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Optimization of Dynamic Priority Call Admission Control for WCDMA Uplink Transmission

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Abstract: *The well-defined improvements in terms of increased data rate, enhanced network capacity, and improved quality of service (QoS), with the introduction of new generation mobile devices like smartphones and tablets, have inspired the advancement of series of new services under certain constraint. With the remarkable growth in mobile subscribers, a suitable call admission control strategy that supports a diverse range of multimedia services with guaranteed QoS is essential in achieving efficient resource management. Quite a lot of call admission control schemes have been proposed in the literature pieces; among the schemes considered, the dynamic priority CAC scheme was shown to achieve a better balance between system utilization and QoS requirements. This paper compares the DP-CAC scheme and the optimized DP-CAC scheme for handoff calls dropping probability and the new calls blocking probability in the universal mobile telecommunication system. The results obtained from the extensive simulation show that the optimized DP-CAC achieves an improved new call success probability by an average percentage value of 17.9%. Moreover, at different verified scenarios with varied traffic arrival rates, the service and system utilization grade is significantly improved.*

Keywords — *3G, CAC, QoS, WCDMA, DP-CAC.*

I. INTRODUCTION

With the advancement in technology of the generation of mobile communication networks from the first to the third generation (3G) systems, the networks have experienced a significant change in the quality of the system, speed, data capacity, and technology. The 3G technology is a developing technology that has added a valuable mobile dimension to services that have already become an essential part of modern life [1]. Yet, achieving an optimum quality of service (QoS) provision remains a challenge due to the rapidly increasing number of mobile subscribers, scarcity of bandwidth, diversity of multimedia services, and computational difficulty of the radio resource allocation mechanism [2]. An important feature of 3G networks is the call admission control (CAC) mechanism that plays a significant role in defining how the wireless channels or radio resources have to be efficiently shared among users [3].

CAC schemes have to ensure that the network meets the QoS of newly arriving calls if accepted [4] but are significant to the success of future generations of wireless cellular networks. Consequently, an efficient call admission procedure would be required to maintain more reliable links and achieve better utilization of the radio channels [5]. Therefore, it is conceivable that CAC policy is one of the critical design considerations in today's wireless cellular networks. The CAC mechanism's main goal is to regulate the admission of new users while controlling the QoS of the current connections without any call drops [6].

In the design of CAC schemes, preserving the call quality is vital. One of the most important connection-level QoS issues is how to reduce handoff drops due to the lack of available channels in the new cell [7]. Since mobile users experience severe service disruption when handoff calls are dropped, several CAC schemes employ guard channels for prioritizing, and handoff calls protection [8]. In recent years, researchers' key design goals are to minimize the call dropping probability, which is exactly the objective of most existing schemes on call admission control. There has been exhaustive research on the design of CAC strategies, among the schemes considered, the dynamic priority CAC algorithm was shown to have favorable performance in achieving better admission for under-loaded traffic class with efficient bandwidth utilization.

The rest of this paper is organized as follows. Section II presents the related works. Section III provides an overview of wideband code division multiple access (WCDMA) uplink load factor and estimation. Section IV presents the system model and the proposed dynamic priority call admission control (DP-CAC) scheme. Section V presents the traffic model and performance analysis, while section VI presents the obtained simulation results and discussion. Finally, the concluding remarks are discussed in section VII.

II. RELATED WORKS

Carvalho et al. [3] proposed an optimal joint call admission control (JCAC) based on Semi-Markov Decision Process (SMDP) Framework for inter-radio access technology (RAT) cell re-selection problem that supports both the real-time and non-real-time services. To properly meet the JCAC goals, a cost function that weighs two criteria: the blocking cost function, which considers the priority of each service class in each RAT, and the alternative acceptance cost, which reflects the multiplicity of radio access technologies (RATs) working collaboratively. Another aspect of the optimal JCAC model consists of investigating how the ratio between the radiuses of the co-located RATs may impact the optimal initial RAT selection. The numerical results, supported by an analysis of the optimal policy structure, show that the proposed optimal JCAC accommodates real-time incoming service requests in the largest RAT and non-real-time incoming service requests in the smallest one. In [9], network traffic analysis was done with known traffic descriptors using the knowledge base of existing sciences of network engineering. The effective bandwidth available in a Mobile Switching Center (MSC) of a wireless network providing multiclass multimedia services was analyzed. The bandwidth requirement of the users for a customized Quality of Service (QoS) is estimated. The QoS estimation findings are applied for the capacity planning and admission control of the multiclass traffic flows coming into the MSC. Patil and Deshmukh [10] proposed a QoS-based call admission control scheme for a 3G wireless cellular network to provide QoS. Queuing techniques were introduced because the main focus of this scheme was to reduce the handoff failures. The proposed scheme is prioritized-based; hence it gives higher priority to handoff calls over new calls. Performance analysis of this scheme through simulation with different scenarios shows that the scheme reduces the dropping probability of the handoff call and increases the total system capacity. Kumar [11] presents an extensive review of different CAC schemes used for mobile multimedia networks using soft computing techniques like artificial neural networks, fuzzy logic, and genetic algorithms. The soft computing used was to obtain optimized results from many parameters used in mobile multimedia networks.

