QoS Satisfaction Based Charging and Resource Management Policy for Next Generation Wireless Networks

W. Ibrahim, J. W. Chinneck, S. Periyalwar and H. El-Sayed, *Member, IEEE*

Abstract—**Wireless networks are currently evolving to provide access to interactive multimedia and video conferencing in addition to traditional services such as voice, email and web access. These new applications demand large amounts of network bandwidth to achieve the highest levels of quality. However, some customers may content to pay less in exchange for a lower Quality of Service (QoS). Accordingly, charging and resource management policies that control the QoS provided to existing calls must evolve to explicitly consider the trade-off among the service pricing, offered QoS, and customer's QoS perception This paper proposes a novel charging and resource management policy that allocates resources to customers based on their QoS satisfaction levels, thereby charging fairly while improving resource allocation efficiency.**

***Index Terms*— Wireless, Multimedia, Charging, QoS, Resource Allocation, Call Admission Control**

I. Introduction

A proper charging and resource management (RM) policy is crucial to the successful deployment of telecommunication networks. Such policies allocate network resources and recover costs fairly and competitively from the diverse population of customers. By tuning the charging and RM policy, a service provider can attract new customers, compete with other service providers, and introduce new services and promotions. Hence, it is widely believed that an appropriate charging policy should provide incentives for customers to behave in ways that improve overall utilization and performance of the network [1].

Due to the limited resources of wireless networks, a new class of adaptive QoS multimedia applications has been introduced for next generation wireless networks to replace traditional multimedia applications that require a guaranteed hard QoS from the network [3], [9]. If the proper incentive is applied, adaptive QoS applications can reduce the network Call Blocking Ratio (CBR) and the Call Dropping Ratio (CDR) significantly compared to traditional QoS applications. Adaptive QoS applications can cut down the amount of resources they consume in order to free more resources to accommodate new/handoff calls. Similarly, a QoS negotiation policy can adjust the amount of resources allocated to incoming calls according to the resources utilization level.

Unlike tradition hard QoS application where all customers receive the same QoS level, the QoS level received by the users of adaptive QoS application will vary according to the amount of available resources. Moreover, different customers are believed to have different QoS perception levels for the same multimedia application. For instance, a black and white video session might be satisfactory for one customer and unacceptable for another. The value of information is also variable across and within the applications. An audio file download might be more valuable than an email while a business email might not be as valuable as a personal message. *We believe that only customers can determine the value of their transmitted data.*

Several flavors of adaptive RM policies have been proposed in the literature [4], [5], [12], [16]. They all share the main idea of adjusting the amount of resources allocated to existing calls within a minimum and maximum threshold according to the traffic load. In addition, the proposed policies treat all customers similarly despite the expected variance in their QoS perception. They assume that all customers using the same application have the same maximum and minimum bandwidth requirements. However, treating customers equally wastes scarce network resources and increases the network CBR and CDR. It also leads to the loss of business opportunities for the service provider since some customers would have paid more in order to receive a higher QoS Satisfaction Level (QSL). On the other hand, treating customers differently based on their QSLs has its obstacles. Permitting customers to define their QSLs may persuade them to overbook the scarce network resources in order to guarantee their maximum QoS satisfaction. To prevent this expected resources overbooking, charging and RM policies should be integrated to provide customers with a strong incentive to reveal their true QoS requirements.

Current wireless networks charge customers based on a flat

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W. Ibrahim is with the UAE University, College of Information Technology, P.O. Box 17555, ALAIN, AbuDhabi, UAE phone: 971-3-713-3659; fax: 971-3-762-6309; e-mail: walidibr@uaeu.ac.ae.

