Adaptive Admission Control with Bandwidth Quantization and Dynamic Reallocation for Mobile WiMAX

Kai-Wei Ke, Ho-Ting Wu, D. Jayasakthi, and Shiao-Ting Huang

Abstract—The paper utilized the idea of bandwidth quantization and proposed a dynamic and adaptive bandwidth reallocation for admission control in mobile WiMAX networks. Based upon four QoS mechanisms (excluding the best effort), adaptively degrade and recover bandwidth to an existing user may improve the system performance but with tradeoff of complexity. Hand over and new calls were taken into account. The paper did analytical evaluations with multidimensional Markov chain; bandwidth utilization and blocking/dropping probability were the performance indices for comparison. The results presented that the utilization was increased and those probabilities were reduced simultaneously.

Index Terms—QoS, adaptive admission control, bandwidth quantization and reallocation, hand over

I. INTRODUCTION

The IEEE802.16 standard has been developed by IEEE802.16 Working Group since 1999. In June2004, a revision of IEEE Std 802.16-2001, called IEEE Std 802.16-2004, was approved [1]. In December 2005, the amendment project IEEE 802.16e was approved. This amendment expands the IEEE 802.16 fixed access system into a combined fixed and mobile system, allowing a single base station (BS) to support both fixed and mobile terminals. This amendment was later included in the newest revision of the standard, called IEEE Std 802.16-2009, in May 2009 [2].

There were many researches discussed the QoS architecture (since it is not specified clearly by IEEE 802.16 series specifications) and resource allocation for WiMAX networks, some of the papers designed admission control mechanism by considering delay constrain [3]-[10]. In view of related studies, those methods proposed by references [8]-[10] were similar to our work. They applied the concept of bandwidth degradation in the design of admission control and modeled the strategy by continuous-time Markov chain to analyze the performance. However, there were two common drawbacks presented in the papers: (1) Once the bandwidth degradation was activated to admit a new connection in, it was imposed on all existing connections in progress, this may yield excess bandwidth and cause bandwidth waste as well as performance degradation due to unnecessary reduction of the granted bandwidth of some connections, (2) The excess bandwidth taken back from existing connections is no longer reused while a new connection is granted, this causes the bandwidth waste even worse.

The idea of bandwidth quantization was first proposed by C. T. Lea et al [11]-[12] for broadband networks. In those work, it was shown that supporting continuous data rate (any value as requested) does not guarantee a good performance from the viewpoint of resource utilization/throughput and blocking probability, and proved that supporting only certain fixed data rates (called quantized bandwidth) would be appropriate in terms of system performance, but reduce the complexity drastically.

This paper is based upon the quantization concept and design a adaptive Call Admission Control (CAC) strategy that dynamically reallocate bandwidth by taking back from existing connections (i.e. bandwidth degrade) and reassigned excess bandwidth to incoming connections (bandwidth upgrade), and is abbreviated as BDR_CAC. In addition to resolving the issues in [3]-[5], effectively increasing radio resource utilization and decreasing blocking and dropping probabilities for IEEE 802.16e/Mobile WiMAX networks with QoS support, are the major concerns of the study.

The rest of the paper is organized as follows. Section II describes the proposed admission control, Section III builds the analytical model for analysis, Section IV illustrates the numerical results, and finally Section V draws the conclusion.

II. ADAPTIVE ADMISSION CONTROL WITH BANDWIDTH QUANTIZATION AND DYNAMIC REALLOCATION

Consider a Mobile WiMAX system supporting finite amount of fixed data rates and it is deployed similar to the public cellular phone system, as shown in Fig. 1, where each base station handles both new and hand over connection requests and a hand over request is given higher priority.

Without loss of generality, four types of eight different bandwidth requirements, UGS, ertPS, rtPS1, rtPS2, rtPS3, nrtPS1, nrtPS2, nrtPS3, are discussed in this paper. The best effort (BE) is not specifically considered in admission control due to its QoS-free property. The precedence for four service types is UGS > ertPS > rtPS > nrtPS, and thus the following priority for handling various connection requests can be established: H-UGS > H-ertPS > N-UGS > N-ertPS > H-rtPS > N-rtPS > H-nrtPS > N-nrtPS in which N stands for a new and H for a hand over request, respectively. Also, assume

