A Multiple Access Protocol for Multimedia Transmission over Wireless ATM Networks

Hong Yu
Capitol College
yhong@capitol-college.edu

Mohammed Arozullah
The Catholic University of America
arozullah@cua.edu

Abstract

This paper develops and evaluates the performance of an advanced multiple access protocol for transmission of full complement of multimedia signals consisting of various combinations of voice, video, data, text and images over wireless networks. The protocol is called Advanced Multiple Access Protocol for Multimedia Transmission (AMAPMT) and is to be used in the Data Link Layer of the protocol stack. The protocol grants permission to transmit to a source on the basis of a priority scheme that takes into account a time-to-live (TTL) parameter of all the transactions, selectable priorities assigned to all the sources and relevant channel state information (CSI) in this order. Performance of the protocol is evaluated in terms of quality of service parameters like cell loss ratio (CLR), mean cell transfer delay (MCTD) and throughput. Using a simulation model based on an OPNET simulation software package does the evaluation. under various traffic loads with constant distributions with various mean arrival rates and transaction sizes results obtained show that the performance is improved when this priority scheme is used than when it is not used.

Introduction

Wireless Networks can be used to transmit multimedia services consisting of Voice, Data, Video, Ftp, and Text. These networks are required to provide desired qualities of service (QoS) to the various media with diverse flow characteristics [1]. For example, cell loss ratio requirement for all loss sensitive services such as email and cell delay requirements for all delay sensitive services as voice are to be satisfied simultaneously and adequately. For a given input traffic load a certain amount of resources (e.g., buffer space and link capacity) are needed to satisfy these QoS requirements. Thus it is required to develop simple and efficient resource management protocols for these networks that can provide better use of network resources. In this paper such a protocol for multimedia transmission called Advanced Multiple Access Protocol for Multimedia Transmission Protocol (AMAPMT) is presented. Performance of this protocol is evaluated in terms cell loss ratio (CLR), mean cell transmission delay (MCTD) and throughput under various traffic loads with constant with various mean arrival rates and transaction sizes. The protocol uses parameters like time to live (TTL) of transactions, priority of individual medium and relevant channel state information (CSI) in this order to grant permission to the sources to transmit. Performance is evaluated by implementing a simulation test bed using OPNET simulation software package. In this test bed a wireless network consisting of a selectable number of source stations, mobiles and a base station has been implemented. The performance of the AMAPMT protocol is evaluated by using this test bed. Results for CLR, MCTD and throughput are obtained and presented in tabular and graphical forms for various combinations of the above-mentioned parameters. And Performance of this protocol is compared to that of a currently available multiple access protocol called Adaptive Request Channel Multiple Access (ARCMA) and AMAPMT protocol is shown to out perform ARCMA protocol[2].

Service Types of Constituting Multimedia Signal

A multimedia signal may consist of some or all of the five service categories: constant bit rate (CBR), real-time variable bit rate (RT-VBR), non-real-time variable bit rate (NRT-VBR), available bit rate (ABR) and unspecified bit rate (UBR) [3]. Constant bit rate (CBR) services generate output at a constant bit rate, requires time synchronization between the traffic source and destination, require predictable response time and a static amount of bandwidth for the lifetime of a connection with low latency. Real-Time Variable Bit Rate (RT-VBR) services compressed video stream or mobile Internet access application, generate information at a rate that is variable with time, requires time synchronization between the traffic source and destination require the delay to be less than a specified maximum value and a variable amount of bandwidth. Non-Real-Time Variable Bit Rate (NRT-VBR) services that include File transfer, image applications, generate variable bit rate traffic for which there is no inherent requirement on time synchronization between the traffic source and destination and require no guaranteed delay bound. Available Bit Rate (ABR) is a best effort service. Neither data rate nor delay is guaranteed. The minimum and maximum rates are guaranteed, as is a bound on cell loss rate. This service includes data and allows wireless system to fill its channels to the maximum capacity when CBR or VBR traffic is low. Unspecified Bit Rate (UBR) service category is similar to NRT-VBR without guaranteed minimum rate or bound on the cell loss rate. It is used for connections that transport variable bit rate traffic for which there is no requirement on time synchronization between the traffic source and destination, file transfer, back up transfer and email without delay guarantee.

Wireless Network

A typical Wireless network consists of a base station, a number of mobiles and source stations. Each mobile is connected to a number of source stations. The source stations may be of different types such as voice stations, data stations, Ftp stations and Email stations. In this network the source stations generate and save information (voice, video, data, Ftp, email). The source stations send Request Access (RA) packets to the relevant mobiles to ask permission to send information. The mobiles forward these requests to the base station. The base station considers all such requests for a frame time and grants permission to transmit information, according to some multiple access protocol, to the source stations via relevant mobiles. Performance of the protocol is measured in terms of some desired qualities of service.

Available Multiple Access Protocols, Their Applicability and Shortcomings

Three multiple access protocols are available. These are Packet Reservation Multiple Access (PRMA) [4], Distributed queuing Request Update Multiple Access (DQRUMA) [5] and Adaptive Request Channel Multiple Access (ARCMA).
The currently available multiple access protocols deal with voice and data and not a full complement of multimedia signals. Further these protocols do not assign explicit priority to the different types of information namely voice and data. There is a need for multiple access protocol for handling full complement (CBR, RT-VBR, NRT-VBR, ABR and UBR) of multimedia signals. Some of the media may be delay sensitive while others are loss sensitive. However, the problem with priority assignment according to the type of the media type only is that some lower priority media may have to wait too long and the information may become stale. Also the stations have limited buffer space, so some of the information may be lost due to buffer overflow and discarding traffic coming through channels with inferior transmission quality can improve processing and transmission times for other traffics coming through channels with superior transmission qualities. Thus consideration of explicit priorities, Time to Live (TTL) of transactions and Channel State Information (CSI) parameters may improve the situation [6]. A protocol that assigns priorities on the basis of TTL, explicit priorities for the various media and CSI is proposed and evaluated in the section 4.