J. W. Chinneck is with Carleton University, Dept of Systems and Computer Engineering, Ottawa, Ontario K1S 5B6, Canada

S. Periyalwar is with Carleton University, Dept of Systems and Computer Engineering, Ottawa, Ontario K1S 5B6, Canada

H. El-Sayed is with the UAE University, College of Information Technology, P.O. Box 17555, ALAIN, AbuDhabi, UAE

rate policy in which customers are charged a fixed fee for a predefined amount of transferred data or access minutes. The main appeal of flat rate pricing is its simplicity, which reduces risks and administrative costs. However, the charging fee is usually predetermined during the network planning phase which makes it completely independent of the network conditions. Therefore, it is inappropriate for the new generation of QoS-sensitive applications since it does not give customers a strong incentive to control their traffic or to reveal their true QSLs. At the same time, existing wireline multi-service charging techniques [1], [3] ,[13] ,[14] ,[15] are not suitable for wireless networks due to the fundamental differences between wireline and wireless environments, especially limited bandwidth and mobility. Therefore, several QoS based charging techniques have been proposed for next generation wireless networks to overcome the above limitations [7][18]. However, to the best of our knowledge, no QSL based charging policy has yet been proposed.

To overcome the limitations of the currently proposed RM and charging policies, we have proposed a novel charging and RM policy that takes into consideration the customer's QoS perception[8]. The policy allows customers to submit their QoS requirements during call setup. It motivates customers to reveal their true QoS requirements by charging them differently based on the amount of resources they consume. The policy provides service providers with a set of parameters to tune the policy performance according to market conditions.

In this paper we study the effect of maximizing the customer's QSL on the CBR, CDR, and average network revenue. We also study the effect of the tuning parameters on the policy performance. The remainder of the paper is organized as follows. The proposed policy is discussed in Section 2. Implementation details are presented in Section 3 followed by the simulation results in Section 4.

II. CHARGING AND RESOURCE MANAGEMENT POLICY

The proposed policy utilizes a competitive market model where customers are competing for the amount of available bandwidth. Customers try to maximize their QSL by reserving the maximum amount of bandwidth possible. In order to obtain access to the customer's QoS preference, the policy introduces the QoS profile concept (described in detail in Section II.A). The QoS profile allows customers to specify their QoS preferences in terms of QoS parameters offline. The QoS profile is then transmitted during call setup.

To motivate customers to reveal their true QoS requirements, the policy charges them differently based on amount of resources they consume. Charging customers differently may increase the network and economic efficiency since some existing customers may pay a higher price for better service, while others may accept a lower QoS in return for a cheaper price. It also provides fairer and more competitive services. The level of customer happiness will also improve since customers will be getting the service that best fits their needs.

Customers are charged based on the amount of bandwidth they reserve and the Bandwidth Market Price (BMP). The BMP is the current price to transmit one Gbit of traffic using one kbps of network bandwidth. It changes dynamically with the network traffic. Every customer pays the same price for the same service. Customers who get more bandwidth from the network should expect to pay more.

Instead of reserving a fraction of the network resources exclusively for handoff calls, the proposed policy uses a two steps handoff policy in order to reduce the network CDR. During the first step, if the amount of resources available at the target cell is not enough to admit the handoff call at its current QSL, the handoff policy may degraded the QSL of the handoff call up to its minimum threshold. If the call is still inadmissible, the handoff policy starts degrading the QSL of the existing calls to free enough resources to accommodate the handoff calls at its minimum QSL. The policy compensates the degraded calls by reducing the charging rate to match the actual amount of resources allocated to each call.

A. *QOS PROFILE*

The QoS profile is a way to capture the customer's QoS perceptions and the associated price he/she is willing to pay. An example QoS profile is shown in Table 1. It contains a record for every customer's QSL. This allows customers to compete for a lower QSL if they cannot afford the QSL they currently have. In this paper, customers are limited to four records per QoS profile corresponding to their "excellent", "good", "fair", and "poor" QSLs.

TABLE I
A QOS SATISFACTION PROFILE.