In [12], and adaptive bandwidth borrowing-based QoS approach for call admission control in multiclass traffic in wireless cellular networks was proposed. This scheme was developed to deal with CAC problems and to provide QoS guarantees for multiclass traffic services. The simulation results show that the proposed CAC scheme, using fair bandwidth adaptation techniques, reduces the blocking probability and dropping probability and notably improves bandwidth utilization. Falowo and Ventura [13] proposed a bandwidth-based dynamic threshold (DT) CAC scheme for IEEE 802.16 networks. The control threshold changes dynamically in order to respond to the varying traffic of connections. The performance evaluation shows that the proposed scheme can improve CAC decisions with lower blocking probability when compared with the generic bandwidth partitioning scheme. V. S. Kolate [14] presents a review of CAC schemes and handoff prioritization for cellular networks. Several call admission control schemes were described, and it was shown that handoff prioritization schemes such as guard channels and queuing can improve handoff related system performance. In [15], the performance evaluation of dynamic partitioning based guard channel (DPGC) calls admission control scheme in a system that accepts three different customer classes was analyzed. A system technique was developed, and the system performance was obtained. The results show that the new and handoff customers which require more channels for their service are blocked more. Server utilization was also considerable improved when the arrival rate of higher bandwidth requiring customers is high.

In this paper, an effort has been made to extend the dynamic priority call admission control (DP-CAC) scheme, which utilizes the predefined load partition and the current system load to dynamically admit the queue calls [16]. We introduce a queuing model according to the code division generalized processor sharing (CDGPS) scheduling discipline [17] to enhance the estimation of accumulated traffic arrival rate and accelerate the control of call requests that have delayed in the queue for a longer time. Secondly, we analyzed the guard channel concept to predict the effect of varying the percentage arrival rate of handoff call on the system utilization and grade of service.

III. OVERVIEW ON WCDMA UPLINK LOAD FACTOR

A WCDMA cell's theoretical spectral efficiency can be computed from the load equation whose derivation is shown below. The maximum capacity is achieved when the cumulative interference becomes so great that the energy per bit to noise density ratio (E_b/N_0) requirement cannot be fulfilled for the class i traffic. We first define the E_b/N_0 energy per user bit divided by the noise spectral density [18]:

$$(E_b/N_0)_i = \textit{processing gain of user } i \cdot \frac{\textit{Signal of user } i}{\textit{Total received power}} \qquad (1)$$

This can be written thus:

$$(E_b/N_0)_i = \frac{W}{v_i R_i} \cdot \frac{P_i}{I_{total} - P_i} \qquad (2)$$

Where W is the chip rate, P_i is the received signal power from the user i, v_i is the activity factor of the user i, R_i is the bit rate of the user i, , and I_{total} is the total received wideband power including thermal noise power in the base station. Solving for P_i gives

$$P_i = \frac{I_{total}}{1 + \frac{W}{(E_b/N_0)_i \cdot R_i \cdot v_i}} \quad (3)$$

