A Study on Dynamic Queue Buffer Allocation Queuing Scheme in a UMTS Core Network

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ABSTRACT

As 3rd Generation Cellular Network (UMTS) systems have evolved into an all-IP stage, packet switching becomes a prerequisite for all UMTS applications within an UMTS core network, where the traffic of UMTS applications consist of four types: conversational, streaming, interactive, and background, each of which has its QoS features and packets transmission priority. In this paper, we propose a dynamic queue buffer allocation (queuing scheme) within an UMTS core network gateway to support differentiated services for packet forwarding among UMTS applications. In the proposed queuing scheme, there are two major modules, the priority-based enqueue module and the weighted round robin dequeue module. Many scenarios are simulated using the platform built on ns2. Based on the simulation results, the performance of UMTS traffic with a high priority always gets a better packet forwarding performance than that of UMTS traffic with a low priority. A differentiated packet forwarding service among UMTS traffic can be found within a UMTS core network.

Keywords: queuing scheme, enqueue / dequeue module, dynamic queue buffer allocation, differentiated service packet forwarding

動態佇列空間配置等候機制應用於 UMTS 核心網路之研究

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摘　　要

UMTS 核心網路在 3GPP R5 以後的規格，為全 IP 化的分封交換網路架構，以 IP 為主要通訊協定，並定義了四種的服務等級(QoS)需求應用服務：語音會話、影音串流、聊天室和簡訊背景服務的不同優先順序傳送之特性，本研究提出在 UMTS 核心網路中的動態佇列緩衝器配置機制去支援不同的封包服務等級處理，我們提出的佇列緩衝記憶體機制是由優先佇列為基礎的進入佇列與加權輪詢佇列送出的機制，對全 IP 化核心網路的各種不同服務等級封包並藉由不同的邏輯佇列保證空間大小與四組 RED 參數的設定，進行多組的想定模擬，以期能瞭解這些參數設定對於 UMTS 差別性等候機制應用動態佇列空間配置運作效能的影響，經模擬結果分析，透過 NS2 模擬各種方案在不同服務等級的封包在進入與送出佇列時，可以得到很好的效能。

關鍵字：動態佇列記憶體配置，差別性服務封包傳送，排隊佇列機制，服務等級

文稿收件日期 98.4.6; 文稿修正後接受日期 99.7.12; *通訊作者
Manuscript received April 6, 2009; revised July 12,2010; * Corresponding author

I. INTRODUCTION

In the present situation, the Universal Mobile Telecommunications System (UMTS) [1], one of the 3G mobile communication standards developed in Europe, applications and services can be divided into different groups, depending on how they are considered. UMTS attempts to fulfill Quality of Service (QoS) requests from the application or the user. In UMTS application of traffic type can be divided into four classes: conversational, streaming, interactive, and background. According to the 3GPP planning, an all IP-based architecture [2, 3] will be adopted in the UMTS core network eventually to support diversified 3G services [4, 5]. These new services need a guaranteed level of QoS from the network in order to work properly. In an all-IP network, traffics are packetized and transmitted within an UMTS core network and external IP networks. Since the features and QoS of these four types of UMTS traffic defined by 3GPP are different, differentiated services must be supported within an UMTS core network to satisfy the required QoS of all UMTS traffic. The packet transmission performance is one of the important factors that affect QoS of UMTS traffic [6]. For packet transmissions, a queuing scheme in an UMTS core network gateway always plays an important role. A proper packet forward operation of a queuing scheme within an UMTS core network usually provides the required differentiated services among UMTS traffic.

This study proposes a queuing scheme with dynamic queue buffer allocation in a UMTS core network gateway. The proposed queuing scheme is implemented in an ns2 simulator and several simulation scenarios are assumed. The simulation results are collected and analyzed to understand the performance of the proposed queuing schemes. Finally, a conclusion is provided.

II. LITERATURE REVIEW

Compared to other existing mobile networks, UMTS provides a new and important feature, namely it allows negotiation of the properties of a radio bearer. Attributes that define the characteristics of the transfer may include throughput, transfer delay and data error rate. To be a successful system, UMTS has to support a wide range of applications that possess different QoS requirements.

In the network engineering, queuing play an especially important role that is the act of storing packets where they are held for subsequent processing. Nowadays, most of the existing network routers play a passive role in the network communication. As packets enter a queue, the router then queues packets for service onto the next-hop link. Queue management is defined as the algorithms that manage the length of packet queues by dropping packets when necessary or appropriate. To enhance the throughput and fairness of the link sharing, also to eliminate the synchronization, the Internet Engineering Task Force (IETF) recommends active algorithm of buffer management [7]. Active queue management is expected to eliminate global synchronization and improve QoS of networks. The expected advantages of active queue management are increase in throughput, reduced delay, and avoiding lock-out. Among various active queue management schemes, Random Early Detection (RED) is probably the most popular studied.

RED was proposed to improve the performance of TCP connections [8]. RED is an effective mechanism to control the congestion in the network routers. To be able to apply RED mechanism in the DiffServ service, it is important to survey its queuing behavior. For example, to figure out any guarantees on throughput and delays one needs to survey these as a function of the RED parameters. It is useful to complement these efforts with an analytical study.

III. QOS CLASSES OF UMTS APPLICATIONS

In the existing IP world QoS is handled by widening the pipe. Obviously, this approach does not fit into mobile communications, where the radio resources are limited. With a QoS solution based on different QoS classes the use of the mobile network resources can be optimized. According to the features of UMTS traffic, four QoS types [9, 10], conversational, streaming, interactive, and background, are defined by 3GPP for UMTS traffic. The QoS requirements of UMTS traffic are summarized in Table 1.