The Advance Multiple Access Protocol For Multimedia Transmission (AMAPMA)

In this paper a new multiple access protocol for wireless network called Advanced Multiple Access Protocol for Multimedia Transmission (AMAPMT) is developed and its performance is evaluated. This protocol handles the full complement of multimedia signals and uses the time to live (TTL) parameter and explicit priority assignments to media types to improve its performance and to treat the various types of media fairly. It also uses channel state information (CSI) (e.g., bit error rate) in assigning access to media. Media received over a channel with unacceptably low channel state information (e.g., high BER) are denied access.

The Principle of Operation of AMAPMT Protocol

In this protocol, the stations generate and save information (voice, video, data, Ftp, email). The stations send Request Access (RA) packets to the relevant mobiles to ask permission to send information. The mobiles forward these RA packets to the base station over a reservation channel using a multiple access protocol likes slotted ALOHA and TDMA [7]. The base station acknowledges the requests, saves the RA packets for a frame time. The Request Access (RA) packets contain information on the source address, media type, bit rate, time-to-live, CSI and the requested quality-of-service (QoS) of the traffic to be transmitted. The base station processes the RA packets and grant permission to the relevant stations to transmit in a fair queuing basis using the parameters contained in the RA packets in the order of TTL, CSI and traffic type.

The Flow Charts of Operation of AMAPMT Protocol

The flow charts in Figures 1 through 5 describe the various aspects of operation of the AMAPMT multiple access protocol.

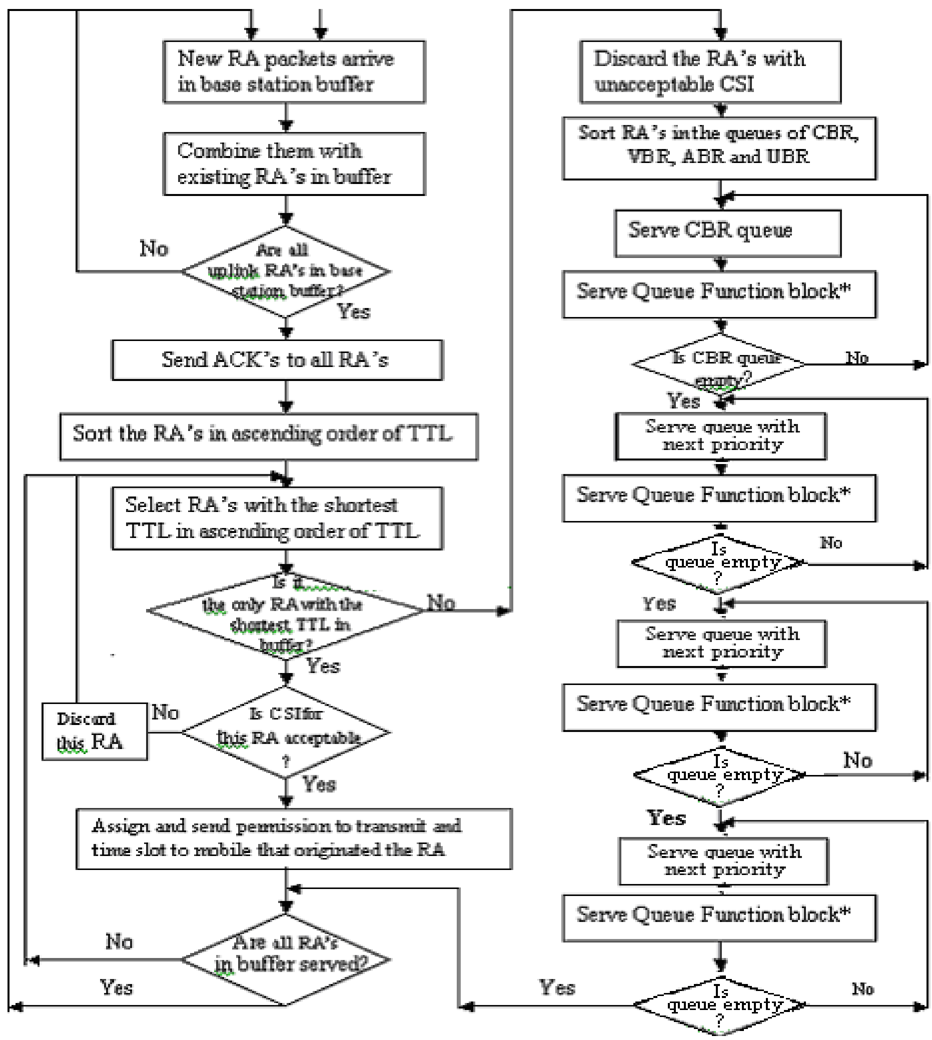


Figure 1: Protocols for the Handling of RA Packets at the Base Station

For the flow chart in Figure 1, Protocol for handling RA packets at base station presents the way the base station handles the arriving Request Access (RA) packets from all mobiles. All arriving RA's are saved at the buffer. The RA's are selected in ascending order of TTLs. The RA's with the lowest TTL are selected first. If there is only one RA with the lowest TTL then the mobile that generated this RA is given permission to transmit if the corresponding channel CSI is acceptable. Otherwise this RA is rejected and RA's with the next TTL are selected. If there are multiple RA's with the same TTL then discard the TTLs with unacceptable CSI. Sort the remaining RAs into individual

ISBN 978-1-60643-379-9

queues of RAs from CBR, VBR, ABR and UBR sources. Serve these queues in this order one by one according to Serve Queue Function in Figure 2

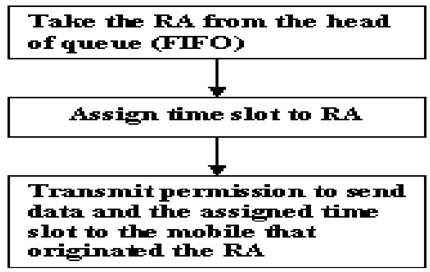


Figure 2: Serve Queue Function Block at the Base Station

For the flow chart Figure 2, Serve Queue Function block at the base station presents the way the base station assigns time slots and Permission to transmit to the CBR, VBR, UBR and VBR mobiles according to FIFO queuing strategy. At same time, the signal information with the low priority will be discarded by the base station of the network. The signal with the highest priority will be received the acknowledgment response to upload the information data.

