Performance Analysis of Adaptive Rate Scheduling Scheme for 3G WCDMA Wireless Networks with Multi-Operators

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***Abstract*— Sharing of 3G network infrastructure among operators offers an alternative solution to reducing the investment in the coverage phase of WCDMA. For radio access network (RAN) sharing method each operator has its own core network and only the RAN is shared. Without an efficient RRM, one operator can exhausts the capacity of others. This paper proposes and analyzes an efficient uplink-scheduling scheme in case of RAN sharing method. We refer to this new scheme as Multi-operators Code Division Generalized Processor sharing scheme (M-CDGPS). It employs both adaptive rate allocation to maximize the resource utilization and GPS techniques to provide fair services for each operator. The performance analysis of this scheme is derived using the GPS performance model. Also, it is compared with static rate M-CDGPS scheme. Numerical and simulation results show that the proposed adaptive rate M-CDGPS scheduling scheme improves both system throughput and average delays.**

Keywords-component; *adaptive rate scheduling, GPS, Performance analysis, multi-operator, RRM, utilization, WCDMA*

I. INTRODUCTION

Sharing the radio resources between more than one operator is one of the new important trends of current and future 3G wideband code-division with multiple access (WCDMA) system. The sharing methods available for 3G network operators were proposed in [1-3]. These sharing methods include, site sharing, radio access network (RAN) sharing, common network sharing, and geographical network sharing. These previous proposals and studies of WCDMA wireless sharing methods presented the problem from architectural and technical point of view. Implementation of these techniques through radio resource management (RRM) is not investigated. The RAN based sharing method is of special importance as it reflects the most recent and critical sharing option. In RAN sharing, which is the focus in this study, each operator has its own core network and only the RAN is shared. RAN consists of base station and radio resource controller. It implies that multiple operators fully share the same RAN. Therefore, there is a critical need for radio resource control between multiple operators to prevent one operator from exhausting the capacity allocated for others.

Service level agreements (SLA) specify the usage of the radio network capacity for each operator under the RAN based sharing agreement [16]. Each operator receives the agreed upon QoS level by following the specified operation rules in the SLA. More about SLA and service management can be found in [16]. In order to secure fair access to the network resources and to optimize the usage of the allotted capacity, it is very important to allow the RRM to separately control each operator and guarantee its minimum required capacity. In other word, the RRM procedure should guarantee that the maximum traffic per operator as defined by SLA is not exceeded unless permitted. RRM can allow an operator's traffic to exceed its limit in an adaptive way if there are unused resources related to other unbacklogged operator in order to increase the overall system utilization. Hence, the shared radio resources must be controlled in a fair and efficient way between operators. The call admission control (CAC) is key element of RRM and is used to control the admission of the connection request of an operator. However, after the admission of the connection request, packets belonging to this operator connection are transmitted based on the scheduling scheme used. The scheduling scheme, as part of RRM, controls the packets transmissions during the connection time. This study focuses on designing an efficient and fair scheduling scheme for multi-operator WCDMA system.

A. Related Works and Motivation

An ideal fair scheduling discipline is the well known generalized processor sharing (GPS), and also known as weighted fair queuing (WFQ) [4][5]. The GPS discipline was introduced in [4][5]. Several GPS-based fair scheduling schemes have been proposed for wireline packet network [4]-[6]. In addition, these GPS-based scheduling algorithms have been adapted to wireless networks [7-10].

Radio resources for CDMA networks are mainly related to the spreading bandwidth, transmission power, and channel rates. Therefore, the time scheduling approach used for conventional GPS is not directly applicable for CDMA wireless networks [8][11][12]. Ideally, GPS assumes that multiple sessions can be served simultaneously and at variable rates [4]. Hence, the significant feature of GPS is that it treats different traffic types differently according to their QoS requirements. Parallel service is natural to direct sequence (DS)-CDMA systems where multiple sessions (i.e., traffic flows) can be served simultaneously and using different direct sequence codes (i.e., different rates). Moreover, the share of each session from CDMA channel resources can be varied theoretically by varying the corresponding spreading factor and/or using a multiple of orthogonal code channels. Due to the similarity existing between WCDMA system and GPS fluid-flow model, GPS service discipline seems to be a logical candidate for modeling CDMA systems [8][12]. This is our motivation to utilize GPS-scheduling for WCDMA system with multi-operator sharing the same RAN.

