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FAIR SCHEDULING WITH DYNAMIC RESOURCE ALLOCATION IN CDMA/GPS SYSTEM FOR IP-MULTIMEDIA WIRELESS NETWORKS

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Over the last few years, research has provided the cellular network system with the capability of fair channel access to multimedia users, while at the same time, insuring a given QoS and optimal utilization of network resources. Scheduling policies play a crucial role in achieving desired QoS goals and optimum utilization of limited resources. Many scheduling approaches have been proposed for the efficient utilization of the network resources. This paper deals with the experimental study of a new proposed scheduling policy for achieving fairness, QoS, and optimal use of resources. The proposed scheduling policy Code Division Multiple Access based on Generalized Processor Sharing with Dynamic Weights (CDMA/GPS-DW) is an improvement of a previous GPS policy. Simulation results show that the proposed policy achieves fairness of the specified QoS and makes efficient use of the network resources.

Keywords: QoS; fair scheduling; CDMA; GPS; wireless networks.

1. Introduction

In recent years, there has been a tremendous growth in the wireless mobile networking environment. With increasing usage of mobile and wireless networks in both indoor and outdoor environments. The issue of providing fair channel access among multiple contending Mobile Terminals (MTs) over a scarce and shared wireless channel has surfaced. In wireline networks, fair scheduling has long been a popular paradigm for providing fairness and bounded delay link access. However, adapting fair scheduling to the wireless domain is nontrivial because of the unique problems in wireless channels, such as location-dependency and burstiness of errors, and channel contention. Consequently, the scheduling algorithms proposed in literature for wireline networks do not apply directly to wireless networks.

Wireless channel access and scheduling policies are two critical and essential components in the design of wireless networks. The key issues in wireless channel access are the following: (a) channel capacity is time varying, (b) channel errors are location-dependent and bursty in nature, (c) there are hidden and exposed MTs, and (d) the scheduling algorithm must take care of both uplink and downlink flows. Thus, any wireless scheduling and channel access algorithm must work within the constraints imposed by the environment. At the same time, in order to support communication-intensive real-time and nonreal-time data flows over scarce, time varying and shared channel, the scheduling algorithm must support both delay sensitive and error sensitive data flows.

Policies which schedule the order of transmission for multimedia packets will have a great impact on the efficiency and performance of MAC protocols for 3G wireless networks. Several criteria can be used as guidelines for the design of an efficient packet scheduler, e.g., maximization of throughput, minimization of packet losses, upholding of quantitative QoS guarantees, and scheduling according to a predefined priority structure. Several scheduling disciplines have been proposed for guaranteed performance service in wireline packet-switching networks. QoS provisioning in mobile networks is more complex than in fixed networks due to two major reasons: mobility and wireless channel impairments. QoS provisioning against wireless channel impairments is substantially dependent on the air interface technology.

Recently, many efforts have been made in order to adapt fair scheduling schemes to the wireless environment. Several new schemes based on a time-scheduling approach which may only be suitable for TDMA (Time Division Multiple Access) networks have been proposed. Some of these schemes are listed as follows:

- IWFQ (Idealized Wireless Fair Queuing).[1] It is idealized assuming perfect knowledge about the link states. The problem with IWFQ is that it permits a flow to gain infinite priority, allowing a lagging flow to starve other flows for a long period of time.
- WFS (Wireless Fair Scheduler).[2] The WFS scheduler draws upon the previous ideas of IWFQ and improves the slot allocation algorithm of IWFQ to avoid disturbing in-sync-flows.
- WPS (Wireless Packet Scheduler).[1,3] It is an implementation of a practical algorithm that approximates IWFQ.
- CIF-Q (Channel Condition Independent Fair-Queuing).[4] The CIF-Q is an improvement over WPS. Although the basic idea is the same, a few modifications are implemented. The virtual time of a session is not related to the actual service, but to the service in the error free reference system. Hence, compensation among lagging flows is fair. In addition, service degradation for leading flows is graceful.
- WGPS (Wireless Generalized Processor Sharing).[5] In WGPS the service degradation of the error free flows can be prevented by reserving a part of the bandwidth for compensation. WGPS is absolutely fair between flows in the same class, but not between flows in different classes.

TDMA-based protocols lack well-documented disadvantages when applied to CDMA networks.[6] Therefore, it is of interest to explore fair scheduling schemes for these networks.

In this work, we consider Wideband Code Division Multiple Access (W-CDMA), as the potential air interface technology of third generation (3G) wireless communication systems. W-CDMA packet-based networks, such as the one considered in the UMTS (Universal Mobile Telecommunications System) Terrestrial Radio Access (UTRA) proposal, provide an inherent flexibility to handle the provision of future 3G mobile multimedia services. The Radio Resource Management (RRM) entity is responsible for the utilization of the air interface resources and, consequently, for the adoption of efficient algorithms needed to guarantee Quality of Service (QoS) as well as to provide high capacity. Packet scheduling is one of the RRM functions that will help to achieve such objectives. Packet scheduling in W-CDMA can be done in two ways[7,8]: code scheduling, where a large number of MTs can have a low bit rate channel available simultaneously, and time scheduling, where capacity is provided to select MTs at a given moment so that the MT can experience very high bit rates, over small periods of time.