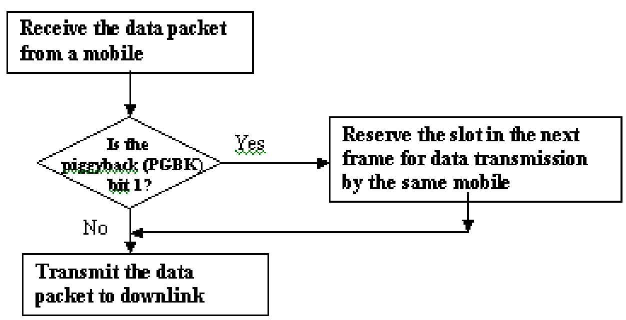


Figure 3: Protocol for the Handling of Data Packets at the Base Station

The flow chart Figure 3 shows the protocol for handling of data packets at the base station presents the way the base station assigns time slots and permission to transmit to the CBR, VBR, UBR and VBR mobiles. After a mobile is given permission to transmit it transmits to the base station data packets requesting permission for transmission for further packets. If this is the first request for permission to transmit then it puts the piggyback bit in the requesting data packet to 0 and if it is repeat request for permission to transmit then it puts the piggyback bit in the requesting data packet to 1. The base station uses this piggyback bit to give preference to mobiles requesting permission to transmit for the first time according to this protocol.

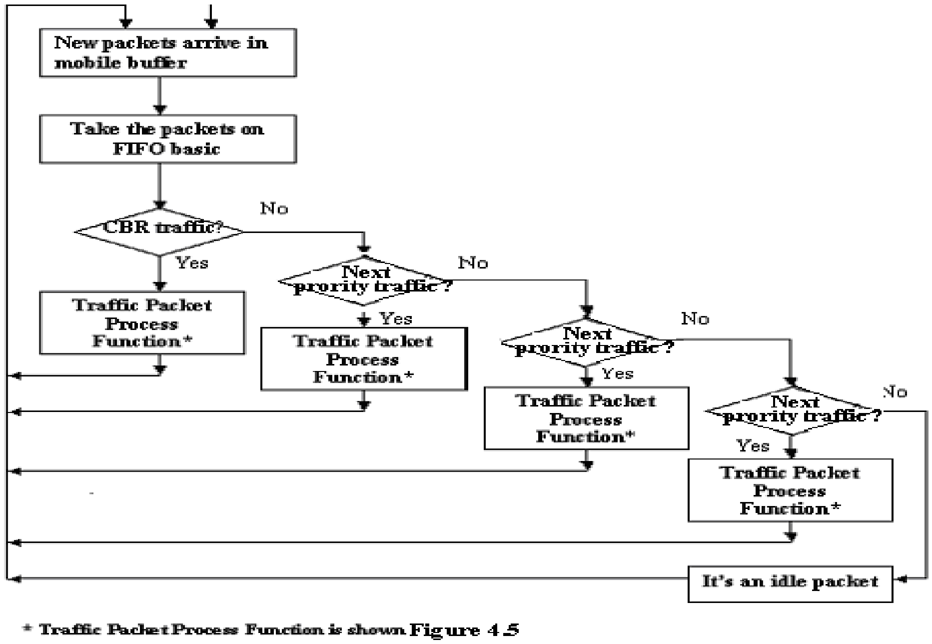


Figure 4: Protocol at the Mobiles for the Handling RA Packets from the Stations

For the flow chart in Figure 4, Protocol at the Mobiles for Handling RA Packets from Stations presents the way the mobiles assigns time slots and Permission to transmit to the CBR, VBR, UBR and VBR mobiles. RA packets arriving at the mobiles are queued in CBR, VBR, ABR and UBR queues and are served in this order according this protocol using the Data Packet Process Function at the Mobiles shown in Figure 5.

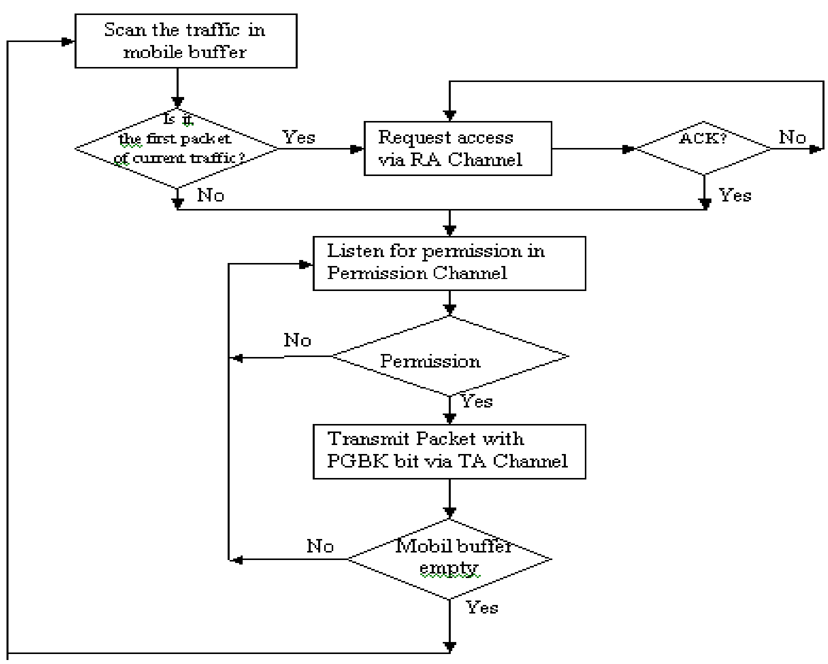


Figure 5: Data Packet Process Function at the Mobiles

ISBN 978-1-60643-379-9

PGBK ------ Piggyback, TA -------Transmission Access, ACK ------Acknowledgement
For the flow chart in Figure 5, Data Packet Process Function at the Mobiles presents the way the mobiles select and transmit the requests for service from stations.