We define $P_i = L_i \cdot I_{total}$ and obtain the load factor L_i for each connection as, [18];

$$L_i = \frac{1}{1 + \frac{W}{(E_b/N_0)_i \cdot R_i \cdot v_i}} \quad (4)$$

Using a similar principle of the Greatest Common Divisor (GCD) in [19], the load factor of each class can be represented as an integer multiple i of $\Delta\eta$:

$$\frac{L_i}{\Delta\eta} = i \quad (5)$$

Where i is a positive integer. To realize the call admission control for WCDMA systems, firstly, an evaluation of the total cell load must be calculated and subsequently be employed in the decision process of accepting or rejecting new connections. In this analysis, perfect power control is assumed for operation where the mobile station (MS) and its a home-based station (BS) use only the minimum needed power to achieve the required performance. Considering the interference on the uplink, the load factor increment $\Delta\eta_i$ for a new request i can be estimated as [16];

$$\Delta\eta_i = \frac{1}{1 + G_i/\rho_i} \quad (6)$$

Where $G_i = W/R_i$ is the processing gain for the ith MS, R_i is the bit rate associated with the ith MS, and W is the chip rate of the WCDMA system. ρ_i is the bit-energy to noise-density (E_b/N_0) figure corresponding to the desired link quality. Using the load factor increment definition, the current total load factor η_c, for such an interference system is the sum of the load factor increments brought by all N active mobile stations. Therefore,

$$\eta_c = \sum_{i=1}^{N} \Delta\eta_i = (1+f)\sum_{i=1}^{N} \frac{1}{1 + G_i/\rho_i} \leq \eta_{max} \quad (7)$$

Where f is the factor accounting for interference from other cells and is defined as the ratio of inter-cell interference to the total interference in the referenced cell, whereas v_i is the average traffic activity factor of ith MS.

IV. SYSTEM MODEL

A 3G wideband code division multiple access (WCDMA) cellular network supporting varied traffic is the system under discussion. The system adopts two classes of services: real-time (RT) service, such as conversational and streaming traffic, and non-real-time (NRT) service, such as interactive and background traffic. The four priority classes are classified according to their request type to new and handoff calls. These classes are: class (1) RT service handoff requests; class (2) NRT service handoff requests; class (3) newly originating RT calls; and class (4) newly originating NRT calls. The four priority classes are depicted in Table 1 in the descending order of priority.

TABLE 1: Priority Classes

Class	Traffic type	Request type	Call class description
1	voice/RT	Handoff calls	Conversation and streaming
2	data/NRT	Handoff calls	Interactive and background
3	voice/RT	New calls	Conversation and streaming
4	data/NRT	New calls	Interactive and background

We define a standard WCDMA cell's capacity in terms of its cell load [16], where the load factor η is the instantaneous resource utilization upper bounded by maximum cell capacity. We adopt a different bandwidth requirement for each traffic class, i.e., they have different multiples of the greatest common divisor defined above. We assume that the handoff and new calls arrival rate are $\lambda_{h1}, \lambda_{h2}, \lambda_{n1}$, and λ_{n2} for handoff voice, handoff data, new voice, and new data, respectively. The instantaneous values for the cell load η range from 0 to 1. Applying the load factor, we formulate a QoS-aware CAC scheme for WCDMA-based networks by using the concept of thresholds and queuing techniques [20]. Each call class has its queues: Q1, Q2, Q3, and Q4 with finite capacities K, L, M, and N, respectively. A call class request is placed in its corresponding queue if it cannot be serviced upon its arrival and assigned a resource when available based on its calculated priority. Let η_i be the load margin (LM) corresponding to the ith ($i = 1, 2, 3,$ and 4) traffic class, and η_{max} be the maximum loading that can be admissible, as shown in figure 1.

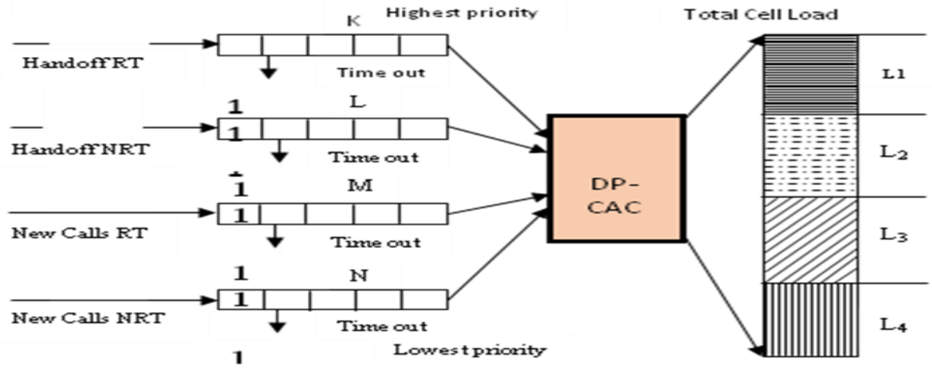

Figure 1. Dynamic Priority Call Admission Control (DP-CAC) scheme

We considered only the uplink in the DP-CAC scheme. Subject to how these loading limits are set and without loss of generality, let the RT call increases the load by the basic GCD $(\Delta\eta_{RT})$, and the NRT call increases it by $(\Delta\eta_{NRT})$.

