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Adaptive bandwidth allocation for call-level quality-of-service (QoS) in wireless mobile networks

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Different quality-of-service (QoS) required types of multimedia services and need a guaranteed service rate in wireless multimedia networks. When the number of user arrivals increases, bandwidth degradations may occur due to limited bandwidth nature of cellular wireless networks. The bandwidth that should be assigned to user cannot be met for QoS provisioning in congested network. In this paper, a priority-based call admission control scheme with bandwidth adaptation is proposed to provide the required QoS to service users and to utilize the bandwidth effectively. An analytical model is developed to evaluate the numerical results. Proposed scheme differentiates the services according to their call-level QoS priorities as non-prioritized and prioritized calls and provides the satisfactory QoS under the upper bound limitations. Further, bandwidth adaptation policy maintains the higher performance results in terms of blocking and dropping probabilities, resource utilization and throughput of non-prioritized calls.

Key words: Priority-based call admission control (CAC), bandwidth adaptation, quality-of-service (QoS), bandwidth allocation.

INTRODUCTION

To support multiservice with different quality-of-service requirements such as multimedia streaming (voice and video streaming), interactive data services, in cellular wireless networks, it is important to enable efficient resource allocation schemes while required level of quality-of-service (QoS) provisioning is ensured to users in each different types of multiservice classes (Manvi and Venkataram, 2005). In a mobile wireless network, transmission delay, maximum packet-round trip time, allowed packet jitter time must be guaranteed for real time or delay sensitive services. Also, error-free transmission, low packet loss rate must be guaranteed for non-real time services, which require variable data rates during the congested network. User variant mobility characteristics, handoff failures and lack of adequate bandwidth are important restrictions for QoS provisioning in wireless networks. The quality of service can be measured in three different levels in terms of performance metrics. These are:

1. Packet-level performance metrics: End to end packet transmission delay, packet lost probability and jitter which are needed to be guaranteed especially for non-real time (data) services. To enable the system admit more new or handoff data calls, bandwidth allocation for data calls can be adapted. This leads to variations on transmission rate of the total system and packet level performance metrics are affected directly and must be measured to guarantee

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Abbreviations: QoS, Quality-of-service; CAC, call admission control; DP-CAC, dynamic priority call admission control; **CP-CAC,** complete partitioning call admission control; **QP-CAC,** queuing priority call admission control.

the required QoS.

2. Call-level performance metrics: Call level performance metrics are measured by blocking and dropping probability of new and handoff calls. Both blocking and dropping probability must be reduced to required minimum value to avoid the handoff failures and call blockings from the system. The dropping probability of handoff calls always should be maintained in lower value than that of the blocking probability of new calls. This leads to a trade-off between both probability rates. When dropping probability of handoff calls is reduced by call admission control (CAC) or resource management techniques, blocking probability of new calls increases at the same time.

3. Class-level performance metrics: Class-level performance metrics meet the quality of service of different types of traffic classes. Traffic classes can be divided according to service priorities of their users that belong to a class. User priorities determine the class level quality of service metrics. They are measured in terms of blocking or dropping probability. High priority classes are expected to be smaller blocking or dropping probability.

CAC schemes are used for the utilizing of the resources effectively as an important aspect of resource management. CAC controling for the arriving traffic to the system by admitting or rejecting the new or handoff calls to maximize the allocation of bandwidth for each user belonging to a class with required QoS was studied by Yilmaz and Chen (2009), Chowdhury et al. (2013), Marchese and Mongelli (2010) and Leong et al. (2006). With an efficient CAC, the system can provide bandwidth allocation for real-time or non-real time services efficiently in terms of capacity of the network and guarantee their required QoS. In literature, many CAC schemes have been proposed for performance evaluation by Aboelaze et al. (2004), AlQahtani et al. (2007), Phuong et al. (2006), Xiao et al. (2002) and Shih and Lin (2004). To prioritize the handoff calls over new calls, many priority-based CAC schemes have been proposed via channel reservation, guard channel, and adaptive bandwidth policy for handoff calls by Aboelaze et al. (2004), AlQahtani et al. (2007) and Phuong et al. (2006).