Simulation and Performance Evaluation of AMAPMT Protocol

Introduction of the Network Simulation Model and Architecture
Introduction of the Simulation Model

The wireless ATM network that is simulated consists of a base station, five mobiles, and four stations per mobile. The five traffic types namely Voice, Video, Data, Ftp and Email are simulated in OPNET by using CBR for the Voice, RT-VBR for Video, NRT-VBR for Ftp, ABR for data traffic and UBR for Email. The performance of the protocol is evaluated under various combinations of operational conditions of relative priorities of various media, time-to-live (TTL) and channel state information (CSI) parameters. In each case, three performance metrics, namely, Cell Loss Ratio (CLR) and Mean Cell Transmission Delay (MCTD) are obtained and compared.

Architecture and Operation of the Simulation Model

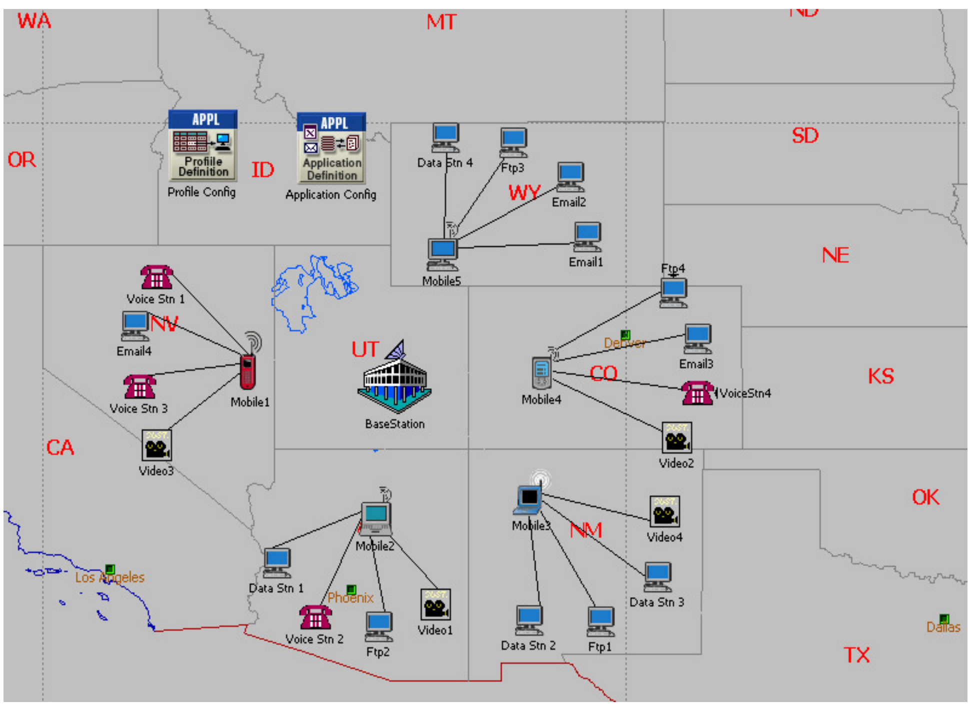


Figure 6: Simulation Model of a Wireless Network

The network model consists of a base station, five mobiles and four source stations per mobile. The source stations are of different types. In this network the source stations generate and save information (voice, video, data, Ftp, email). The stations send Request Access (RA) packets to the relevant mobiles to ask permission to send information. The mobiles forward these requests to the base station. The base station considers all such requests for a frame time and grants permission to the stations to transmit information according to the AMAPMT multiple access protocol. A number of simulations are run and results are collected to evaluate the performance of the protocol in terms of Cell Loss Ratio (CLR) and Mean Cell Transmission Delay (MCTD).

Simulation Results for Performance Evaluation of AMAPMT Protocol

Simulation results in terms of cell loss ratio (CLR), mean cell transfer delay (MCTD) and throughput are obtained and presented for the following combinations of different relative priorities of the various media, different TTL values of transactions and channel state information (CSI) for constant source generation rates.

a. The sources have same priority, same TTL and same CSI (BER=1E-06)
b. The sources have different priorities, same TTL and same CSI (BER=1E-06)
c. The sources have same priority, different TTL's and same CSI (BER=1E-06)
d. The sources have different priorities, different TTL's and same CSI (BER=1E-06)

The sources generate cells at a rate whose distribution constant with mean rates of up to 250,000 cells per second. The buffer size at the source stations is set up as 512 Kbytes. The buffer size at the mobile stations and the base station are assumed to be unlimited. The channel state information (CSI) is taken as bit error ratios (BER) of 1E-06 or 1E-12 with 1.54Mbps transmission rate [8]. The utilization factor ρ= .259, obtained as the ratio of the average generation rate of 50 Kbytes per second and service rate of 1.544 Mbps, is used in all cases. The various actual values of TTL, priorities and CSI used in the simulation are shown in the following Tables 1 through 4.