This work examines how to provide diverse QoS to MTs generating/receiving heterogeneous traffic. It addresses QoS and dynamic bandwidth allocation. Due to the distinct characteristics of wireless/mobile networks, we need to develop mechanisms tailored to support QoS for MTs. With the capability of dynamically assigning MTs channel rates, W-CDMA systems can provide more flexibility in bandwidth allocation. Although a Code Division Generalized Processor Sharing (CDGPS)[9] fair scheduling scheme was recently adopted as a discipline to provide fair services in a W-CDMA system, fair scheduling issue has not been well addressed. In CDGPS,[9] it is formulated as a basic principle of Generalized Processor Sharing (GPS), and fixed positive real numbers (namely weights), instead of a fixed bandwidth. In our work, we have developed an improved scheduling model based on the dynamic allocation of weights for each service, taking into account QoS, and the number of MTs in operation mode. This improved scheduling algorithm assigns each service a minimum required bandwidth, and controls the available system codes, while considering important system parameters such as buffer size, packet length and cycle life for each MT. Our improved CDMA/GPS scheduling discipline seeks to achieve fair and maximum allocation of the shared wireless channel bandwidth.

The remainder of this work is organized as follows. Section 2 describes the system model. Section 3 analyzes how processing gain affects bit error rate (BER) and the impact it has on the Multiple Access Interference (MAI). By taking into account these effects, a dynamic bandwidth allocation procedure is proposed. Section 4 adds the GPS strategy to the dynamic bandwidth proposed allocation procedure in Sec. 3 and analyzes how the entire procedure equitably assigns resources while ensuring QoS. Section 5 presents the experimental setup and its corresponding results. Finally, Sec. 6 provides the conclusions of this work.

2. The System Model

This paper assumes the system model to be an uplink-only, MT to Base Station (BS) wireless networks that utilizes a cellular architecture. We consider a frequency-division duplex W-CDMA wireless communication network system, with a perfect power control and an error free channel where the packets arrive at the MTs according to bursty random processes. Slotted-ALOHA, as a part of the CDMA access protocol, is used in the Request Access mini slot, where a MT chooses a PN (Pseudo Noise) code sequence for spreading over this mini slot. In order to reduce random access collisions, there are K different PN sequences assigned to the Request Access protocol, being K smaller than the number of MTs admitted into the system.

We consider a centralized scheduling scheme similar to the one described by Covarrubias[10] and Karol *et al.*[11] In this model, the BS updates the Request Table (RT) as soon as transmission requests from the MTs have been received. In this RT, the following information about the MTs is stored: identification, number of packets in the MT's buffer, service type, packet life time, and the time the packet is generated. Then, the packets are queued at the MTs, and the BS serves them according to a desired packet transmission policy in a slot-by-slot sequence. Each time a MT transmits a packet, it includes piggybacking bits to indicate whether it has more packets in its buffer. This is used as a contention free request for transmission.

When the BS assigns transmit permission to an MT, it includes a field indicating the processing gain that the MT can use in the next slot and the PN code assigned to the MT for the next slot. In this work we consider that the rate of each dedicated channel can be changed dynamically, by varying the CDMA's processing gain. However, the total uplink capacity, in terms of the sum of all the uplink channel rates, is limited by intracell and intercell MAI, and varies as the interference varies. It is assumed that the total capacity of the rate-variable dedicated channels is known by the scheduler since the interference level can be estimated by the BS.

The scheduling algorithm performed at the BS is responsible to decide who has permission to transmit and the number of packets that can be transmitted in the following time slot. By utilizing this information, the scheduling algorithm decides which MTs will transmit during the next time slot, and the processing gain that will be assigned to them. In order to guarantee QoS for all MTs, the Generalized Processor Sharing (GPS) scheme — previously-defined — is used. The scheduling algorithm should provide the QoS required by the different services supported by the mobile network, while maximizing the W-CDMA throughput. The scheduling algorithm utilizes both the channel condition and the delay requirement of the traffic, to minimize the resource usage while meeting the hard deadlines of real-time packets.

3. Dynamic Processing Gain Allocation Oriented to Packet Data Service

Code Division Multiple Access (CDMA) is a fixed-assignment protocol for sharing a common channel simultaneously through applications of individual spread spectrum codes. CDMA is particularly interesting for channels that have other characteristics suitable for spread spectrum, such as jamming or multipath distortion. CDMA processing gain (protection against multiuser interference) is an important parameter that allows us to establish the intrinsic relationship between the number of MTs, associated bit error rate (BER), and system protection against interuser interference (IUI), also referred to as multiple access interference (MAI).

