1,2l,2h,3,4\}$ and denote set V' as $\{1,2h,3,4\}$. In addition, let $n_{i,2l} = Mn_{i,2}$ and $n_{i,2h} = n_{i,2}$, ($1 \le i \le N$). Within the ith mobile user, the average SINR of voice, video using LBR spreading codes, video using HBR spreading code, web-browsing and data services are given by

$$S_{i,k}G_k / \{ \sum_{j=1;j\neq i}^{N} \sum_{k\in V} p_k n_{i,k} S_{i,k} + E[I_{intercell}] + \eta \} = \gamma_k^* , \tag{4}$$

where $k \in \{1,2l,2h,3,4\}$, respectively.

Let $\Gamma_i = \sum_{k\in V} p_k n_{i,k} \gamma_k^* / G_k$ and $\bar{S}_i = \sum_{k\in V} p_k n_{i,k} S_{i,k}$. $\bar{S}_i$ denotes the average received power from the ith mobile user at the base station. Rearrange equation (4) algebraically and the following equation is satisfied.

$$[1+\Gamma_i]\bar{S}_i = \Gamma_i(\sum_{j=1}^{N} \bar{S}_j + E[I_{intercell}] + \eta), \ 1 \le i \le N \tag{5}$$

$E[I_{intercell}]$ denotes the mean of the intercell interference. According to [2], the total intercell interference can be approximated by a Guassian distribution and a path loss exponent of 4 is assumed. Thus, the mean and variance of the intercell interference are given by

$$E[I_{intercell}] \leq [\sum_{i=1}^{N} \sum_{k \in V} p_k n_{i,k} S_{i,k}] \iint f(r_m / r_d) dA / A, \tag{6}$$

and

$$Var[I_{intercell}] \leq \sum_{i=1}^{N} \{ \sum_{k \in V'} S_{i,k}^2 n_{i,k} \iint [p_k g(r_m / r_d) - p_k^2 f^2 (r_m / r_d)] dA / A$$
$$+ S_{i,2l}^2 n_{i,2} \iint [M p_{2l} [1 + (M-1) p_{2l}] g(r_m / r_d) - (M p_{2l})^2 f^2 (r_m / r_d)] dA / A \}, \tag{7}$$

where $f(r_m / r_d)$ and $g(r_m / r_d)$ are given by [2-5]

$$f(r_m / r_d) = (r_m / r_d)^4 e^{(\sigma \ln 10/10)^2} [1 - Q(40 \log(r_m / r_d) / \sqrt{2\sigma^2} - \sqrt{2\sigma^2} \ln 10/10)], \tag{8}$$

and $$g(r_m / r_d) = (r_m / r_d)^8 e^{(\sigma \ln 10/5)^2} [1 - Q(40 \log(r_m / r_d) / \sqrt{2\sigma^2} - \sqrt{2\sigma^2} \ln 10/5)]. \tag{9}$$

In equations (8) and (9), ε_m and ε_d are two independent Guassian random variables with zero mean and σ^2 variance. Let us suppose that r_m (r_d) denote the distance between an intercell service and its own base station (the intracell base station).

Thus, based on equation (6), equation (5) is algebraically rearranged as follows.

$$(1+\Gamma_i)\bar{S}_i / \Gamma_i = [1 + \iint f(r_m / r_d) dA / A] \sum_{i=1}^{N} \bar{S}_i + \eta, \; 1 \leq i \leq N \tag{10}$$

The power vector of the ith mobile user $\boldsymbol{S}_i$ is defined as $[S_{i,1}, S_{i,2l}, S_{i,2h}, S_{i,3}, S_{i,4}]$. Therefore, it is clear that the objective of the power distribution is to derive a positive solution for the vector $\boldsymbol{S}_i$. Let $\varepsilon = 1 - \sum_{i=1}^{N} \Gamma_i [1 + \iint f(r_m / r_d) dA / A] / (1+\Gamma_i)$. According to [8], for equation (10), if and only if $0 \leq \varepsilon \leq 1$ is satisfied, $\bar{S}_i$ has a positive solution. The solution is easily given by

$$\bar{S}_i = \eta \Gamma_i / [\varepsilon (1+\Gamma_i)]. \tag{11}$$

Otherwise, it is impossible to find a positive solution for equation (10). From the definition of $\bar{S}_i$, if a feasible $\bar{S}_i$ is available, the positive power vector $\boldsymbol{S}_i$ exists and the desired received powers within the ith mobile user are formulated for each type of services. Thus, we have

$$S_{i,j} = \eta \gamma_j^* / [\varepsilon (1+\Gamma_i) G_j], \; 1 \leq i \leq N, \; j = \{1, 2l, 2h, 3, 4\}. \tag{12}$$

Accordingly, if the condition $0 \leq \varepsilon \leq 1$ holds, equation (12) satisfies the SINR requirements in equation (4). Obviously, if all positive received powers are increased by the same ratio, the achieved SINR will exceed the corresponding SINR requirements and the data link layer QoS of the system is improved. Therefore, in our calculation of outage probability, the positive power solutions of all services obtained from equation (12) are multiplied by a common factor, θ ($\theta > 1$).