Table 1: Parameter Values for Same TTL, Same Priorities and Same CSI

Station #		1	2	3	4	All Stations	All Stations
		TTL	TTL	TTL	TTL	PRIORITY	CSI (BER)
CBR	VOICE	10	10	10	10	Low Latency	10^{-6}
RT-VBR	VIDEO	10	10	10	10	16	10^{-6}
NRT-VBR	FTP	10	10	10	10	16	10^{-6}
ABR	DATA	10	10	10	10	16	10^{-6}
UBR	EMAIL	10	10	10	10	16	10^{-6}

Table 2: Parameter Values for Different Priorities, Same TTL and Same CSI

Station #		1	2	3	4	All Stations	All Stations
		TTL	TTL	TTL	TTL	PRIORITY	CSI (BER)
CBR	VOICE	10	10	10	10	Low Latency	10^{-6}
RT-VBR	VIDEO	10	10	10	10	16	10^{-6}
NRT-VBR	FTP	10	10	10	10	8	10^{-6}
ABR	DATA	10	10	10	10	4	10^{-6}
UBR	EMAIL	10	10	10	10	2	10^{-6}

Table 3: Parameter Values for Different TTL, Same Priorities and Same CSI

Station #		1	2	3	4	All Stations	All Stations
		TTL	TTL	TTL	TTL	PRIORITY	CSI (BER)
CBR	VOICE	10	35	60	85	Low Latency	10^{-6}
RT-VBR	VIDEO	15	40	65	90	16	10^{-6}
NRT-VBR	FTP	20	45	70	95	16	10^{-6}
ABR	DATA	25	50	75	100	16	10^{-6}
UBR	EMAIL	30	55	80	105	16	10^{-6}

Table 4: Parameter Values for Different TTL, Different Priorities and Same CSI

Station #		1	2	3	4	All Stations	All Stations
		TTL	TTL	TTL	TTL	PRIORITY	CSI (BER)
CBR	VOICE	10	35	60	85	Low Latency	10^{-6}
RT-VBR	VIDEO	15	40	65	90	16	10^{-6}
NRT-VBR	FTP	20	45	70	95	8	10^{-6}
ABR	DATA	25	50	75	100	4	10^{-6}
UBR	EMAIL	30	55	80	105	2	10^{-6}

Simulation Results

Results for Sources with Constant Source Generation Rate Distribution and BER= 1E-06

The results in terms of CLR, MCTD and Throughput for Utilization factor ρ= .259, constant source generation rate distribution and BER=1E-06 is shown in the form of graphs in the following Figures 7 through 9.

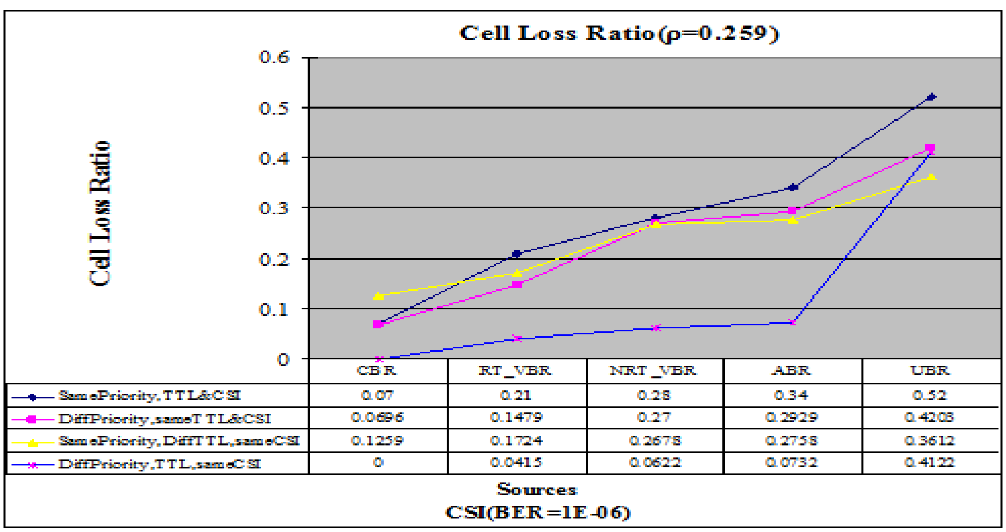
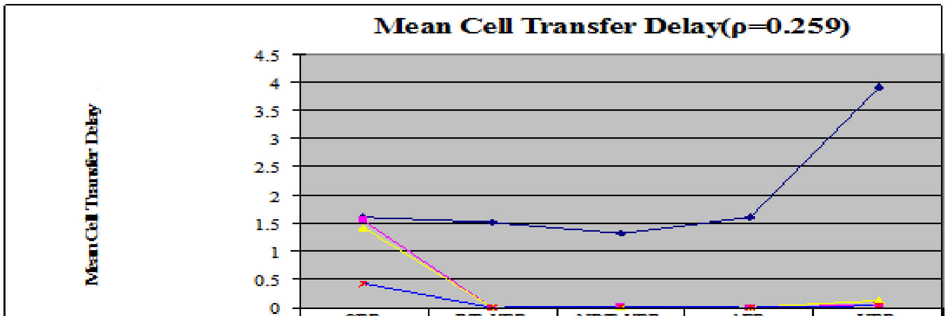


Figure 7: Comparison of CLR for a Number of Combinations of Priority, TTL and CSI as Indicated on the Graph

It is observed from Figure 7 that the CLR is the highest for all media except CBR when priorities considered in granting permission to transmit. The CLR is slightly reduced in the cases when only priorities. Finally, the CLR values are substantially reduced for all the media when priorities and TTL's are simultaneously considered as proposed in the AMAPMT protocol. Thus the AMAPMT protocol can be used to substantially improve the CLR performance for the various components of multimedia signals.