In Aboelaze et al. (2004), a priority-based call admission control protocol depending on borrowing bandwidth from connections is proposed. Protocol can assign priorities both in admitting traffic and bandwidth degradation for different types of traffic. In AlQahtani et al. (2007), a novel dynamic priority call admission control (DP-CAC) that can be able to achieve a better balance between system utilization and quality of service provisioning is proposed and its performance is compared with complete partitioning CAC (CP-CAC) and queuing priority CAC (QP-CAC). In Phuong et al. (2006), a traffic control scheme for improving QoS is presented by describing the priority-based QoS classes to handle the multimedia calls. With this proposed scheme, resources are given to the higher prioritized call traffic with higher probability.

In this study, a priority-based CAC scheme with bandwidth adaptation policy is to meet the desired QoS and to increase network performance by using the total bandwidth more efficiently via demand function formulating.

SYSTEM MODEL

In proposed CAC, it is assumed that the system is in statistical equilibrium that is, the mean rate of handoff arrival calls is equal to the mean rate of handoff departure calls in the cell and rounded six cells have the uniform traffic conditions. Service classes can be classified in four different QoS classes in cellular networks: Conversational class (voice), streaming class (streaming video), interactive class (web browsing) and background class (e-mail) (Castro, 2004). The conversational and streaming classes can be classified as real-time service classes or prioritized-class of calls. Interactive and background classes can be classified as non-real time service classes or non-prioritized class of calls. It is assumed that arrival calls in the cell are non-prioritized-calls and prioritized calls. As dropping an ongoing prioritized call is less desired than blocking a non-prioritized call arrival, an amount of capacity *C* is reserved as a guard channel for only handoff call arrivals. Non-prioritized and prioritized call arrivals to cellular system are assumed to be Poisson arrival process. Call duration and the cell residence time of prioritized calls are assumed to be exponentially distributed with means, $\eta_{v_2}\ \mu_{v_2}$, respectively. The channel occupancy time is also assumed to be exponentially distributed with mean $(\eta_{v_2}+\mu_{v_2})^{-1}$ (Ramjee et al., 1997; Rappaport, 1990). Non-prioritized calls can adapt to variable bandwidth traffic conditions, here, CAC scheme admit non-prioritized and prioritized calls without dropping bandwidth below the minimum pre-determined level. The channel occupancy time and the cell residence time of non-prioritized calls also are exponentially distributed with means $(\eta_{d_1}+\mu_{d_1})^{-1}$, η_{d_1}, respectively.

Priority-based call admission control

Priority-based policy is used in the proposed CAC for better QoS maintaining and resource allocation, in which prioritized service calls are admitted to the system with high access priority while both types of service class share the bandwidth. Prioritized-calls can use the entire resource (bandwidth) if the number of free channels is less than the total capacity, *C.* If non-prioritized calls arrive to the system, they are accepted if the number of occupied channels is less than the (*C*-reserved channels) otherwise non-prioritized calls are blocked. On the other hand, prioritized-calls are blocked only when all the resources are used. Admittance of non-prioritized calls are limited into the system to provide the call level QoS while not degrading the non-prioritize calls QoS requirements significantly.

If the number of non-prioritized calls exceeds the N_1, they are blocked; otherwise admitted. N_1 is the number of maximum non-prioritized calls. N_2, when the occupied bandwidth used by prioritized calls is less than the C in the system, defines maximum acceptable number for non-prioritized calls.

The offered prioritized and non-prioritized load when a prioritized and non-prioritized call users are in the system and are given by $\rho_2 = \lambda_2 \big/ (\eta_{v_2}+\mu_{v_2})^{-1}$ and $\rho_1 = \lambda_1 \big/ (\eta_{d_1}+\mu_{d_1})^{-1}$, where λ_1 and λ_2

are the total mean arrival rate of non-prioritized and prioritized calls. c_{dmin} and c_{vmin} denotes the required capacity to maintain the QoS requirements for non-prioritized calls. When there are i non-prioritized calls and j prioritized calls in the system, the steady-state probability of these i and j non-prioritized and prioritized calls in the system, $p(i,j)$ is obtained by the following

$$(ic_{d\min} + jc_{v\min}) \leq C,$$

$$p\ (i,j) = \frac{\rho_1^{\ i}}{i!} \frac{\rho_2^{\ j}}{j!} .p\ (0,0) \quad (1)$$

Where,

$$p\ (0,0) = \left[\sum_{i=0}^{N_1} \frac{(\rho_1)^i}{i!} . \sum_{j=0}^{C-i} \frac{(\rho_2)^j}{j!} \right]^{-1} \quad (2)$$

The state space is defined as $S=\{(i,j)| \quad 0 \leq i \leq N_1, \ 0 \leq j \leq N_2, \ 0 \leq ic_{dmin}+jc_{vmin} \leq C\}$. Thus, non-prioritized call blocking and prioritized call dropping probabilities can be obtained as:

$$BN_1 = \sum_{j=0}^{\left\lfloor (C-N_1 c_{d\min}) / c_{v\min} \right\rfloor} p(N_1, j) \quad (3)$$

$$BN_2 = \sum_{i=0}^{N_1} p\ (i, C-N_1) \quad (4)$$

Where, $\lfloor \ \rfloor$ represents the floor function that rounds its input to the nearest integer less than or equal to the value of input itself.