4 Analysis of Outage Probability

In a WCDMA system, the outage probability refers to the probability that the achieved SINR is below the SINR requirement or the achieved BER is above the BER requirement. Within the ith mobile user, the outage probabilities for voice, video using a LBR spreading code, video using a HBR spreading code, web-browsing and data services are expressed as $P_{out,i,k}, 1 \le i \le N$, $k \in \{1, 2l, 2h, 3, 4\}$, respectively.

$$P_{out,i,k} = \sum_{l_{1,1}=0}^{n_{1,1}} \sum_{l_{1,2l}=0}^{Mn_{1,2}} \sum_{l_{1,2h}=0}^{n_{1,2}} \sum_{l_{1,3}=0}^{n_{1,3}} \sum_{l_{1,4}=0}^{n_{1,4}} \cdots \sum_{\substack{l_{j,1}=0 \\ j\neq i}}^{n_{j,1}} \sum_{\substack{l_{j,2l}=0 \\ j\neq i}}^{Mn_{j,2}} \sum_{\substack{l_{j,2h}=0 \\ j\neq i}}^{n_{j,2}} \sum_{\substack{l_{j,3}=0 \\ j\neq i}}^{n_{j,3}} \sum_{\substack{l_{j,4}=0 \\ j\neq i}}^{n_{j,4}} \cdots \sum_{l_{N,1}=0}^{n_{N,1}} \sum_{l_{N,2l}=0}^{Mn_{N,2}} \sum_{l_{N,2h}=0}^{n_{N,2}} \sum_{l_{N,3}=0}^{n_{N,3}} \sum_{l_{N,4}=0}^{n_{N,4}} \tag{13}$$

$$\{Q(\frac{\delta_{i,k}-\mu_i}{\sigma_i})\prod_{\substack{j=1 \\ j\neq i}}^{N}\prod_{k\in V}\binom{n_{j,k}}{l_{j,k}}(p_k)^{l_{j,k}}(1-p_k)^{n_{j,k}-l_{j,k}}\},$$

where $\mu_i = \sum_{j=1;j\neq i}^{N} \sum_{k\in V}(l_{j,k}S_{j,k}) + E[I_{intercell}]$, $Q(x) = \int_x^{\infty} e^{-t^2/2}dt/\sqrt{2\pi}$,

$\delta_{i,k} = S_{i,k}G_k/\gamma_k^* - \eta$, $\sigma_i^2 = Var[I_{intercell}]$, $k \in \{1, 2l, 2h, 3, 4\}$.

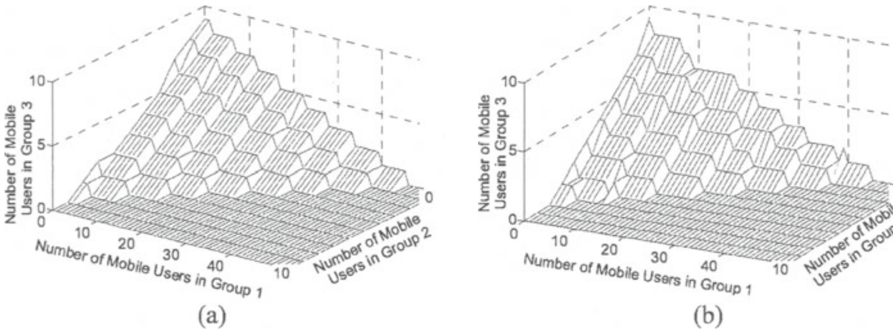


Fig. 2. System Admission Regions for (a) Analytical Admission Region, and (b) Simulation Admission Region

Table 1. Parameters value used

η	-103.2 dBm	M	8	θ	100.0
n	9	r_{coding}	1/2	$\int\int f(r_m/r_d)dA/A$	0.456
p_k, $\{1, 2l, 2h, 3, 4\}$			$\{0.4, 0.3867, 0.5, 0.1, 0.2\}$		
γ_k^*, $\{1, 2l, 2h, 3, 4\}$			{2 dB, 2 dB, 2 dB, 3 dB, 3 dB}		
G_k, $\{1, 2l, 2h, 3, 4\}$			{64, 128, 64, 32, 16}		
BER_k^*, $\{1, 2l, 2h, 3, 4\}$			$\{10^{-2}, 10^{-2}, 10^{-2}, 10^{-3}, 10^{-3}\}$		

5 Numerical Results for Admission Region

In a WCDMA network, the admission control scheme must guarantee that all admitted mobile users are assured of the required QoS levels, which are referred to as the outage probability at the data link layer. In this paper, the admission region is provided by satisfying all services simultaneously. In this section, we present an admission region with three dimensions. Firstly, we assume all mobile users in the network can be divided into three groups. In the first group, each mobile user only serves one voice service. In the second group, each mobile user serves one voice service and one video service. In the third group, each mobile user serves one web-browsing service and one data service. The maximum acceptable outage probability is set at 10^{-2} for voice and video and is set at 10^{-3} for web-browsing and data. The admission region is obtained based on the following parameters in Table 1 and is given by Fig. 2.

In Fig. 2, a 3-dimensional feasible admission region is shown. The region on or below the surface indicates the admission region under the assumed conditions. Any set of mobile users with the given services can be guaranteed for their outage probability requirements at the data link layer. The parameters in Table 1 can be varied to achieve different admission regions. In order to verify the accuracy of our analytical work in sections 3 and 4, an analytical admission region and a simulation admission region are presented in Fig. 2(a) and Fig. 2(b), respectively. Clearly, the regions in Fig. 2(a) and Fig. 2(b) match well with each other. Thus, the proposed outage probability formulation is accurate and can be used to examine the QoS performance and system capacity at the data link layer of a wideband CDMA cellular mobile network.

6 Conclusion

This paper deals with the QoS performance in terms of the outage probability at the data link layer in a cellular WCDMA network. Multiple services are supported in each mobile user. The power allocation scheme is presented under the assumption of perfect power control and outage probabilities are formulated mathematically. As a criterion of call admission, the satisfaction of outage probabilities determines the admission region of the system at the data link layer. In this paper, a typical numerical admission region is shown in a three-dimensional graph in the Numerical Results section. The analytical formulation in this paper can be used to dimension the system capacity of multi-connection multiclass services in a WCDMA network.

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