three bandwidth requirements for rtPS services are rtPS1 > rtPS2 > rtPS3 and for nrtPS are nrtPS1 > nrtPS2 > nrtPS3. That is, rtPS1 ≤ bandwidth request for rtPS service ≤ rtPS3, and nrtPS1 ≤ bandwidth request for nrtPS ≤ nrtPS3.
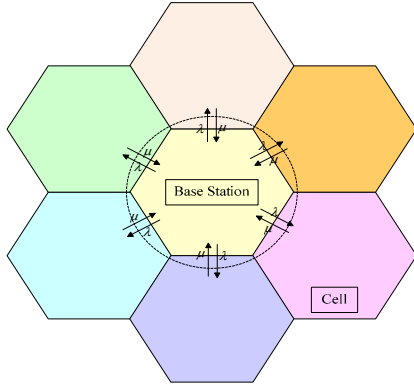

Fig. 1. Deployment of a WiMAX network.

Fig. 2 shows the architecture of BDR_CAC. As the flow shows, different service type of connection will be processed by its corresponding CAC mechanism (e.g. UGS connection block, Handoff rtPS connection block, etc.). Furthermore, as a connection leaves the BS, either terminated normally or hand over to an adjacent BS, the Recovery Algorithm will be activated for bandwidth upgrade by adding up bandwidth to some existing connections as they were taken by the BS (borrowed) to accommodate a new request in the first place.
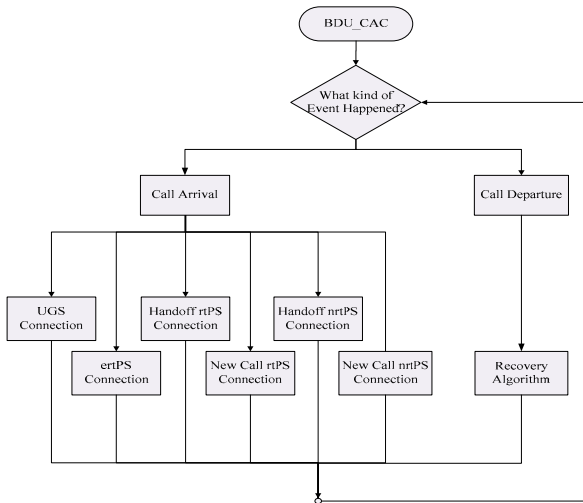

Fig. 2. The architecture of BDU_CAC.

Let the 8-tuple vector *(i, j, k, l, m, n, p, q)* be the system state indicating that there are *i*'s UGS, *j*'s ertPS1, *k*'s rtPS1, *l*'s rtPS2, *m*'s rtPS3, *n*'s nrtPS1, *p*'s nrtPS2, and *q*'s nrtPS3 connections in progress (i.e. handled by a BS currently), and b_i, 1≤*i*≤8 be the corresponding bandwidth requirements for above eight connection types. Because of limitations of space, we illustrate detailed flow of CAC blocks in Fig. 2 for an ertPS connection request (Fig. 3) and bandwidth recovery (update) algorithm when a connection leaves the system (Fig. 4). The symbols are interpreted below: R (or B_{rem}) = residual capacity, D_r = the number of rtPS connections that can be chosen for upgrading their bandwidth $=\lfloor bi + R/\Delta_r \rfloor$, while D_n = the number of nrtPS connections that can be chosen for

upgrading their bandwidth $= \lfloor B + R - (B_{used} + B_{rem}) \cdot \Delta_r/\Delta_n \rfloor^+$.