When the channel traffic is low, high processing gain is not necessary since there is minimum interference in the CDMA system. During low channel traffic, processing gain can be reduced to increase the actual bit rate. Since the need for processing gain depends on the channel load, the system performance can be improved by changing adaptively the transmission rate algorithm according to the channel load conditions. Therefore the channel bit rate can be dynamically-controlled, varying the CDMA processing gain.[12] However, the complete uplink capacity is strongly limited by the MAI, which is directly influenced by the interference level due to the number of MTs in the cellular system. As mentioned before, we assume that the scheduler is intimately aware of the assigned capacity of each variable bit rate channels. Indeed, the BS could predict the level of MAI interference.

By considering the analysis made by Sallent and Agust,[13] we can achieve the optimal CDMA system performance via dynamic processing gain variation, and obtain our goal of dynamically assigning a suitable bandwidth allocation for each MT attending the heterogeneous QoS request. Successful implementation of this procedure assures that the CDMA system will properly function within traffic channel variations. However, in order to utilize dynamic bandwidth allocation, it is necessary to achieve an optimum bit rate combination in order to obtain, under the simultaneous presence of n MTs, the maximum CDMA system throughput. Therefore, the problem can be formulated as follows:

$$\begin{aligned} &\text{maximize}_{(n_v, n_{2v}, n_{4v})} S(n_v, n_{2v}, n_{4v}) \\ &\text{subject to} \quad n_v + n_{2v} + n_{4v} = n\,, \end{aligned} \tag{1}$$

where $S(n_v, n_{2v}, n_{4v})$ is the system throughput, n_v refers to the number of MTs with a transmission rate of v bps, n_{2v} indicates a transmission rate of $2v$ bps, and n_{4v} indicates a transmission rate of $4v$ bps. For simplicity, we only write up to $4v$ of channel bit rate.

To illustrate the effects of dynamic processing-gain control, we have simulated IS-95 CDMA system behavior considering one cell with uplink path, and parameters of 1.25 MHz bandwidth, BPSK modulation scheme, 200 bits packet data-length, 80 MTs, 40 codes, and Processing Gain (PG) values of 32, 64 and 128. Since the BS has a perfect knowledge of the number of MTs attempting to transmit, it is

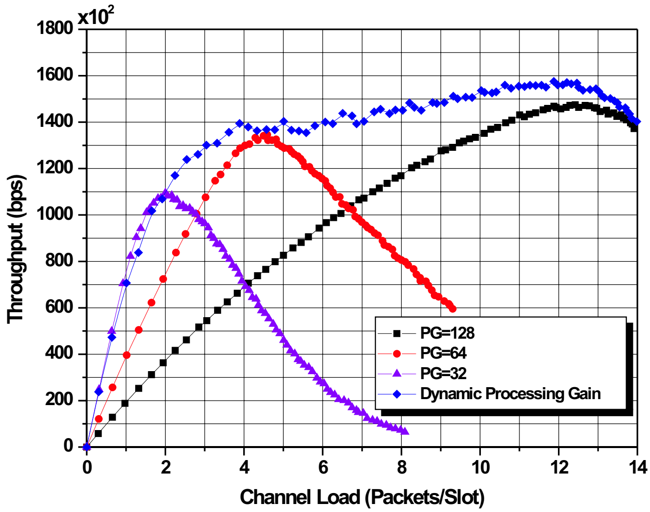


Fig. 1. CDMA system throughput behavior with a dynamic processing gain control.

able to assign a channel bit rate to each MT. This BS ability illustrates the CDMA system capability to adapt itself to varying channel traffic.

Figure 1 is a computer simulation that illustrates a CDMA system throughput versus dynamic processing-gain control. During low traffic channel, MTs increase their bit rate transmission. As traffic increases, processing gain also increases, obtaining as a result a dynamic CDMA system bandwidth control.

Finally, in the case of different types of traffic, it is necessary to implement a dynamic bandwidth allocation together with a fair resources system sharing, so that the MT QoS requirements can guaranteed an increased allocation of resources. Therefore, the next section analyzes the GPS strategy of the dynamic bandwidth allocation procedure and how this entire procedure equitably assigns resources, while at the same time, maximizes the QoS.

4. Fair Resource Allocation in a CDMA/GPS-DW Scheme

The analysis of the proposed CDMA/GPS-DW (DW — dynamic weights) scheme is based on a slot-by-slot arrangement where each MT in its idle state can generate a World Wide Web (WWW) data packet according to a Pareto distribution, and voice and video services based on ON–OFF processes.[14] At the instant a data packet is generated, the MT switches to an active state. In this state the MT makes the request to transmit, randomly choosing a code from the group of available codes. A collision will occur every time two or more MTs choose the same code and the involved MTs will have to contend in the next available time slot. The MTs not involved in the collision send a request to transmit to the BS. This request contains the type of service, amount of generated information, time of generation, the time slot where the information was generated, and the buffer state. With this information the BS updates its Request Table (RT) and makes a fair allocation of resources beginning with the codes assigned to the MTs.

