PERFORMANCE MEASURES OF WIRELESS PROTOCOLS FOR ATM NETWORKS

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ABSTRACT

The concept of wireless ATM is now being actively considered as a potential framework for next-generation wireless communication networks capable of supporting integrated multimedia services with different QoS requirements. Several key subsystem design issues for wired ATM and wireless networks needs to be readdressed in the scope of the wireless ATM, which has the capability to extend the statistical multiplexing of wired ATM network into the wireless medium. One of the key subsystem issues is the development of appropriate medium access control (MAC) protocol. The extension of the ATM network into wireless environment faces many interesting problems. The original ATM network was designed for high speed, noiseless, and reliable channels. None of these characteristics are applicable to the wireless channel. One of the critical aspects of a wireless ATM network is the Medium or Multi Access Control (MAC) Protocol used by the Mobile station (MS) to request service from the BS, which has to consider the Quality of Service (QoS) of the specific applications. This paper analyses recently proposed MAC protocols, particularly those of Demand Assignment Multiple Access protocols using TDMA technique with Frequency Division Duplex (FDD). It also gives performance measures of two best suited protocols for wireless network environment Distributed Queuing Request Update Multiple Access (DQRUMA) protocol and Adaptive Request Channel Multiple Access (ARCMA) protocol.

KEYWORDS

Multiple Access Control Protocols, ATM, DQRUMA and ARCMA

1. INTRODUCTION

The wired communication network will be dominated by the broad band ATM network, which is an integrated multimedia wireless network. Therefore, the provisioning of transparent transmission packets between wireless and wired network in which packet header processing is kept to minimum, is highly desirable. Therefore the transmitted packets in the wireless medium are in the ATM format encapsulated with an additional header and trailer for the usage of wireless network protocols stacks. This scenario provides the following advantages: compatibility with wired ATM network and less processing time of wireless/wired interface.

The concept of ATM is end-to-end communication i.e. in a Wide Area Network environment, the communication protocol will be the same i.e. ATM, and companies will no longer have to buy

DOI : 10.5121/ijmnct.2012.2203

extra equipment (like routers or gateways) to interconnect their LANs (local area networks). Also ATM is considered to reduce the complexity of the network and improve the flexibility while providing end-to-end consideration of traffic performance.

1.1 ATM Cell

ATM is a fixed size packet-based switching and multiplexing technology designed to be a connection-oriented transfer mode that supports a wide range of services. Its transmission scheme can operate at either constant or variable bit rates. ATM also supports applications of different QoS, which specifies tolerable cell delay and cell loss probability. The primary unit (packet) in ATM is called a cell. The ATM standard defines a fixed-size cell with a length of 53 bytes, which is composed of 5-byte header and a 48-byte payload. These fixed-sized cells reduce the complexity of ATM switches and multiplexers allowing cells to be relayed at very high speeds. The typical bit rates at the terminals are 25 Mbps, 155 Mbps, and 622 Mbps. The conversion of user data into ATM cells, and vice versa, is performed by the ATM Adaptation Layer(AAL), which resides directly above the ATM layer of the network.

1.2 ATM Services

Users request services from the ATM switch in terms of destination(s), traffic, type(s), bit rates(s), and QoS. These requirements are usually grouped together and categorized in different ATM classifications. The prototypical ATM services are categorized as follows:

Constant Bit Rate (CBR): Connection-oriented constant bit rate service such as digital voice and video traffic.

Real-Time Variable Bit Rate (rt-VBR): Intended for real-time traffic from bursty sources such as compressed voice or video transmission.

Non-Real-Time Variable Bit Rate (nrt-VBR): Intended for applications that have bursty traffic but do not require tight delay guarantees. This type of service is appropriate for connectionless data traffic.

Available Bit Rate (ABR): Intended for sources that accept time-varying available bandwidth. Users only guaranteed a minimum cell rate (MCR). An example of such traffic is LAN emulation (LANE) traffic.

Unspecified Bit Rate (UBR): Best effort service that is intended for non-critical applications. It does not provide traffic-related service guarantees.

2. MULTIPLE ACCESS PROTOCOLS

A multiple access protocol is a scheme to control the access to a shared communication medium among various users. Access protocols can be grouped according to the bandwidth allocation, which can be static or dynamic, and according to the type of control mechanism implemented. Multiple access protocols can be categorized into fixed assignment, random assignment and demand assignment.