From Table 1, we can understand that the major distinguishing factor among these QoS types is the time sensitivity of packet transfer delay. Conversational traffic is the most delay sensitive, followed by streaming and interactive applications. Background traffic is the least delay sensitive. Moreover, compared to conversational and streaming traffic, interactive and background traffic is sensitive to packet error rate since most of them are traditional internet applications. In addition, interactive traffic bases on a request/response operation pattern, a long packet delay is not allowed. Thus, interactive traffic receives a higher packet transmission priority than background traffic.

Table 1. UMTS QoS classes [10]

Traffic class	***Fundamental features***	***Application example***	***Packet transmission priority***
Conversational class	- Preserve time relation between information entitles of the stream -Sensitive to packet delay -Conversational pattern (stringent and low delay)	voice, video telephony	1st
Streaming class	- Preserve time relation between information entities of the stream - Sensitive to packet delay	streaming video	2nd
Interactive class	-Request/Response pattern - Preserve payload content -Low error packet rate	web browsing	3rd
Background class	-Destination is not expecting the-data within a certain time -Preserve payload content, -Insensitive to packet delay, -Low error packet rate	background download of emails	4th

IV. A DYNAMIC QUEUE BUFFER ALLOCATION QUEUING SCHEME IN AN UMTS CORE NETWORK GATEWAY

F. Liu, C.H. Fu, and C. Yang have proposed the priority-based queuing scheme in [11]. The priority-based queuing scheme is based on the QoS features and packet transmission priorities of four types of UMTS traffic, and supports a differentiated packet forwarding process among UMTS traffic. This extension study is one of the greatest challenges for parameters troubleshooting and selection on the RED queuing mechanism.

In this study, a priority queuing [12, 13] scheme with a dynamic queue buffer allocation is proposed, according to the QoS features of conversational, streaming, interactive, and background UMTS traffic. Since each type of UMTS traffic has its QoS requirements, differentiated services [14] should be supported for UMTS applications within an UMTS core network. Based on the packet transmission priority of each type of UMTS traffic, the proposed dynamic queue buffer allocation [15 - 17] queuing scheme supports differentiated services among UMTS applications. The following subsections describe the queue buffer allocation, the processes of the enqueue and dequeue modules in details.

4.1.1. A Dynamic Queue Buffer Allocation

In order to provide differentiated services among four types of UMTS traffic, the gateway queue buffer in the proposed queuing scheme is divided into four logical queue buffers: conversational, streaming, interactive, and background. Each logical queuing buffer stores its corresponding UMTS packets. Each logical queuing buffer is divided into two segments: promised buffer and dynamic buffer. A promised buffer is a dedicated buffer to store packets unconditionally if space is available. A promised buffer size depends on the packet transmission priority of its corresponding UMTS traffic. Usually, a logical queue buffer with a high packet transmission priority can receive a large promised buffer to enqueue more packets. When there is no space in a promised buffer to store its corresponding arrival packet, the RED [18, 19]-based dynamic buffer allocation process is invoked by the enqueuing module. According to available space in queue buffer and related parameters settings, the enqueuing module performs a dynamic buffer allocation process to decide to enqueue or drop an arrival packet. As an arrival packet is allowed to enqueue into queue buffer; a dynamic buffer [15] is allocated and appended to a corresponding logical queue buffer. A dynamic buffer size of each logical queue buffer depends on its corresponding parameter settings. One logical queuing buffer with a high packet transmission priority always receives a larger dynamic buffer.

A promised buffer in a logical queue buffer ensures a minimum number of corresponding packets can be enqueued by the proposed queuing scheme. This method avoids a packet forwarding starvation among four types of UMTS traffic, especially for background UMTS traffic. Moreover, with a dynamic buffer allocation in a logical queue buffer, it helps the proposed queuing scheme to enhance differentiated packet enqueuing performance among UMTS traffic in an UMTS core network gateway. Figure 1 shows the diagram of the queuing buffer allocation in the proposed queuing scheme.

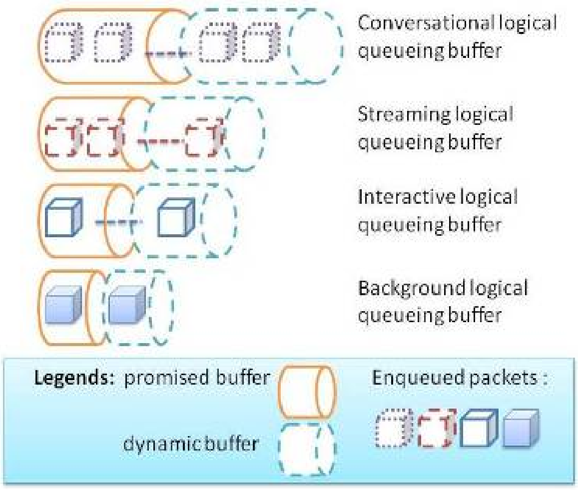


Fig. 1. A diagram of the dynamic queue buffer allocation.

4.1.2. A Priority-Based Enqueuing Module

For enhancing differentiated service performance in a packet enqueuing process, a priority-based enqueuing module is applied to process arrival UMTS packets in this enqueuing module. Since there are two segments in each logical queue buffer; two different packet enqueuing schemes are used. The first-in-first-out (FIFO) scheme is used in promised buffers; the RED-based enqueuing scheme is applied to dynamic buffers. The enqueuing module bases on related parameter settings to perform a packet enqueuing process; the related parameters include promised buffer size in each logical queue buffer, minimum limits, maximum limits, and packet enqueuing probabilities [18], are required in the RED-based enqueue scheme process. These parameter settings are corresponding to packet transmission priorities of four types of UMTS traffic.