CUSTOMER QOS PROFILE			
QSL	**BITRATE** (Kbps)	**Budget** (¢/Gbit)	**BID** ¢/(Gbit × kbps)
Excellent	12.2 Kbps	1000	81.97
Good	10.2 Kbps	900	88.24
Fair	8.8 Kbps	800	90.91
Poor	7.4 Kbps	700	94.59

The QoS profile, discussed in this paper, allows customers to define their QSL only in terms of the required bandwidth. However, the concept can be extended to include multiple QoS parameters such as end-to-end delay, delay jitter, etc. A customer can also use multiple QoS profiles, if it wants to run the same application with different QoS settings on different occasions (e.g. weekdays, weeknights).

The ability to predict the call cost is one of the major reasons why customers prefer fixed charging policies over dynamic ones in which costs are difficult to forecast. To improve the call cost prediction of the proposed charging policies, customers are asked to assign a "budget" to each QSL. The budget constitutes a compulsory agreement to pay the service provider up to a maximum price equal to the assigned budget per Gbit of transmitted traffic in order to reach the specified QSL. Since customers are expected to have different QSLs, and to assign different budgets, thse policy compares customers based on the bid per kbps of allocated bandwidth (1).

$$\text{bid}_{ij} = \text{bud}_{ij} / \text{bw}_{ij} \qquad ¢/\,(\text{Gbit} \times \text{kbps}) \qquad (1)$$

Customers may assign lower budgets for lower QSLs. However, the budget and QoS parameters should provide a higher rate as the QSL decreases. This allows the call to compete effectively as network congestion increases. See Table 1 for an example QoS profile.

It may seem difficult for the average customer to construct an efficient QoS profile, but built-in default QoS profiles (usually provided by the application vendor) and user-friendly interfaces for tuning the settings within acceptable limits will simplify the process. Customers may have to tune the default settings only once before they run their applications for the first time. Trained customer support can also help customers set their QoS profiles before signing the service agreement.

The QoS profile has other benefits in addition to gathering customer QoS preferences. It reduces control and negotiation messaging overhead by transmitting the customer's QoS profile only once during call setup. It allows customers to define the preferred way to degrade service in case of a resource crisis. It provides customers with both guaranteed and best effort services. A customer can guarantee a certain QSL by assigning an infinite budget to that level. In this case, the customer commits to paying the current BMP in order to achieve and maintain the specified QSL.

B. *TUNING PARAMETERS*

Service providers can tune the performance of the proposed RM policy by adjusting one or more of the following parameters: minimum QoS admission threshold (adm^{min}), minimum BMP (μ^{min}), maximum CDR (CDR^{max}), and maximum CBR (CBR^{max}).

We define the initial QSL for call i (adm_i) as the highest QSL the call can achieve based on the call's QoS profile and the current BMP. The minimum QoS admission threshold is the lowest QSL the call must achieve to be admitted to the network. This controls the number of calls admitted to the network and hence the QSL achieved by existing calls. The minimum BMP is the service provider minimum acceptable price. The customer's competitive behavior should set a reasonable BMP, but the μ^{min} parameter prevents customers from dragging the BMP below the minimum acceptable threshold.

The CDR^{max} and CBR^{max} parameters are used to control the call dropping and blocking rate respectively. CBR and the CDR are calculated based on the number of calls blocked and dropped during the last evaluation period. The evaluation period is a configurable parameter. For simulation purposes, the evaluation period is set to the last 1000 calls.

Since dropping an existing call drastically reduces a customers QoS perception, the policy's highest priority is to maintain the CDR below the maximum acceptable threshold. In case of a resource crisis or unusual traffic conditions the policy may have to increase the CBR above the maximum threshold in order to maintain the CDR below the maximum threshold. A service provider may set CDR^{max} to zero in order to prevent the framework from dropping any calls regardless of the call's QoS profile or the CBR.

