Effect of RLC Transmission Modes for Differentiated Traffic Types in HSDPA via GEO Satellite

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Abstract— **This paper investigates the effect of the Radio Link Control (RLC) operation modes for different types of UMTS traffic over a Satellite High Speed Downlink Packet Access (S-HSDPA) air interface. Satellite Systems are expected to complement the terrestrial access network and work with the same core network. The geostationary bent-pipe satellite has been considered for this work. The transmission of different traffic types was observed for both Acknowledge Mode (AM) and Unacknowledged Mode (UM) by investigating the effect of the cross-layer interactions between the application layer and RLC sub-layer of the data link layer. Our aim is to recommend which transmission mode is best for each traffic types and to compare the results with the Terrestrial HSDPA air interface scenario.**

Keywords- S-HSDPA;GEO Satellite;RLC Mode; Acknowledged Mode; Unacknowledged Mode

I. INTRODUCTION

High Speed Downlink Packet Access (HSDPA) is an upgrade of the current 3G (WCDMA) systems that is aimed at improving the performance of downlink packet data traffic with downlink speeds ranging from 1 to 5 Mbps by means of Adaptive Modulation Coding (AMC), a fast packet scheduling due to Transmission Time Interval (TTI) reduction from 10ms to 2ms, an extensive multi-code operation and a fast and spectral efficient retransmission strategy known as Fast Physical Layer Hybrid ARQ (F-L1 HARQ)[1],[2].

Satellite Systems are a valid alternative to provide broadband communications services to both fixed and mobile users in scenarios where terrestrial networks cannot be used due to technical and economical viability. The Satellite Systems' air interface is expected to provide the same characteristics as the terrestrial counterparts and used the same core network as the terrestrial access networks. The Satellite Universal Mobile Telecommunications Systems (S-UMTS) Family G specification set aims at achieving the satellite interface that will be fully compatible with Terrestrial UMTS (T-UMTS)-based systems, even if some modifications are made due to the differences between the terrestrial and satellite channels[3],[4].This paper focuses on satellite HSDPA which is achieved by extending the terrestrial HSDPA to a geostationary satellite network, so as to support broadband applications for mobile users.

In S-HSDPA, the different types of traffic such as conservational voice traffic, video streaming, interactive web traffic and background File Transfer Protocol (FTP) download can be transmitted in three different Radio Link Control (RLC) operation modes namely Acknowledged Mode (AM), Transparent Mode (TM) and Unacknowledged Mode (UM). The RLC is one of the major radio interface protocols which consist of flow control and error recovery. It is a sub-layer on top of the Media Access Control (MAC) layer which consists of the three operations mode namely AM, TM and UM. The AM offers a reliable data delivery while UM and TM does not guarantee data delivery. In this paper, we have studied the impact of this RLC transmission modes in the four different UMTS/HSDPA traffic types and recommend which transmission modes is best for each traffic type. We used both the Proportional Fair (PF) scheduler and our newly proposed scheduler that is sensitive to real time traffic called Queue Aware Channel Based (QACB) Scheduler for the investigation. We also did a brief comparison of our work to a similar work on terrestrial access network.

The remainder of the paper is organized as follows; a system description including the channel characteristics and traffic models are given in Section 2. Section 3 gives a brief overview of the existing three RLC operation modes in S-HSDPA. The simulation setup and results are presented in Section 4. Finally, we conclude this paper in Section 5.

II. SYSTEM DESCRIPTION

A. S-HSDPA Air Interface

In the envisaged HSDPA, the User Equipment (UE) sends a feedback of its channel conditions to the Base Station (Node B) at certain interval. Based on the channel conditions, HSDPA makes use of Adaptive Code Modulation (ACM) and multi-code operation to transmit the corresponding Modulation and Coding Scheme (MCS) at every Transmission Time Interval (TTI) of 2ms. It is worthy to note that only one MCS level can be used for each TTI and that a user can concurrently use up to 15 multi-codes for downlink transmissions [5].