In order to improve radio resource utilization and achieve fairness with low complexity in such WCDMA-based wireless networks, number of recent algorithms for GPS-based uplink scheduling for WCDMA are studied and adapted in [11]-[15]. In [11], a rate-scheduling approach based on GPS is applied to the CDMA downlinks. Given the limit of the total downlink transmission power, the rate-scheduling scheme dynamically allocates the downlink power and rates according to weights assigned to the users. The user weights are optimized for each scheduling period to guarantee the required minimum channel rates, adapting to the time-varying channel condition, at the cost of high complexity. In [12]-[13], an uplink low-complexity code-division GPS (CDGPS) scheme for dynamic fair scheduling is proposed. The CDGPS scheduler makes use of the adaptability of the WCDMA physical layer to perform fair scheduling on a time-slot basis by using a dynamic rate-scheduling approach rather than the conventional time scheduling approach as in GPS. A low-complexity GPS-based bandwidth-scheduling scheme similar to the CDGPS is also proposed in [14], where a multi-carrier CDMA system is considered. Based on the minimum power allocation algorithm, a WCDMA GPS scheduling scheme is proposed in [15]. However, all theses WCDMA-based scheduling schemes are designed for single operator systems without considering how to control and schedule the resources that are shared among more than one operator in an efficient and a unified way.

B. Research Contribution

In this study, the CDGPS discipline is adapted and extended in order to design a new high performance GPS-based scheduling scheme which can effectively control the shared resources among WCDMA multi-operators in an efficient and fair manner. Efficiency means higher system utilization and fairness means that each operator is guaranteed at least a capacity equals to its capacity share specified in the SLA. Therefore, a multi-operator CDGPS (M-CDGPS) rate scheduling scheme for the uplink WCDMA cellular network is designed and analyzed. The scheme employs both adaptive rate allocation to maximize the resource utilization and M-CDGPS to provide fair services for each operator. The resource allocated to each operator session is proportional to an assigned weight factor as per the SLA specification. After the initial allocation of the allotted capacity, M-CDGPS scheme uses the CDGPS service discipline to dynamically schedule the assigned channel rates of one operator among the traffic classes within that operator independently. Moreover, the system performance measures in terms of bounded delay and buffer size are also derived using the GPS performance model.

The rest of this paper is organized as follows. Section II describes the system model and assumptions. Section III explains the proposed scheme in details while section IV presents the performance analysis. In section V, the obtained results, as well as the discussion are presented. Finally, the paper is concluded in section VI.

II. System Model and Assumptions

Frequency-division duplex (FDD) direct sequence WCDMA (DS-WCDMA) cellular network with multi-operators sharing the same RAN is considered here. The radio link in the FDD WCDMA system is characterized by orthogonal channels in the downlink (from BS to MS) and multiple access channels in the uplink (from MS to BS). A pair of multi-operators schedulers is assumed to be implemented on each Node B. In this paper, our discussion focuses on the uplink, while similar approaches can be applied to the downlink. It is assumed that whenever the uplink channel is assigned the downlink is established. In addition, this study assumes perfect power control operation for each operator’s user where a mobile station (MS) and its home base station (BS) use only the minimum needed power in order to achieve the required performance (i.e. bit error rate (BER)). The channels are also assumed to be error free. Since we are focusing on scheduling packets within an operator’s connections after their admission, the uplink capacity of WCDMA cell is defined in term of the uplink WCDMA channel rate.

The new RRM system model is shown in Fig. 1. We assume that N number of operators can share the cell radio resource, i.e. the channel rate. Each operator has a number of mobile stations (MS). When an MS of an operator wants to connect, it needs to send a connection requests in the random access channel (RACH). When this request is received at the BS, the multi-operator CAC scheme is first used to check the admission of the connection request of an operator. If the answer is positive, the connection request of this operator is accepted and the MS becomes ready to transmit traffic. This is called the admitted connections. When packets in a frame of an operator are available for transmission, they need to be scheduled according to the minimum capacity assigned to the corresponding operator and according to the corresponding QoS and BER requirements as a second phase using the multi-operator uplink scheduler. The multi-operator schedulers allocate the rate of the channels in the uplink to all operators then each operator’s local scheduler in its turn allocates its assigned rate to its MSs in the same cell covered by the BS. However, how the resources are allocated to the operator and how the packets of this operator’s connections are transmitted in each frame is determined by our proposed M-CDGPS scheduling scheme.