III. Policy Implementation

We assume that each cell has a maximum bandwidth capacity bw^{max}. The bandwidth has a market price μ $¢/(\text{Gbit} \times \text{kbps})$. The cell has a set of customers Φ. Each customer $i \in \Phi$ has a QoS profile. For each QSL j, customer i has a budget bud_{ij} and asks for an amount of bandwidth bw_{ij}. The total bandwidth used is $bw^u = \sum_i bw_i$, where bw_i is the amount of bandwidth assigned to customer i. Hence, the available bandwidth is denoted by $bw^f = bw^{max} - bw^u$

The proposed policy consists of three main sub policies: resource allocation, CAC, and charging. Upon the arrival of a handoff/new admission request, the policy launches the CAC policy to perform a preliminary admission check. If the call is admissible, the policy starts the resource allocation policy to calculate the projected resource allocation and BMP assuming that the call is admitted. If the admission request is granted after a final admission check, then the policy commits the projected resource allocation and instructs the charging policy to start charging customers based on the new resource allocation and BMP.

A. *Resource Allocation Policy*

The resource allocation policy supports two types of welfare fairness that are common in the literature: *Utilitarian Criterion* and *Equality Criterion* [6]. The utilitarian criterion, sometimes referred to as utility maximization, is a Pareto-Optimal allocation that results in the greatest sum of the customer utilities (2).

$$\text{Max } Z = \sum_i u_i \quad \forall i \in \Phi, \; u_i \in (u^{xl}, u^{gd}, u^{fr}, u^{pr}) \qquad (2)$$

On the other hand, the equality criterion is a Pareto-Optimal allocation that results in an equal level of utility for all customers. The customer's utility is the value corresponding to the customer's QSL as shown in Table 2. The numbers in Table 2 are arbitrarily selected to show the increase in the customer's utility due to the increase in the QSL.

TABLE 2
CUSTOMER'S UTILITY

QSL	Excellent	Good	Fair	Poor
UTILITY	$u^{xl} = 4$	$u^{gd} = 3$	$u^{fr} = 2$	$u^{pr} = 1$

where u_i denotes the customer's utility.

The utility criterion policy (*utPol*) operates recursively. Upon the arrival of a new/handoff call, the projected bandwidth for each existing call is set to zero. The policy then identifies the call that needs the least bandwidth to reach the next affordable QSL. The QSL is affordable if its associated bid is $\geq \mu^{min}$. The policy then updates the call's projected bandwidth, the call projected QSL, and the amount of resource available at the base station, and begins a new iteration. The policy stops when either all customers reach the excellent QSL or when the amount of free bandwidth left is insufficient to upgrade any of the existing calls to the next higher affordable QSL. To minimize the CDR, the policy can be configured to initialize each active call with enough resource to reach the poor QSL. The policy can also minimize the CBR by initializing an admitting call at the poor QSL as well.

Instead of maximizing the average customer's QSL, the equality criterion policy (*eqPol*) tries to allocate bandwidth to customers such that all of them have the same QSL. The bandwidth allocation policy operates in steps. Starting with the poor QSL, it sets a target QSL at each step and allocates bandwidth to calls so that each call reaches the target level. A call is considered only if the bid associated with the target QSL is not lower than μ^{min}. If enough bandwidth is available, the policy updates the call's projected bandwidth, QSL, and the amount of free bandwidth, advances the target QSL, and starts a new iteration. If there is insufficient bandwidth, calls are prioritized based on the bid associated with the target level: bandwidth is allocated first to the call with the highest bid to insure that the bandwidth is allocated to the call that most appreciates the QoS satisfaction level received.

B. CAC policy

Upon the arrival of a new call admission request (k), the CAC policy starts a preliminary check of the call admissibility. The call is admissible if the following two conditions are satisfied. First, the maximum amount of bandwidth available at the base station is sufficient to satisfy the poor QSL for all existing calls as well as the minimum admission threshold for the admitting call ($bw^{max} \geq \sum_i bw_{i,pr} + bw_{k,\min}$). Second, the admitting call has enough budget to reach the minimum admission threshold ($bid_{i,min} \geq \mu^{min}$). If the call is not admissible, it is blocked unless this will force the CBR > CBR^{max}. The CAC policy then pauses until the resource allocation policy calculates the projected resource allocation.