A multi-beam GEO bent-pipe satellite is considered in this paper. The RLC protocol runs in the Radio Network Controller (RNC), which is located on the earth, as shown in the Fig. 1 and operates as a gateway to the existing core

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network that is also used by the terrestrial counterparts. The RLC protocol also runs on the User Equipment (UE).

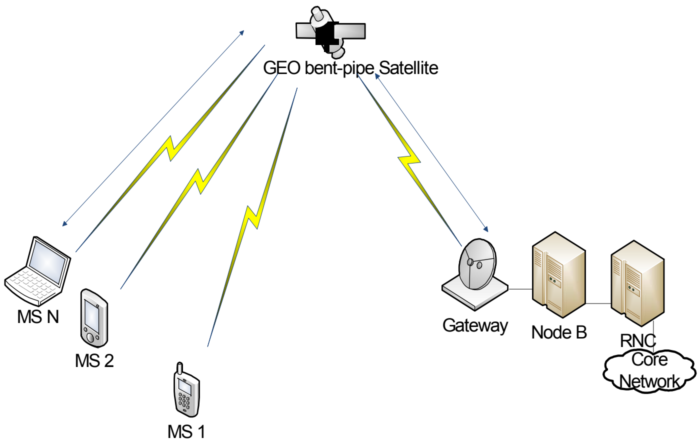

Figure 1. System Architecture of S-HSDPA

The UE reports its channel Quality Information (CQI) at certain reporting interval, which is 40ms (20 TTI) for the purpose of this research, as requested by the RNC. Based on the CQI value which varies from 1 to 30, the Node B transmits at the corresponding MCS level that will cope better with the channel conditions.

B. Channel Characteristics

For the purpose of this research, a 3-state channel model has been considered rather than the 2-state Good-Bad channel model. This enables us to have a more realistic channel modeling.

A comprehensive data set which corresponds to an S-band (2GHz) measurement was process in order to obtain the required model propagation parameters and the simulations of the S-UMTS channel model that is capable of reproducing the complex envelope variations in the received signal due to shadowing and multipath fading. This was conducted for each state at different elevation angles in different environments [6]. The three states are Line of Sight (LOS), Moderate Shadowing and Deep Shadowing. At each instance, the state is decided by using a 3-state markov chain using its state and transition probabilities.

The corresponding parameters for suburban area at an elevation angle of 60^o have been considered for this research. A shadow fading is generated using the corresponding state, transition probabilities and a set of Loo model parameters. After which, the corresponding SNR for the shadow fading is generated using Link Budget analysis. Note that the loss due to shadow fading is added to the total loss. The corresponding CQI of the generated SNR values is determined using (2) which was derived from (1) [7];

$$SNR = \frac{\sqrt{3}-\log_{10} CQI}{2}.\log_{10}(BLER^{-0.7}-1)+1.03CQI-17.3 \qquad (1)$$

$$CQI = \begin{cases} 0 & \text{if } SNR \leq -16, \\ \dfrac{SNR}{1.02} + 16.02 & \text{if } -16 \leq SNR \leq 14, \\ 30 & \text{if } 14 \leq SNR. \end{cases} \qquad (2)$$

The SNR and corresponding CQI values were generated using a MATLAB script and the channel trace input for over 400s was generated for the simulation. Due to long propagation delay, there is misalignment between the present SNR of the UE and the reported CQI value used by the Node B. This will result in either inefficient use of resources due to the use of a lower CQI value or lead to loss of packets due to the use of higher CQI value. To compensate for the long RTPD, a SNR margin, h of value 3.5 dB have been introduced [4], so as to avoid over estimation of the CQI value.

$$CQI = CQI\ (SNR - h, BLER), \text{ where } h = 3.5dB \qquad (3)$$

C. Traffic Models

There are four classes of traffic in UMTS/HSDPA which are conversational class (e.g. voice, video telephony), streaming class (e.g. video streaming, video on demand), interactive class (e.g. web browsing) and background class (e.g. FTP downloading, email messages). We have considered all the four classes for our simulation and assume that we have video streaming, Voice over IP (VOIP), web and FTP users demanding traffic within the GEO satellite spot beam.