Medium access control (MAC) protocol [13] is applied to support the scheduler. Under the MAC scheme, the uplink channels for different operators’ users are synchronized at time slot level, where the duration of a time slot, denoted by T, equals to a scheduling period. The general procedure of the MAC is described in [13]. Two types of services are supported be each operator MS. These two types are: 1) Real-time traffic (RT) such as voice or video, 2) non-real-time traffic (NRT) such as data traffic. The required QoS in terms of delay and BER are different according to RT and NRT traffic. In the next sections, the detail descriptions of the proposed scheme are presented.

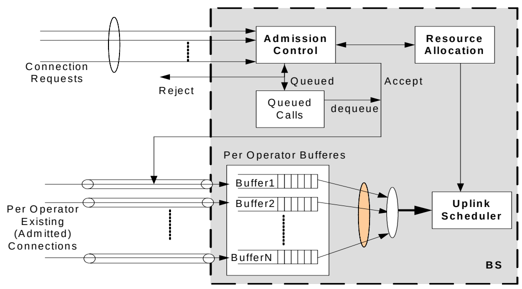

Figure 1. RRM model for RAN sharing.

III. PROPOSED MCDGPS SCHEMES

The shared resources will be the WCDMA channel rate, C, assumed here to be equal to 5 Mbps. We have N operators sharing the same channel. The queuing model of the proposed M-CDGPS scheme is shown in Fig. 2. Each operator has its own assigned soft capacity defined based on the SLA. The assigned weight for operator j is g_j , where j = 1, 2,…N. Therefore the total cell capacity in terms of channel rate is divided into N groups. The j^{th} operator maintains two of connections with link rate $C_j(k)$ during the k^{th} MAC slot with capacity $g_j C$.

It is assumed that the traffic characteristic of each input traffic input or stream of the M-CDGPS model is shaped by a Leaky-Bucket regulator [4] in order to achieve a bounded delay and bounded buffer size for traffic queue. Leaky Bucket characterization of a traffic stream is based on specifying two parameters (σ_{ij}, ρ_{ij}) where σ_{ij} and ρ_{ij} are the token buffer size and the token generate rate of the leaky bucket, respectively.

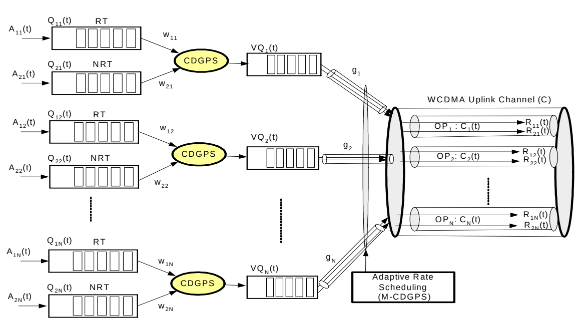

Figure 2. Queuing detail mode for M-CDGPS scheme.

In M-CDGPS scheduling schemes, the allocated resources to an operator during the k^{th} slot is $C_j(k)$. At the beginning of each time slot, the minimum rate guaranteed to traffic i from the assigned capacity share of its corresponding operator j is

$$r_{ij} = \frac{w_{ij} C_j(k)}{\sum_{i=1}^{S} w_{ij}} \tag{1}$$

Where w_{ij} is a weight assigned for each operator's session and S is the number of sessions (traffic classes) per operator. $C_j(k)$ can be fixed or adaptive as follows.

A. *Fixed rate M-CDGPS*

Let c_j is the minimum assigned rate for j^{th} operator such that;

$$c_j = g_j C \quad , j = 1,..,N \tag{2}$$

where; $\sum_{j=1}^{N} g_j = 1$ and $\sum_{j=1}^{N} c_j \leq C$.

With this mechanism and at each time slot, an operator j is given $C_j(k)= c_j$ share if there it has a backlogged session. If no packet is ready, then $C_j(k)= 0$ and the unutilized capacity of an operator is not allowed to be used by other backlogged operators. This scheduling is called fixed rate M-CDGPS scheduling and the system can be viewed and multi-independent CDGPS systems. Therefore, the assigned rate for each operator is based on (2).