A. *The Dynamic Priority Call Admission Control (DP-CAC) Scheme*

The purpose of exploiting the dynamic priority CAC scheme is to meet the desired dropping probability for handoff calls and simultaneously reduce the blocking probability of new calls to the achievable degree. The DP-CAC scheme utilizes the predefined load partition and the current system load to dynamically admit the queue calls [16]. The priority is dynamically adjusted such that the total resource capacity is accessible to different calls admission request classes to enhance the resource utilization. The higher priority class in DP-CAC remains higher in priority, provided that the lower priority class is not adversely affected by the higher priority class. The dynamic priority CAC technique can be stated thus:

1. The arrived class *i* call is served as long as the condition in equation 8 is satisfied.

$$\Delta\eta_i + \eta_c \leq \eta_{max} \tag{8}$$

2. When all resources are utilized, afterward, the arrived call is placed in its corresponding queue.
3. Any call that exceeds the queuing time limit is deleted from its queue.
4. Upon capacity released, the dynamic priority value is calculated for all call classes with non-empty queues using the total load presently occupied by class i calls as in equation (8) and the load partition predefined for class i calls in equation (9).

$$O_i = (1+f)\sum_{i=1}^{B_i}\frac{v_i}{1+G_i/\rho_i} \leq L_i \tag{9}$$

The load partition $L_i$of each dividing line is carefully chosen based on the traffic characteristics and the predefined QoS requirements of each service class. Equation (9) O_i is the total current usage load occupied by each connected class and B_i is the number of the currently connected class i call. Once all resources of class i calls are occupied, afterward arrival of class i calls is queued in the corresponding buffer and served based on the first-in-first-out (FIFO) policy. Hence, the dynamic priority value for class i calls is given by

$$P_i = \frac{O_i}{L_i} \tag{10}$$

The highest priority traffic class i will have a minimum priority P_i value. At this juncture, the priority value of class i calls will decrease as the total current load drops below the predefined load partition L_i, ; for this reason, it will receive a high priority traffic class. The moment two or more traffic classes have the same priority value; then the higher priority traffic class will be served first. Using this procedure, the unutilized load of one traffic class can be utilized by other traffic classes when needed. In addition, at high system load, the priority value will prevent the traffic classes from negatively affecting each other. The DP-CAC scheme is extended using a one-step estimation approach [17]. In this approach, the estimated traffic arrival rate $r_i(k)$ of class i calls during time slot k can be estimated from past traffic measurement and is given by

$$r_i(k) = \frac{a_i(k-1)}{T} \tag{11}$$

Where $a_i(k-1)$ is the total amount of the arrival traffic (in bits) during the time slot $(k-1)$, and T is the scheduling period in the CDGPS scheme.

V. TRAFFIC MODEL AND PERFORMANCE ANALYSIS

A. *Traffic Model*

Markov model is used to validate the system performance. Where the arrivals of class 1, 2, 3, and 4 calls are controlled by four independent Poisson processes each with arrival rate of $\lambda_{h1}, \lambda_{h2}, \lambda_{n1}$, and λ_{n2} (calls/seconds), for RT handoff calls, NRT handoff calls, RT new calls and NRT new calls, respectively. In addition, we define the aggregate mean arrival rates of RT (handoffs and new calls) and NRT (handoffs and new calls) traffic classes as $\lambda_{RT} = \lambda_{h1} + \lambda_{n1}$ and $\lambda_{NRT} = \lambda_{h2} + \lambda_{n2}$, respectively. The total arrival rate of the system is Poisson with rate $\lambda = \lambda_{h1} + \lambda_{h2} + \lambda_{n1} + \lambda_{n2}$. . Also, we assume that the time a connection of class i holds resources in a cell is exponentially distributed random variable with mean $1/\mu_i$ seconds while the queuing time limit of each handoff calls class is exponentially distributed with mean $1/\gamma_i$. Using the above explanations, the generated load of each traffic class i, denoted by, ρ_i is given by $\rho_i = \mu_i^{-1} \cdot \lambda_i$. The total offered load for the system, denoted by ρ, is given by

$$\rho = \mu_i^{-1}(\lambda_{h1} + \lambda_{h2} + \lambda_{n1} + \lambda_{n2}) \quad (12)$$