The CAC policy then finalizes the admission decision as follows. The call admission request is rejected if it forces the $CDR > CDR^{max}$ (i.e. admitting the new call forces one or more existing calls below the poor QSL). To reduce the social cost of admitting a new call, the admission request is also rejected if the projected total utility is lower than the current value. Finally, before blocking a new call the CAC policy checks whether the new $CBR > CBR^{max}$. In such case, the call is admitted unless admitting the call forces the $CDR > CDR^{max}$.

Since dropping an ongoing call is more serious than blocking a new one, the admission control policy treats handoff calls differently. A handoff admission request is accepted if the target cell has enough bandwidth to guarantee at least the poor satisfaction threshold to the existing active calls in addition to the handed-off one.

C. Charging Policy

After the admission request is accepted, the charging policy calculates the new BMP and uses it to charge customers according to their new bandwidth allocation (3). The charging policy first scans the new QSL assigned to each call and recovers their associated bid. It then sets the new BMP to the lowest bid found. This insures that customers will never pay more than the maximum budget they specify in their QoS profile.

$$\text{Tariff} = bw_i \times \text{BMP} \ \text{¢/Gbit} \qquad (3)$$

IV. Simulation Results

The proposed policy is compared with the rate-based borrowing policy (*rbb*) [4] via simulation. Two flavors of the proposed policy have been simulated; namely the *utPol* and the *eqPol*.

The performance of the proposed policy is assessed using the average CBR and CDR as well as following performance metrics: 1- average revenue per unit of resource, 2- admitted calls average QSL, 3- network average QoS[6]. To calculate the admitted calls average QSL, the total time all calls spent at each QSL is measured and weighted based on the utility scale in Table 2 (4). The network average QoS is calculated by penalizing the admitted calls average QSL for each dropped and blocked call. It is calculated by adding −2 and −1 utility for each dropped and blocked call respectively. The negative utility is assigned to each dropped call regardless of the QSL it received prior to being dropped.

$$QSL_{avg} = \frac{\sum_j u^{xl} \times t_j^{xl} + u^{gd} \times t_j^{gd} + u^{fr} \times t_j^{fr} + u^{pr} \times t_j^{pr}}{\sum_j t_j^{xl} + t_j^{gd} + t_j^{fr} + t_j^{pr}} \quad \forall j \in \Phi \qquad (4)$$

A. Simulation Parameters

We model call arrivals as a Poisson process with a mean arrival rate λ = 5 calls/min. Assuming medium call mobility, the probability that an arriving call is a handoff call is 0.5 [16]. There are five representative application types: narrowband audio, wideband audio, narrowband video, wideband video, and data transfer. In [4] and [16] the traffic types of new calls are assumed to have equal probabilities, i.e. 0.2 for each of the five types. However, we assume that voice calls will have a larger fraction of the market in the near future, and so voice calls are assigned a probability of 0.3 while wideband video calls are assigned a probability of 0.1, with the other three types having probabilities of 0.2.

The traffic module assigns a random QoS profile to each call. The bitrate associated with each QSL is selected randomly based on the call type and the IEEE recommended

QoS parameters for wireless broadband applications [9]. For realism, the selection of the audio QSLs is guided by the QoS *Mean Opinion Score* (MOS) in [10], while the selection of the video QSLs is guided by the customer's MOS and the video profiles and levels in [11]. Since the Lognormal distribution has been widely used to model personal income [17], we model the customer's excellent QoS budget as a lognormal distribution with mean of 5 and std of 1.