Total channel utilization efficiency, n is the ratio of used bandwidth and the total system bandwidth. From the all users' channel occupancy probabilities, n is calculated as:

$$n = \frac{\sum_{i=0}^{N_1} \sum_{j=0}^{(C-ic_{d\min})/c_{v\min}} p(i,j)(ic_{d\min} + jc_{v\min})}{C} \quad (5)$$

Total mean throughput T_h (calls/s) is the mean rate that all non-prioritized calls are served and calculated as

$$Th = \sum_{i=0}^{N_1} \sum_{j=0}^{(C-ic_{d\min})/c_{v\min}} p(i,j) i (\eta_{d_1} + \frac{c_{d\min}}{f_1}) \quad (6)$$

Where, f_1 is the mean file size for non-prioritized calls.

Bandwidth adaptation

When incoming call arrival rates and also traffic load increase in the system, more bandwidth is needed to meet the resource allocation demand. In adaptation control policy, the demand function is used to respond to system traffic load changes effectively (Fishburn and Odlyzko, 1998). Demand function is given by

$$Demand\ function: D(i) = e^{-(\frac{\lambda_2(i)}{\lambda_2(i)^*} - 1)^2} \quad (7)$$

Where, $\lambda_2(i)^*$ is normal prioritized-call arrival rate. When the prioritized-call arrival rate $\lambda_2(i)$ increase as regard to $\lambda_2(i)^*$, bandwidth adaptation policy recalculates the new c_{vmin} capacity by demand function criteria.

$$for\ i = 1,2,......26 \quad c_{v\min}^{\ *} = 17\ kbps \quad (8)$$

$$for\ i = 1,2,......26 \quad 0.5\lambda_2^{\ *} \leq \lambda_2(i) \leq 1.5\lambda_2^{\ *} \quad (9)$$

$$\begin{aligned} &if \quad \lambda_2(i) \leq \lambda_2^{\ *} \\ &\qquad c_{v\min}(i) = c_{v\min}^{\ *} \\ &if \quad \lambda_2(i) > \lambda_2^{\ *} \\ &\qquad c_{v\min}(i) = c_{v\min}^{\ *} .(D(i))^{-1} \end{aligned} \quad (10)$$

Adaptation control by demand function can maintain the dropping and blocking probabilities under the upper bound limitation. When priotized-call arrival rate is lower than the normal call arrival rate, the value of c_{vmin} remains the same. However, prioritized-call arrival rate is higher than the normal call arrival rate, and c_{vmin} is reduced with respect to this prioritized-calls reaction to the normal call arrival rate formulated by demand function.

RESULTS AND DISCUSSION

Results obtained from analytical model developed for proposed call admission control scheme are shown in Figures 1 to 4 for different prioiritzed-calls arrival rate. Analysis parameters are set as follows: Non-prioritized-calls and prioritized calls arrival rates are λ_1=0.0072-0.0122 calls/, λ_2=0.0578-0.5340 calls/s respectively and c_{dmin}=34 Kbps, f_1=512 KB, η_{d1}=0.07 calls/s, $\mu_{d1}=c_{dmin}/f_1$=0.0664 calls/s, $\mu_1=(\eta_{d1}+\mu_{d1})^{-1}$, η_{v2}=0.00166 calls/s, μ_{v2}=0.00555 calls/s, $\lambda_2^{\ *} = 0.2310\ calls/s$, $c_{v\min}^{\ *} = 17\ kbps$.

