DYNAMIC BANDWIDTH SCHEDULING FOR WCDMA UPLINK TRANSMISSION

Henry O. Osuagwu, Augustine C. Ajibo, Stephen O. Ugwuanyi, Juliana Nwachi-Ikpo, Cosmas I. Ani

Abstract—Providing quality of service is a challenging issue in UMTS mobile networks for multimedia traffic (video, voice and data). Critical services such as real-time audio, voice and video are given priority over less critical ones, such as file transfer and web surfing. One of the approaches that efficiently provide standard quality of service for multimedia traffic in wireless networks is to dynamically allocate bandwidth to varying traffic load and channel conditions. There are several of such dynamic bandwidth allocation approaches developed in the recent time by researchers. The choice of which one to implement at an instance and for a specific condition is an issue in mobile communication networks. In this work, the popular Code-Division Generalized Processor Sharing (CDGPS) was analyzed. The CDGPS variations – priority and non-priority – were compared, the two techniques were modelled and simulated using MATLAB Simulink object oriented environment. Simulation results show that priority CDGPS provides the best performance and improvement in the delay and loss rate, while still maintaining a high bandwidth utilization of percentage value of 90.2%.

Index Terms— CDGPS, EDGE, GPRS, GSM, Scheduling, UMTS, WCDMA

1. Introduction

Today, mobile communications play a central role in the voice/data network arena. From the early analog mobile first generation (1G) to the third generation (3G) the standard has changed. The new mobile generations do not pretend to improve the voice communication experience but try to give the user access to a new global communication reality [1]. The aim is to reach communication universality and to provide users with a new set of services. The cellular networks are evolving through several generations; the first generation (1G) wireless mobile communication network was analog system which was used for public voice service with the speed up to 2.4kbps. The second generation (2G) is based on digital technology and network infrastructure. As compared to the first generation, the second generation can support text messaging [2]. Its success and the growth of demand for online information via the internet prompted the development of cellular wireless system with improved data connectivity, which ultimately leads to the third generation systems (3G). Overtime users and applications have had demand for more communication power. As a response to this demand a new generation with new standards has been developed-third generation (3G). Third Generation (3G) networks offer greater security than their 2G predecessors. By allowing the UE (User Equipment) to authenticate the network it is attaching to, the user can be sure the network is the intended one and not an impersonator [3]. Third generation (3G) mobile communication system, called Universal Mobile Telecommunication System (UMTS) within European Telecommunication Standard Institute ETSI/Europe, aim to support a wide range of voice and data services, focusing on mobile packet switched data services based on Internet Protocol (IP) technology [4]. Third Generation Technology was developed in order to face up to the new requirements of services that were coming, as high-quality images and video or to provide access to the Web with higher data rates. Third-generation radio access technologies aim to provide the commercial market with high quality, efficient and easy-to-use wireless mobile multimedia services [5]. Since the third-generation (3G) mobile radio systems could provide high data rate services with a maximum data rate of 2 Mbps, it became imperative that it could be used in several multimedia applications such as voice, audio/video, graphics, data, Internet access, and e-mail. Resource available in 3G network is limited and as such there is need to properly manage them. Radio Resource Management functions are highly interrelated and coupled as long as they are all influencing the air interface. Since the objectives of the Radio Resource Management scheme are to achieve acceptable QoS levels for the user application traffic and to design efficient radio resource utilization. In order to achieve an efficient utilization of radio resource, it is very important to clearly identify the QoS requirements of services and the characteristics of user traffics. Based on these, the overall performance can be improved by efficiently combining different Radio Resource Management functions. Packet scheduling is also a very

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important aspect of radio resource management in packet switched wireless networks. It interacts with other RRM control functions in order to ensure that the user quality of service (QoS) requirements are respected. The nature of a scheduling framework can greatly impacts the QoS levels that can be provided in the system. Based on dynamic changes in the network topology and different types of heterogeneous access networks, next-generation wireless networks must be able to support the multimedia communications of multiple QoS requirements, and simultaneously ensure high system throughput and low transmission delay [6]. These require a scheduling technology of wireless networks with very high specific performance. Since there will be different kinds of users in wireless networks, each with its distinct QoS demands, basically due to some of the applications users will be accessing on their devices. These users will therefore require certain characteristics from the assigned radio resources in order to work, while some other users application may be are more insensitive. This raises the need for assigning resources in a smart way, to meet the requirements of the users and also to utilize the available resources most efficiently.

Several scheduling scheme exist in literature but the Generalized Processor Sharing (GPS) have proven to provide more flexibility in bandwidth allocation as they ensure fairness while dynamically allocating resources. Amidst the qualities of the GPS it has over time failed in addressing the issue of backlogged flow loss rate. In this paper, we propose a noble Code-Division Generalized Processor Sharing (CDGPS) scheme to critically handle the aforementioned issues associated with the GPS.