In addition, let $\overline{\Delta\eta}$, according to [21] represent the average loading increment for RT and NRT calls.

$$\overline{\Delta\eta} = \frac{\lambda_{RT}}{\lambda_{RT} + \lambda_{NRT}} \cdot \Delta\eta_{RT} + \frac{\lambda_{NRT}}{\lambda_{RT} + \lambda_{NRT}} \cdot \Delta\eta_{NRT} \quad (13)$$

Where $\Delta\eta_{RT}$ and $\Delta\eta_{NRT}$ are load factor increments for RT and NRT calls, respectively.

B. System Performance Measures

For key performance indicators (KPIs) for the network optimization process, both handoffs call dropping probability and new calls blocking probability are important measures used for the network quality evaluation in terms of the traffic serving efficiency. We evaluate the proposed scheme based on four metrics: handoff call dropping probability, new call blocking probability, grade of service (GoS), and the system utilization, and they are defined thus:

1) ***Handoff call dropping probability***: this is defined as the ratio of the total number of handoff calls dropped to the total number of handoff calls request.

$$P_{hj} = \frac{\textit{total number of handoff calls dropped}}{\textit{total number of handoff calls request}} \quad (14)$$

2) ***New call blocking probability***: this is defined as the ratio of the total number of new calls blocked to the total number of the new call request.

$$P_{nj} = \frac{\textit{total number of new calls blocked}}{\textit{total number of new calls request}} \quad (15)$$

3) ***Grade of service (GoS):*** The grade of a service metric is defined thus:

$$GoS_j = \alpha P_{hj} + \beta P_{nj} \quad (16)$$

Where P_{hj} is the handoff call dropping probability, and P_{nj} is the new call blocking probability; $j = 1, 2$ stands for RT and NRT traffic, respectively. $\alpha = 10$ Indicates the penalty weight for dropping a handoff call relative to blocking a new call $\beta = 1$ is the new call blocking weighting factor.

4) ***System utilization (U):*** the bandwidth (b_i) of the connection i is defined by its load increment, $\Delta\eta_i$, such that $b_i = \Delta\eta_i$. The average system utilization is defined as:

$$U = \sum_{i=1}^{4} n_i \cdot \Delta\eta_i \quad (17)$$

Where n_i is the average number of connections in each traffic class that the system can accept for given average traffic.

VI. SIMULATION RESULTS

A. Simulation Parameters

The parameters used for the traffic classes and the physical layer for the WCDMA network are as detailed in Table 2.

TABLE 2: Simulation Parameters

Parameters	Value
Radio access mode	WCDMA (FDD) uplink with perfect power control
Chip rate	3.84 Mbps
Bandwidth	5 MHz
WCDMA channel rate	2.0 Mbps
Dedicate channel rate for RT and NRT traffic classes	12.2, 64, 128, 256, 384 Kbps
Frame duration	10 ms
RT- activity factor (class 1 and 3)	0.4
NRT- activity factor (class 2 and 4)	1
Required (E_b/N_0) for RT and NRT traffic classes, corresponding to each dedicated channel rate, respectively	5, 3.5, 2.5, 2.0, 2.0 dB
Max. cell load	100% of pole capacity
Class 1, 2, 3, and 4 load margin	0.375, 0.25, 0.2, 0.175
Call arrival	Poisson
Call generating type	Exponential
Call queue type	FIFO, Priority
Transmission Time Interval (TTI)	100 ms

B. Simulation Results and Discussion

In this section, the simulation results are presented to demonstrate the performance of the proposed DP-CAC scheme. We take into consideration the regular QoS parameters such as the handoff calls dropping probability and the new calls blocking probability. A comparison study was made between the DP-CAC and the optimized DP-CAC scheme for handoff calls dropping and the new calls blocking probability. In addition, simulations were generated for different scenarios to ascertain the effect of adjusting the percentage of call arrival rate for each traffic class on the grade of service (GoS) and the system utilization. To analyze the GoS in four different scenarios, we simultaneously decrease the handoff calls and increase the new calls arrival rate by 10% each step decrease or increase from the total number of handoff calls or new calls request, respectively. Finally, the system utilization was generated for scenarios 1, 2, 3, and 4 when the percentage of each arrival rate out of the total offered traffic is as follows:

- Scenario-1:
  $\lambda_{h1} = 0.15\lambda, \lambda_{n1} = 0.2\lambda, \lambda_{h2} = 0.25\lambda, and$
  $\lambda_{n2} = 0.4\lambda;\ \lambda_{RT} = 0.35\lambda, \lambda_{NRT} = 0.65\lambda$
- Scenario-2:
  $\lambda_{h1} = 0.15\lambda, \lambda_{n1} = 0.25\lambda, \lambda_{h2} = 0.2\lambda, and$
  $\lambda_{n2} = 0.4\lambda;\ \lambda_{RT} = 0.4\lambda, \lambda_{NRT} = 0.6\lambda$
- Scenario-3:
  $\lambda_{h1} = 0.2\lambda, \lambda_{n1} = 0.25\lambda, \lambda_{h2} = 0.25\lambda, and$
  $\lambda_{n2} = 0.3\lambda;\ \lambda_{RT} = 0.45\lambda, \lambda_{NRT} = 0.55\lambda$
- Scenario-4:
  $\lambda_{h1} = 0.2\lambda, \lambda_{n1} = 0.3\lambda, \lambda_{h2} = 0.2\lambda, and$
  $\lambda_{n2} = 0.3\lambda;\ \lambda_{RT} = 0.5\lambda, \lambda_{NRT} = 0.5\lambda$

Mobility variation complicates the admission of varied traffic in a mobile cellular network; the proposed DP-CAC scheme offers the best service variation but still achieves an improved system utilization and a good balance at traffic congestion. The graphs of handoff call dropping probability and the new calls blocking probability versus the system utilization are shown in figures 2 and 3, respectively.

Figure 2 shows the handoff call dropping probability comparison of the DP-CAC scheme and the optimized DP-CAC scheme. It is confirmed that, at various points on the system utilization curve, the handoff call dropping probability achieved by the optimized DP-CAC scheme does not present any improvement to that of the DP-CAC scheme. Also, at the peak value of 0.0212 for handoff calls dropping probability, both schemes prove to attain an efficient system utilization of 98%. In figure 3, the performance achieved by the DP-CAC scheme and the optimized DP-CAC scheme were compared for new calls blocking probability versus the system utilization. The optimized DP-CAC scheme achieves an improved system performance for new call blocking probability with a reduced average percentage value of 17.9%, attributable to the enhanced queuing model that ameliorates the new call success probability by accelerating the control of call requests that have delayed in the queue for a longer time.