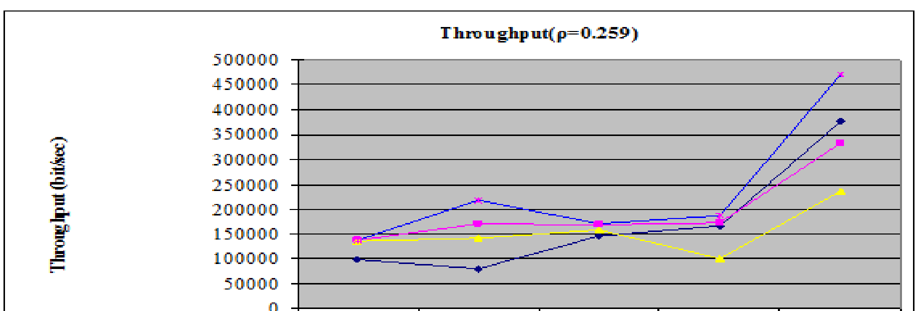


	CBR	RT_VBR	NRT_VBR	ABR	UBR
SamePriority,TTL&CSI	1.601	1.515	1.307	1.607	3.907
DiffPriority,sameTTL,CSI	1.5491	0.0071	0.0139	0.008	0.0534
SamePriority,DiffTTL,sameCSI	1.4308	0.0041	0.0053	0.0058	0.121
DiffPriority,TTL&CSI	0.4376	0.001	0.0142	0.008	0.0271

Sources
CSI (BER=1E-06)

Figure 8: Comparison of MCTD for a Number of Combinations of Priority, TTL and CSI as Indicated on the Graph

It is observed from Figure 9 that the MCTD is considerably reduced in the cases when only priorities but not TTL's and when only TTL's and not priorities and both priorities and TTL's are considered as proposed in the AMAPMT protocol. Thus the AMAPMT protocol can be used to substantially improve the MCTD performance for the various components of multimedia signals.



	CBR	RT_VBR	NRT_VBR	ABR	UBR
SamePriority,TTL&CSI	99487	80206	145294	166232	376202
DiffPriority,SameTTL,CSI	138137	171639	168908	172055	332628
SamePriority,DiffTTL,sameCSI	135993	142104	159155	100509	236221
DiffPriority&TTL,SameCSI	138138	217423	171282	187446	471746

Sources
CSI (BER=1E-06)

Figure 9. Comparison of Throughput for a Number of Combinations of Priority, TTL and CSI as Indicated on the Graph

It is observed from Figure 9 that the throughput is the highest for all media when priorities and TTL's are simultaneously considered in assigning permission to transmit, as proposed in the AMAPMT protocol. Thus the AMAPMT protocol can be used to improve the throughput performance for the various components of multimedia signals.

Results for Constant Source Generation Rate Distribution and BER= 1E-12

The results in terms of CLR, MCTD and Throughput for utilization factor ρ= .259, constant source generation rate distribution and BER = 1E-12 are shown in the form of graphs in the following Figures 10 through 12.

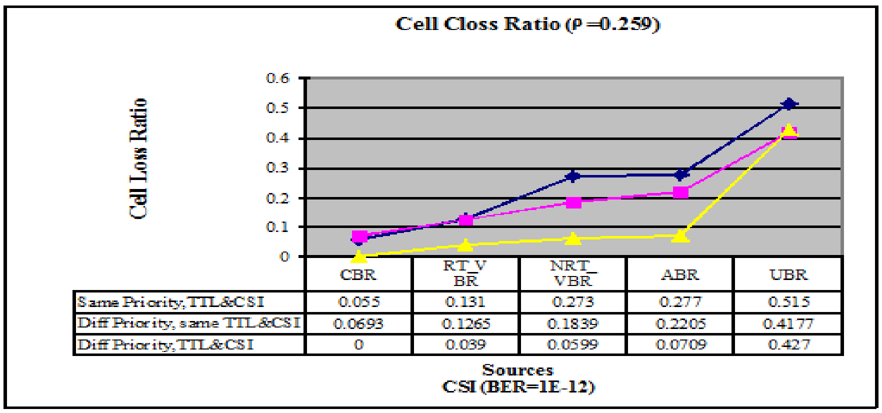


Figure 10: Comparison of Throughput for a Number of Combinations of Priority, TTL and CSI as Indicated on the Graph

It is observed from Figure 10 that the CLR is slightly reduced in the case when only priorities but not TTL's are considered as proposed in the AMAPMT protocol and the CLR values are substantially reduced for all the media when priorities and TTL's are simultaneously considered as proposed in the AMAPMT protocol.

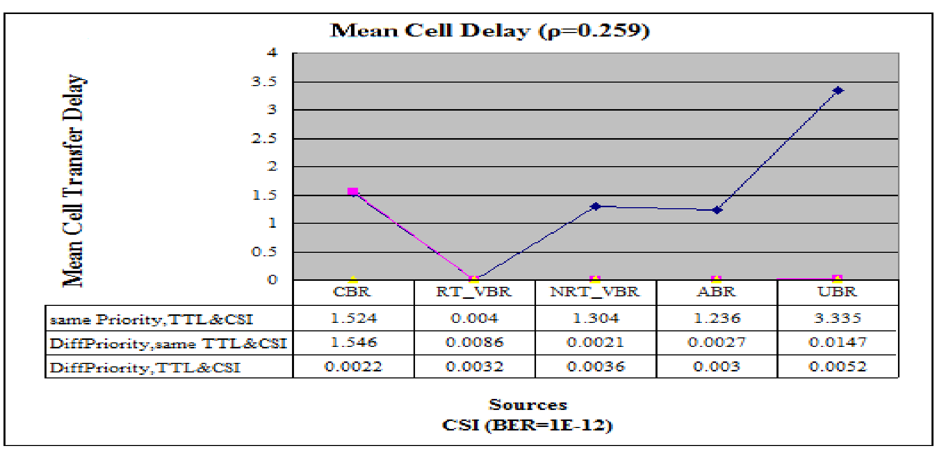


Figure 11: Comparison of MCTD for a Number of Combinations of Priority, TTL and CSI as Indicated on the Graph

It is observed from Figure 11 that the MCTD is reduced in the case when only priorities but not TTL's are considered as proposed in the AMAPMT protocol. Finally, the CLR values are substantially reduced for all the media when priorities and TTL's are simultaneously considered as proposed in the AMAPMT protocol. Thus the AMAPMT protocol can be used to substantially improve the CLR performance for the various components of multimedia signals.