Figure 1 shows blocking probability of non-prioritized calls with respect to increase values of prioritized calls arrival rate. As the incoming prioritized-calls arrival rate is increased, the system cannot have the same BN_1 performance, hence, blocking probability of non-prioritized calls increases. Adaptive policy can achieve lower blocking probability rate than non-adaptive proposed policy especially when the prioritized-calls arrival rate is larger than the normal rate (0.2310 calls/s). Figure 2 shows dropping probability of prioritized calls as a function of prioritized-calls arrival rate. As prioritized calls arrival rate increases, dropping probability of prioritized-calls increases. Dropping probability of prioritized-calls is lower than the blocking probability of non-prioritized calls for high priority access of prioritized-calls (*0.025<0.055* at max value). Adaptive policy also uses the bandwidth by rearranging the cv_{min} effectively and hence in adaptive policy case, dropping probability is

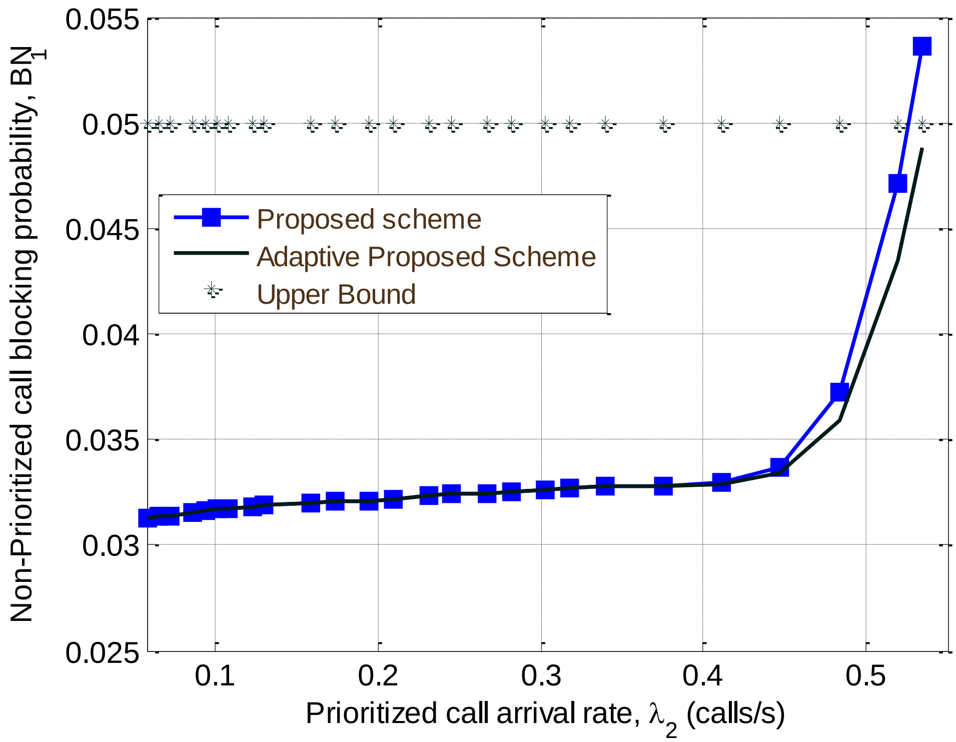

Figure 1. Blocking probability of non-prioritized calls.