A Variable Bit Rate (VBR) MPEG-4-coded video streaming traffic was used which was modeled using a Transform-Expand-Sample (TES) model. The TES modeling procedure involved two stages. The first stage involves each frame type (I, P and B) being modeled by a TES process and the second stage involves interleaving the three TES models in the correct order [8]. The I-frame (intra-coded picture), the P-frame (Predicted Picture) and the B-frame (Bi-predictive picture) are used for video compression. This model generates twenty five (25) frames every second. The VOIP traffic was modeled using an exponential ON/OFF model.

A Transmission Control Protocol (TCP) based Web traffic was modeled using M/Pareto ON/OFF model. The random variable parameters used for the Pareto packet size distribution are $\alpha = 1.1$, k=81.5 bytes with IP packet size of 1500 bytes [9],[10] while the default network simulator 2 (ns-2) TCP based FTP source was used for FTP traffic.

III. RLC TRANSMISSION MODES

The S-UMTS/HSDPA network architecture consists of three components: the Core Network (CN), same CN which the terrestrial counterparts uses, the UMTS Satellite Radio Access Network (USRAN) and the User Equipments (UE), as shown in Fig. 1. There is a radio interface in between USRAN and UE called the Uu. The Layer 2 of this radio interface is called the link layer which has both MAC and RLC as sub-layers [11]. The RLC sub-layer is on top of the MAC sub-layer. The MAC sub-layer handles the scheduling of radio bearers and mapping of the logical channels to transport channels. It provides data transfer services over logical channels while the RLC provides the data transfer service of higher layer Protocol Data Units (PDU). But due to the fact that MAC data transfer mode is unacknowledged, the RLC ensures reliability of the delivery of higher layer PDUs [1]. Each RLC instance is configured by Radio resource Control (RRC) to operate in one of the three modes: Transparent Mode (TM), Acknowledged Mode (AM) or Unacknowledged Mode (UM).

A. Transparent Mode

In this mode, no protocol overhead is added to higher layer data. RLC entity in this mode is unidirectional because association between the uplink and downlink is not needed. Transmissions with limited or no segmentation can be accomplished in this mode e.g. the streaming traffic type. Erroneous PDUs can be discarded or marked as erroneous

B. Acknowledged Mode (AM)

This operation mode is used for reliable transmissions. It uses Automatic Repeat Request (ARQ) mechanism for error corrections. The RRC is used to control the performance of RLC through the configuration of the number of retransmissions. If the maximum number of transmissions configured is reached or transmission time is exceeded and the RLC is unable to deliver the data correctly, the upper layer is notified and the RLC Service Data Unit (SDU) is discarded. RLC entity in this mode is bidirectional and it's capable of piggybacking which is an indication of the status of the link in the opposite direction into user data. The AM mode is normal for packet-type services like web browsing, email messaging and downloading.

C. Unacknowledged Mode (UM)

In this mode, there is no guarantee for data delivery since no retransmission protocol is used. The RLC entity in UM mode is unidirectional because association between the uplink and the downlink is not needed. Received erroneous data are either marked or discarded depending on the configuration. The sequence number of the PDU structure is used to ensure that the integrity of higher layer PDUs are observed. The cell broadcast service and VOIP are example of user services that can be used in this mode.

IV. SIMULATION SET-UP AND RESULTS

The investigation of the effect of RLC operation modes on differentiated traffic types was based on a discrete event simulations using Network Simulator 2 (NS-2) [12]. NS-2 itself doesn't support UMTS and HSDPA, therefore, a UMTS/HSDPA extension to NS-2 was used called Enhanced UMTS Radio Access Network Extension (EURANE) [13].As stated in [14], there are only two RLC operation modes that are provided in the EURANE module which are AM and UM, so TM is not considered in this simulation. The Proportional Fair (PF) scheduler and our newly proposed scheduler in [15], Queue Aware Channel Based (QACB) scheduler were used for the simulation, so as to know if the effects observed will be similar for both schedulers since the former is strictly channel based while the latter considers QoS factors in addition with channel conditions. These two schedulers are added to EURANE using the guidelines provided in [16]. For this simulation, only one user is allocated resources at every Transmission Time Interval (TTI).