As a packet arrives at the gateway, the priority-based [20] enqueuing module checks available space queue buffer in a gateway. If space is available, the enqueuing module depends on arrival packet’s type to invoke a two-stage enqueuing process to handle an arrival packet enqueuing process. According to the class of the arrival packet, the two-stage enqueuing process selects its corresponding logical queue buffer. In the first stage, an arrival packet is allowed to be enqueued in the promised buffer if space in a promised buffer in its corresponding logical queue buffer is available. Otherwise, if queue buffer’s space is available to enqueue an arrival packet, the RED-based enqueuing scheme is invoked by two-stage enqueuing process to decide to enqueue or drop an arrival packet. Figure 2 shows the flowchart of the two-stage enqueuing process.

According to the corresponding parameter settings of four types of UMTS traffic, the RED-based enqueuing scheme performs an arrival packet enqueuing process in a dynamic buffer. The RED parameter settings depend on packet transmission priorities of four types of UMTS traffic; usually, a logical queuing buffer with a high packet transmission priority receives favorable settings in its corresponding RED parameters. It is easy for arrival packets with a high packet transmission priority to enqueue the dynamic buffer in its corresponding logical queue buffer. By a way of differentiated parameter settings, a differentiated packet enqueuing process can be supported by the RED-based scheme. Figure 3 shows the pseudo code of the RED-based enqueuing process.

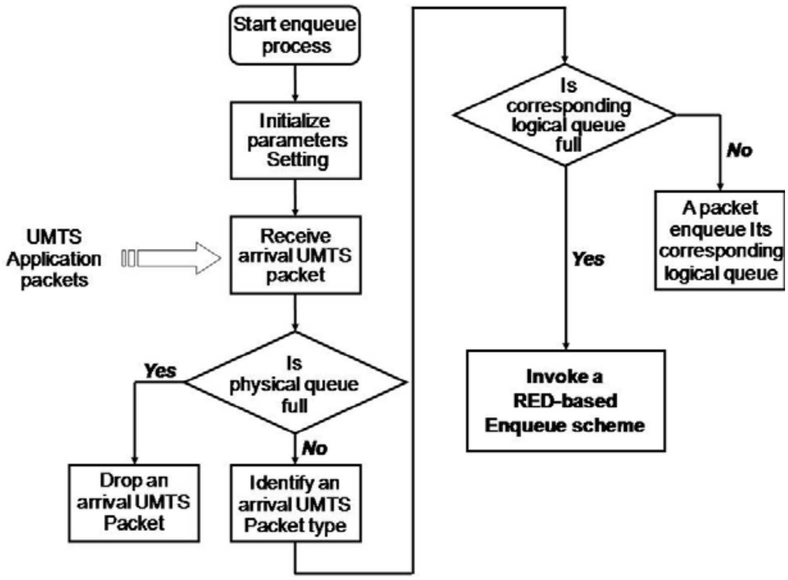


Fig. 3. The flowchart of the two-stage enqueuing process.

RED-based enqueuing scheme
According to the class of the arrival packet, the related parameters used in the RED-based scheme would be set

(The related parameters include ***the minimum limit***, ***the maximum limit*** and ***the packet enqueue probability***)

```
if (the gateway queue buffer is not full)
   {
    if (the corresponding logical buffer length < the minimum limit )
      {
            enqueue the arrival packet
      } else {
              if (the corresponding logical buffer length ≧ the maximum limit )
                {
                  drop the arrival packet
              } else {
                      generate a random probability based on an uniform distribution
                      if (the random probability ≦ the packet enqueue probability )
                        {
                              enqueue the arrival packet
                      } else {
                                    drop the arrival packet
                        }
                }
} else { /* the gateway queue buffer is full */

        drop the arrival packet
   }
```

Fig. 2. The pseudo code of the RED-based enqueuing process.

4.2. A Weighted Round Robin Dequeuing Module

Since the dynamic queue buffer allocation is adopted in this dynamic queue buffer allocation queuing scheme, all enqueued UMTS packets are stored in their corresponding logical queue buffers. To avoid causing a long packet delay among UMTS applications, a round robin-based dequeue scheme is implemented in this proposed dequeuing module. Moreover, for supporting a differentiated packet dequeuing service among UMTS packets, packets with a high transmission priority are more easily forwarded to their next hop gateways than packets with a low transmission priority. Thus, a weighted round robin (WRR) [21, 22] dequeuing module is adopted in the proposed queuing scheme.

In WRR queuing, packets are first classified into various service classes and then assigned to a queue that is specifically dedicated to that service class. Each of the queues is serviced in a round-robin order. With a congruence process, the packet dequeuing counter and packet forwarding cycle are the two core parameters in the WRR dequeuing module to handle packets dequeuing from logical queuing buffers. The proposed dequeuing scheme depends on the congruent number to decide which UMTS traffic can dequeue one packet from its corresponding logical queue buffer. The congruent number can be expressed as follows.

congruent number = packet dequeue counter mod packet dequeuing cycle

Packets in all logical queue buffers can be selected and dequeued, and a packet dequeuing counter is incremented as a packet is dequeued from the queue buffer. As the value of the packet dequeuing counter keeps increasing, a different congruent number value will be assigned in a cycle and packets are selected from different logical queue buffers sequentially. With the congruent number process, a round robin process serves among the logical queue buffers in the WRR dequeuing module.