To study the effect of the tuning parameters, the performance of the proposed policy is simulated at different minimum QoS admission thresholds (Fair to Excellent) and at different μ^{min} values. To keep in line with the customer's budget (mean = 5.0 $¢/(\text{Gbit} \times \text{kbps})$), we have studied the effect of changing the μ^{min} in the range from 3.0 to 4.0 $¢/(\text{Gbit} \times \text{kbps})$. To control the CBR and the CDR rate, the CBR^{max} and CDR^{max} are set to 20% and 2% respectively.

B. Results

As expected, by setting its object to maximize the customer's QSL, the *utPol* policy provides customers with 8% higher average QSL than the *rbb* policy at μ^{min} = 3.0 (Fig. 1). While providing customers with equal QSL, the *eqPol* generates the lowest average QSL. Increasing μ^{min} reduces the average QSL provided by the proposed policy as more customers became unable to afford higher QSLs. At the same time, increasing μ^{min} improves the *rbb* policy average QSL significantly since more bandwidth became available for the fewer admitted calls.

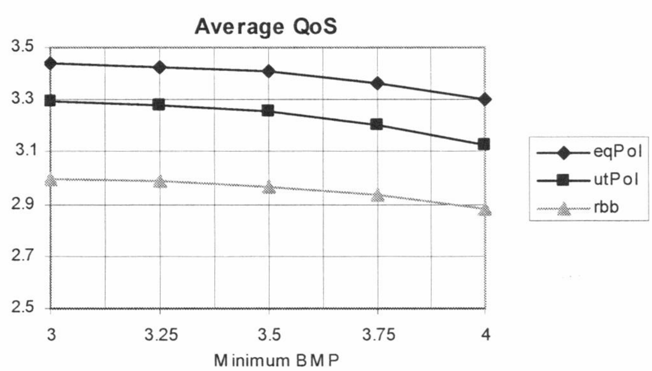

Fig. 1. Network Average QoS vs. BMP^{min}

When call blocking and dropping dissatisfaction are considered, the proposed policy clearly outperforms the *rbb* policy average QoS. The *eqPol* outperforms the *rbb* policy by 14% and the *utPol* by 4% (Fig 2). Although increasing μ^{min} increases the average QSL provided by the rbb policy, it deteriorates its network average QoS. This is mainly because the increase in the QSL is out weighted by the increase in the calls dropping and blocking dissatisfaction. At the same time, increasing μ^{min} deteriorates the proposed policy average QoS as more customers became unable to afford higher QSLs.

As shown in Fig. 3, the proposed policy generates as much as 33% higher revenue than the fixed pricing policy utilized by the *rbb* policy. Adjusting the bandwidth market price dynamically and admitting calls at lower QSL allows the

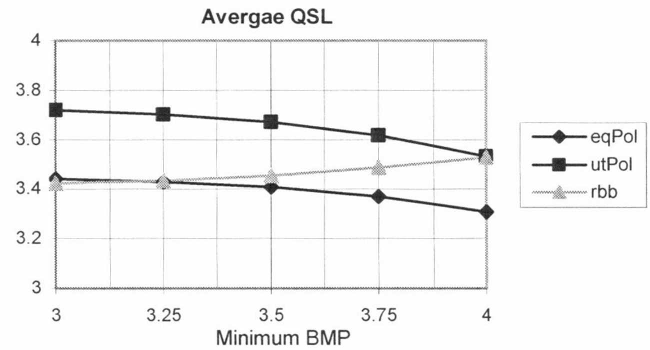

Fig. 2. Admitted Calls Average QSL vs. BMP^{min}

proposed policy to maintain reasonable bandwidth utilization and generated revenue levels. On the other hand, the *rbb* policy loses potential revenue by reserving 10% of the network bandwidth exclusively for handoff calls. The simulation results show that the revenue generated by the rbb policy is very sensitive to the minimum BMP. It improves by 25% when μ^{min} is raised from 3.0 to 4.0.