The input trace files (physical layer parameters) for EURANE were generated using a MATLAB preprocessed code for a terrestrial HSDPA; therefore a newly built MATLAB preprocessed script was used to generate satellite physical layer parameters' input trace file for S-HSDPA air interface.

For our simulation study, we have 12 users made up of 2 video streamers, 4 VOIP users, 4 web users and 2 FTP downloaders. We have two scenarios for the simulation. Firstly, the simulation was done in AM mode for both schedulers and later in UM mode for both schedulers as well. The simulated network is shown in Fig. 2, where Node B is connected to Wired Node 1 through RNC, Serving GPRS Support Node (SGSN), Gateway GPRS Support Node (GGSN) and Wired Node 2.

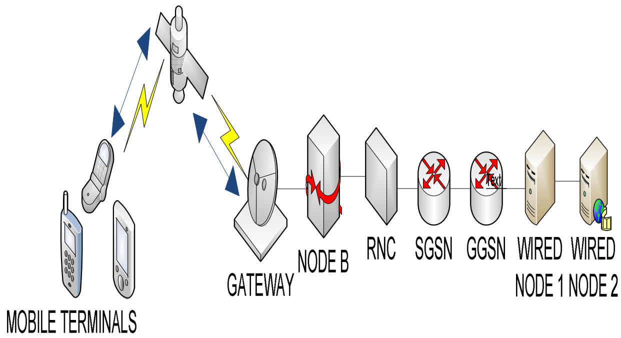

Figure 2. Simulated S-HSDPA Network

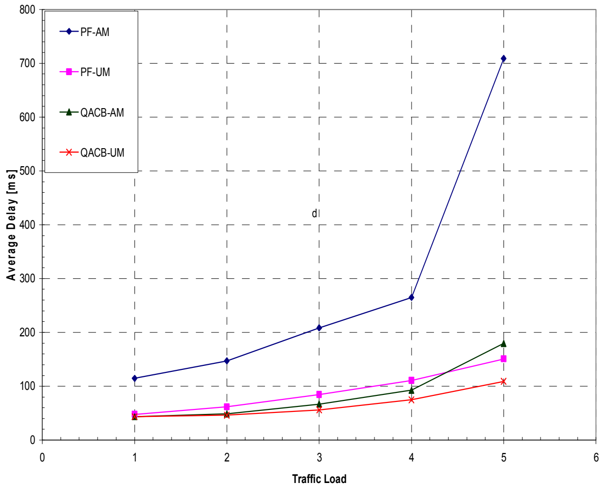

Figure 3. Average Delay of Video Users for PF and QACB Schedulers.

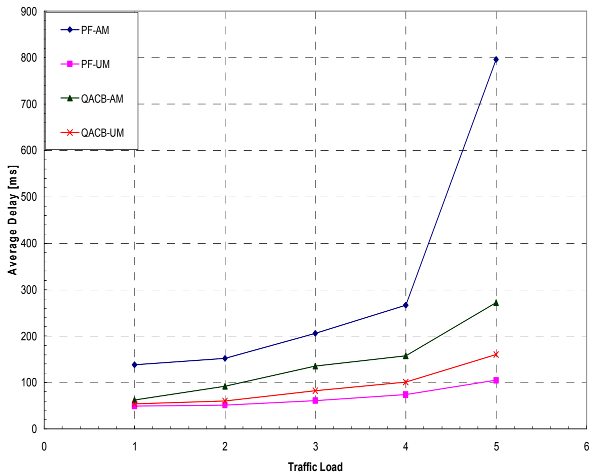

Figure 4. Average Delay of Voice Users for PF and QACB Schedulers .