B. *Adaptive rate M-CDGPS*

In case of adaptive rate M-CDGPS scheduling, the residual capacity of an unbacklogged operator in time slot k is allowed to be used by other backlogged operators in a fair manner. First, operator j is given its minimum c_j as in (2) only if it has a backlogged session. Let the set of all backlogged operator is denoted by B. After allocating each backlogged operators its minimum capacity, if there are unutilized resources such that:

$$C_r(k) = C - \sum_{\forall j \in B}^{N} c_j \geq 0 \tag{3}$$

Then the excess resources are divided (distributed) amongst the backlogged operator in proportional to their g_j's such that:

$$c_e(k) = \frac{g_j C_r(k)}{\sum_{\forall i \in B} g_i} \tag{4}$$

Therefore, at each time slot k, an operator j is given a channel rate defined as

$$C_j(k) = c_j + c_e(k) \tag{5}$$

This assigned rate has a range of $c_j \leq C_j(k) \leq C$. The assigned capacity share to each operator j, $C_j(k)$, is also shared by K traffic classes or flows. Each traffic class i within each operator j has its arrival rate, queue, and maintains a connection with link rate $r_{ij}(k)$ during the k^{th} MAC slot. Each session ij is given a weight w_{ij} based on its QoS requirements. The sum of $r_{ij}(k)$ over all classes of one operator j should not exceed $C_j(k)$ (the index ij means i,j).

IV. PERFORMANCE ANANLYSIS

In this section, we analyze the performance bounds of M-CDGPS systems for operator's sessions that operate under Leaky Bucket constraint. Our next analysis of M-CDGPS follows the basic idea of GPS performance model done in [4] but is extended to cover the case of multi-operator with multi-traffic class in 3G WCDMA networks.

A. Basic assumptions

In order to achieve a bounded delay and bounded buffer size for user traffic, the operator's sessions are assumed to operate under Leaky Bucket constraint. The constraint imposed by the leaky bucket is as follows. If $A_{ij}(\tau,t)$ is the amount of session's flow *i* of operator *j* that leaves the leaky bucket and enters the network in time interval (τ ,t], then we have:

$$A_{ij}(\tau,t) \le \sigma_{ij} + \rho_{ij}(t-\tau) \quad ,\forall t \ge \tau \ge 0 \tag{6}$$

Let $S_{ij}(\tau,t)$ be the amount of session's *ij* traffic served in the interval (τ ,t]. From Fig. 3, $S_{ij}(0,t)$ is continuous and non-decreasing for all t. The session *ij* backlog at time τ is denoted by $Q_{ij}(\tau)$ and defined as:

$$Q_{ij}(\tau) = A_{ij}(0,\tau) - S_{ij}(0,\tau) \tag{7}$$

The session *ij* delay at time τ , denoted by $D_{ij}(\tau)$, is the amount of time that would take for the session *ij* backlog to clear if no session ij packets were to arrive after time τ . Thus,

$$D_{ij}(\tau) = \inf\left\{ t \ge \tau : S_{ij}(0,\tau) = A_{ij}(0,\tau) \right\} - \tau \tag{8}$$

From Fig. 3, we see that $D_{ij}(\tau)$ is the horizontal distance between curves $A_{ij}(0,t)$ and $S_{ij}(0,t)$ at the ordinate value of $A_{ij}(0,\tau)$.

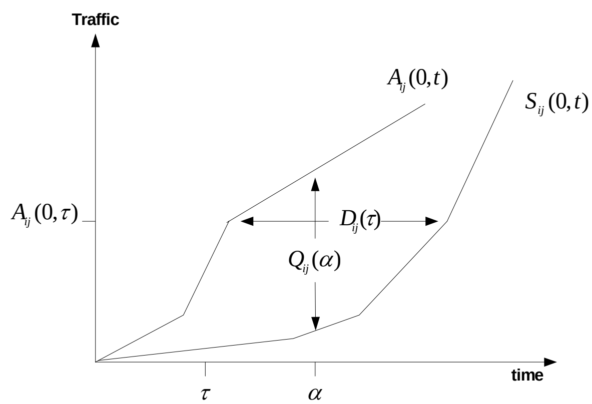

Figure 3. Defention of $A_{ij}(0,t)$, $S_{ij}(0,t)$, $Q_{ij}(\tau)$ and $D_{ij}(\tau)$ [4].