If there are enough codes for all the MTs present at the cell, the BS assigns codes based on priority of service, where video has the highest priority and WWW data has the lowest priority. According to the information stored in its RT, the BS assigns codes to MTs beginning with those of video traffic that have their buffers full. In cases where there are more video MTs than available codes, the BS assigns codes to those MTs that were not assigned a code in the previous time slot. If codes remain after servicing video MTs, then these codes are assigned to voice MTs. If codes remain after servicing voice MTs, then these codes are assigned to WWW data MTs according to the priority of service. Finally, if codes still remain after servicing WWW data MTs, then these codes are assigned to MTs whose life time are close to expiration.

After assigning codes to MTs, the BS is aware of the number of MTs designated to video, voice, WWW data, as well as the bandwidth each MT is requesting. Since GPS calculates the minimum required bandwidth for each service, it is necessary to determinate dynamic weights for each service, while taking into consideration the number of video, voice and WWW data MTs. Excess bandwidth is assigned in proportion to the weight of each service. Based on this information, the BS is able to select and adjust the processing gain of each MT ready to transmit in the next available time slot. If after transmitting, a MT has no information in its buffer, it frees its codes and switches to an idle state. In case the MT has additional information to transmit, it informs the BS to avoid contending during the next time slot. The proposed scheme is shown in Fig. 2.

Since the BS performs MT code assignment, it is constantly aware of the number of MTs assigned for each service. In the following section the analysis to calculate the minimum bandwidth for each service is presented.

4.1. *Analysis of the CDMA/GPS-DW model*

For the assignment of the minimum bandwidth for each service the Generalized Processor Sharing (GPS) scheme, also known as Fluid-flow Fair Queuing (FFQ), is used. GPS is a generalization of uniform processor sharing and is based on a fluid-flow traffic model.[15]

The strategy of the fair scheduling schemes for TDMA networks[1–5] is to use time-scheduling to remedy the fairness guarantees. The channel rate of each MT is usually fixed by using time-scheduling.

For the proposed scheme (CDMA/GPS-DW) a rate scheduling is used, where different packets in the same flow may be transmitted at different rates. This is achieved in our case by varying the processing gain, rather than allocating service time. In addition, the fair scheduling schemes for TDMA networks[1–5] are based on the concept of virtual time (VT). In order to compute this VT they need to