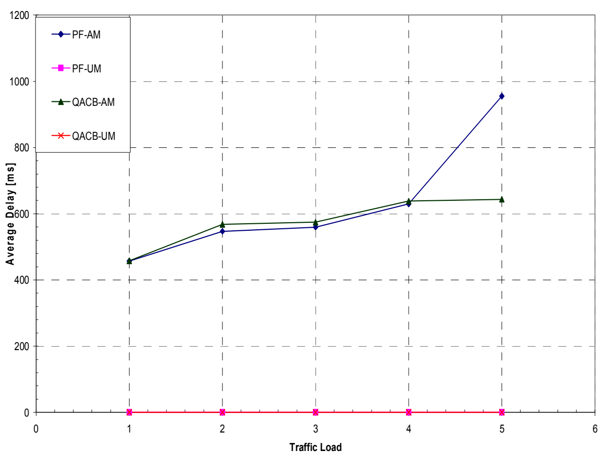

Figure 5. Average Delay of Web Users for PF and QACB Schedulers

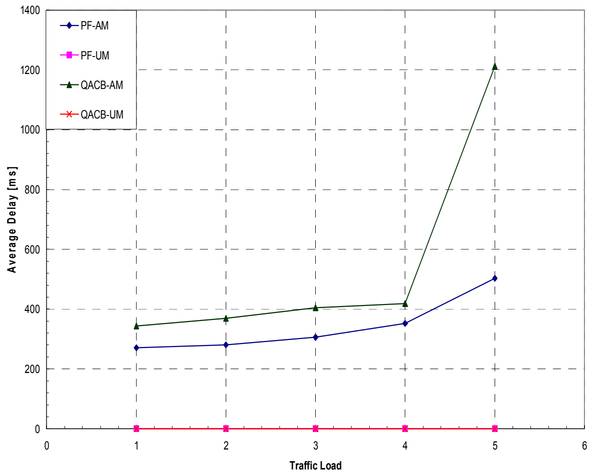

Figure 6. Average Delay of FTP Users for PF and QACB Schedulers

The average delay experienced by various users in both AM and UM RLC modes for the two schedulers are shown in Fig. 3 – Fig. 6. It is observed that the delay sensitive traffic users, video and voice users, have better average delay performance in RLC UM mode compare to RLC AM mode while for the delay insensitive traffic users, web and FTP users, only users in AM mode experienced delay but the users in RLC UM mode experienced zero delay. The delay performance of QACB scheduler is observed to be better than PF scheduler except for voice case in UM mode which are close.

From Fig. 7 and Fig. 8, generally, the video and voice users in UM mode for both schedulers has better average jitter performance compared to AM mode. It is also observed that the PF scheduler is more unstable and has greater spikes compare to QACB scheduler, this is due to the the fact that the PF scheduler can't distinguish delay sensitive trafffic from other traffic types, so therefore, it's not suitable for mixed traffic scenarios.