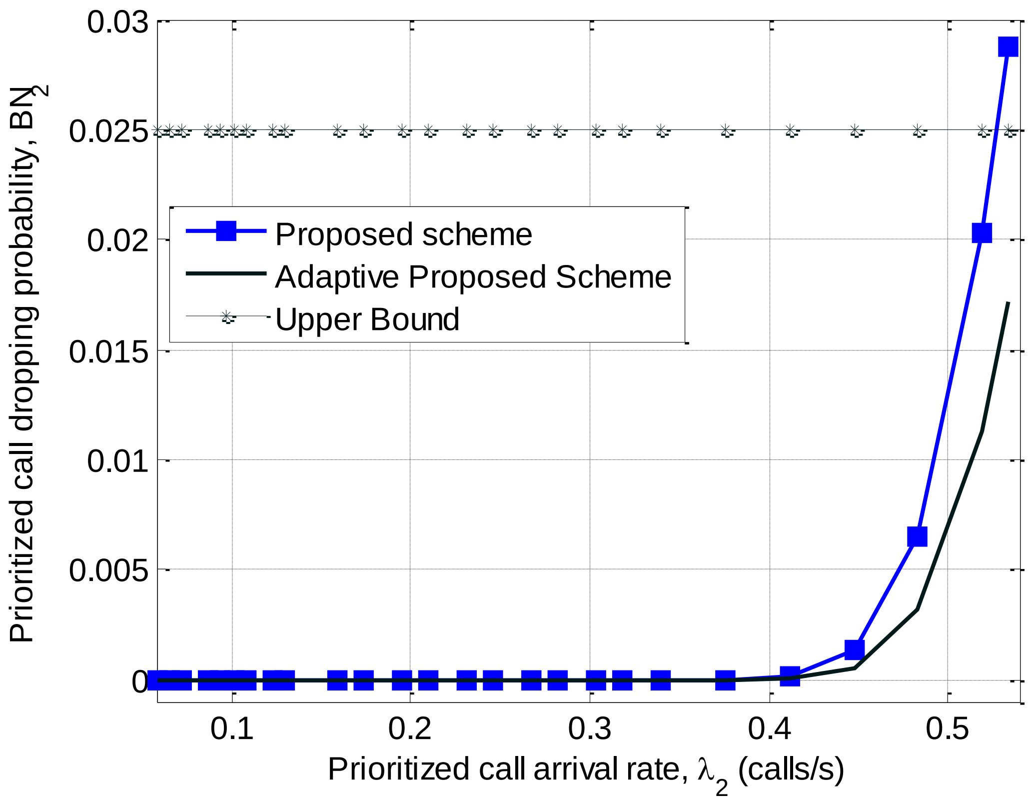

Figure 2. Dropping probability of prioritized-calls.

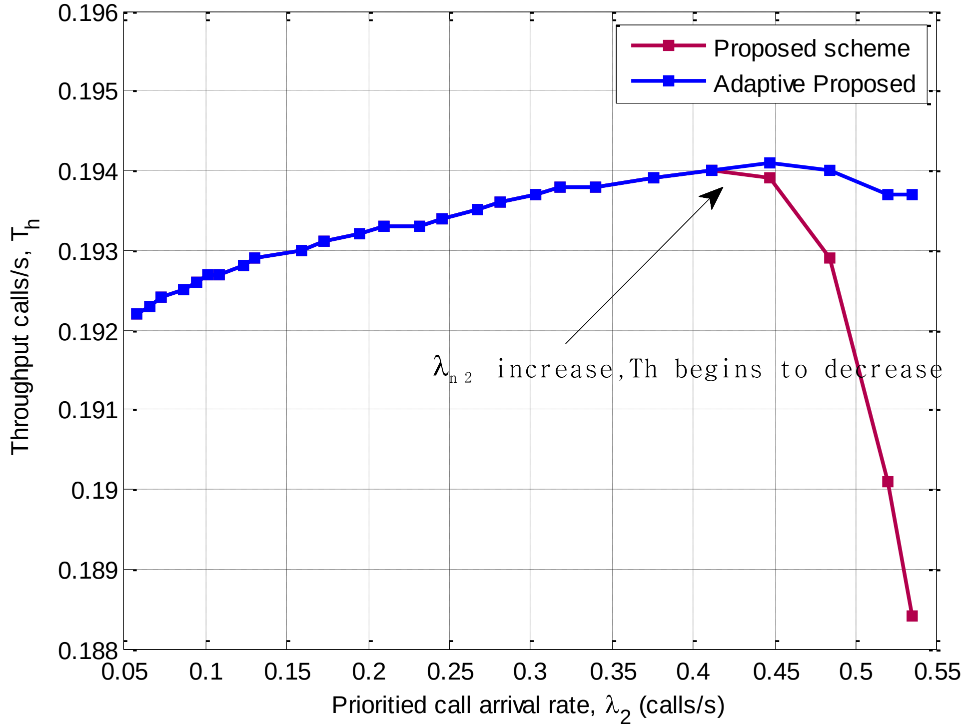

Figure 3. Throughput of non-prioritized calls.

much better than non-adaptive policy. When the analytical results of prioritized and non-prioritized call blocking probability are compared with other proposed literature schemes, it can be seen that non-prioritized call blocking probability and prioritized call dropping probability in Figures 1 and 2 are kept below 0.035 and 0.005%, respectively, at 0.1 to 0.5 (calls/s) arrival rate. In AlQahtani et al. (2007), even at lower system loads, (arrival rate only 0 to 0.1 calls for per second), it is seen that blocking and dropping probability can be maintained in the range between 0.5 and 0.7%. This performance results are high to ensure the required QoS.