2.1 Fixed Assignment

Time-division multiple access (TDMA) and frequency-division multiple access (FDMA) are fixed assignment techniques that incorporate permanent subchannel assignment to each user. These traditional schemes perform well with stream-type traffic, such as voice but are inappropriate for integrated multimedia traffic because of the radio channel spectrum utilization. In a fix assignment environment, a subchannel is wasted whenever the user has nothing to transmit. It is widely accepted that most services in the broadband environment are VBR (bursty traffic). Such traffic wastes a lot of bandwidth in a fix assignment scheme.

2.2 Random Assignment

Typical random assignment protocols like ALOHA and Carrier Sense Multiple Access with Collision Detection (CSMA/CD) are more efficient in servicing bursty traffic. These techniques allocate the full channel capacity to a user for short periods, on a random basis. These packet-oriented techniques dynamically allocate the channel to a user on per-packet basis.Although there are few versions of the ALOHA protocol, in its simplest form it allows users to transmit at will. Whenever two or more user transmissions overlap, a collision occurs and users have to retransmit after a random delay. The ALOHA protocol is inherently unstable due to the random delay. That is, there is a possibility that a transmission may be delayed for an infinite time.Slotted ALOHA is a simpler modification of the ALOHA protocol. After a collision, instead of retransmitting at a random time, slotted ALOHA retransmits at a random time slot.In a plain CSMA protocol, a user will not transmit unless it senses that the transmission channel is idle. In CSMA/CD, the user also detects any collision that happens during transmission. The combination provides a protocol that has a high throughput and low delay. However, carrier sensing is a major problem for radio networks. Hence carrier sensing requires sophisticated directional antennas and expensive amplifiers for both the base station (BS) and mobile station (MS). Such requirements are not feasible for the low powered mobile terminal end.

Code-division multiple access is a combination of fixed and random assignment. CDMA has many advantages such as near zero channel access delay, bandwidth efficiency and excellent multiplexing. However, it suffers from significant limitations such as limited transmission rate, complex BS, and problems related to the power of its transmission signal. The limitation in transmission rate is a significant drawback to using CDMA for integrated wireless networks.

2.3 Demand Assignment

In this protocol, channel capacity is assigned to users on demand basis, on needed. Demand assignment protocols typically involve two stages: a reservation stage where the user requests access and a transmission stage where the actual data is transmitted. A small portion of the transmission channel, called reservation sub channel, is used solely for users requesting permission to transmit data. Short reservation packets are sent to request channel time using some simple multiple access schemes, typically, TDMA or slotted ALOHA. Once channel time is reserved, data can be transmitted through the second sub channel contention-free. Unlike a random access protocols where collisions occur in the data transmission sub channel, in demand assignment protocols, collisions occur only in the small-capacity reservation sub channel.

This reservation technique allows demand assignment to avoid bandwidth waste due to collisions. In addition, unlike fixed assignment schemes, no channels are wasted whenever a VBR user enters an idle period. The assigned bandwidth will simply be allocated to another user requesting access. Due to these features, protocols based on demand assignment techniques are most suitable for integrated wireless networks.

Demand assignment protocols can be classified into two categories based on the control scheme of reservation and transmission stages. They can be either centralized or distributed. An example of a centralized controlled technique in demand assignment is polling. Each user is sequentially queried by the BS for transmission privileges. This scheme, however, relies heavily on the reliability of the centralized controller.
An alternative approach is to use distributed control, where MSs transmit based on information received from all other MSs. Network information is transmitted through broadcast channels. Every user listens for reservation packets and performs the same distributed scheduling algorithm based on the information provided by the MS in the network. Requests for reservation are typically made using contention or fixed assignment schemes.

3. DEMAND ASSIGNMENT MULTIPLE ACCESS PROTOCOLS

Most Demand Assignment Multiple Access (DAMA) protocols use time-slotted channels that are divided into frames. Depending on the transmission rate and the type of services, the channel bandwidth can be represented by a single or multiple frame(s). Each frame is divided into uplink and downlink period (channel). These periods are further divided into two subperiods or slots. They can be partitioned on a slot-by slot or period basis.

In the slot-by-slot method, each uplink and downlink period consists of a single time slot. In the method by period, the uplink and downlink period contain multiple time slots, encapsulated as a frame. The uplink and downlink communications can be physically separated using different frequency channels or dynamically shared using the time-division duplex (TDD) system.