The outline of this paper is as follows. Section 2 presents a short survey of the related works and our proposition. Section 3 presents an overview of the proposed model and the performance metrics of the QoS. Section 4 displays and discusses the simulation results. Finally, Section 5 concludes the paper.

2. State of the Art

Radio Resource Management (RRM) techniques are used to improve the utilization of radio resources of the wireless network [7], [8]. RRM operations include essential functions like admission control, congestion control, power control, handover management, radio resource allocation and transmission parameters management [8]. Radio Resource Management functions are highly interrelated and coupled as long as they are all influencing the air interface. Since the objectives of the Radio Resource Management scheme are to achieve acceptable QoS levels for the user application traffic and to design efficient radio resource utilization.

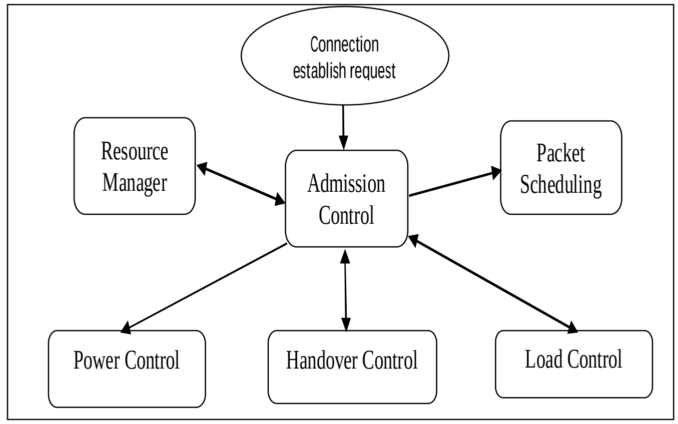

Fig. 2.1: Radio Resource Management Functions Interaction [9]

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There will be different kinds of users in wireless networks, which do have distinct quality of service demands. Some applications require certain characteristics from the assigned radio resources in order to work, while others are more insensitive. This arises the need for assigning resources in a smart way, to meet the requirements of the users and also to utilize the available resources most efficiently.

Schedulers are capable of improving transmission for certain services. However, this improvement is at the expense of worse performance for other services. This fact is revealed by the conservation law. Consider a set of N connections at a scheduler. Traffic at i arrives at a mean rate λ_i and the mean service time for a packet from connection i is x_i.

Then $p_i = \lambda_i \cdot x_i$ is the mean utilization of the link due to connection i. If the mean waiting time for packets of connection i is denoted as q_i, then the conservation law becomes:

$$\sum_{i=1}^{N} p_i \cdot q_i = const \quad (2.1)$$

Since this equation is independent of the scheduling discipline, reduction of the delay for a certain connection results in a higher delay of other connections. In WCDMA, packet scheduling algorithms can be done in two ways, in a time or code division manner.

2.1 Related works

IP-based network entities integrated voice and data on unified IP backbone, which can increase the resource utilization over existing mobile networks. WCDMA radio access network must manipulate the delay-sensitive real-time packets to provide IP multimedia service. Several scheduling schemes have been proposed in the literature for IP-based radio access networks in WCDMA to efficiently utilize radio resources.

Skoutas and Rouskas [13] proposed a Dynamic Priority Allocation scheduling algorithm, which is designed to operate within a cross-layer framework that provides Dynamic Priority Allocation (DPA) with the necessary information in order to take into account the variations of the wireless channel. The proposed scheme is designed for QoS provisioning in the Downlink-Shared Channel (DSCH) in WCDMA 3G systems. The QoS differentiation between connections is based on their delay sensitivity and head-of-line (HOL) packet delay. The DPA scheme has low computational complexity and provides fair distribution of the available DSCH capacity to the connections. By providing a guaranteed rate per traffic flow at each scheduling period, DPA is able to offer a deterministic delay bound to each session when the transmission is constantly reliable and a stochastic delay bound for identical DSCH connections with certain constraints. Simulation results demonstrate Dynamic Priority Allocation (DPA) fairness property and its efficiency.

Wan, Shih and Chang [14] proposed three real-time scheduling algorithms to support quality-of-service at IP-based radio access networks for the UMTS. The real-time generic scheduling (RTGS) algorithm applies the functionalities of the radio management framework to establish new data sessions for real-time service requests. The real-time bandwidth scheduling (RTBS) algorithm implements the early-deadline-first (EDF) scheme to do the schedulability analysis and to schedule the data sessions to reduce power consumption. The real-time code scheduling (RTCS) algorithm applies Dynamic Code Assignment (DCA) scheme to improve radio resource utilization. Experimental results show that, under various traffic loads, RTCS performs best in terms of power consumption, session drop rate and bandwidth utilization. It also shows that RTBS outperforms RTGS.