A differentiated service for UMTS packets forwarding in the WRR dequeuing module depends on the setting of the packet dequeuing cycle parameters and the packet dequeuing turn parameters of four types of UMTS traffic. In a packet forwarding cycle, at least one packet, possibly more, will be dequeued from each logical queue buffer. One packet dequeuing turn allows the WRR dequeuing module to dequeue one packet from its corresponding logical queue buffer in a packet dequeuing cycle. According to the assigned packet dequeuing turns, corresponding packets would be dequeued from their logical queue buffer.

The scheduling of packet dequeuing is based on the packet transmission priorities of four types of UMTS traffic. For UMTS traffic with a high packet transmission priority, it always receives more packet dequeuing turns. In general, a conversational UMTS traffic receives more packet dequeuing turns in a packet dequeuing cycle. On the other hand, background UMTS traffic receives the least number of packet dequeuing turns in a cycle. Therefore, disparity in performance among UMTS traffic is decided by the settings of packet dequeuing turns for the UMTS traffic. The WRR dequeuing module can always use the assignments of packet dequeuing turns among UMTS traffic to create differentiated packets dequeuing behaviors among all UMTS traffic. With proper assignments of packet dequeuing frequencies among UMTS traffic, the proposed queuing scheme can support to receive a healthy differentiated packet dequeuing service for all UMTS traffic. The packet dequeuing cycle value depends on UMTS traffic's packet forwarding turns; it can be expressed as follows.

$$\textit{packet dequeuing cycle} = \sum_{i=1}^{4} \textit{packet dequeuing turns}_{\,i}$$

where *i* indicates 4 types of UMTS traffic

Moreover, a packet forwarding sequence table needs to be established to have a mapping between the computed congruent number and the UMTS packets forwarding sequence set by the WRR dequeuing module. Using the packet forwarding sequence table, the congruent number determines which UMTS traffic forwards one packet from its corresponding logical queue buffer. The congruent number is set in the range between 0 and N-1, where N is the packet forwarding cycle. As enqueued UMTS packets are dequeued; the congruent number circulates within its range. With a switching congruent number, the WRR dequeuing module can base on a predetermined order in a packet forwarding cycle to dequeue UMTS packets and supports a differentiated packets dequeuing behavior among UMTS traffic. A flowchart of the proposed WRR packet dequeuing module is shown in Figure 4.

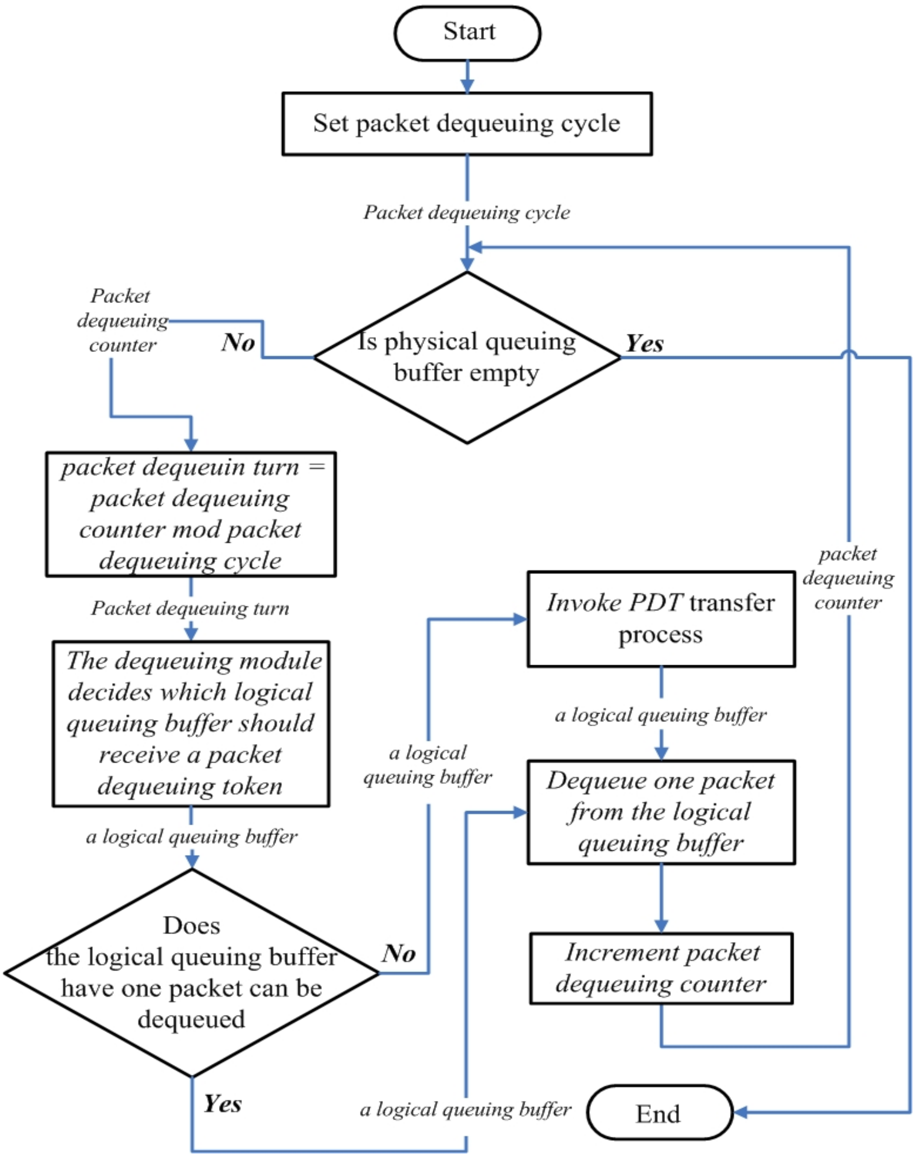


Fig. 4. The flowchart of the proposed weighted round robin packet dequeuing module.