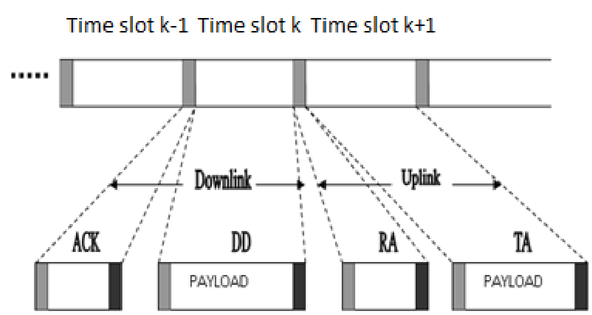

Fig.3.1 Radio Channel Classification: (Slot-By-Slot)

The uplink channel (mobile-to-base) is divided into the request access (RA) and data transmission access (TA) subperiods. On the other hand, the downlink is divided into the acknowledgement (ACK) and the data downstream (DD) subperiods. A user requests bandwidth using the RA subperiods (uplink). When the BS hears a successful request (no collision) it will notify the corresponding user through the ACK subperiods (downlink). Successful users are then assigned bandwidth, if available, in the TA subperiods. The DD periods are used by the BS to transmit downstream data to mobiles. These subperiods (also known as slots) vary in length depending on the type and amount of information they carry (determined by the protocol designer). The RA and ACK slots are much smaller than the data slots; hence their time intervals are called minislots. Depending on the protocol, they may not have equal lengths.DD transmissions are controlled by the BS and are performed contention free; typically using a time-division multiplexing (TDM) broadcast mode. Mobile access requests uses random access schemes like ALOHA or slotted ALOHA.

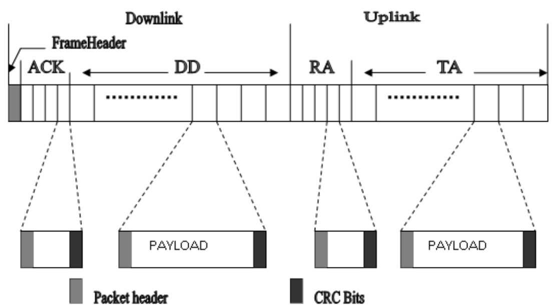

Fig.3.2 Radio Channel Classification by Period

4. DQRUMA

The Distributed Queuing Request Update Multiple Access protocol is designed specifically for data packet networks. It attempts to provide an efficient bandwidth-sharing scheme that can satisfy QoS parameters and support various types of ATM services. Naturally, DQRUMA is designed for fixed-length packets arriving at the mobile at some bursty random rate. The uplink and downlink periods are configured on a slot-by-slot basis. The uplink slot comprises a single data transmission slot (i.e. TA slot) and one or more RA slots.

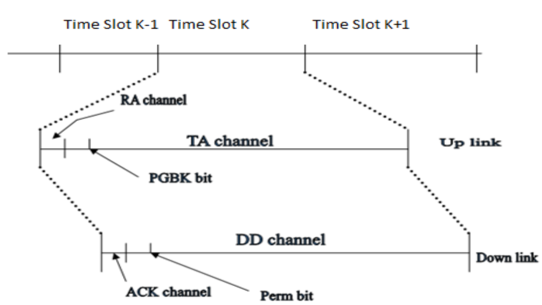

Fig 4.1 DQRUMA Timing Diagram

DQRUMA introduces the concept of a dynamic uplink slot where the uplink slot may be converted into a whole RA channel filled only with RA minislots. This conversion occurs when the BS senses that there is significant amount of collisions in the RA channel. It allows as many as 25 RA minislots in a single time slot where mobile can send their requests. This method drastically reduces request contention in the RA channel. Request in the RA channel use a random access protocol like slotted ALOHA. The downlink slot contains the typical DD time slot, and one or more ACK minislots, and transmission permission, Perm slot. In situations where the uplink slot is converted into a series of RA minislots, the subsequent downlink slot is converted into a series of corresponding ACK minislots. When a mobile terminal transmits its RA packet, it listens to the downlink slot for its ACK. ACK only indicates that the request has been received by the BS. Mobile users may not transmit their data until they hear their b-bit access ID in the Perm slot. Upon hearing the transmission permission (b-bit ID), users may transmit their data in the next uplink time slot. This is the distributed queuing aspect of the protocol, where packets are queued at the mobile's buffer until the BS services them according to scheduling policy.

DQRUMA also introduces an extra bit called piggyback (PGBK) bit in the uplink channel. Each time a mobile transmits a packet (uplink), it also includes this PGBK bit to indicate whether it has more packets in the buffer. This bit serves as a contention-free transmission request for a mobile transmitting a packet. The BS checks this bit and updates the appropriate entry in the Request Table (in the BS) accordingly. When this bit is included, a mobile does not need a request for channel access in the following time slot. The BS knows that the mobile has more data to transmit and will assign a time slot to the mobile accordingly. This is the update portion of the protocol. The PGBK bit drastically reduces contention in the RA channel and greatly improves the overall performance, especially for bursty traffic.