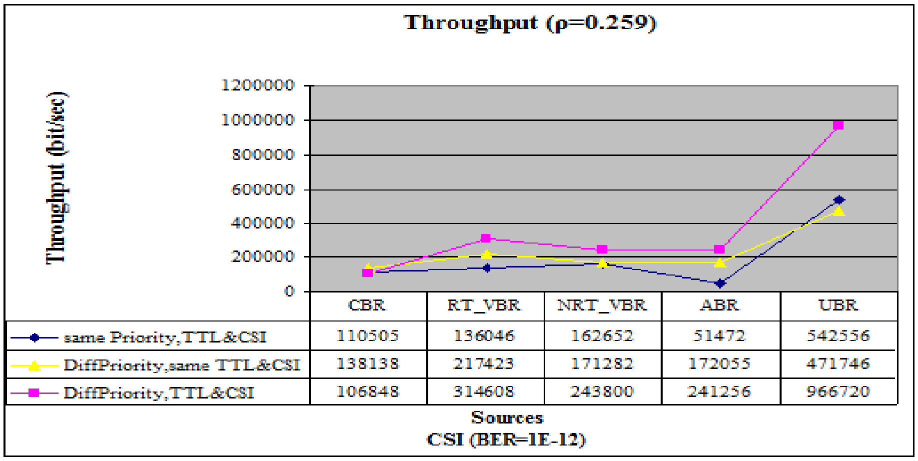


Figure 12: Comparison of Throughput for a Number of Combinations of priority, TTL and CSI as Indicated on the Graph

It is observed from Figure 13 that the throughput is the highest for all media when priorities and TTL's are simultaneously considered in assigning permission to transmit, as proposed in the AMAPMT protocol. Thus the AMAPMT protocol can be used to improve the throughput performance for the various components of multimedia signals.

Comparison of Performance of ARCMA and AMAPMT Protocols for Constant Source Generation Rate Distribution and BER = 1E-06

Performance of ARCMA and AMAPMT protocols are Evaluated and compared under the following set of parameter values and the LL stands Low latency.

Table 5: Parameter Values for ARCMA and AMAPMT Protocol Performance

Type	TTL	Priority of Signal types		CSI	Transaction size		Transmission rate
		Types	weight		Distribution	Mean	
ARCMA Protocol	same	CBR RT_VBR NRT_VBR ABR UBR	16 1 1 1 1	same (BER=1E-06)	constant	500KB	DS1 (1.544 Mbps)
AMAPMT Protocol	different	CBR RT_VBR NRT_VBR ABR UBR	LL 16 8 4 2	same (BER=1E-06)	constant	500KB	DS1 (1.544 Mbps)

The TTL and priority values used in Table 5 correspond to the following figures. ARCMA protocol CBR is assigned the highest priority and other media are assigned same low priorities and same TTL values. Sources with constant generation rate distribution are used. The results are shown in Figures 13 through 15.

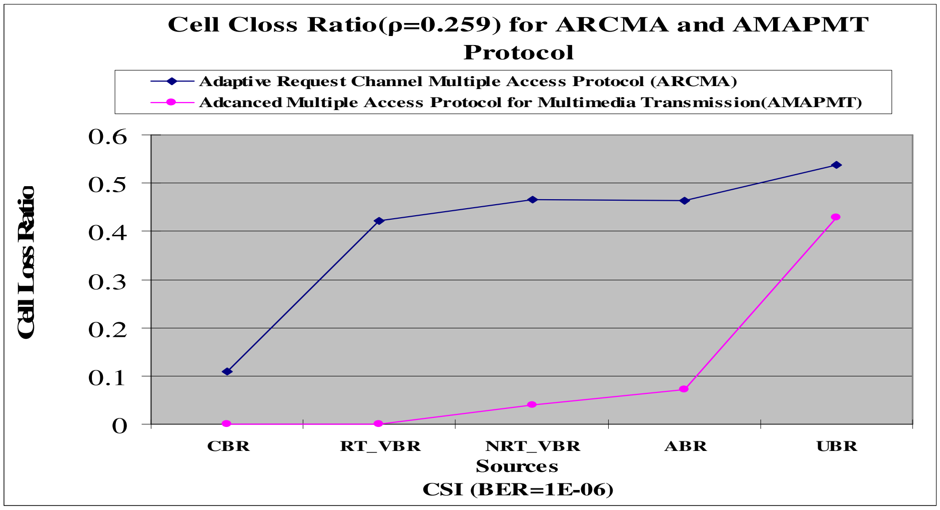


Figure 13: Comparison of CLR for ARCMA and AMAPMT Protocols

It is observed from Figure 13 that the performance in terms of CLR of the AMAPMT protocol is much better than that of ARCMA protocol for all the media of a multimedia signal. Thus the AMAPMT protocol can be used to improve the CLR performance for the various components of multimedia signals.

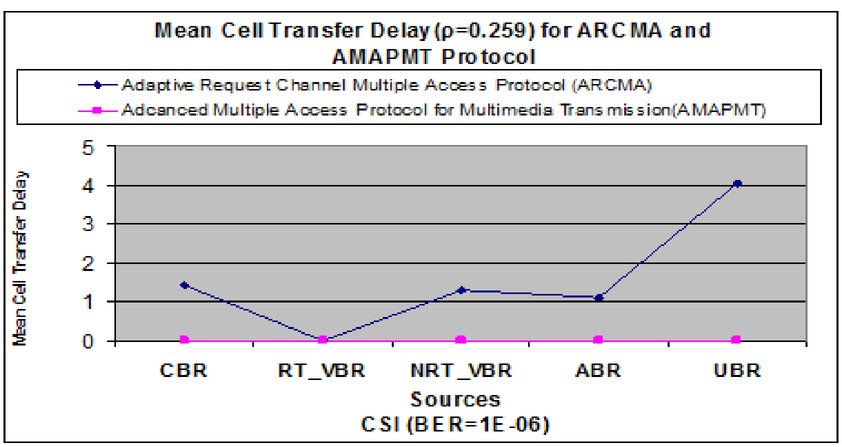


Figure 14: Comparison of MCTD for ARCMA and AMAPMT Protocols

It is observed from Figure 14 that the performance in terms of MCTD of the AMAPMT protocol is much better than that of ARCMA protocol for all the media of a multimedia signal except for RT-VBR. Thus the AMAPMT protocol can be used to improve the MCTD performance for the various components of multimedia signals.