V. SIMULATION RESULTS

In this study, a network simulator is used to simulate an operational platform of an UMTS core network. According to possible situations about UMTS applications packets forwarding within an UMTS core network gateway, several simulation scenarios are simulated to understand the performance of packet forwarding of the proposed queuing scheme and differentiated service behavior of packets forwarding among UMTS traffic is also observed in these simulation results.

Usually, throughput, packet loss, packet delay, and packet jitter are the four indicators to assess packet forwarding performance of a queuing scheme. According to our previous study [11], we can find that a close relationship exists between throughput/packet loss and packet delay/jitter. UMTS traffic receives better throughput/packets loss; it also always receives better packet delay/jitter. Thus, throughput and packet loss are the two most indicators of packet forwarding performance; they will be used to evaluate to the packet forwarding performance of UMTS traffic which is supported by the proposed queuing scheme.

5.1 Simulation Topology and Key Simulation Parameters

The Network Simulator – ns2 (version 2.26) [23] is used as the simulation platform in this study. The dynamic queue buffer allocation queuing scheme and UMTS applications are implemented in ns2 with C++ programs. The simulation scenarios are coded with TCL. In the simulation scenarios, the bandwidth of the UMTS core network backbone is 2 Mbps. Four connections are established over the UMTS core network backbone among the senders and the receivers. Packets of one type of UMTS traffic is transmitted from one sender to another receiver through a connection. Except the bandwidth of a UMTS core network backbone, several parameters are used in simulation scenarios; they include promised buffer sizes of four types of UMTS traffic and four groups of RED parameters which are corresponding to four types of UMTS traffic, dynamic buffer's minimum limit, dynamic buffer's maximum limit and dynamic buffer's packet enqueue probability. The simulation topology is shown in Figure 5.

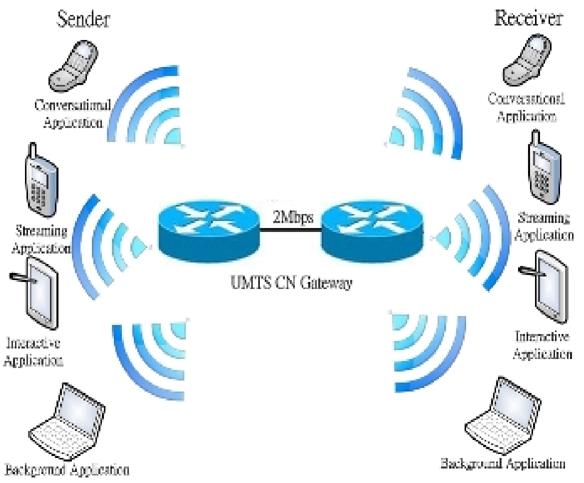


Fig. 5. The diagram of the simulation topology.

5.2 Simulation Results and Analysis

According to the above mentioned simulation parameters, simulation scenarios can be divided into two categories. The simulation results are described and analyzed in the following subsections.

5.2.1 Bandwidth over a UMTS Core Network Backbone Bandwidth is Insufficient

Two simulation scenarios are performed in this simulation category. One scenario is that UMTS applications keep sending packets continuously; the other scenario is that UMTS applications send packets intermittently.

- UMTS traffic transmission in a continuous pattern

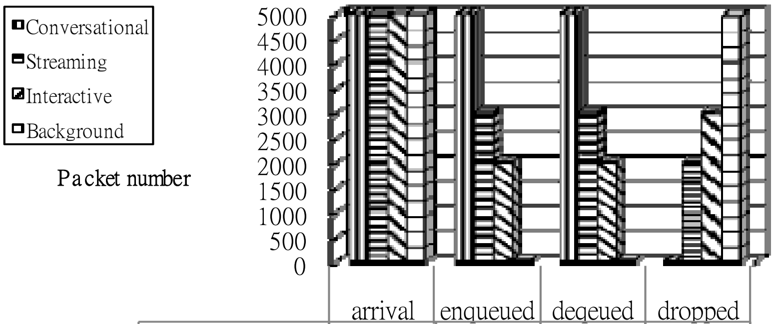
This simulation scenario tries to understand UMTS packets forwarding behaviors among UMTS traffic when a UMTS core network backbone bandwidth is insufficient for bandwidth requirements of all UMTS traffic and all UMTS applications keep sending packets. Figure 6 shows the simulation results.

Figure 6 shows that the conversational traffic receives the best packet forwarding performance and all conversational packets are forwarded. The streaming and interactive traffic receive the second and third packet forwarding performance, respectively. Almost 60% streaming packets are forwarded and the rest 40% streaming packets are dropped. For the interactive traffic, approximately 40% packets are forwarded and the other 60% packets are dropped. The background traffic receives the worst packet forwarding performance. Only 30 background packets are forwarded and most of background packets are dropped. A packet forwarding starvation may occur for background traffic when all UMTS applications keep sending packets continuously. It is obvious that packet forwarding performance received by four types of UMTS traffic is corresponding to their packet transmission priority. Therefore, a differentiated packet forwarding service is supported by the proposed queuing scheme among UMTS traffic.