B. Performance Bounds

The problem that will be analyzed in the next subsection is as follows: Given the parameters σ_{ij} , ρ_{ij} , and w_{ij}'s of each session *ij* and g_j's of each operator for a M-CDGPS system of rate *C*, what will be the bounded delay, queue size and throughput for each session *ij*?.

1) Throughput

In case of static M-CDGPS with $\rho_{ij} \le r_{ij}$, the maximum throughput per session and per operator are as follows:

$$u_{ij} = r_{ij}; \quad U_j = \sum_i u_{ij} , \tag{9}$$

respectively. In case of adaptive scheme, the upper bound of the throughput can be higher based on the residual capacity and ρ_{ij} .

2) Delay and Queue Size Bounds

Let Q_{ij_Max} be the maximum of $Q_{ij}(t)$ and D_{ij_Max} be the maximum of $D_{ij}(t)$. The delay and backlog bound of the traffic session *i* of operator *j* can be derived using following two lemmas.

Lemma 1: if $r_{ij} \ge \rho_{ij}$, where r_{ij} is given by (1) then the maximum queue size (backlog) is

$$Q_{ij\_\max} \le \sigma_{ij} + \rho_{ij} T \tag{10}$$

Proof: Assume that session *i* of operator *j* (i.e., session *ij*) start to backlog at time t_1, such that $\tau_{k-1} < t_1 \le \tau_k$ where τ_{k-1} and τ_k are starting instant of slot (*k-1*) and slot (*k*), respectively. Assume t_m to be the time when session *ij* backlog reaches the maximum Q_{ij_Max} . Based on (6) the total amount of arrival $A_{ij}(t_1,t)$ during the interval [t_1,t_m] can be defined as

$$A_{ij}(t_1,t_m) \le \sigma_{ij} + \rho_{ij}(t_1,t_m) \tag{11}$$

According to M-CDGPS service discipline, a minimum service rate r_{ij} is assigned to session *ij* at time τ_k. Therefore, the amount of service for this session during the allowed interval [t_1,t_m] can de written as

$$S_{ij}(t_1,t_m) \ge \max(0, r_{ij}(t_m - \tau_k)) \tag{12}$$

Based on the (7) and having that $r_{ij} \ge \rho_{ij}$ we have

$$Q_{ij\_\max} = A_{ij}(t_1,t_m) - S_{ij}(t_1,t_m) \tag{13}$$

Also we have; $Q_{ij\_\max} \le \sigma_{ij} + \rho_{ij}(t_m - t_1) - \max(0, r_{ij}(t_m - \tau_k))$ and can be written as $Q_{ij\_\max} \le \sigma_{ij} + \rho_{ij}(\tau_k - t_1)$ Also we have $\tau_{k-1} < t_1 \le \tau_k$, $\tau_k - \tau_{k-1} = T$ and $\tau_k - t_1 < T$, hence the maximum backlog can be written as:

$$Q_{ij\_\max} \le \sigma_{ij} + \rho_{ij} T \tag{14}$$

Using lemma 1 the following lemma specifying the delay bound of session *ij* can be obtained.

Lemma 2: if $r_{ij} \ge \rho_{ij}$, where r_{ij} is given by equation (1) then the packet delay bound of session *ij* is:

$$D_{ij\_\max} \le \frac{\sigma_{ij}}{r_{ij}} + T \tag{15}$$

Proof: Let $D_{ij}(t_2)$ the delay experienced by traffic of session *ij* arrived at time t_2, where $t_2 \ge t_1$. As stated before, the session *ij* starts backlog at time t_1, such that $\tau_{k-1} < t_1 \le \tau_k$.