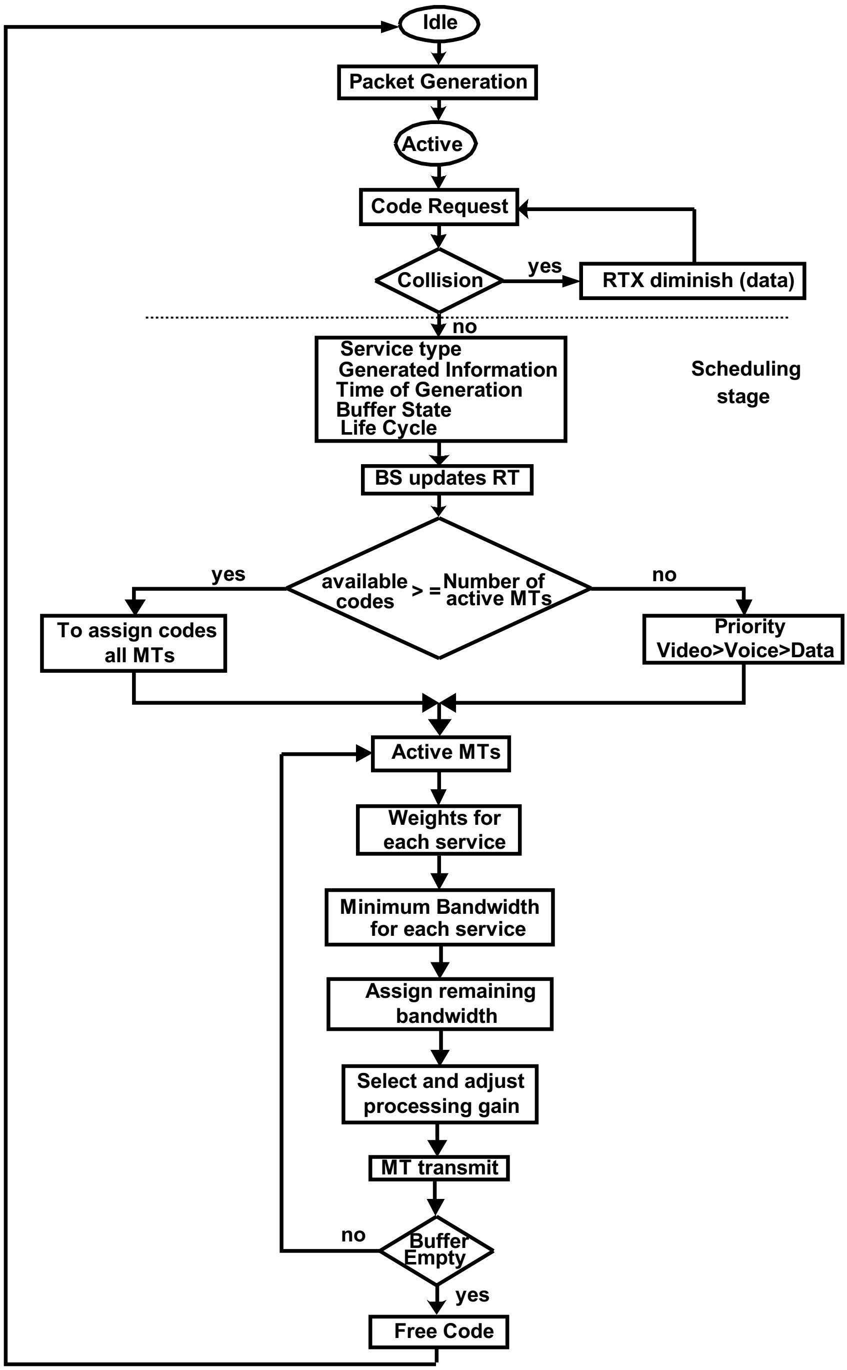


Fig. 2. Flow diagram of the CDMA/GPS-DW scheme.

run a parallel error free system. In our proposed scheme we do not need the VT, therefore, we do not need to run an extra system. This helps, of course, to a lower complexity in our implementation.

Total link capacity C in the CDMA/GPS-DW scheme is shared by N sessions. Each session i maintains a connection with link rate $C_i(k)$ during the kth time slot, such that,

$$\sum_{i=1}^{N} C_i(k) \leq C\,. \tag{2}$$

Any session i enters a single server queuing system with a service rate $C_i(k)$. Different from conventional single server queue, the service rate $C_i(k)$ can vary with time.

Let ϕ_i be the weight for session i, where $i = 1, 2, \ldots, N$, and $W_i(k)$ the amount of traffic served during slot k. Then, according to the GPS resource assignment discipline, Eq. (3) should be maintained for any session that is continuously backlogged at slot k, i.e.,

$$\frac{W_i(k)}{W_j(k)} \geq \frac{\phi_i}{\phi_j}\,, \quad j = 1, 2, \ldots, N\,, \tag{3}$$

in our case $N = 3$ because we consider video, voice and WWW data only.

The amount of backlogged traffic of session i during slot k is the backlogged traffic in the previous slot plus the estimated traffic of session i during slot k. If the backlogged traffic is zero then the traffic served is zero, and in case the backlogged traffic is not zero the traffic served of the ith session is

$$W_i(k) = g_i T\,, \tag{4}$$

where $g_i = (\phi_i / \sum_{j=1}^{N} \phi_j) C$ is the minimum rate guaranteed for session i, T is the slot length, and C is the maximum amount of service rate that can be provided by the network.

The rate assigned to session i can be determined by $C_i(k) = W_i(k)/T$, so the bandwidth assigned to each session (video, voice and WWW data) is given by

$$C_i(k) = \frac{\phi_i}{\sum\limits_{j=1}^{N} \phi_j} C\,, \tag{5}$$

and the remaining bandwidth will be distributed proportionally to the individual weight ϕ_i.

In the GPS scheme used in CDGPS[9] the weights are related as follows: $(1/3)\phi_1 = (1/2)\phi_2 = \phi_3$, with $\phi_1 \geq \phi_2 \geq \phi_3$, where ϕ_1 corresponds to the highest priority and ϕ_3 to the lowest. These values $(1/3, 1/2, 1)$ do not guarantee the maximum data transmission rate under UMTS platform (384 kbps). Therefore, we propose a different set of values $(1/5, 1/3, 1/2)$ that better exploits the available data bandwidth for UMTS.

The dynamic assignment weights for video, voice and WWW data, depends on the number of active MTs and the level of priority of service, where a minimum bandwidth is guaranteed for each service. The weights are updated dynamically according to Eqs. (6)–(8), as opposed to CDGPS that considers fixed weights.

$$\phi_1 = \phi_{\text{video}} = \frac{5\sqrt{N_{1\text{act}}}}{5\sqrt{N_{1\text{act}}} + 3\sqrt{N_{2\text{act}}} + 2\sqrt{N_{3\text{act}}}}\,, \tag{6}$$

$$\phi_2 = \phi_{\text{voice}} = \frac{3\sqrt{N_{2\text{act}}}}{5\sqrt{N_{1\text{act}}} + 3\sqrt{N_{2\text{act}}} + 2\sqrt{N_{3\text{act}}}}\,, \tag{7}$$

$$\phi_3 = \phi_{\text{data}} = \frac{2\sqrt{N_{3\text{act}}}}{5\sqrt{N_{1\text{act}}} + 3\sqrt{N_{2\text{act}}} + 2\sqrt{N_{3\text{act}}}}\,, \tag{8}$$

where $N_{1\text{act}}$ is the number of active video MTs, $N_{2\text{act}}$ is the number of active voice MTs, and $N_{3\text{act}}$ is the number of active WWW data MTs.