The rule for bandwidth recovery is: upgrading rtPS connections first and then nrtPS if there is residue bandwidth available; for both rtPS and nrtPS connections to be upgraded, the priority gives to rtPS3 > rtPS2 > nrtPS3 > nrtPS2. The details of upgrading procedure is shown in Fig. 4.
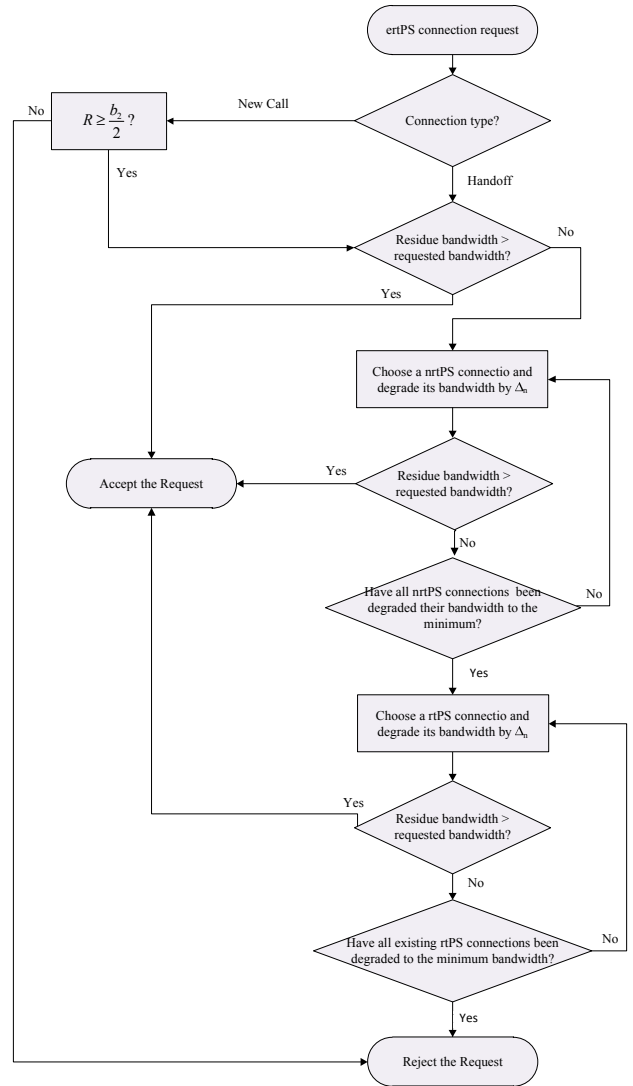

Fig. 3. CAC for ertPS connection requests.

III. SYSTEM MODEL AND PERFORMANCE ANALYSIS

A connection request is similar to a call request in PSTN or cellular system, and the Poisson arrival process is assumed in analysis. Let [λ_{nu}, λ_{ne}, λ_{nr}, and λ_{nn}] and [λ_{hu}, λ_{he}, λ_{hr}, λ_{hn}] be the arrival rates for new and hand over UGS, ertPS, rtPS, and nrtPS connection requests, respectively. Thus, to a base station, the total arrival rate will be $\lambda_T = \lambda_{hu} + \lambda_{he} + \lambda_{hr} + \lambda_{hn} + \lambda_{nu} + \lambda_{ne} + \lambda_{nr} + \lambda_{nn}$. The dwelling time inside the cell of a BS and holding time of different service types are independently and exponential distributed. Their mean values are represented by $1/\mu_u$, $1/\mu_e$, $1/\mu_{r1}$, $1/\mu_{r2}$, $1/\mu_{r3}$, $1/\mu_{n1}$, $1/\mu_{n2}$, and $1/\mu_{n3}$. The granted bandwidth will be occupied also in exponential distribution [10] with mean value of $\mu_T = 1/(\mu_u + \mu_e + \mu_{r1} + \mu_{r2} + \mu_{r3} + \mu_{n1} + \mu_{n2} + \mu_{n3})$, where the subscripts [u, e, r, n] represents [UGS, ertPS, rtPS, nrtPS (with different rates)] connections, for both new and hand
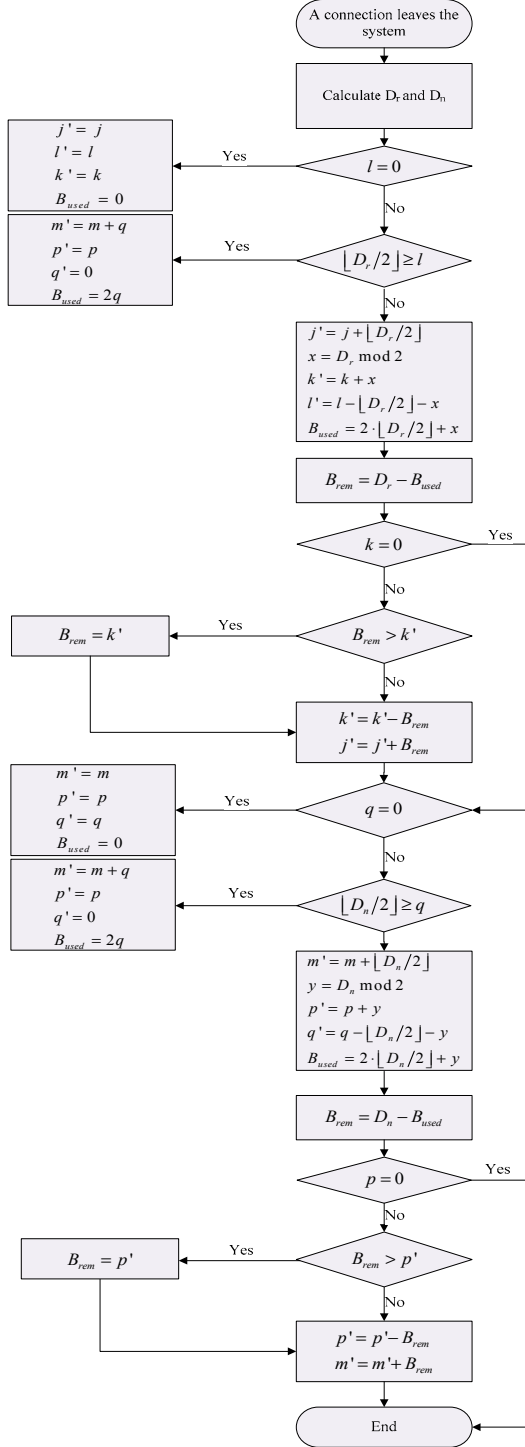
over ones, respectively.