From the definition of delay in (8) and since the session *ij* starts backlog at time t_1, we have, $A_{ij}(t_1,t_2) = S_{ij}(t_1, t_2 + D_{ij}(t_2))$

Also since $Q_{ij}(t_2) = A_{ij}(t_1,t_2) - S_{ij}(t_1,t_2)$ and $S_{ij}(t_1, t_2 + D_{ij}(t_2)) = S_{ij}(t_1,t_2) + S_{ij}(t_2, t_2 + D_{ij}(t_2))$ where $A_{ij}(t_1,t_2) - S_{ij}(t_1,t_2) = S_{ij}(t_2, t_2 + D_{ij}(t_2))$, we have

$$Q_{ij}(t_2) = S_{ij}(t_2, t_2 + D_{ij}(t_2)) \tag{16}$$

Now we have two cases for t_2:

Case 1($t_2 \geq \tau_k$ *):* During the interval [t_2, $t_2 + D(t_2)$], the M-CDGPS scheduler can guarantee a minimum rate r_{ij} to session *ij*, hence we have $S_{ij}(t_2, t_2 + D_{ij}(t_2)) \geq r_{ij} D_{ij}(t_2)$ using (16) and from lemma 1 we know that $Q_{ij\_\max} \leq \sigma_{ij} + \rho_{ij} T$ Thus we have $D_{ij}(t_2) \leq \frac{\sigma_{ij} + \rho_{ij} T}{r_{ij}} \leq \frac{\sigma_{ij}}{r_{ij}} + \frac{\rho_{ij} T}{r_{ij}} \leq \frac{\sigma_{ij}}{r_{ij}} + T$, or

$$D_{ij}(t_2) \leq \frac{\sigma_{ij}}{r_{ij}} + T \tag{17}$$

Case 2($t_2 < \tau_k$): Using the backlog definition in lemma1, $Q_{ij}(t_2) \leq \sigma_{ij} + \rho_{ij}(t_2 - t_1)$. Now (12) can be rewritten as $S_{ij}(t_2, t_2 + D_{ij}(t_2)) \geq r_{ij}[D_{ij}(t_2) - (\tau_k - t_2)]$, $D_{ij}(t_2) \leq \frac{\sigma_{ij} + \rho_{ij}(t_2 - t_1)}{r_{ij}} + (\tau_k - t_2)$. Having $r_{ij} \geq \rho_{ij}$, $D_{ij}(t_2) \leq \frac{\sigma_{ij}}{r_{ij}} + (\tau_k - t_1)$, and $(\tau_k - t_1) \leq T$, therefore,

$$D_{ij}(t_2) \leq \frac{\sigma_{ij}}{r_{ij}} + T \tag{18}$$

From (17) and (18), we can conclude that the maximum delay is bounded by $\frac{\sigma_{ij}}{r_{ij}} + T$.

V. Simulation and Numerical Results

In this section, the simulation results are presented to demonstrate the performance of the proposed M-CDGPS scheme in terms of delay and system throughput. Further, the theoretical delay bound is also compared with the maximum delay obtained by simulation. Perfect power control on the WCDMA uplink and error-free channels are assumed. The scheduling period *T* is 10 ms whereas, the total bandwidth is assumed to be a constant *C* = 5Mbps. Three operators are considered and each operator is assigned different weight based on SLA. We assume that each operator is given (g_j=1/3) of the bandwidth as a minimum. To ensure reaching steady, each simulation will run with more than 5,000,000 incoming calls. Poisson process with CBR traffic model is commonly used in the literature for validating the correctness and fairness of packet scheduling algorithms by observing whether the proportion of resources (bandwidth) obtained by each operator's flow is consistent with its scheduling parameter.

All operator's flows are modeled by a Poisson process with average arrival rate λ packets per second, and packet length *L* shaped by a leaky-bucket regulator for providing bounded delay. In this simulation, packet size *L* is equal to 512 bits, σ_{ij} =100L, ρ_{ij} = *C*/3= 3220 token/sec, and λ can be varied in order to change the system load. One resultant flow per operator is assumed in order to focus on the performance aspect of sharing resources among operator. The M-CDGPS scheme is compared in case of adaptive rate and static rate.

In the following experiment, the performance comparison between static and adaptive M-CDGPS in terms of system throughput and delay are described. The traffic loads of operator 2 (OP2) and operator 3 (OP3) are fixed to 512 Kbps and the traffic load for operator 1 (OP1) is varied. The system throughput and the average packet delay against the total offered traffic of OP1 are depicted in Fig. 4 and Fig. 5, respectively. A long range of offered traffic is used in order to observe the system behavior at low and high traffic loads. As expected, the throughput of adaptive rate M-CDGPS is higher in case of using adaptive rate because of utilizing the residual resources of other operators. Hence the system throughput increases. Also, we can note that, the throughput is linearly increases as the offered traffic increase. When the saturation point is reached, the OP1 flow is limited to its minimum assigned rate (3220 packets/sec).