The main objective of Eqs. (6)–(8) is to define, in an adaptive manner, the weights that give to our algorithm the following characteristics:

(i) If the numbers of MTs in the different services are the same, then our scheduler should work as a conventional GPS scheduler.
(ii) If the numbers of MTs in the different services are different then the weights should be adjusted. This will be done in such a way that the service with higher MT's number will determine an increase in its weight and a change in its priority.

The square root is a way to soften the influence, on the resulting weight, of great variations in the number of MTs.

After assigning the bandwidth to each service, the remaining bandwidth is assigned proportionally to the weight of each service. It is necessary to remember that since the video and voice services are continuous flows of information, the remaining bandwidth will only be assigned to the WWW data MTs because real-time video and voice cannot increase their transmission rate. If video or voice terminals do not require their bandwidth, it is provided to WWW data, and therefore WWW data MTs can increase their transmission rate.

The previous analysis shows that we can make a distinction of services (video, voice and WWW data) that will allow us to guarantee the QoS (in our case delay and dropping packets). The results of the performance evaluation of this scheme are presented in the next section.

5. Experimental Setup and Results

The performance of the proposed CDMA/GPS-DW scheme will now be evaluated. The simulation assumes error free uplink connections in a single isolated cell. The

Table 1. Simulation parameters (UMTS standard).

Parameter	Value
Bandwidth	5.0 MHz
WCDMA channel rate	2.0 Mbps
Chip rate	4.096 Mcps
Data modulation	BPSK (uplink)
Processing gain for data	Variable
Voice source rate	16 kbps
WWW data source rate	16 to 384 kbps
Video source rate	97.6 kbps
Slot duration	0.625 ms
Total number of video MTs	50
Total number of voice MTs	50
Total number of WWW data MTs	100
Average duration of talkspurt	1.41 s
Average duration of silent gaps	1.74 s
Average duration of video call	180 s
Maximum tolerable BER of video traffic	10^{-5}
Maximum tolerable BER of voice traffic	10^{-3}
Maximum tolerable BER of WWW data traffic	10^{-9}

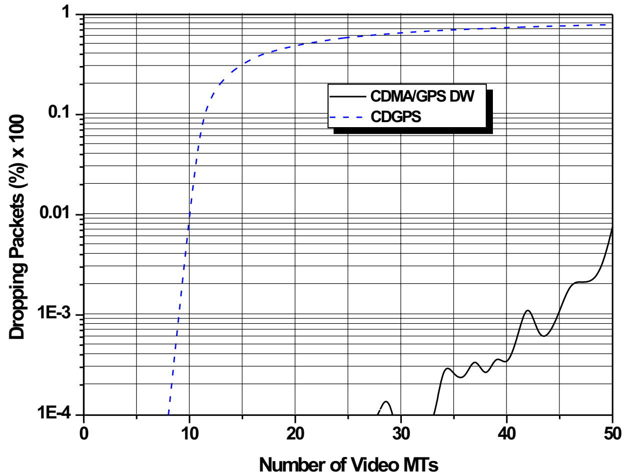
parameters for simulation are based on the UMTS standard and consider the following traffic characterization services:

- Voice traffic: this model generates speech patterns of a conversation and is based on a Markov model for a slow speech detector.[14]
- Video traffic (videophone): this model generates a continuous bit flow. The length of video transmissions is assumed to be exponentially distributed with a mean of 180.0 ms.
- In our simulation, WWW data traffic is considered in the model presented by the UMTS standard,[16] where the WWW data service application follows a Pareto distribution with fixed values of $\alpha = 1.1$ and $k = 81.5$ and maximum burst size of 66 666 bytes.

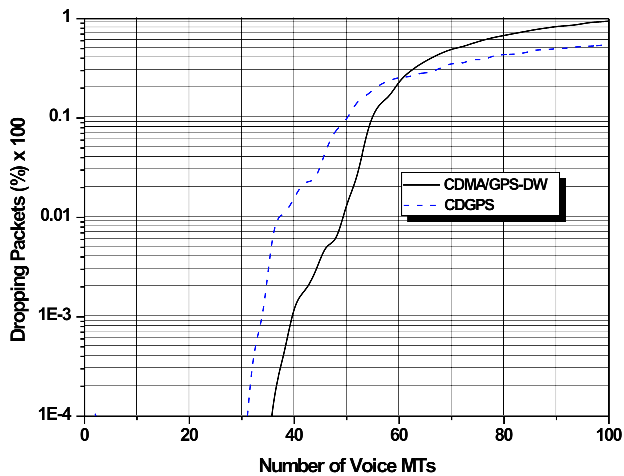
Table 1 shows the parameter values (UMTS standard) used in the simulation. Here, the processing gain is variable for WWW data only since we are considering continuous information flows for video and voice (then the processing gain for these two services should be fixed).