Fig. 4. Bandwidth recovery algorithm (applying bandwidth upgrade).

The system operation can be modeled by an eight-dimension Markov chain with the same state vector (i, j, k, l, m, n, p, q) as defined in section 2. The bandwidth requirement can be described by an 8-tuple vector of $(b_1, b_2, b_3, b_4, b_5, b_6, b_7, b_8)$. In addition, define $\Delta_r = b_3 - b_4 = b_4 - b_5$ as the bandwidth deviation for three rtPS connection types, it represents the amount of bandwidth can be degraded (released) or upgraded (recovered) by one step; Similarly, $\Delta_n = b_6 - b_7 = b_7 - b_8$ will be those for three nrtPS connection types, and thus the bandwidth requirement for connections $(b_1, b_2, b_3, b_4, b_5, b_6, b_7, b_8)$ equals to $(b_1, b_2, 3\Delta_r, 2\Delta_r, \Delta_r, 3\Delta_n, 2\Delta_n, \Delta_n)$.

All allowable states form the state space S:

$$S = \left\{ (i, j, k, l, m, n, p, q) \middle| i \cdot b_1 + j \cdot b_2 + k \cdot b_3 + l \cdot b_4 \right. \\ \left. + m \cdot b_5 + n \cdot b_6 + p \cdot b_7 + q \cdot b_8 \le C \right\} \quad (1)$$

where C is the total amount of resource. Define $\pi_{(i,j,k,l,m,n,p,q)}$ as the steady-state probability for state (i,j,k,l,m,n,p,q) and $\pi_{(i,j,k,l,m,n,p,q)} = 0$, if $(i, j, k, l, m, n, p, q) \notin S$. For all legal states $(i, j, k, l, m, n, p, q) \in S$,

$$\sum_{(i,j,k,l,m,n,p,q) \in S} \pi_{(i,j,k,l,m,n,p,q)} = 1 \quad (2)$$

For a general system state (i,j,k,l,m,n,p,q), all possible transitions can be described in Fig. 5, with indicating functions defined by:

$$\delta_u = \begin{cases} 1, & if \left\{ R + \left[(2k+l) \cdot \Delta_r + (2n+p) \cdot \Delta_n \right] \right\} \ge b_1, and\, (i+1,j,k',l',m',n',p',q') \in S \\ 0, & otherwise \end{cases}$$

$$\delta_u^+ = \begin{cases} 1, & if\, (i,j,k',l',m',n'p',q') = (i,j,k,l,m,n,p,q), and\, (i+1,j,k',l',m',n',p',q') \in S \\ 0, & otherwise \end{cases}$$

$$\delta_u^- = \begin{cases} 1, & if\, (i,j,k',l',m',n'p',q') = (i,j,k,l,m,n,p,q), and\, (i-1,j,k',l',m',n',p',q') \in S \\ 0, & otherwise \end{cases}$$