Figure 3 shows the throughput value of non-prioritized calls. In light prioritized-calls arrival rate (<*0.2310* calls/s), throughput increases as the prioritized-calls arrival rate increase. After normal arrival rate (>*0.2310*), system cannot tolerate the increase of call arrival rate without any increase of its resources (total capacity). In heavy calls arrival rate, adaptive policy rearranges the cv_{min} with respect to incoming arrival rate increase and more aggregate capacity remains to non-prioritized calls and throughput also increase. Figure 4 shows efficiency of the system resources (capacity) utilization. As shown from the Figure 4, adaptive policy performs better than the non-adaptive proposed call admission control scheme. Resource utilization efficiency increase to 1; as the prioritized-calls arrival rate increase the whole capacity is used especially for the high prioritized-calls arrival rate.

For the aim of comparing the utilization performance with those of other proposed adaptive bandwidth degradation schemes (Xiao et al., 2002; Shih and Lin, 2004), we find that bandwidth utilization performance results are the same for all proposed and compared schemes, when the network traffic congestion is low. However, the proposed CAC outperforms when the network traffic is heavily loaded. Proposed CAC meets the increase of prioritized calls by utilizing the adaptive bandwidth concept effectively. At 0.1 to 0.5 (calls/s), bandwidth utilization is below 0 to 0.9% from proposed scheme, whereas results from other schemes are kept below 0 to 0.9 and 0 to 0.7%.

Conclusion

In this paper, a prioritized-based call admission scheme with bandwidth adaptation policy is proposed for non-prioritized and prioritized calls in cellular network. Different capacity requirements of non-prioritized and prioritized calls have been considered and according to two service differentiation, an analytical model is developed. Also, considering the network traffic load due to increase of prioritized-calls arrival rate, the new cv_{min} capacity is formulated, which depends on call arrival rate increase weights determined by demand function. Numerical results show that proposed call admission

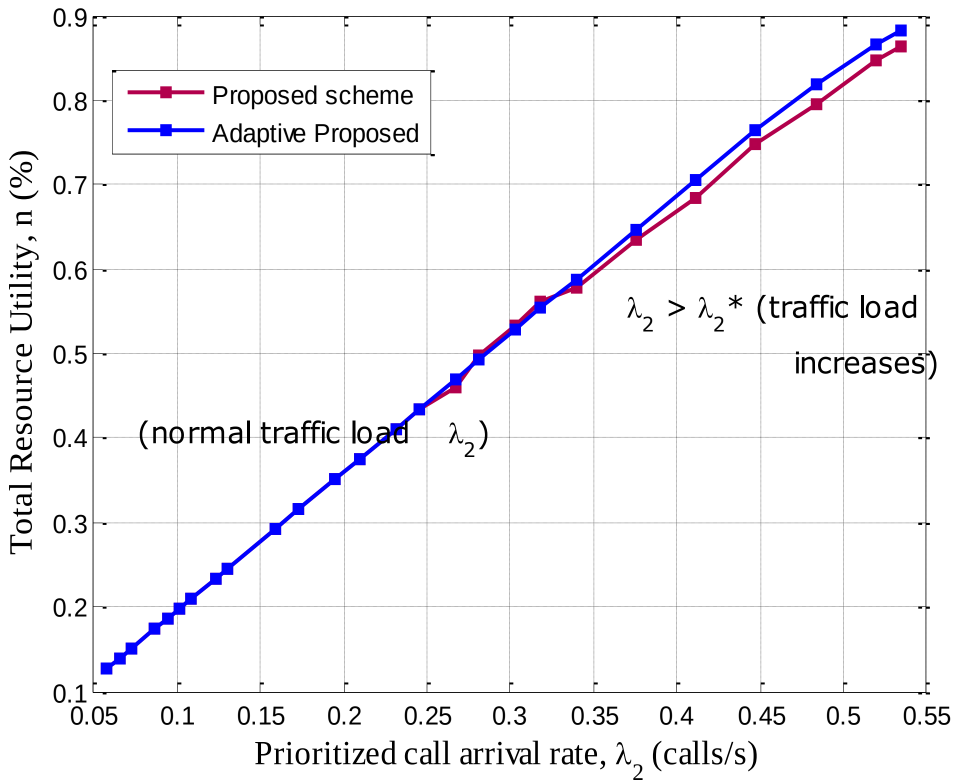

Figure 4. Resource utilization efficiency.

control scheme with bandwidth adaptation policy increase the system performance in terms of blocking and dropping probabilities, non-prioritized-calls throughput and system efficiency of resources utilization.

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