The first simulation studies the percentage of dropped packets (video and voice) taking into account that the required QoS imposes a maximum of 1% loss for video and voice. The result of this simulation is shown in Fig. 3.

Figure 3(a) shows that if we fix the dropping packets to a level of 1%, then the CDGPS scheme can handle only 10 MTs while our proposed scheme can handle up to 50 MTs (a 400% improvement). When compared to the CDGPS scheme (with $\phi_1 = 5$, $\phi_2 = 3$, $\phi_3 = 2$) our proposed CDMA/GPS-DW scheme illustrated in Fig. 3(b), improves voice traffic by 39%. This improvement is due to



(a)



(b)

Fig. 3. Dropping packets percentage for (a) video and (b) voice. CDMA/GPS-DW and CDGPS (with $\phi_1 = 5$, $\phi_2 = 3$, and $\phi_3 = 2$) schemes.

the CDMA/GPS-DW code assignment method that takes into account the service type, the required bandwidth, the buffer state, and the packet life cycle of each MT. In addition, the CDMA/GPS-DW scheme performs a dynamic bandwidth assignment for each MT.

We have just seen how the number of MTs increases with video and voice traffics under the proposed CDMA/GPS-DW scheme. We will now see how the system throughput varies as the channel load varies (see Fig. 4).

Figure 4 illustrates that our CDMA/GPS-DW scheme achieves a maximum throughput improvement of 20% as compared to the existing CDGPS scheme. This

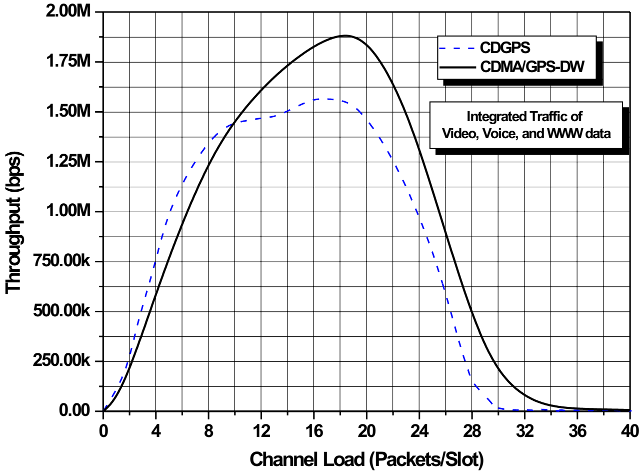


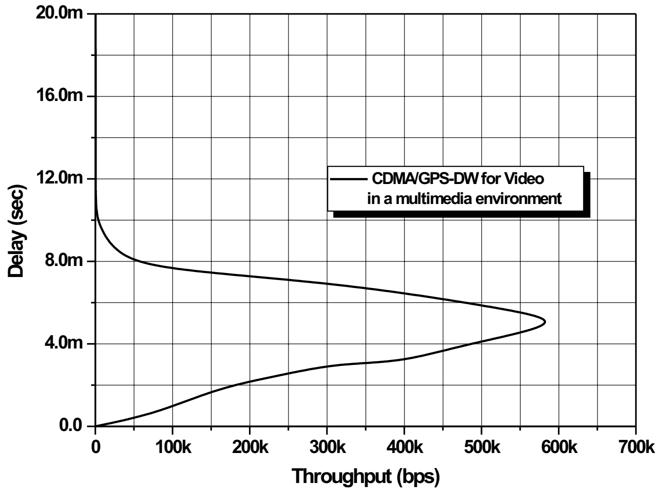
Fig. 4. Throughput behavior under CDGPS and CDMA/GPS-DW schemes in a multimedia environment.

improvement is attribute to the limited number of assigned codes. As illustrated in Fig. 4, an increase in channel load results in an increase in throughput. Additional increases in channel load results in a corresponding increase of throughput until throughput reaches its maximum value. Continuing increases in channel load causes a decrease in the throughput. This decrease is a result of increased collisions which are directly proportional to the number of MTs for a fixed number of codes, and is not related to the method used for resource assignment.

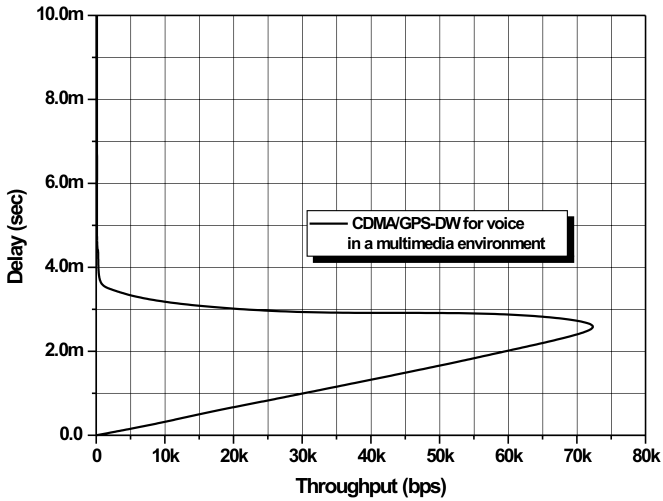
We have seen the advantages of our proposed CDMA/GPS-DW in terms of the throughput. We are now going to analyze the behavior of another very important system parameter, which is the delay. This parameter has an upper bound that depends on the service being considered. Since we are considering the UMTS standard, this upper bound is 150 ms for video, 20 ms for voice, and 4 s for WWW data.