$$\delta_e = \begin{cases} 1, & if \left\{ R + \left[(2k+l) \cdot \Delta_r + (2n+p) \cdot \Delta_n \right] \right\} \ge b_2, and\, (i,j+1,k',l',m',n',p',q') \in S \\ 0, & otherwise \end{cases}$$

$$\delta_e^+ = \begin{cases} 1, & if\, (i,j,k',l',m',n'p',q') = (i,j,k,l,m,n,p,q), and\, (i,j+1,k',l',m',n',p',q') \in S \\ 0, & otherwise \end{cases}$$

$$\delta_e^- = \begin{cases} 1, & if\, (i,j,k',l',m',n'p',q') = (i,j,k,l,m,n,p,q), and\, (i,j-1,k',l',m',n',p',q') \in S \\ 0, & otherwise \end{cases}$$

$$\delta_{hr} = \begin{cases} 1, & if \left\{ R + \left[(2j+k) \cdot \Delta_r + (2m+p) \cdot \Delta_n \right] \right\} \ge b_3, and\, (i,j,k',l',m',n'p',q') \in S \\ 0, & otherwise \end{cases}$$

$$\delta = \begin{cases} 1, & if\, (i,j,k',l',m',n',p',q') = (i,j,k,l,m,n,p,q), and\, (i,j,k',l',m',n',p',q') \in S \\ 0, & otherwise \end{cases}$$

$$\delta_{nr} = \begin{cases} 1, & if\, R + \left[(2n+p) \cdot \Delta_n \right] \ge b_5, and\, (i,j,k',l',m',n',p',q') \in S \\ 0, & otherwise \end{cases}$$

$$\delta_{hn} = \begin{cases} 1, & if \left[R + (2n+p) \cdot \Delta_n \right] \ge b_8, and\, (i,j,k,l,m,n'p',q') \in S \\ 0, & otherwise \end{cases}$$

$$\delta_n = \begin{cases} 1, & if\, (i,j,k,l,m,n',p',q') = (i,j,k,l,m,n,p,q), and\, (i,j,k,l,m,n',p',q') \in S \\ 0, & otherwise \end{cases}$$

$$\delta_{nn1} = \begin{cases} 1, & if\, R \ge b_6, and\, (i,j,k,l,m,n+1,p,q) \in S \\ 0, & otherwise \end{cases}$$

$$\delta_{nn2} = \begin{cases} 1, & if\, R \ge b_7, and\, (i,j,k,l,m,n,p+1,q) \in S \\ 0, & otherwise \end{cases}$$

$$\delta_{nn3} = \begin{cases} 1, & if\, R \ge b_8, and\, (i,j,k,l,m,n,p,q+1) \in S \\ 0, & otherwise \end{cases} \quad (3)$$

Based upon the state diagram, the balance equations can be derived in (4), with

$$\lambda_{tu} = \begin{cases} \lambda_{hu} + \lambda_{nu}, & if\, R \ge \frac{b_1}{2} \\ \lambda_{nu}, & otherwise \end{cases} \quad and \quad \lambda_{te} = \begin{cases} \lambda_{he} + \lambda_{ne}, & if\, R \ge \frac{b_2}{2} \\ \lambda_{ne}, & otherwise \end{cases}$$

And the steady-state probabilities can then be calculated.

Finally, the performance indices, the blocking probability for new connection requests P_{CBP}, the dropping probability for hand over connection requests, and utilization of radio resource can then be calculated as follows.
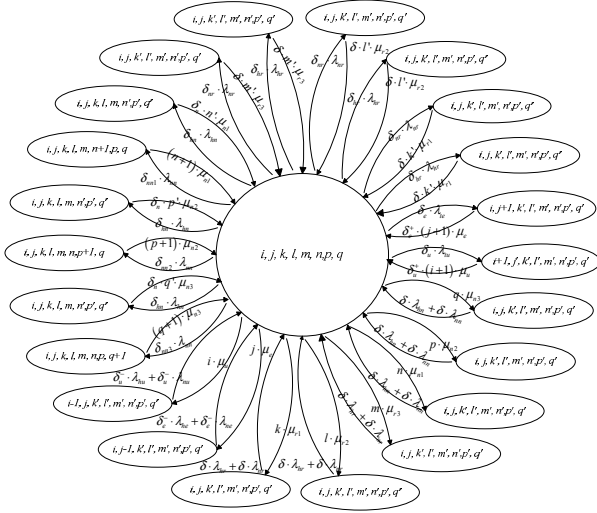
Fig. 5. State transitions for a state *(i,j,k,l,m,n,p,q)* in the BDU_CAC.