- UMTS traffic transmission in an intermittent pattern

This simulation scenario is helpful to

observe packets forwarding variations among UMTS traffic when bandwidth over a UMTS core network backbone is insufficient for all UMTS applications and UMTS traffic is transmitted intermittently. The simulation results are shown in Figure 7.



	arrival	enqueued	deqeued	dropped
Conversational	5000	5000	5000	0
Streaming	5000	3006	3006	1994
Interactive	5000	2003	2003	2997
Background	5000	30	30	4970

Fig. 6. Simulation results of all UMTS traffic in a continuous transmission pattern.

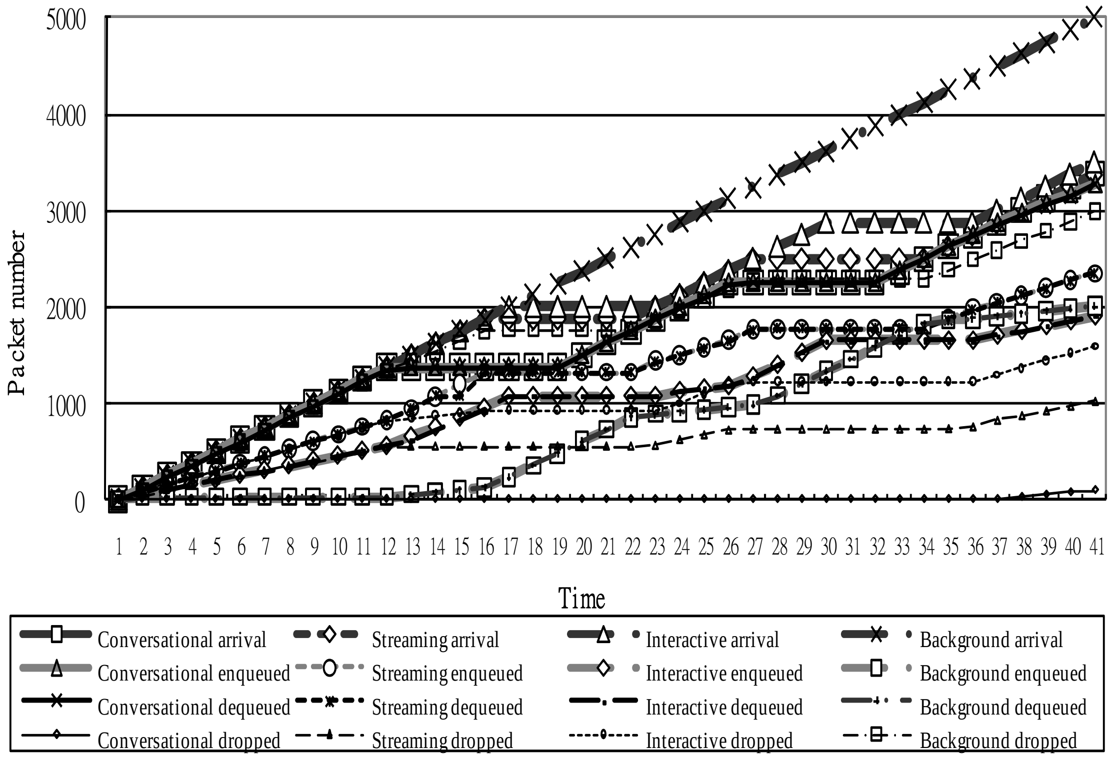


Fig. 7. Simulation results of UMTS traffic transmission in an intermittent pattern.

From Figure 7, we can clearly observe that the packets forwarding situation of each type of UMTS traffic. The proposed queuing scheme bases on the packet transmission priorities of four types of UMTS traffic to perform differentiated services in UMTS packet forwarding operation. The simulation results show that the packet forwarding performance of

UMTS traffic is corresponding to their packet transmission priorities. Therefore, the conversational and streaming UMTS traffic get better packet forwarding performance than the interactive and background UMTS traffic. Table 2 shows the statistics of the packet forwarding performance of UMTS traffic.

In addition, observing further the variations among the lines shown in Figure 7 and Table 2, we can find two interesting simulation results

- The average packet forwarding performance received by four types of UMTS traffic is corresponding to their packet transmission priorities in an intermittent transmission pattern; there exists a differentiated packet forwarding behavior in the continuous / intermittent transmission patterns.
- For UMTS traffic with a low packet forwarding priority, a packet forwarding starvation issue is not serious when all UMTS traffic sends packets intermittently. Background UMTS traffic can always send its packets when bandwidth is available over a UMTS core network backbone.

Table 2 Packet forwarding performance statistics of UMTS traffic

UMTS Application	*Enqueue/Dequeued*	*Dropped*	*Avg. packet forwarding performance*
Conversational	97.10%	2.90%	122.11 *packets/sec*
Streaming	69.59%	30.41%	80.04 *packets/sec*
Interactive	54.43%	45.57%	68.07 *packets/sec*
Background	40.18%	59.82%	50.23 *packets/sec*

Legends: **Avg.**: Average

5.2.2 The Priority-Based Enqueuing Module with Different Parameter Settings

In the priority-based enqueuing module, a set of parameters, promised buffer size, minimum limit, maximum limit and packet enqueuing probability, are used to allocate logical queuing buffers and manipulate packets enqueuing for one type of UMTS traffic. With different parameter settings, UMTS traffic may receive different packet forwarding performance.