Figure 5 illustrates that the proposed CDMA/GPS-DW scheme performs well within the UMTS standard regarding video, voice, and WWW data delays. At maximum throughputs, the proposed scheme operates at maximum delay of 5.0 ms for video (Fig. 5(a)), 2.5 ms for voice (Fig. 5(b)), and 80 ms for WWW data (Fig. 5(c)). Figure 5(d) compares the performance of the proposed CDMA/GPS-DW scheme with the existing CDGPS scheme and illustrates that the proposed scheme clearly outperforms the existing scheme by providing a 35% increase in the maximum throughput.

Based on our evaluation of the proposed variable channel rate CDMA/GPS-DW scheme, we conclude that it accomplishes the fair resources assignment and the QoS imposed by the UMTS standard. Moreover, it clearly outperforms the existing CDGPS scheme.

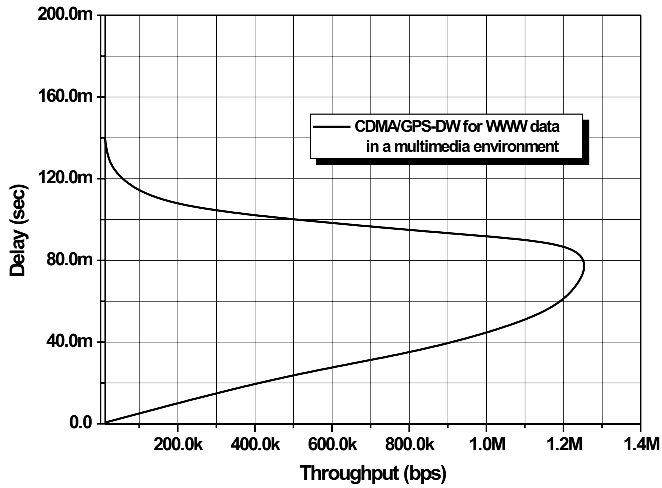


(a)

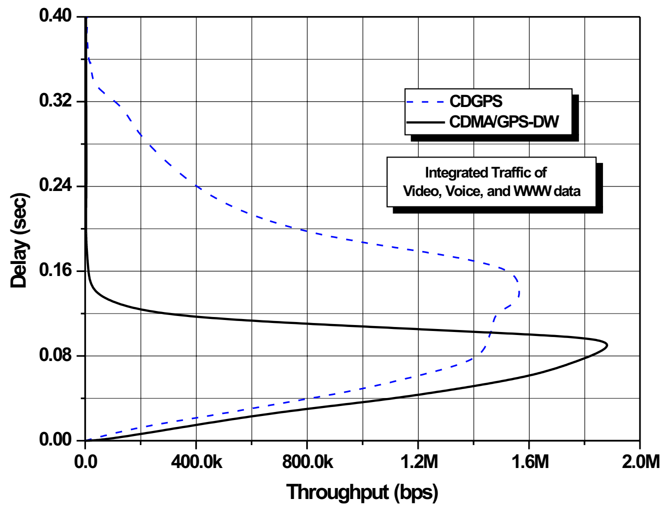


(b)

Fig. 5. Delay behavior for the CDMA/GPS-DW scheme: (a) video, (b) voice, and (c) WWW data. (d) Delay comparison for the CDMA/GPS-DW and CDGPS.



(c)



(d)

Fig. 5. (*Continued*)

6. Conclusions

This paper has presented a proposed CDMA/GPS-DW scheme that utilizes dynamic bandwidth allocation. An analysis of the performance of this scheme against the UMTS has also been presented. Based on this analysis, the CDMA/GPS-DW scheme is an obvious improvement of the recently-proposed CDGPS scheme. This improvement is based on the dynamic weight assignment of bandwidth allocation for each type of service provided (e.g., video, voice and WWW data), as compared to the static weight assignment of bandwidth allocation utilized by CDGPS schemes.

When comparing the proposed CDMA/GPS-DW scheme to the existing CDGPS scheme, our simulation results show an obvious improvement in system performance that includes the number of MTs that can be addressed for a fixed value of dropped packets, lower delay of video, voice, and WWW data, and increased operational throughputs.

Future research will be targeted to improve the operational performance of this scheme by incorporating a preemptive strategy that minimizes the allocation of nonrequired resources.

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