Chandramathi, Raghuram, Srinivas and Singh [15] proposed a fuzzy logic (FL)-based dynamic bandwidth allocation algorithm for multimedia services with multiple quality of service QoS: Probability of blocking (P_B), Service access delay (SAD), Access delay variation (ADV) and the arrival rate requirements. In this algorithm, each service can declare a range of acceptable quality of service levels (e.g. high, medium, and low). As quality of service demand varies, the proposed algorithm allocates the best possible bandwidth to each of the services. This maximizes the utilization and fair distribution of resources. Simulation results show that the required quality of service can be obtained by appropriately tuning the fuzzy logic controller (FLC).

Xu, Shen and Mark [16] proposed a code-division generalized processor sharing (CDGPS) fair scheduling dynamic bandwidth allocation (DBA) scheme for WCDMA systems. The scheme exploits the capability of the WCDMA physical layer by allowing channel rates to be dynamically and fairly scheduled by varying the spreading factor and/or using multiple code channels, rather than allocating service time to each packet. Analysis and simulation results of the model shows that bounded delay can be provisioned for real-time application by using generalized processor sharing (GPS) service discipline, while high utilization of system resources is achieved.

Gürbüz and Owen [17] proposed Dynamic Resource Scheduling (DRS) Scheme as a framework that will provide quality of service provisioning for multimedia traffic in W-CDMA systems. This scheme is an extended DRS family that is aimed at examining the temporal quality of service in terms of delays. The DRS framework monitors the traffic variations and adjusts the transmission powers of users in an optimal manner to accommodate different service classes efficiently. Variable and optimal power allocation is also suggested to provide error requirements and maximize capacity, while prioritized queuing is introduced to provision delay bounds. Simulations of this scheme shows that the delay performance can be provisioned for guaranteed services by multiple queues.

Xu, Shen and Mark [18] proposed a credit-based CDGPS (C-CDGPS) scheme to further improve the utilization of the soft capacity by trading off the short-term fairness. With the C-CDGPS scheme, the soft uplink capacity is allocated by using a combination of credit-based scheduling and CDGPS fair scheduling. The model considered a frequency division duplex (FDD) Wideband DS-CDMA network supporting a large number of multimedia users. Packetized multimedia traffic is considered. Simulation results shows that bounded delays, increased throughput, and long-term fairness can be achieved for both homogeneous and heterogeneous traffic.

ISSN 2229-5518

Xu, Shen and Mark [19] proposed a dynamic fair resource allocation scheme to efficiently support real-time and non-real-time multimedia traffic with guaranteed statistical quality of service (QoS) in the uplink of a wideband code-division multiple access (CDMA) cellular network. The scheme provides a trade-off between the Generalized Processor Sharing (GPS) fairness and efficiency in resource allocation to maximize the radio resource utilization under the fairness and quality of service constraints. Analysis and simulation results show that, in a multipath fading environment, the proposed scheme can reduce the inter-cell interference, increase the network capacity, guarantee a statistical delay bound for real-time traffic and a statistical fairness bound for non-real-time users.

Salman [20] proposed a Multi-operators Code Division Generalized Processor sharing (M-CDGPS) scheme for supporting Multiservice in the uplink of WCDMA cellular networks with multi-operators. The scheme employs both adaptive rate allocation to maximize the resource utilization and Generalized Processor Sharing (GPS) techniques to provide fair services for each operator. The simulation results show that the proposed scheme improve both system utilization and average delays. The proposed scheme allows for a flexible trade-off between the GPS fairness and efficiency in resource allocation and is an effective way to maximize the radio resource utilization under the fairness and QoS constraints.

3. System Model

A code-division generalized processor sharing (CDGPS) is proposed for WCDMA systems, to support differentiated quality of service (QoS) with a central controller that can dynamically allocate bandwidth to mobile users according to the variation of channel condition and traffic load. The CDGPS scheduler makes use of both the traffic characteristics in the link layer and the adaptivity of the WCDMA physical layer to achieve efficient utilization of radio resources. It adjusts only the channel rate (service rate) of each traffic flow in the WCDMA system by varying the spreading factor and/or using a multiple of orthogonal code channels, rather than allocating service time to each packet. This results in lower implementation complexity of the CDGPS scheme than for a conventional GPS-based time scheduling scheme.

The system model considered in this work, is the frequency division duplex UMTS cellular network (UMTS-FDD) where user equipment (UE) are interconnected with the Internet through Node B, Radio Network Controller (RNC) and core network, as shown in fig. 3.1. The radio link in the UMTS-FDD system can be characterized by orthogonal channels in the downlink (from Node B to UE) and multiple access channels in the uplink (from UE to Node B). A pair of bandwidth schedulers are assumed to reside in each Node B. The schedulers allocate the power and respective rate of the channels in the downlink and uplink to all UEs in the same cell covered by Node B. Although the capacity of the downlink is equal to the uplink capacity, the discussion in this work only focuses on the uplink.