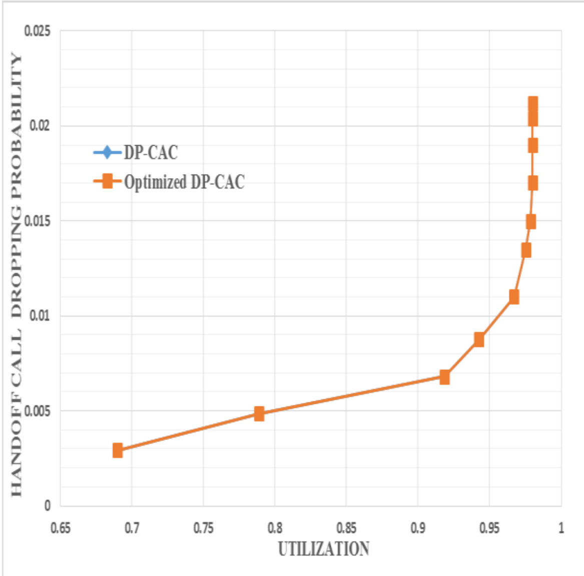

Figure 2. Handoff call dropping probability versus system utilization

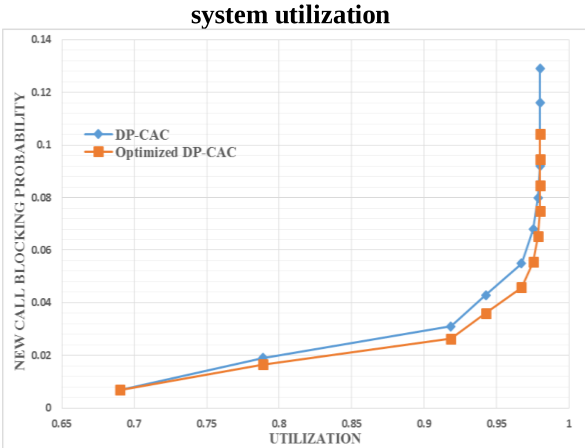

Figure 3. New call blocking probability versus system utilization

The grade of service (GoS) curve as a function of traffic intensity is shown in figure 4. The different scenarios are verified for the system grade of service. It is demonstrated that the simultaneous decrease of handoff calls and the increase of new call arrival rate by 10%, respectively, improves the grade of service of the system by an average percentage value of 3.94%. This is owing to the reality that the handoff call requests are granted higher priority than the new call request and are also allocated a higher weight in the GoS configuration.

Figure 5 shows how the system utilization is affected by the average number of traffic connections. The percentage of the real-time arrival rate λ_{RT} of $0.35\lambda, 0.4\lambda, 0.45\lambda$, and 0.5λ out of the total offered traffic λ are varied for different scenarios 1, 2, 3, and

4, respectively. We observe that as the RT arrival rate of each traffic connection decreases from $0.5\lambda, 0.45\lambda, 0.4\lambda$, to 0.35λ, the system utilization was improving by a percentage value of 6.1%, respectively.

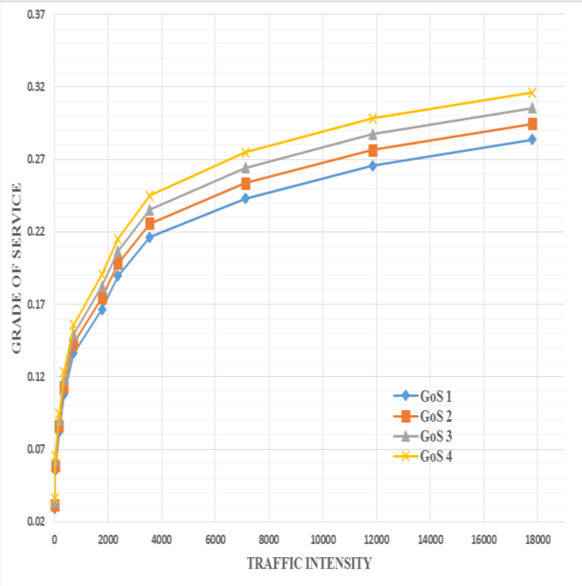

Figure 4. Grade of service as a function of traffic intensity

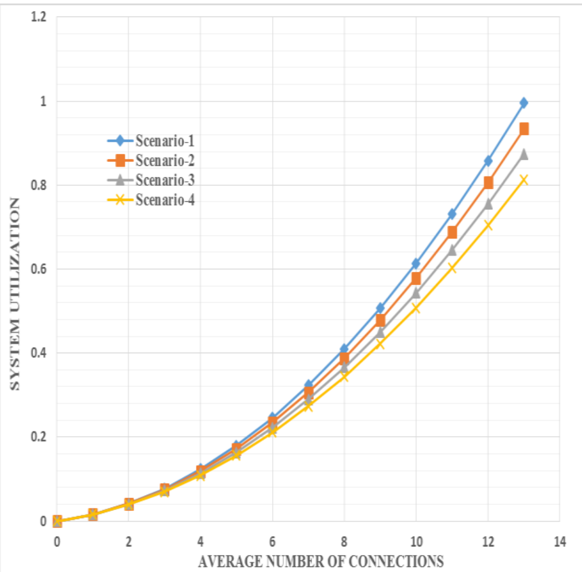

Figure 5. System utilization versus the average number of traffic connections

VII. CONCLUSION

Call admission control for radio links remains an exciting research topic in a universal mobile telecommunication system. In this paper, we have extended the DP-CAC scheme, which exploits the one-step estimation approach to enhance the estimation of traffic arrival rate and accelerating the control of call requests that have delayed in the queue for a longer time. In the performance analysis, we made a comparison between the DP-CAC and the optimized DP-CAC scheme for the handoff calls dropping probability and the new calls blocking probability. The extensive simulation results show that the proposed scheme provided an improved system performance of the new calls' success probability. Also, it has been demonstrated through simulation with different scenarios at varied traffic arrival rates that the proposed scheme improves the grade of service and the system utilization appreciably.

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