5. ARCMA

This new protocol scheme is based on the DQRUMA protocol while incorporating the periodic traffic handling of PRMA. In addition, this protocol attempts to reduce collisions in the RA channel by using an efficient adaptive request strategy. Hence, protocol is called Adaptive Request Channel Multiple Access (ARCMA) protocol.

ARCMA is essentially a demand assignment multiple access protocol with dynamic bandwidth allocation. Its basic architecture is modeled after the DQRUMA protocol. This scheme is designed to function in a cell-based wireless network with many Mobile Station (MS) communicating with the Base Station (BS) of their particular cell. Transmissions are done on a slot-by-slot basis without any frames. As with DQRUMA, each slot is divided into a TA slot and a RA minislot. However, the RA channel is capable of carrying additional information for different classes of ATM service (e.g. CBR, VBR, etc). This additional information is used by the BS to provide better QoS support for different classes of traffic. As in PRMA, transmission from CBR traffic may reserve an incremental series of slots in the duration of their transmission. No further is required until the CBR transmission is finished. ARCMA uses a more complex algorithm slotted ALOHA with Binary Exponential Backoff as the random access scheme in the RA channel.

5.1 Description of The Protocol

Since this protocol is modeled after DQRUMA, it is composed of request/acknowledgement and a permission/transmission phase. Data transmission from the BS to MS is a straight forward operation where the BS merely broadcasts the information to the entire cell. The destination MS listens to the broadcast channel and retrieves the appropriate data packets. If the transmission destination does not reside in the same cell, the BS will forward the packet to an ATM switch to be routed to the proper destination.

5.2 Request/Acknowledgement Phase

The request is made in the RA channel. The mobile's b-bit access ID, assigned during setup. In addition to the Access ID, the request packet also includes the type of service being requested.

After every random transmission the MS needs to know if the request was successful. Since it does not detect collision by sensing the channel, the BS has to send a response to the MS indicating a successful request. When the BS receives a request from the RA channel it immediately broadcasts an acknowledgement to the MS.

The BS then inserts the new request in the request table to indicate that the MS has packet(s) to transmit. The Request Table contains all the unprocessed requests, received by the BS. After the MS receives its acknowledgement, it listens to the downlink Perm Channel for transmission permission. MS that does not receive acknowledgement for their requests will retransmit their requests according to the slotted ALOHA scheme. As in DQRUMA, PGBK bit is used to reduce contention in the RA channel.

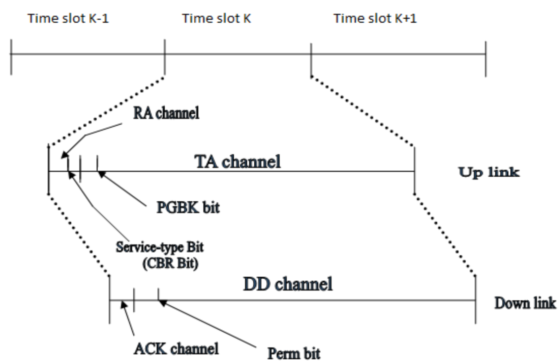

Fig.5.1Timing Diagram For the ARCMA Protocol

5.3 Permission/Transmission Phase

General Traffic

The BS is responsible for allocating bandwidth (time slots) to the MS by using a packet transmission policy. This protocol uses First In, First Out (FIFO) policy. The MS that makes a request first, is given permission to transmit first. The request table is implemented as a queue. The MS that has successfully requested for transmission listens for its ID in the Perm Channel. Once an MS hears its Access ID, it is allowed to transmit its data in the following time slot. The MS transmits its data in the TA channel collision free. The BS forwards the data from the TA channel to the appropriate destination through the DD downlink channel.

CBR Traffic

This connection-oriented delay-sensitive traffic is given priority in the request phase. When a CBR request arrives at the BS, it is inserted in special CBR Request Queue. The CBR Request Queue also uses FIFO policy but requests in the queue have precedence over those in the request table. Since transmission priority is always given to CBR traffic, number of MSs with CBR traffic has to be limited. The transmission rate of CBR traffic is given in the form of arrival rates. This arrival rate depends on the rate of the CBR traffic and the transmission rate of the channel.
CBR traffic arrives at the mobile's buffer every Nth time slot. Since the BS is aware of this, the BS automatically assign a time slot, by generating a request in the CBR Request queue for that

particular MS. No request is required by the MS, for the duration of the CBR traffic. PGBK bit is used by the CBR traffic to indicate the end of a CBR transmission. After sending the Perm bits, the BS waits for the CBR packet in the next time slot and checks its PGBK it. A PGBK bit with a zero value indicates the end of a CBR transmission and the BS will stop assigning periodic time slot for this particular MS. By using the PGBK, no additional data overhead is needed for the termination procedure.