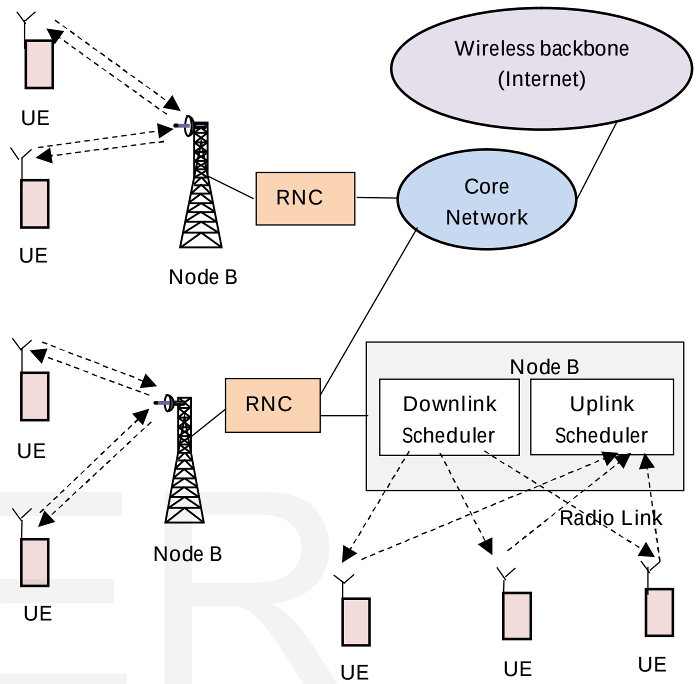

Fig. 3.1: Network Structure

The network architecture illustrated in fig. 3.1 was adopted for this work. Multimedia IP traffic (e.g., voice, video, and data) are supported by this network. In a multimedia IP traffic, the quality of service requirements general consist of two parts: Delay and Loss rate.

3.1 The Code-Division Generalized Processor Sharing (CDGPS) Scheme

The proposed scheme in this research work is the code-division generalized processor sharing (CDGPS) fair scheduling scheme. This scheme uses the GPS fair scheduling discipline to dynamically allocate channel rates. The model of fig. 3.2 comprise of a server of capacity, *C* Mbps. The input traffic is from varied sources comprising of voice, video, and data traffic, which are bundled into flow classes. Each flow maintains a connection with link rate $C_i(k)$ during the k^{th} time slot. The sum of $C_i(k)$ over all users should not exceed *C*.

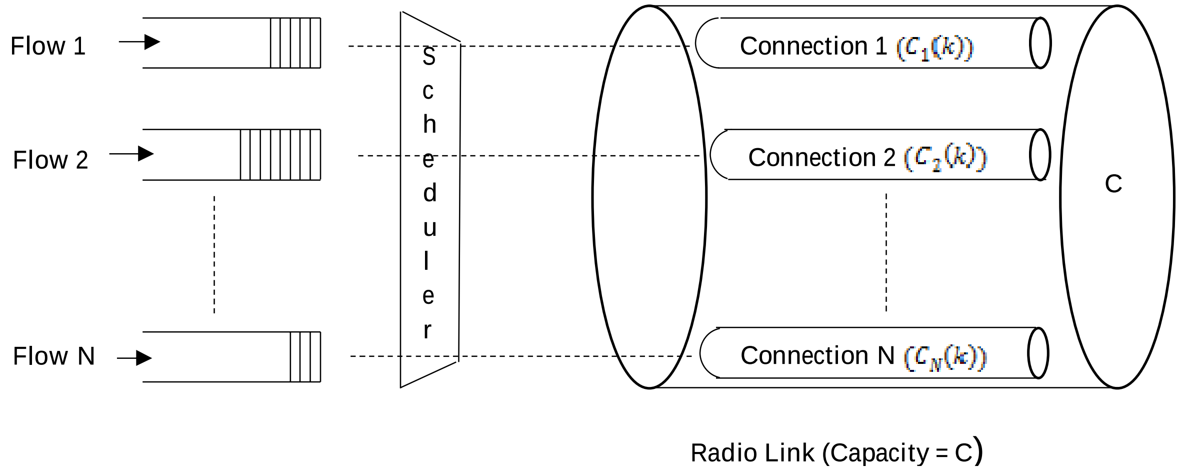

Fig. 3.2: A queuing model of the CDGPS scheme

For each slot, the scheduler allocates adequate service rates to the *N* flows, using the following scheduling procedure:

➢ Let the pre-assigned weight for flow i be $\phi_i, i = 1,2,\dots,N$ and $S_i(k)$ to denote the amount of session i traffic that would be served during time slot *k*. According to the GPS scheduling discipline, Eq. (3.1) should hold for any flow i that is continuously backlogged in the time slot *k*. Then, the proposed CDGPS server allocates each $C_i(k)$ using the following steps:

Step 1: Let $B_i(k)$ be the total amount of backlogged traffic of flow i during time slot *k*. Estimate $B_i(k), i = 1,2,\dots.N$, as follows:

$$B_i(k) = Q_i(\tau_k) + r_i(k)T \qquad (3.1)$$

Where τ_k is the end time of slot $(k-1)$,

$Q_i(\tau_k)$ = Backlogged traffic at time τ_k,

$r_i(k)$ = Estimated traffic arrival rate of flow i during time slot *k*.