$$\pi_{(i,j,k,l,m,p,q)} \cdot \{\delta_u \cdot \lambda_u + \delta_e \cdot \lambda_{te} + \delta_{hr} \cdot \lambda_{hr} + \delta_{nr} \cdot \lambda_{nr} + \delta_{hr} \cdot \lambda_{hr} + \delta_{nr} \cdot \lambda_{nr} + \delta_{hr} \cdot \lambda_{hr} + \delta_{nr} \cdot \lambda_{nr}$$

$$+\delta_{hn} \cdot \lambda_{hn} ++\delta_{hn} \cdot \lambda_{hn} + \delta_{hn} \cdot \lambda_{hn} + \lambda_{nn} \cdot [\delta_{nn1} + \delta_{nn2} + \delta_{m3}] + i \cdot \mu_u + j \cdot \mu_{r1} + k \cdot \mu_{r2}$$

$$+l \cdot \mu_{r3} + m \cdot \mu_{n1} + p \cdot \mu_{n2} + q \cdot \mu_{n3}]\}$$

$$= \delta_u^+ \cdot (i+1) \cdot \mu_u \cdot \pi_{(i+1,j,k',l',m',n',p',q')} + \delta_e^+ \cdot (j+1) \cdot \mu_e \cdot \pi_{(i,j+1,k',l',m',n',p',q')}$$

$$+\mu_{r1} \cdot \left[\delta \cdot k' \cdot \pi_{(i,j,k',l',m',n',p',q')} + \delta \cdot k' \cdot \pi_{(i,j,k',l',m',n',p',q')}\right] + \mu_{r2} \cdot \left[\delta \cdot l' \cdot \pi_{(i,j,k',l',m',n',p',q')}\right.$$

$$\left.+\delta \cdot l' \cdot \pi_{(i,j,k',l',m',n',p',q')}\right] + \mu_{r3} \cdot \left[\delta \cdot m' \cdot \pi_{(i,j,k',l',m',n',p',q')} + \delta \cdot m' \cdot \pi_{(i,j,k',l',m',n',p',q')}\right]$$

$$+\mu_{n1} \cdot \left[\delta_n \cdot n' \cdot \pi_{(i,j,k,l,m,n,p',q')} + (n+1) \cdot \pi_{(i,j,k,l,m,n+1,p,q)}\right] + \mu_{n2} \cdot \left[\delta_n \cdot p' \cdot \pi_{(i,j,k,l,m,n',p',q')}\right.$$

$$\left.+(p+1) \cdot \pi_{(i,j,k,l,m,n,p+1,q)}\right] + \mu_{n3} \cdot \left[\delta_n \cdot q' \cdot \pi_{(i,j,k,l,m,n',p',q')} + (q+1) \cdot \pi_{(i,j,k,l,m,n,p,q+1)}\right]$$

$$+\left(\delta_u^- \cdot \lambda_{hu} + \delta_u^- \cdot \lambda_{nu}\right) \cdot \pi_{(i-1,j,k',l',m',n',p',q')} + \left(\delta_e^- \cdot \lambda_{he} + \delta_e^- \cdot \lambda_{ne}\right) \cdot \pi_{(i,j-1,k',l',m',n',p',q')}$$

$$+\left(\delta \cdot \lambda_{hr} + \delta \cdot \lambda_{nr}\right) \cdot \pi_{(i,j,k',l',m',n',p',q')} + \left(\delta \cdot \lambda_{hr} + \delta \cdot \lambda_{nr}\right) \cdot \pi_{(i,j,k',l',m',n',p',q')}$$

$$+\left(\delta \cdot \lambda_{hr} + \delta \cdot \lambda_{nr}\right) \cdot \pi_{(i,j,k',l',m',n',p',q')} + \left(\delta \cdot \lambda_{hn} + \delta \cdot \lambda_{nn}\right) \cdot \pi_{(i,j,k',l',m',n',p',q')}$$

$$+\left(\delta \cdot \lambda_{hn} + \delta \cdot \lambda_{nn}\right) \cdot \pi_{(i,j,k',l',m',n',p',q')} + \left(\delta \cdot \lambda_{hn} + \delta \cdot \lambda_{nn}\right) \cdot \pi_{(i,j,k',l',m',n',p',q')}, \tag{4}$$