5.4 Adaptive Request Channel Strategy

ARCMA also implements a dynamic RA channel strategy similar to that of the DQRUMA. But ARCMA reduces the idle time slots by considering the probability of retransmission qr. when the TA channel is first converted into multiple RA minislots, all new and previously unsuccessful requests are transmitted with the probability of 1. That is, all requests are sent out immediately regardless of their qr. If no requests are successfully transmitted the uplink channel remains in the multiple RA mode. However, in this case, the MS's retransmit their requests according to their old qr. Conversely, if successful requests were made during the multiple RA slots, the BS reverts the next time slot back to normal mode with a single RA minislot. Any remaining MS's with unsuccessful requests, retransmit their requests using their corresponding qr.

The following table gives an example illustrating the number of mobiles handled by each RA channel in normal and multiple RA mode.

Mobile ID	**Normal mode**		**Multiple RA mode**	
	Channel # (single channel)	# of mobiles per RA channel	Channel# (R =3)	# of mobiles per RA channel
1	1	5	1	2
2	1	5	2	2
3	1	5	3	1
4	1	5	1	2
5	1	5	2	2

Table 5.1 Number of Mobiles

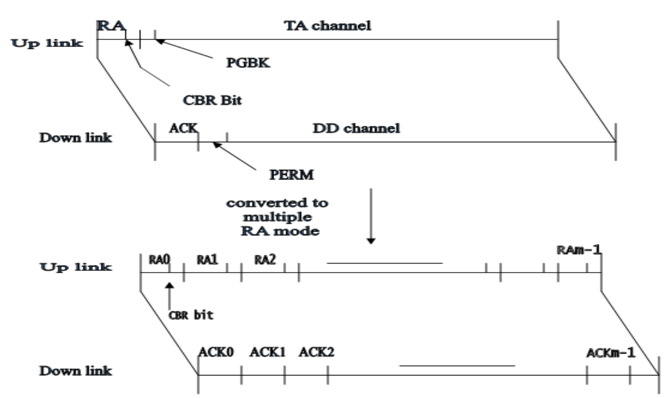

Fig.5.2 Timeslot conversion in multiple RA mode

Although the all above compared protocols have their advantages and limitations when it comes to wireless data packet networks, DQRUMA and ARCMA seem to offer the most efficient scheme for wireless ATM services. But DQRUMA has one major drawback when compared to its successor, its inability to offer any distinction between different types of ATM traffic during the reservation phase.

6. PERFORMANCE ANALYSIS

Simulated Protocols

In this simulation protocols, ARCMA and DQRUMA are compared under identical network environments and specification. DQRUMA and ARCMA have proven to be an effective multiple access protocols that can support integrated traffic in a wireless packet network. Both these protocols are implemented using the FIFO scheduling policy in the Request Table and slotted ALOHA with Binary Exponential Back off algorithm is used as the random access scheme in the RA channel.

6.1 Simulation Environment

The simulation approach is modelled after the environment of a typical cellular mobile communication network. The primary characteristics of the environment are

- The network model is a typical cell in a wireless network with one BS and N active mobiles.
- MSs are buffered portable units that produce data packets according to some bursty random processes. All data packets are queued in the mobiles buffer until the BS allocates them a time slot for transmission.
- The uplink and downlink channels are simulated as separate channel. Both uplink and downlink channels are time slotted.
- The network is assumed to have fixed number of active mobiles throughout each experiment.
- The network traffic stays same for the duration of the experiment.
- The slotted ALOHA with BEB algorithm is used as the random access scheme in the RA channel.
- The length of the time slot is assumed the same for two protocols.
- Network delay is due to access delay and service delay. Propagation delays between mobiles and BS are assumed negligible.
- Simulations are run for 50 time slots.

6.2 Simulation Program

Traffic is randomly generated. These arrival rates are changed to simulate different traffic load in the network. CBR traffic starts at a random time but continues to generate data packets every T time slots. Arriving packets are stored in queues representing the mobile buffers. M number of queues are implemented to represent the M number of active mobiles in the simulated cell. In each iteration, data packets in the buffers (if not empty) go through all the procedures corresponding to the Request/Acknowledgement and Permission/Transmission phase according to the selected protocol. A linked data structure is used to represent the request queues (table) in the BS. Based on the FIFO scheme, the mobile with its Access ID at the head of the linked list is given priority for the transmission. The simulation ends when the time slot iteration reaches the predefined simulation time.