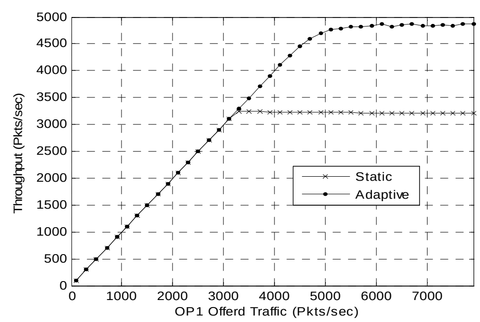

Figure 4. System throughputs

This is explained as follows. When we have $\rho_{ij} \leq r_{ij}$, the minimum assigned rate will be limited by ρ_{ij}. Since we have $\rho_{ij} \leq r_{ij}$, then theoretical maximum throughput in case of static M-CDGPS is ρ_{ij} =3220 packets/sec. The value observed by the simulation is 3217 packets/sec which is approximately equal to the the theoretical limit. When is residual capacity exists in case of adaptive rate M-CDGPS, the throughput will be more due to the utilization of this unused capacity.

Fig. 6 shows the average delay, maximum delay and theoretical bounds at low and high loads. In this figure, it can be seen that the average delay performance of adaptive M-CDGPS is better than M-CDGPS with a static capacity per operator. In adaptive M-CDGPS, the residual resources can be distributed amongst the backlogged flows. Therefore, more packets can be served. Moreover, in this figure, it can be seen that the theoretical delay bounds gives the right delay bound for maximum delay of the system. At low to moderate low packet traffic, the maximum delay is less than the theoretical delay bound.

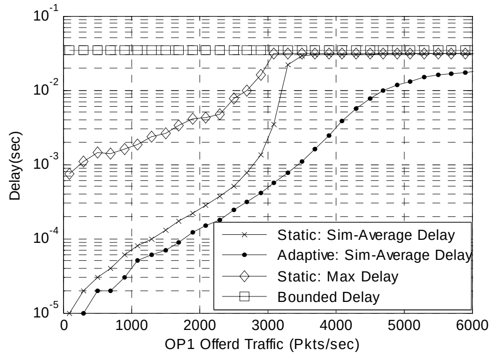

Figure 5. Average, maximum and theoretical bound of OP1's flow delay

The maximum delay and the theoretical delay bounds for the operator's flow as a function of token bucket size are also investigated. We plot OP1 as an example and the other operator's figures will have the same behavior. As shown in Fig. 6, the maximum delay and the theoretical delay bound increase as the token bucket size increase. At the same time, as the token bucket size increase, the theoretical delay bound, bounds well the maximum delay for the operator traffic flow. This validates the accuracy of both simulation and theoretical results.

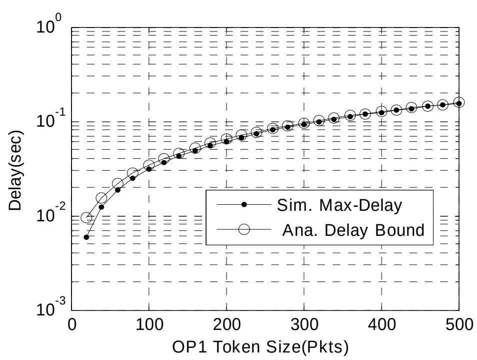

Figure 6. Theoretical delay bound and maximum delay for OP1's flow.

From all these previous figures, we can conclude that, the adaptive M-CDGPS is superior to the static one with respect to delay performance and throughput. In addition, the derived theoretical delay bound gives an accurate estimate for the maximum delay bounds of the system.

VI. CONCLUSION

An efficient M-CDGPS scheme is proposed for the uplink of WCDMA cellular networks with multi-operators. Two modes of M-CDGPS known as static rate M-CDGPS and adaptive rate M-CDGPS are analyzed and evaluated. Performance bounds for throughput, buffer size, and delay are derived and a comparison is presented between the two algorithms. Analysis and simulation results show that bounded delay can be provisioned for the operator's traffic in both schemes. Moreover, the simulation results show that the adaptive rate M-CDGPS scheme improve both system utilization and average delays.

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