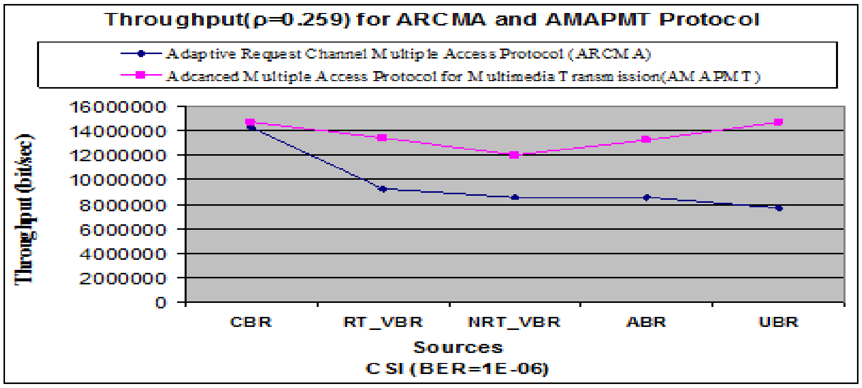


Figure 15: Comparison of Throughput for ARCMA and AMAPMT Protocols

It is observed from Figure 16 that the performance in terms of throughput of the AMAPMT protocol is much better than that of ARCMA protocol for all the media of a multimedia signal except for CBR. Thus the AMAPMT protocol can be used to improve the throughput performance for the various components of multimedia signals.

As we mentioned, the currently available multiple access protocols deal with only voice and data and not a full complement of multimedia signals and with an explicit priority scheme based on traffic types can improve the performance. However, the problem with priority assignment according to the type of the media type only is that some lower priority media may have to wait too long and the information may become stale and may be considered lost. The stations have limited buffer space and some of the information may be lost due to buffer overflow. Further lower quality data coming through the channels compete for resources with good data coming over channels with acceptable CSI. The proposed protocol improves performance in terms of CLR by taking out of consideration any data arriving over channels and assigning highest priority to the most dominant CBR data tempered with providing priority to data of any type with short TTL value. The same procedures reduce the MCTD and improve the throughput at same time. Thus consideration of explicit priorities, Time to Live (TTL) of transactions and Channel State Information (CSI) parameters improve the overall performance.

Conclusion

Wireless networks suitable for multimedia (Voice, Video, Ftp, Data download, Email and others) transmission are considered. A simulation model has been developed and used to evaluate CLR and MCTD and throughput for given link capacity, buffer size and input rate for selectable values of priorities of various media, TTL and CSI values. Thus the algorithm can be used for allocation of resources at the nodes to obtain simultaneous satisfaction of prescribed end-to-end CLR, MCTD and Throughput for a given input rate. The results of this paper will be helpful in implementing and evaluating performance of multimedia communication over wireless networks under many selectable conditions. This will help in the design of such networks and protocols. Ability to communicate with multimedia signals is becoming more and more important and is going to impact society in many ways. The multiple access protocol for multimedia transmission will enhance the performance and capability of wireless networks to handle multimedia signals. This will make these networks more useful to fulfill the need of multimedia signals.

References

[1] Awater, G. J. and Kruys, J., 'Wireless ATM – an overview', Mobile Networks and Applications, January 1996, pp 235-243,

[2] Hac', A. and Chew, B.L., "ARCMA-Adaptive Request Channel Multiple Access Protocol for Wireless ATM Networks", International Journal of Network Management, Vol. 11. 2001, pp 333-363

[3] Itraqi, Y., Boutaba, R. and Leon-Garcia, A. "QoS Control in Wireless ATM", Mobile Networks and Applications, May 2000, pp1-21,

[4] Kwong Kwok, Y. and Lau, V., "A Performance Study of Multiple Access Control Protocol for Wireless Multimedia Services" IEEE International Conference on Network Protocols, November 2000, pp283-292

[5] Karol, M.J., "An Efficient Demand-Assignment Multiple Access Protocol for Wireless Packet (ATM) Networks", Wireless Network, 1995, pp267-279.

[6] Kwok, Y., "On Channel Adaptive Multiple Access Control without Contention Queue for Wireless Multimedia Services", Wireless Networks, 2003. pp379-392

[7] Frigon, J.F., Leung, V. and Chan, H.C., "Dynamic Reservation TDMA Protocol for Wireless ATM Networks", IEEE journal on selected areas in communications, Vol.19, No. 2, February, 2001, pp370-383

[8] Akyildiz, I.F., Driver, H. and Ho, Y.L., "An Adaptive FEC Scheme for Data Traffic in Wireless ATM Networks", IEEE/ACM Transactions on Networking, Vol.9, No.4, August 2001, pp419-426

Biographies

HONG YU received the B.S degree in Electrical Engineering from the University of Hunan, China in 1989 and His Ph.D. degree in Electrical Engineering from the Catholic University of America in 2008. Currently, He is Associate Professor of Electrical Engineering at Capitol College. His teaching and research areas included network communication protocol and embedded system design. Dr. Yu may be reached at yhong2006@gmail.com

MOHAMMED AROZULLAH received his B.S degree in Physics from Rajshahi University, Bangladesh, in 1956. He earned his M. Sc degree in Physics from Dhaka University, Bangladesh. He received the Ph.D degree in Electrical Engineering from University of Ottawa, Canada, 1967. Dr. Arozullah is Professor of Electronics Engineering and Computer Science at The Catholic University of America. His research includes computer communication networks, optical communications, optical networks, Internet and multimedia communications. Dr. Arozullah may be reached at arozullah@cua.edu