The estimated traffic arrival rate $r_i(k)$ of flow i during time slot k can be estimated from past traffic measurement using the following two approaches:

1. One-step estimation – the estimated traffic arrival rate is thus:

$$r_i(k) = \frac{a_i(k-1)}{T} \qquad (3.2)$$

Where $a_i(k-1)$ is the total amount of the arrival traffic (in bits) during time slot $(k-1)$.

2. Exponential averaging –Let t_i^n and l_i^n be the arrival time and length of the n^{th} packet of flow i, respectively. The estimated rate of flow i, r_i, is updated every time a new packet arrives:

$$r_i^{new} = \left(1 - e^{-T_i^n/K}\right)\frac{L_i^n}{T_i^n} + e^{-T_i^n/K} \cdot r_i^{old} \qquad (3.3)$$

Where $T_i^n = t_i^n - t_i^{n-1}$ and K is a constant. An approximate value for K would be between 100 and 500 ms.

T_i^n = Inter packet arrival time.

Step 2: Based on the estimated $B_i(k), i = 1,2,\dots,N$, the expected amount of service $S_i(k)$ received by ith user is determine thus:

$$S_i(k) = \begin{cases} 0, & if\ B_i(k) = 0 \\ g_i T, & if\ B_i(k) > 0 \end{cases}$$

where T is the scheduling period in CDGPS scheme,

$$g_i(k) = \frac{\phi_i C}{\sum_{j=1}^{N}\phi_j} \qquad (3.4)$$

is the minimum guaranteed rate of flow i and *C* is the network capacity.

If $\sum_{i=1}^{N} S_i(k) < CT$, then the remaining network resource is distributed proportionally to users who expect more than their guaranteed service rate. The distribution of the remaining network resources should be in proportion to each user's weight ϕ_i according to the GPS service discipline. The allocated channel rate to user i can then be determined by equation (3.6).

$$C_i(k) = \frac{S_i(k)}{T} \qquad (3.5)$$

The CDGPS scheme weights are related as $(\phi_1 = {\phi_2}/{2} = {\phi_3}/{3})$, that is, different priority values, with $\phi_3 \geq \phi_2 \geq \phi_1$, where ϕ_3 corresponds to highest priority and ϕ_1 corresponds to the lowest priority [22]. These values (1, 1/2, 1/3) do not guarantee the maximum data transmission under UMTS platform (384 Kbps). Therefore, a different set of values (1/5, 1/3, 1/2) that better utilize the available bandwidth in UMTS is presented. Where1/5 corresponds to the lowest priority and 1/2 corresponds to the highest priority.

The priority CDGPS scheme flowchart is depicted in fig. 3.3. The only difference between priority and non-priority CDGPS flowcharts is the different ways in which the backlogged flows $B_i(k)$, are sorted. For priority CDGPS, the backlogged flows are sorted by decreasing order of weight ϕ_i, while for non-priority CDGPS, the backlogged flows are sorted by first-come-first-serve (FCFS) order of weight ϕ_i. After the sorting operation, the first flow from the sorting list is removed. If the total amount of traffic of flow i is greater than zero and the condition in equation 3.2 satisfied, then the estimated rate of flow i is updated every time a new packet arrives, otherwise the sorting list is empty. The expected amount of service $S_i(k)$ by ith user is received based on the estimated amount of traffic of flow i. If the sorting list is empty and the total amount of traffic of flow i is equal to zero, then the amount of service received by ith user is zero