Several scenarios with different parameter settings are simulated to observe UMTS packets forwarding behaviors supported by the proposed queuing scheme. In these scenarios, the queue buffer size in the proposed queuing scheme is 40 packets. The total bandwidth requirement of all UMTS traffic exceeds the bandwidth of a UMTS core network backbone. Table 3 lists the 24 simulation results. By examining these simulation results, some summaries are described in the following paragraphs.

- UMTS traffic with the maximum promised buffer

In these scenarios, all UMTS applications have the maximum promised buffer, 40 packets. There exists an extreme phenomenon of packet forwarding behavior among UMTS traffic. The conversational and streaming UMTS traffic receives pretty good packet forwarding performance. All packets of these two UMTS applications are dequeued except one streaming packet is dropped. However, for the interactive and background UMTS traffic, approximately 99.6% packets are dropped and only 0.4% packets are dequeued. Packet forwarding starvation occurs.

- UMTS traffic with the same promised buffer size and dynamic buffer parameter settings

As all UMTS traffic has the same promised buffer size and dynamic buffer parameter settings; it is obvious that the packet forwarding performance of four types of UMTS traffic depends on the packet enqueuing probability of four types of UMTS traffic.

- UMTS traffic with differentiated promised buffer sizes and the same dynamic buffer parameter settings

No obvious relationship exists between the packet forwarding performance of four types of UMTS traffic and the assigned dynamic buffer parameter settings; UMTS traffic depends on their packet transmission priorities to receive their deserved packet forwarding performance.

- UMTS traffic with differentiated promised buffer sizes and dynamic buffer parameter settings

The simulation results show that the packet forwarding performance of UMTS traffic are corresponding to their packet transmission priorities, and a differentiated packet forwarding behavior is supported among UMTS traffic. From a viewpoint of differentiated services, it is reasonable for all UMTS traffic to receive differentiated promised buffer sizes and dynamic buffer parameter settings. However, when all UMTS applications have the maximum value settings in their dynamic buffer's maximum limit and packet enqueuing probabilities, a packet forwarding starvation might occur for interactive and background UMTS traffic.

By examining the above simulation results, we observe that the promised buffer and the dynamic buffer have their functionalities to support a packet forwarding differentiated service behavior among UMTS traffic. Moreover, with reasonable parameter settings in the proposed queuing scheme, differentiated service packet forwarding performance can be improved and a packet forwarding starvation can be avoided among UMTS traffic.

VI. CONCLUSIONS

As a UMTS system enters an all-IP stage, a packet switching scheme is used to forward packets from all UMTS applications within a UMTS core network. Since four types of UMTS traffic have their QoS requirements, it is necessary for a gateway within UMTS core network to support a differentiated service packet forwarding behavior among UMTS traffic. This study tries to propose a dynamic queue buffer allocation queuing scheme in a UMTS core network gateway. The proposed queuing scheme bases on the packet transmission priorities of four types of UMTS traffic to forward UMTS packets in a differentiated service way; provide differentiated services for UMTS applications in an UMTS core network gateway.

The proposed queuing scheme can be divided into two modules, the priority-based enqueuing module and the WRR dequeuing module. Two schemes, a RED-based scheme and dynamic buffer allocation, are applied and integrated in the priority-based enqueuing module. UMTS packets can depend on their packet transmission priorities to be enqueued into their corresponding logical queue buffers in a differentiated service way. In the WRR dequeuing module, a congruent number process based on the number of sent UMTS packets and packet dequeuing cycle to decide which logical queue buffer should a receive packet dequeuing turn. Usually, a logical queue buffer of UMTS traffic with a high packet transmission priority receives more packet dequeuing turns and dequeues more UMTS packet from itself. With the proposed packet enqueuing and dequeuing modules, a packet forwarding differentiated service behavior is supported among UMTS traffic.

In this study, several C++ programs and TCL scripts are coded and implemented in the ns2 to provide a simulation platform for different scenarios. According to the simulation results, two important points are found. First, the proposed queuing scheme can depend on packet transmission priorities of four types of UMTS traffic to support differentiated packet forwarding performance among UMTS traffic. Second, in the proposed queuing scheme, parameter settings of the promised buffer size, minimum limit, maximum limit and packet enqueuing probability impact four types of UMTS traffic's packet forwarding performance. Proper parameter settings help UMTS traffic to receive differentiated packet forwarding performance with the proposed queuing scheme within a UMTS core network.

Table 3 Simulation results with several groups of parameters settings

No	***TT***	***PBs***	DB_{min}	DB_{max}	DB_p	Q_{arp}	Q_{dep}	Q_{drp}	***TT***	***PBs***	DB_{min}	DB_{max}	DB_p	Q_{arp}	Q_{dep}	Q_{drp}
1	***C***	0	0	0	0.00	0	0	5000	***I***	0	0	0	0.00	0	0	5000
	S	0	0	0	0.00	0	0	5000	***B***	0	0	0	0.00	0	0	5000
2	***C***	40	40	40	1.00	5000	5000	0	***I***	40	40	40	1.00	5000	21	4979
	S	40	40	40	1.00	5000	4999	1	***B***	40	40	40	1.00	5000	18	4981
3	***C***	40	40	40	0.00	5000	5000	0	***I***	40	40	40	0.00	5000	21	4979
	S	40	40	40	0.00	5000	4999	1	***B***	40	40	40	0.00	5000	18	4981

Table 3 Simulation results with several groups of parameters settings (cont.)