6.3 Performance Measures

The simulation involves two different multiple access schemes performing various traffic conditions. Different traffic is simulated by varying the data arrival rates to the mobile's buffer. The number of active mobiles in the cell and the burstiness is also varied. The performance measures are:

Channel Throughput (TP_c): TPc is defined as the ratio of the total number of transmitted packets and the total time number of time slots. That is, TPc = PT/TTL, where PT is denoted as the total number of transmitted packets, and TTL is the total number of time slots. In our simulations, the TTL is the time duration for each our simulation, which is preset to 1000 time slots. TPC is measured as the number of packets transmitted per slot.

Average Transmission Delay (D_{AVG}): DAVG is defined as the ratio of the total packet transmission delay and number of active mobiles. Hence, DAVG = DTL/M, where DTL is the total packet transmission delay and M is the number of active mobile. Each delay is defined as time (number of time slots) taken, when a packet first arrives at the mobile's buffer to the time the packet reaches the BS. M is predefined in each simulation. DAVG is measured by the number of time slots.

Average Queue Length (L_{AVG}): LAVG is defined as the ratio of the total number of packets in all the mobiles buffer and the number of active mobiles. Thus, LAVG = LTL/M, where LTL is the total number of packets in all the buffer, and M is the number of active mobiles. LTL is the total time taken at the end of simulation. LAVG is measured by number of packets.

7. SIMULATION RESULTS

We present the simulation results and the performance analysis of the different multiple access strategies. We simulate protocols in the following traffic environment: with CBR traffic, non CBR traffic. As the arrival rate increases the channel throughput also increases (Fig.8) as the arrival rate increases, more packets are transmitted. Under heavy traffic condition empty request queue are caused by contention in the RA channel. Nevertheless, Tpc is very high at high arrival rates as illustrated in Fig.7.1. Figures 7.1and 7.2 show the performance in a network cell with 100 active mobiles with single packet burst and no CBR traffic.Figure 7.3 represents the combination of the previous two figures. The exact value of the arrival rate is not a concern in our analysis. Figure 7.4 and 7.5 show the result of a simulation in an environment with no CBR traffic and single packet burst. Fig.7.4 illustrates results from a low traffic condition. We can see that as the throughput increases, so does the average delay (Davg). DQRUMA suffers from a very steep increase in delay as the throughput increases. ARCMA follows a similar pattern, but at a much lesser rate. Fig.7.5 shows that the delay increases at a much higher rate, compared to the previous simulation, for all three scheme. From the Fig.7.6 we can see that there is an improvement in performance although there is a twice as many data packets arriving in the channel. The main reason for this improvement is the piggy-backing strategy .The second packet in every burst request accesses collision free using the PGBK bit. Figure 7.7 shows the results from a cell with mobiles with CBR traffic. The gap between their performances grows appreciably as the arrival rate increases. The increase of data arriving due to the CBR traffic causes a steep increase in the average delay for DQRUMA .The special CBR handling in ARCMA allows it take advantages of CBR traffic characteristics.

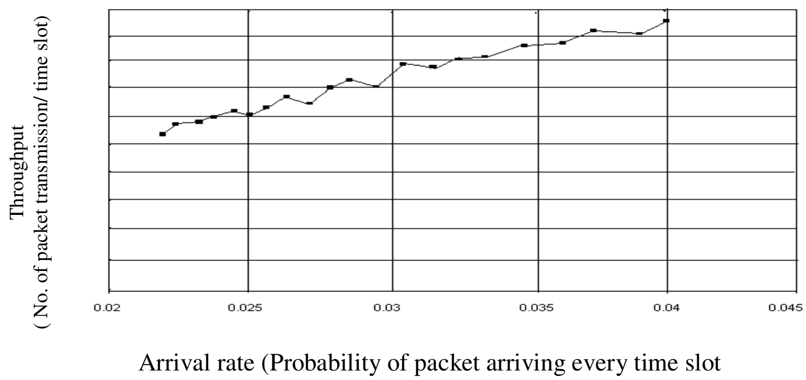

Fig .7.1 Channel Throughput VS Arrival Rate ARCMA (M=100, CBR=0, Burst=1)

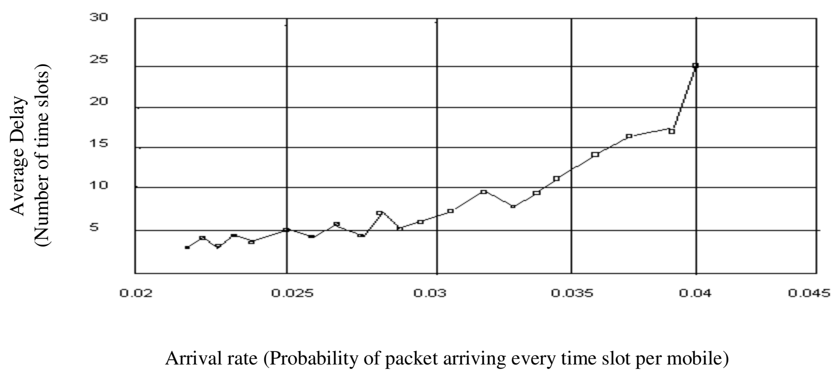

Fig.7.2 Average delay VS Arrival rate for ARCMA (M=100, CBR=0,Burst=1)