A. Blocking Probabilities for New Connections:

$$BP_{UGS} = \sum_{s \in S_{BP\_UGS}} \pi_s, \text{ where } S_{BP\_UGS} = \left\{ s = (i,j,k,l,m,n,p,q) \right| \tag{5}$$

$$\left(R < \frac{b_1}{2}\right) \vee \left[(2k+l)\Delta_r + (2n+p)\Delta_n < (b_1 - R)\right]\right\}.$$

$$BP_{ertPS} = \sum_{s \in S_{BP\_ertPS}} \pi_s, \text{ where } S_{BP\_ertPS} = \left\{ s = (i,j,k,l,m,n,p,q) \right| \tag{6}$$

$$\left(R < \frac{b_2}{2}\right) \vee \left[(2k+l)\Delta_r + (2n+p)\Delta_n < (b_2 - R)\right]\right\}.$$

$$BP_{rtPS} = \sum_{s \in S_{BP\_rtPS}} \pi_s, \text{ where } S_{BP\_rtPS} = \left\{ s = (i,j,k,l,m,n,p,q) \right| \tag{7}$$

$$\left[(2n+p)\Delta_n < (b_5 - R)\right]\right\}.$$

$$BP_{nrtPS} = \sum_{s \in S_{BP\_nrtPS}} \pi_s, \text{ where } S_{BP\_nrtPS} = \left\{ s = (i,j,k,l,m,n,p,q) \right| \tag{8}$$

$$\left(R < b_6\right) \vee \left(R < b_7\right) \vee \left(R < b_8\right)\right\}.$$

B. Dropping Probabilities for New Connections:

$$DP_{UGS} = \sum_{s \in S_{DP\_UGS}} \pi_s, \text{ where } S_{DP\_UGS} = \left\{ s = (i,j,k,l,m,n,p,q) \right| \tag{9}$$

$$\left[(2k+l)\Delta_r + (2n+p)\Delta_n < (b_1 - R)\right]\right\}.$$

$$DP_{ertPS} = \sum_{s \in S_{DP\_ertPS}} \pi_s, \text{ where } S_{DP\_ertPS} = \left\{ s = (i,j,k,l,m,n,p,q) \right| \tag{10}$$

$$\left[(2k+l)\Delta_r + (2n+p)\Delta_n < (b_2 - R)\right]\right\}.$$

$$DP_{rtPS} = \sum_{s \in S_{DP\_rtPS}} \pi_s, \text{ where } S_{DP\_rtPS} = \left\{ s = (i,j,k,l,m,n,p,q) \right| \tag{11}$$

$$\left[(2k+l)\Delta_r + (2n+p)\Delta_n < (b_5 - R)\right]\right\}.$$

$$DP_{nrtPS} = \sum_{s \in S_{DP\_nrtPS}} \pi_s, \text{ where } S_{DP\_nrtPS} = \left\{ s = (i,j,k,l,m,n,p,q) \right| \tag{12}$$

$$\left(2n+p\right)\Delta_n < (b_8 - R)\right\}.$$

C. Resource Utilization:

$$U = \frac{\sum_{s \in S} \pi_s \cdot C_s}{C}, s \in S, C_s = i \cdot b_1 + j \cdot b_2 + \cdots + q \cdot b_8. \tag{13}$$

IV. NUMERICAL RESULTS AND DISCUSSION

In numerical evaluations, we assume that a frame duration = 5ms with data rate of 350Kb/s, and the total data rate for an uplink (assuming one-half of the frame) channel = 2.5ms/frame×(350Kb/s)/2×200frame/s = 35Mbps. Data rates for various connections of different service types, where the best effort (BE) is not considered. Also, assume that arrival rates $\lambda_{hu} = \lambda_{he} = \lambda_{hr} = \lambda_{hn} = \lambda_{nu} = \lambda_{ne} = \lambda_{nr} = \lambda_{nn}$ and mean service times $\mu_u = \mu_e = \mu_{r1} = \mu_{r2} = \mu_{r3} = \mu_{n1} = \mu_{n2} = \mu_{n3} = 0.2$.

TABLE I. QOS PARAMETERS USED IN NUMERICAL ANALYSIS.