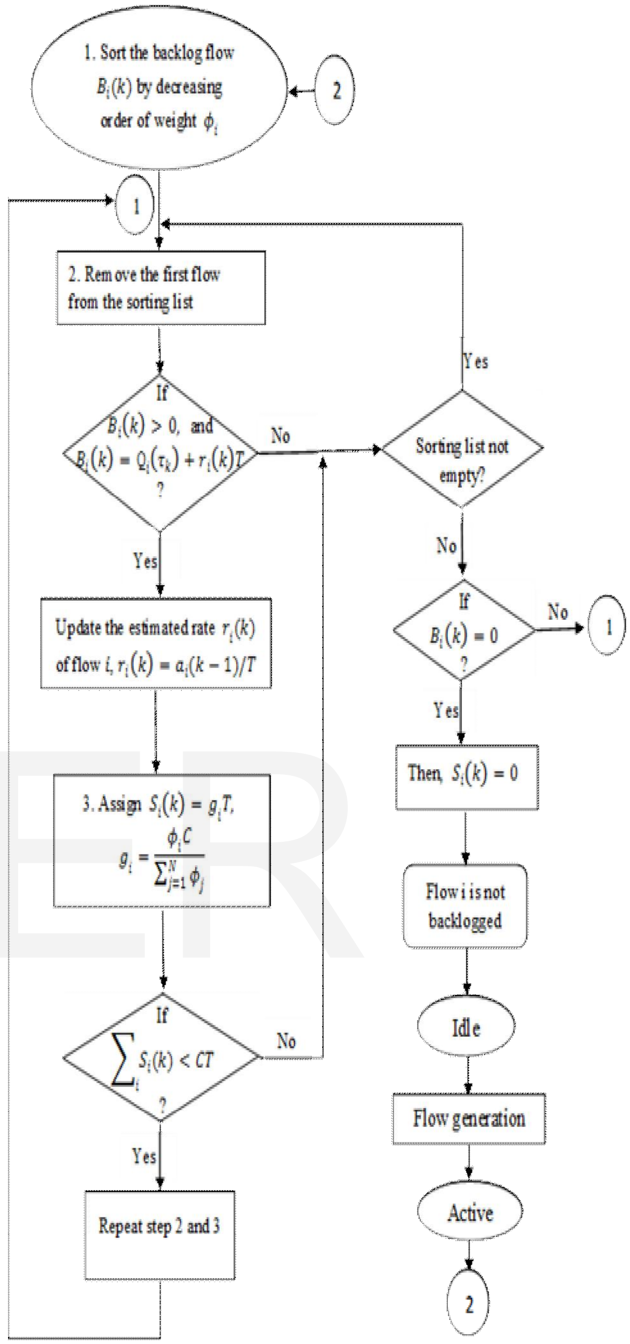

Fig. 3.3: Priority CDGPS flowchart

Table 3.1 Simulation parameters

Parameters	Value
Radio access mode	WCDMA (FDD) uplink
Chip rate	3.84 Mcps
Spread spectrum	5.0 MHz
WCDMA channel rate	2.0 Mbps
Slot duration	0.667 ms
Frame duration	10 ms
Voice source rate	16 Kbps
VBR video source rate	16 to 384 Kbps
Data source rate	256 Kbps
Voice active factor	0.4
Packet arrival	Poisson
Packet generation type	Exponential
Queue type	FIFO
TTI	100

4. Simulation Results

In this section, simulation results are presented to demonstrate the performance of the proposed CDGPS in terms of delay, throughput, loss rate, and utilization. In the simulation, two different scenarios (priority and non-priority) CDGPS scheme were compared under heterogeneous traffic environment. The uplink capacity is assumed to be a constant $C = 2\,Mbps.$ Voice, video, and data traffic were considered for the two scenarios. In priority CDGPS, different set of weight ϕ_i values (1/2, 1/3, 1/5) are assigned to voice, video and data respectively, while in the non-priority CDGPS, equal weight 1/3 is assigned to voice, video and data. In the simulation results, a percentage value is used to compare the performance of the two scenarios.

4.1. Throughput for priority and non-priority CDGPS

Fig. 4.1 shows the throughput comparison of priority and non-priority CDGPS. The traffic intensity is the sum of the average arrival rate of the three service class. It is shown that an increase in traffic intensity results in an increase in throughput but the priority CDGPS do not offer any improvement on the uplink throughput.

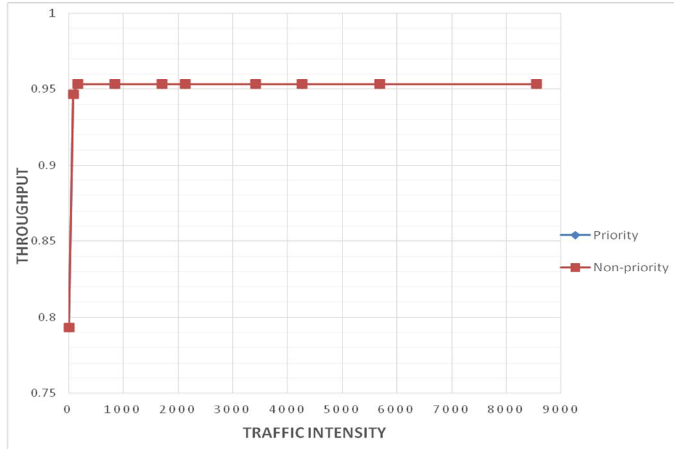

Fig. 4.1: Throughput as a function of Traffic intensity for multimedia IP traffic

4.2 Throughput per flow as a function of traffic intensity

In fig. 4.2, the throughput per flow as a function of traffic intensity is shown. It can be seen that CDGPS scheduler can fairly allocates service rate to different flows, according to their assigned weight. This demonstrates the weighted fairness property of code-division generalized processor sharing (CDGPS).