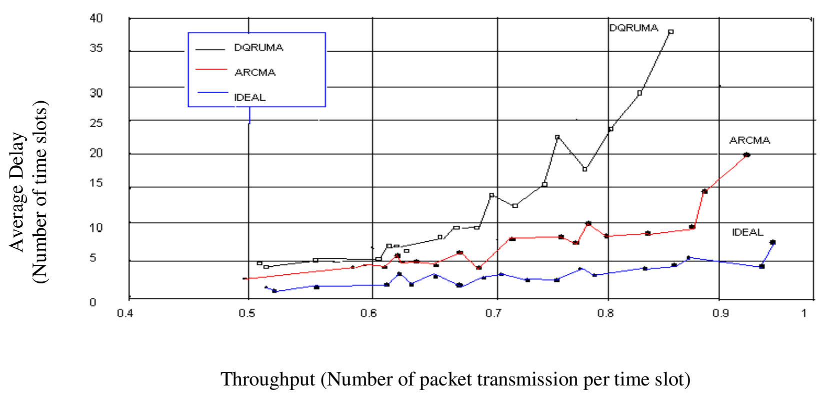

Fig.7.3 Average Delay VS Channel Throughput for ARCMA(M=100, CBR=0, Burst=1)

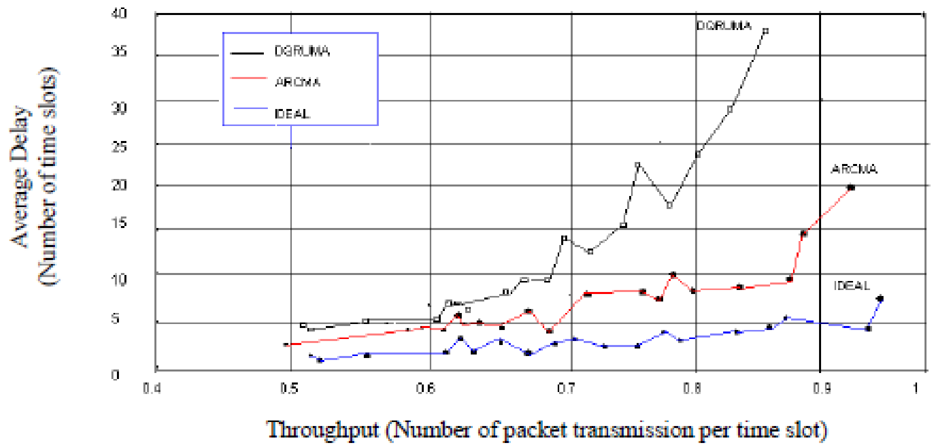

Fig.7.4 Average Delay VS Channel Throughput for ARCMA (M=25, CBR=0, Burst=1)

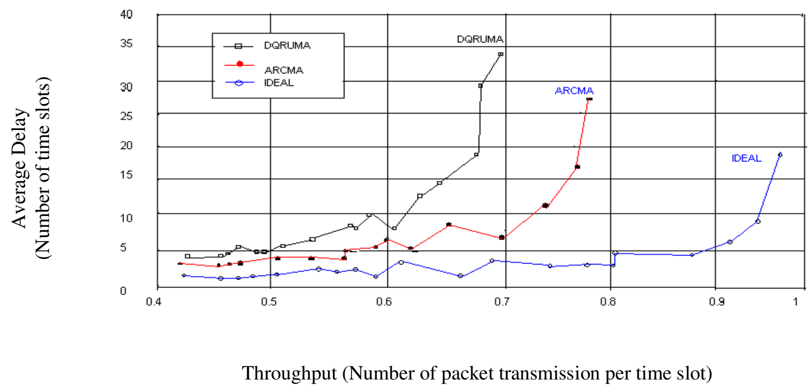

Fig.7.5 Average Delay VS Channel Throughput for ARCMA (M=100, CBR=0, Burst=1)