No	*TT*	*PBs*	DB_{min}	DB_{max}	DB_p	Q_{arp}	Q_{dep}	Q_{drp}	*TT*	*PBs*	DB_{min}	DB_{max}	DB_p	Q_{arp}	Q_{dep}	Q_{drp}
4	***C***	40	0	40	1.00	5000	5000	0	***C***	40	0	40	0.80	5000	21	4979
	S	40	0	40	0.90	5000	4999	1	***S***	40	0	40	0.70	5000	18	4981
5	***C***	10	0	40	1.00	5000	5000	0	***I***	10	0	40	1.00	5000	21	4979
	S	10	0	40	1.00	5000	4999	1	***B***	10	0	40	1.00	5000	19	4981
6	***C***	10	0	40	0.00	5000	4009	991	***I***	10	0	40	0.00	5000	2010	2990
	S	10	0	40	0.00	5000	3010	1990	***B***	10	0	40	0.00	5000	1010	3990
7	***C***	10	0	40	0.50	5000	4010	990	***I***	10	0	40	0.50	5000	2011	2989
	S	10	0	40	0.50	5000	3010	1990	***B***	10	0	40	0.50	5000	1008	3992
8	***C***	10	0	40	1.00	5000	5000	0	***I***	10	0	40	0.80	5000	500	4500
	S	10	0	40	0.90	5000	4522	478	***B***	10	0	40	0.70	5000	17	4983
9	***C***	10	0	40	0.90	5000	4992	8	***I***	10	0	40	0.70	5000	1007	3993
	S	10	0	40	0.80	5000	4017	983	***B***	10	0	40	0.60	5000	23	4977
10	***C***	0	0	40	0.00	5000	0	5000	***I***	0	0	40	0.00	5000	0	5000
	S	0	0	40	0.00	5000	0	5000	***B***	0	0	40	0.00	5000	0	5000
11	***C***	0	0	40	0.50	5000	5000	0	***I***	0	0	40	0.50	5000	21	4979
	S	0	0	40	0.50	5000	4999	1	***B***	0	0	40	0.50	5000	19	4981
12	***C***	0	0	40	1.00	5000	2439	2561	***I***	0	0	40	1.00	5000	2492	2508
	S	0	0	40	1.00	5000	2544	2456	***B***	0	0	40	1.00	5000	2486	2514
13	***C***	0	0	40	1.00	5000	5000	0	***I***	0	0	40	0.80	5000	408	4592
	S	0	0	40	0.90	5000	4524	476	***B***	0	0	40	0.70	5000	107	4893
14	***C***	20	0	40	0.00	5000	5000	0	***I***	12	0	40	0.00	5000	2008	2992
	S	16	0	40	0.00	5000	3016	1984	***B***	8	0	40	0.00	5000	15	4985
15	***C***	20	0	40	0.50	5000	5000	0	***I***	12	0	40	0.50	5000	2003	2997
	S	16	0	40	0.50	5000	3017	1983	***B***	8	0	40	0.50	5000	19	4981
16	***C***	20	0	40	1.00	5000	5000	0	***I***	12	0	40	1.00	5000	27	4973
	S	16	0	40	1.00	5000	4999	1	***B***	8	0	40	1.00	5000	13	4987
17	***C***	20	0	40	1.00	5000	5000	0	***I***	12	0	40	0.80	5000	501	4499
	S	16	0	40	0.90	5000	4520	480	***B***	8	0	40	0.70	5000	18	4982
18	***C***	20	20	40	0.50	5000	5000	0	***I***	12	12	40	0.50	5000	2004	2996
	S	16	16	40	0.50	5000	3017	1983	***B***	8	8	40	0.50	5000	18	4982
19	***C***	20	20	40	1.00	5000	5000	0	***I***	12	12	40	1.00	5000	21	4979
	S	16	16	40	1.00	5000	4999	1	***B***	8	8	40	1.00	5000	19	4981
20	***C***	20	20	40	1.00	5000	5000	0	***I***	12	12	40	0.80	5000	524	4476
	S	16	16	40	0.90	5000	4499	501	***B***	8	8	40	0.70	5000	16	4986
21	***C***	20	20	40	0.50	5000	5000	0	***I***	12	12	32	0.50	5000	2008	2992
	S	16	16	36	0.50	5000	3016	1984	***B***	8	8	28	0.50	5000	15	4985
22	***C***	20	20	40	1.00	5000	5000	0	***I***	12	12	32	1.00	5000	2008	2992
	S	16	16	36	1.00	5000	3016	1984	***B***	8	8	28	1.00	5000	15	4985
23	***C***	20	20	40	1.00	5000	5000	0	***I***	12	12	32	0.80	5000	2008	2992
	S	16	16	36	0.90	5000	3016	1984	***B***	8	8	28	0.70	5000	15	4985
24	***C***	20	20	40	0.95	5000	5000	0	***I***	12	12	32	0.60	5000	2008	2992
	S	16	16	36	0.80	5000	3016	1984	***B***	8	8	28	0.30	5000	15	4985

Legends: **TT**: traffic type, **PBs**: promised buffer size, $\mathbf{DB_{min}}$: dynamic buffer's min limit,
$\mathbf{DB_{max}}$: dynamic buffer's max limit, $\mathbf{DB_p}$: dynamic buffer's packet enqueue probability,
$\mathbf{Q_{arp}}$: arrival packets, Q_{dep}: dequeued packets, $\mathbf{Q_{drp}}$: dropped packets,
C: conversational, **S**: streaming, **I**: interactive, **B**: background

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