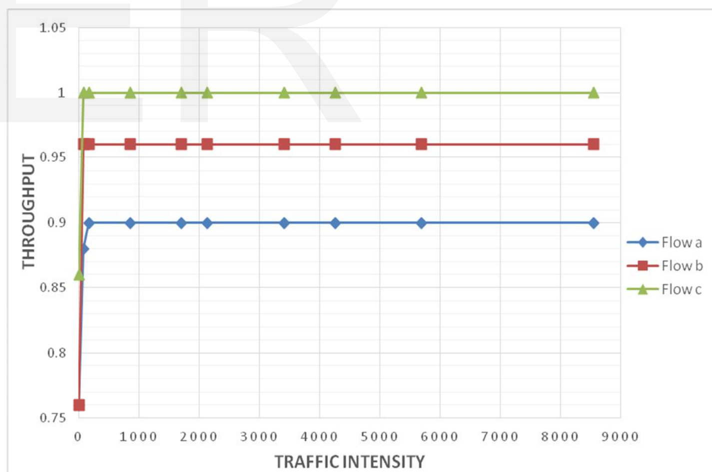

Fig. 4.2: Throughput per flow as a function of traffic intensity

4.3 Average delay as a function of Traffic intensity

Fig. 4.3 shows the average delay of a heterogeneous traffic (voice, video and data) as a function of traffic intensity. The delays considered in this heterogeneous traffic mixed are the queuing and transmission delays. As shown in the fig. 4.3, the average delay of priority CDGPS is better than that of non-priority CDGPS by a percentage value of 52.8% from the point when the average delay remains constant. This constant delay results from the CDGPS scheduler ability to distribute the unused resource more effectively among the backlogged flows (active user). Therefore, resulting to an efficient bandwidth utilization.

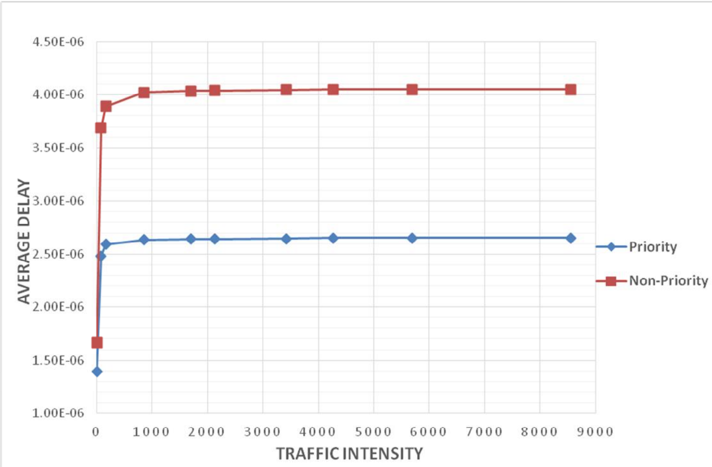

Fig. 4.3: Average delay as a function of Traffic intensity

4.4 Loss rate as a function of traffic intensity

Fig. 4.4 compares the performance achieved by priority and non-priority CDGPS for multimedia IP traffic (voice, video and data). The priority CDGPS provides best performance by a percentage value of 3.5% as the scheduler tends to allocates many bits per frame for higher priority users in priority CDGPS, regardless of the system traffic. The traffic loss is independent of the packet size but only depends on traffic arrival rate.