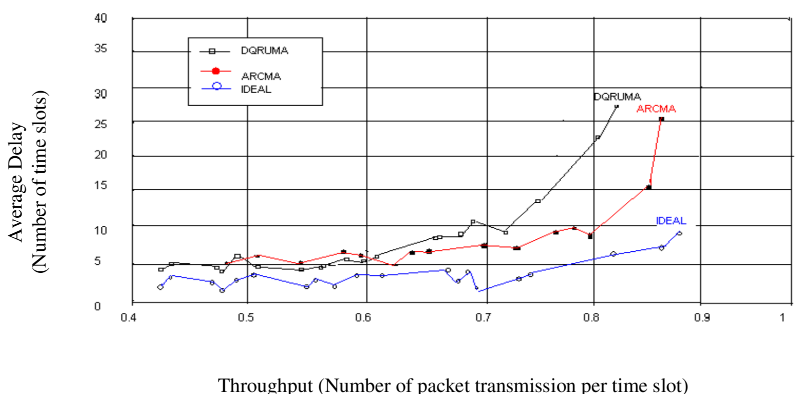

Fig.7.6 Average Delay VS Channel Throughput for ARCMA (M=100, CBR=0, Burst=2)

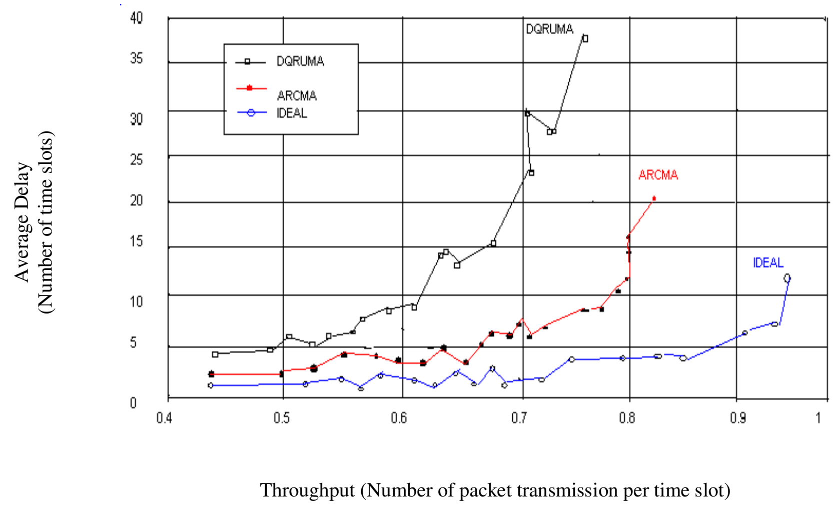

Fig.7.7 Average Delay VS Channel Throughput for ARCMA (M=100, CBR=2%, Burst=1)

8. CONCLUSION

Wireless ATM is considered as a promising technique for future broadband wireless networks and is under research prototyping at various institutions. This paper focuses on the role of the medium access control protocol in supporting multimedia traffic and QoS. Protocols for multimedia wireless ATM are still evolving. Many protocols have been proposed, and most of them are only different in details of implementation, or variant design for specific wireless architectures. The common trend observed in these protocols is requiring the mobiles to request resources through reservations – with or without contentions. The base station can be regarded as an ATM switch that statistically multiplexes the wireless links among the mobiles. This approach will provide a way to integrate similar packet scheduling strategies on wired ATM network.
This paper presents comparison for protocols, which contain most characteristics of current available channel access protocols for wireless ATM. Although all the compared protocols have their advantages and limitations when it comes to wireless data packet networks, DQRUMA and ARCMA seem to offer the most efficient scheme for wireless ATM. Of these protocols compared only DQRUMA and ARCMA have been simulated.

The simulation results show that ARCMA performs better than DQRUMA regardless of the traffic load. ARCMA produces significantly higher channel throughput than DQRUMA because of its ability to differentiate between the services (CBR, VBR) of ATM. ARCMA brings us one step closer to designing a complete protocol suite that could be used in the wireless ATM networks.

Scope For Future Work

The effectiveness of ARCMA protocol was analyzed in comparison with the efficient DQRUMA protocol and the performance of these protocols is a cellular network is evaluated. Further research may be conducted by considering the following aspects.

DQRUMA and ARCMA protocols can be extended to provide direct support for other ATM services such as VBR and ABR traffic. Traffic variations in ARCMA can be constructed with various percentage levels like 10%,20% .etc., Access delay can be reduced if there exists a mechanism to specifically handle VBR or ABR mobiles. Further work is required in providing a more in-depth study of scheduling algorithm and QoS parameters such as delay , throughput and jitter. The protocols can be extended to provide direct support for various types of services provided by ATM. To provide complete MAC sublayer support, it is necessary to include services such as call admission and call handoff.

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