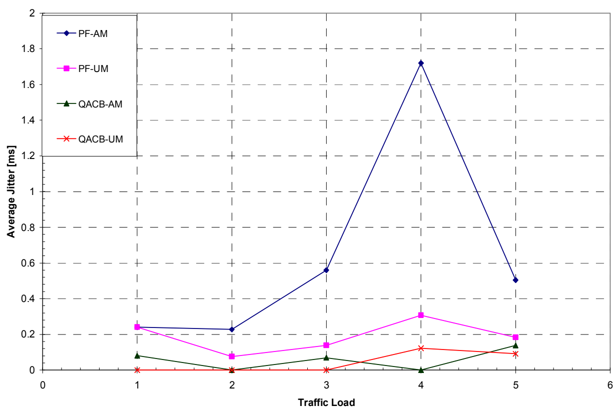

Figure 7. Average Jitter of Video Users for PF and QACB Schedulers

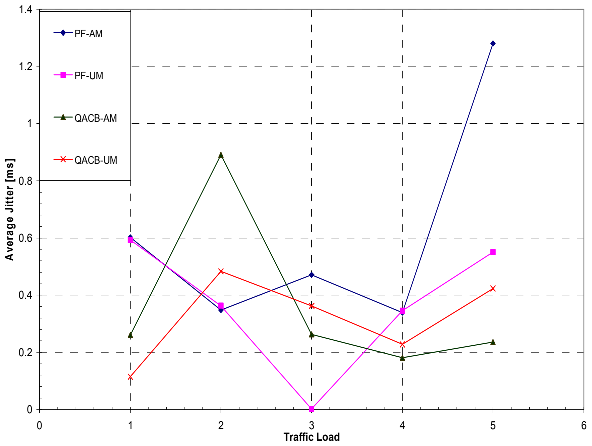

Figure 8. Average Jitter of Voice Users for PF and QACB Schedulers

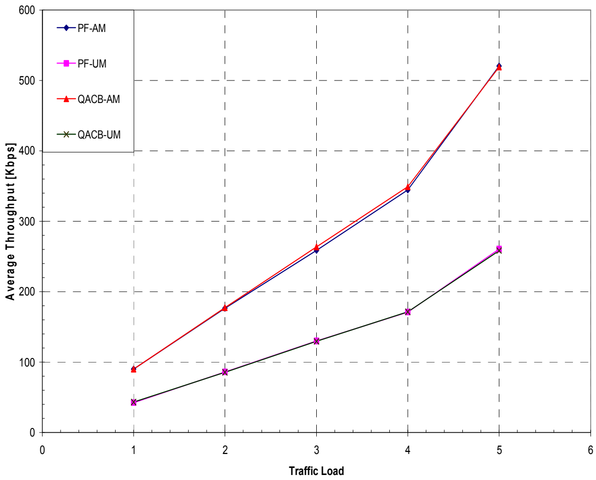

Figure 9. Average Throughput of Video Users for PF and QACB Schedulers

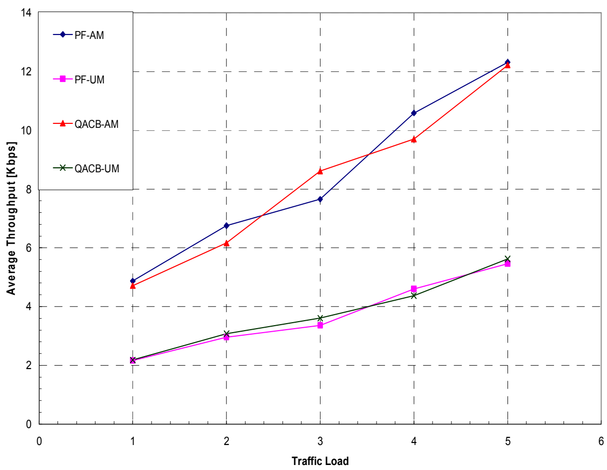

Figure 10. Average Throughput of Voice Users for PF and QACB Schedulers

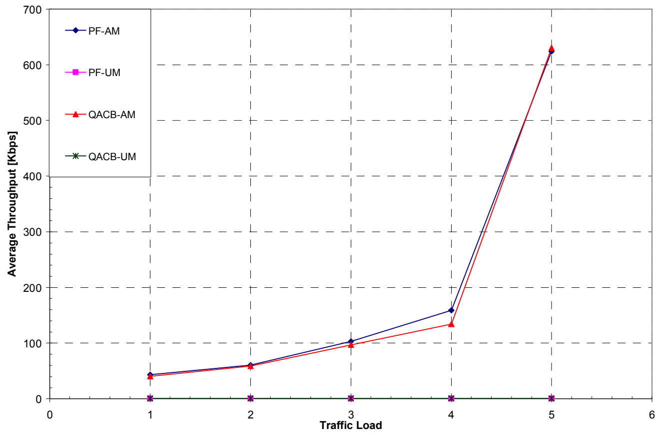

Figure 11. Average Throughput of Web Users for PF and QACB Schedulers

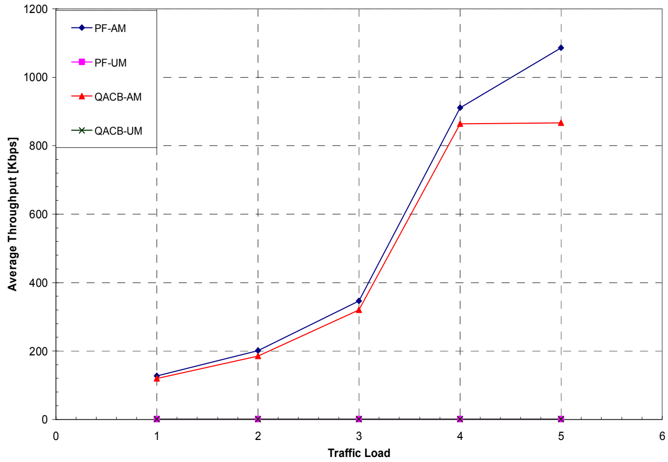

Figure 12. Average Throughput of FTP Users for PF and QACB Schedulers

The average throughput for video and voice users transmitting in UM mode for both schedulers is observed to be almost half of the average throughput in the AM mode as shown in Fig. 9 and Fig. 10.Since in Fig. 13, it is shown that the number of packets sent in each mode for voice users, though not equal but are close to each other, one will expect the throughput in the two modes should be close but due to the retransmission capabiltiy in AM mode, the average throughput experienced by video and voice users in AM mode is higher.

Fig. 11 and Fig. 12 that shows the average throughput of both the web and FTP users respectively explains why the users experience a zero delay in UM mode, the average throughput experienced is less than 1 Kbps and this can also be verified in Fig. 14 which shows the number of packets sent by web users in UM mode is 32 packets which is very negligible compare to that of the web packets transmitted in AM mode.The graphs for number of packet sent for video and FTP users are similar in behaviour