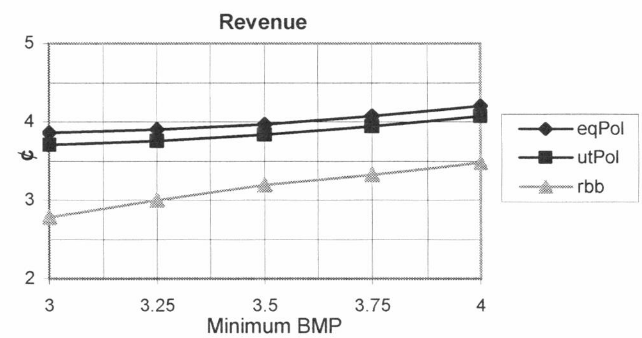

Fig. 3. Revenue vs. BMP^{min}

During its first stages, the *eqPol* allocates enough resources to both exiting and admitting calls to reach their poor QSLs. Consequently, it generates negligible CBR and CDR (Fig. 4, Fig. 5).

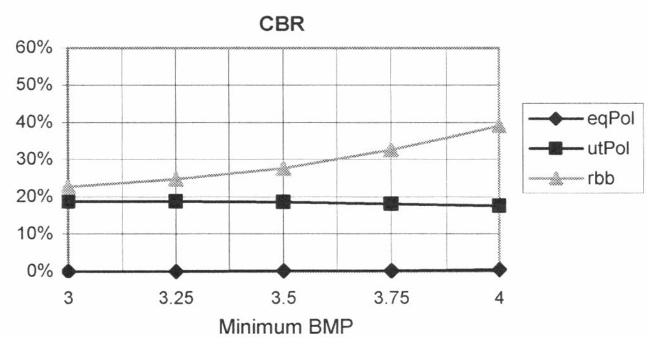

Fig. 4. CBR vs. BMP^{min}

Setting CBR^{max} and CDR^{max} allows the *utPol* to significantly reduce its CBR to 18% and CDR to 2%. Increasing μ^{min} reduces the rbb policy CDR due to increase in the amount of free resource as a fewer number of calls can afford the new service price. At the same time, the rbb policy CBR increases significantly with the increase of μ^{min} as the number of calls blocked due to insufficient budget outstrips the number of calls blocked due to insufficient resources.

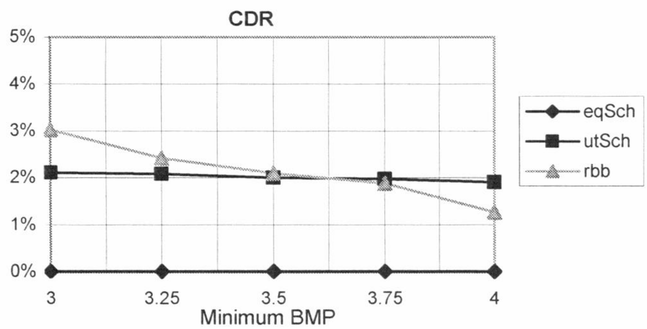

Fig. 5. CDR vs. BMP^{min}

V. CONCLUSION

This paper proposes a novel customer satisfaction based charging and RM policy that manages network resources based on the traffic condition and the customer's QoS profile. By adjusting the BMP dynamically, the proposed policy manages different types of applications and adapts to different traffic loads. The proposed policy outperforms other currently proposed policies in several aspects. It provides customers with better average GoS, reduces the CBR and CDR significantly, and generates more revenue than the rate-based policy.

The QoS profile allows the proposed policy to attract and accommodate different types of customers and provide them with the service that best fits their needs. As the service price increases, customers who cannot afford the new service price are moved to more affordable lower QoS services.

Using the proposed tuning parameters is an effective way to control the performance of the proposed policy. They allow service providers to adjust the performance of the policy to handle changes in market conditions. A service provider may reduce the minimum BMP and/or the minimum QoS admission threshold to provide more affordable services and attract more customers. Another service provider may choose to provide high QoS service by increasing the minimum admission threshold and/or the minimum BMP.

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