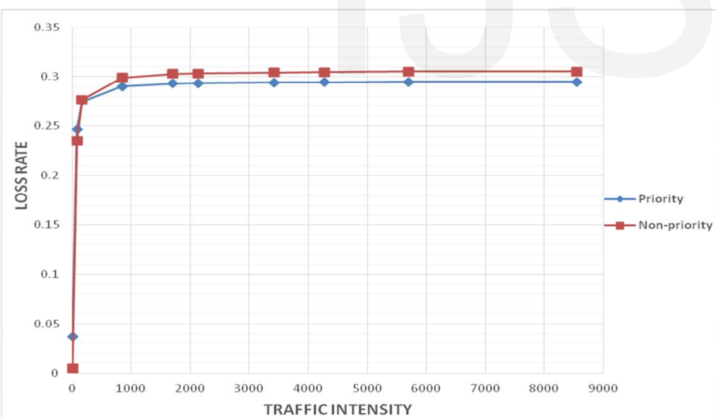

Fig. 4.4: Loss rate as a function of traffic intensity

4.5 Backlogged flow loss rate as a function of traffic intensity

Fig. 4.5 compares the backlogged loss rate for both priority and non-priority CDGPS. To verify backlogged loss rate, if all flows or users are in backlogged mode (i.e. have data to send in their sending queues). A metric called inter-service time, which is the interval that a backlogged users experience, measured in time frames between two successive transmissions. It can be observed that, as the N number of backlogged flows increases with respect to the inter-arrival time, the loss rate also increases. The observation from fig. 4.5 shows that, priority CDGPS outperform non-priority CDGPS by a percentage values of 3.5% irrespective of the number of backlogged flows. This implies that, the backlogged loss rate can be improved on by prioritization so that more packets can be served.

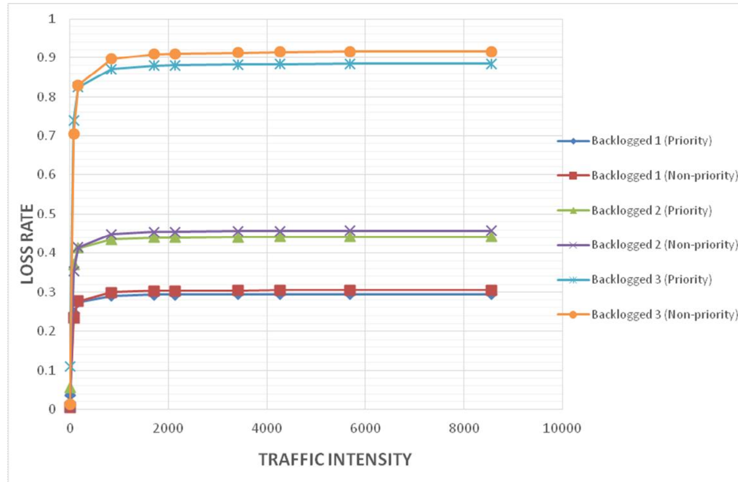

Fig. 4.5 Backlogged flow loss rate as a function of traffic intensity

4.6 Bandwidth utilization as a function of traffic intensity

Another important measure for network provider is the service utilization, shown in fig. 4.6. Non-priority CDGPS outperform priority CDGPS by a percentage value of 0.92%. As expected, the bandwidth utilization decreases with prioritization of multimedia IP traffic (i.e. voice, video and data). This is due to the extra work done by priority CDGPS, by dynamically controlling priority level of queued calls and thus preventing one traffic class from being adversely affecting other service class. Furthermore, the priority CDGPS was still able to maintain a high bandwidth utilization of 98.2%.

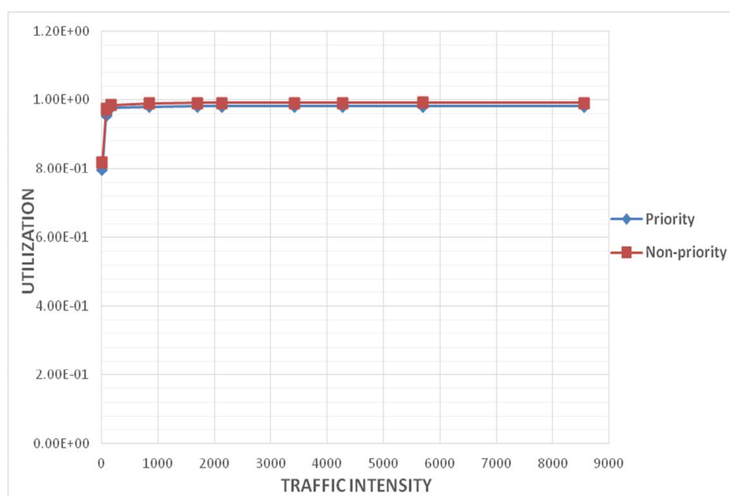

Fig. 4.6 Bandwidth utilization as a function of traffic intensity

International Journal of Scientific & Engineering Research, Volume 8, Issue 2, February-2017
ISSN 2229-5518

5. CONCLUSION

The proposed CDGPS scheduling algorithm, presents a different set of priority values that better utilize the available bandwidth in UMTS system. Results showed that the design satisfied the requirements and fulfills the objectives of a scheduler which include: support of simultaneous operation of different types of services to the same terminal according to their QoS requirements, fair distribution of resources in the network, within the same traffic class connections but also between different traffic class connections; possibility to prioritize resource allocation to connections that have not been allocated resources in the previous scheduling connections due to insufficient resources and Optimization of network bandwidth utilization.

The results also obtained demonstrate the performance of the proposed scheme in terms of the delay, throughput, and loss rate. It shows that bounded delay can be establish by given priority for real time application when GPS service discipline is used, while high utilization of the bandwidth can still be achieved.

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