to that of voice and web users respectively but due to space limit, they are not made available. This average throughput behaviour for web and FTP packets is said to occur due to the fact that they are both TCP based applications and TCP only supports reliable connections.Therefore, it will only have successful transmissions in AM mode.

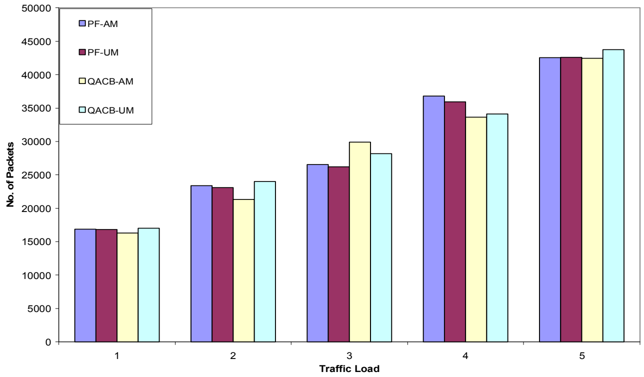

Figure 13. Packet Sents by Voice Users for PF and QACB Scheduler

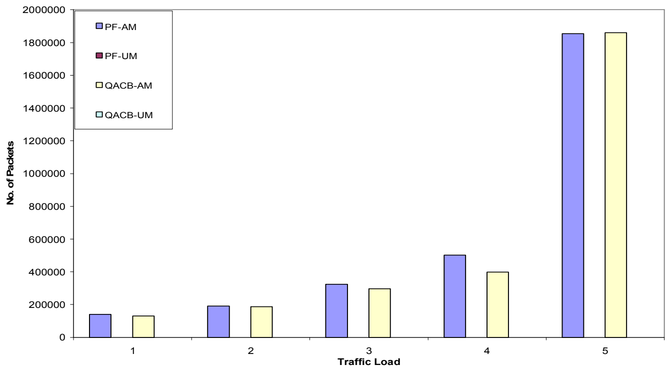

Figure 14. Packet Sents by Web Users for PF and QACB Scheduler

V. CONCLUSION

From simulation results, it is recommended that the delay sensitive traffics like VOIP and video should transmit in RLC UM mode since lower delay and a more stable lower jitter is experienced while for non-delay sensitive traffics like web and FTP, UM mode is not an option for transmissions. They can only operate in RLC AM mode. The result also shows that QACB scheduler provides better performance for delay sensitive traffics like video and voice in the two modes compared to PF scheduler while both schedulers' performances are close for non delay sensitive traffic like web and FTP. Also, our result follows the same trend with similar work done for the terrestrial counterpart as shown in [17]. An average delay of below 300 ms is experienced by delay sensitive traffic like video and voice at all traffic loads for the QACB scheduler and at most of the traffic loads for the PF scheduler, this is close to what was obtained in the terrestrial work as stated in [17]. This shows that satellite systems are valid alternatives for the provision of access network to mobile users.

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