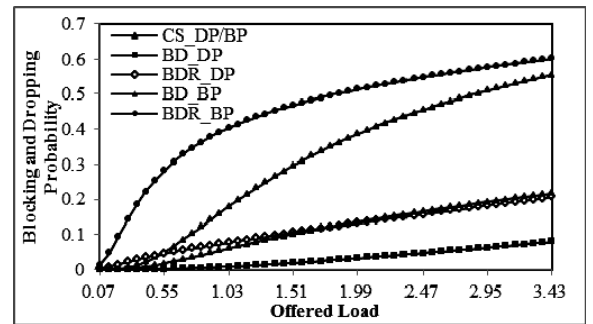| Service	Rate(Kbits)	Service	Rate(K bits)
UGS	32	rtPS3	32
ertPS	64	nrtPS1	48
rtPS1	96	nrtPS2	32
rtPS2	64	nrtPS3	16

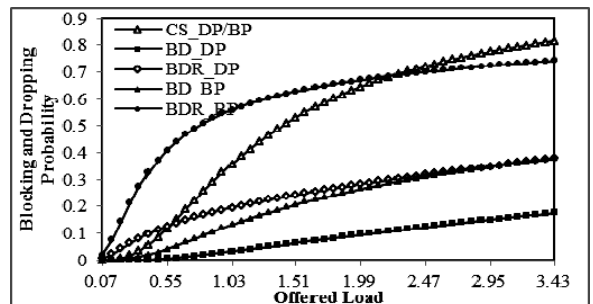Fig. 6. Blocking and dropping probabilities for UGS connections.

Fig. 7. Blocking and dropping probabilities for ertPS connections.
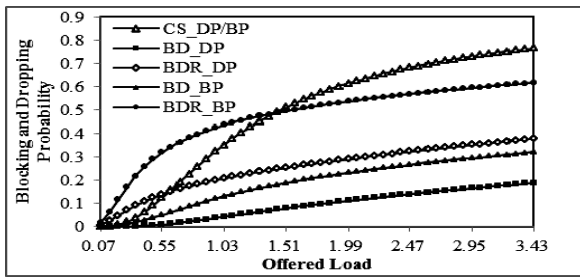
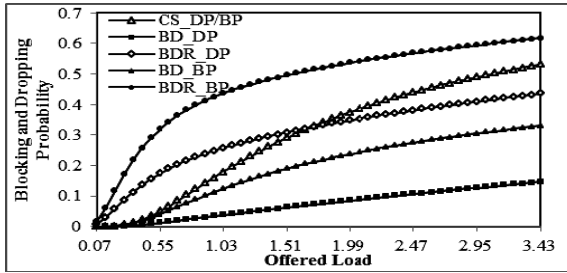Fig. 8. Blocking and dropping probabilities for rtPS connections.

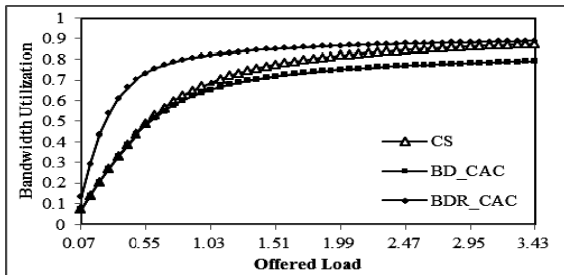Fig. 9. Blocking and dropping probabilities for nrtPS connections.

Fig. 10. Comparison of bandwidth utilization.

The performance of BDR_CAC are compared to complete-sharing control (CS) and Bandwidth Degrade only (BD_CAC), under various offered load conditions. Fig. 6 to Fig. 9 are the blocking and dropping probabilities for UGS, ertPS, rtPS, and nrtPS connections. The results shows that the probability of dropping for hand over connections is always lower than that of blocking for new connections for all service types. This is what we desired in the design. Also, applying bandwidth degrade plus upgrade (the legend marked with BDR) does not cause ping-pong effect that makes the values changing drastically. Fig. 10 presents the utilization, the proposed BDR_CAC raises it to 82%, comparing to 68% for CS_CAC and 65% for BD_CAC.

V. CONCLUSIONS

In this study, we utilized the concept of bandwidth quantization to design a BDR_CAC and reach the feasibility of analytical evaluation. The work can be further extended by taking delay constrain into account; that is, to design a CAC mechanism with both bandwidth and delay guarantee.

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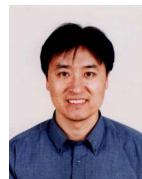
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