Fair Queueing Scheduler for IEEE 802.11 Based Wireless Multimedia Networks

Ravindra S. Ranasinghe, David Everitt, and Lachlan L.H. Andrew
Department of Electrical and Electronic Engineering
The University of Melbourne,
Parkville, VIC. 3052, Australia
{rran, d.everitt, lha }@ee.mu.oz.au

Abstract

Wireless local area networks are a viable technology to support multimedia traffic One of the prominent wireless local area network standards is the IEEE 802.11 standard. In wireless multimedia networks, mobile stations will be capable of generating a heterogeneous traffic mix with varying bandwidth requirements. In this paper, we investigate in detail, a distributed fair queueing scheduler for 802.11 wireless network to schedule both uplink and downlink traffic flows. This scheme is a combination of the distributed deficit round robin scheme together with its centralized counterpart. The performance of the proposed scheduler is evaluated by computer simulation, showing that the fair queueing scheduler outperforms the scheduler based on round robin service discipline from a capacity viewpoint.

Keywords: *Contention free period, Deficit round robin, Distributed deficit round robin, Fair queueing, Medium access control, Point coordinator, Wireless local area network*

1. Introduction

There is an increasing demand for wireless multimedia networks due to the attractiveness of providing network services to communicate using any type of media without any geographical restrictions. Therefore next generation wireless networks are expected to support multimedia services with guaranteed Quality of Service (QoS) for diverse traffic types (video, audio, and data). Wireless Local Area Networks (WLANs) have developed into a viable technology to support multimedia traffic transmission. The IEEE 802.11[17] standard, one of the promising WLAN technologies to transport delay sensitive multimedia traffic, is being adopted by manufacturers and accepted by users as a mature WLAN technology.

The MAC protocol defined in the 802.11 standard uses a polling scheme to grant the channel access permission to transmit delay sensitive data. However the standard does not define the method of managing the polling list. Any scheduling scheme that is considered for policing the stations wishing to transmit multimedia traffic must ensure a fair distribution of bandwidth. On the downlink the centralized coordinator which controls the contention free access can use standard fair queueing (FQ) algorithms such as the Deficit Round Robin (DRR) algorithm[15]. Allocation of bandwidth (by being polled) for uplink traffic having varying bandwidth requirements is more difficult as the details of the traffic awaiting transmission are decentralized. Most of the proposed scheduling schemes for uplink traffic scheduling either suffer from unfairness or require continuos exchange of traffic details explicitly between the central coordinator and stations. In this paper, we examine in detail, a recently proposed distributed FQ strategy [13] to allocate the bandwidth among delay sensitive uplink traffic streams. This scheme is compatible with the 802.11 MAC rules and it does not need additional MAC level frame transmissions to convey the status of distributed uplink traffic queues to the central scheduler.

The behaviour of contention free access control mechanism of the 802.11 MAC protocol in an integrated Voice/Data environment was analysed in [3][16] using the *round robin* scheduling discipline. The round robin scheme is simple and easy to implement on 802.11 networks. It ensures a fair distribution of bandwidth among traffic streams if the average bandwidth requirement of all the streams is similar over the duration of the flow. This assumption does not hold for a multimedia network having traffic streams with varying bandwidth requirements.

The distributed FQ algorithm we examine in this paper[13] is based on the DRR scheme[15]. We call our scheme Distributed Deficit Round Robin (DDRR). We proposed and implemented a fair queueing scheduler for the central coordinator (point coordinator) of IEEE 802.11 MAC protocol based wireless networks using DDRR and DRR schemes. The performance of the proposed scheduler is evaluated by computer simulation, and compared with a scheduler based on the round robin service discipline from a capacity viewpoint.

The remainder of this paper is organized as follows. In Section 2 we outline the IEEE 802.11 access control mechanisms. Section 3 reviews some different schemes proposed for polling list management and provides the details of our proposed DDRR scheme. Section 4 describes the simulation model and the simulation results are presented in Section 5.

2. Description of IEEE 802.11 wireless local area network access protocols

The medium access control (MAC) sublayer of the 802.11 WLAN standard specifies two access modes, Distributed Coordination Function (DCF) and Point Coordination Function (PCF). These medium access modes provide contention based and contention free (CF) access to the physical medium. A centralized access point (AP), which is analogous to the base station in a cellular communication network, controls the CF access to the medium. Transmission time is divided into cycles and each cycle is further divided into two time periods, contention period (CP) and contention free period (CFP) which correspond to DCF and PCF access control mechanisms respectively. This is illustrated in Figure 1. In this paper we will focus on the PCF access method.

The standard has defined mandatory periods of idle times on the physical channel known as interframe gaps between contiguous frame transmissions. We can use these gaps to assigns high priority on delay sensitive traffic which is meant to transmit during the CF period at the MAC layer level.

The PC transmits a beacon frame (**B** in Figure 1) to start CF transmission. When a non-point coordinated (non-PC) station in a cell receives a beacon frame, it will pre-set the Network Allocation Vector (NAV) to the length of the **`CFP_Dur_Remaining`**`[17].` This NAV prevents non-PC stations taking control of the medium during the CFP. After transmitting the beacon frame, the PC polls stations according to a predetermined strategy. Once a mobile station (MS) is polled it is given the right to transmit a single frame while all the other stations remain idle. If the station being polled does not have any data to transmit, the station sends a CF-NULL frame back to the PC. The length of the CF period is bounded by a maximum value **`CFP_Max_Duration`**. Details can be found in [3][16][17]. The “More Data” bit field in the 802.11 MAC header can be effectively used to reduce the chances of polling empty queues. In order to accomplish this, stations must set the “more data” bit field if it has more packets to send or reset it otherwise in the response sent back to the PC.

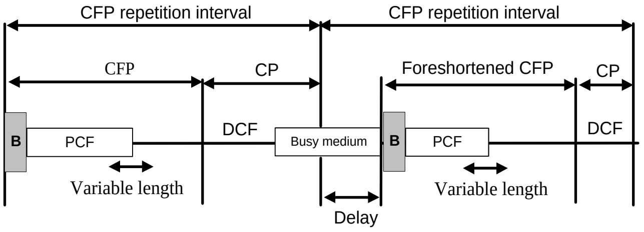

Figure 1: CFP/CP alternation within the Contention-Free repetition interval

Stations wishing to transmit delay sensitive data will have to compete for the channel together with other asynchronous data stations in order to transmit Association or Re-association frames. If the AP receives an Association or a Re-Association frame with “CF Polling Request” bit set, then the scheduler admits the station into the polling list. If the AP receives a Re-Association frame with “CF Polling Request” bit reset, then the corresponding entry is removed from polling list. Stations may be admitted into the polling list as a result of packets coming from the backbone network. All the stations that are admitted into the polling list using either Association or Re-Association frames are called pollable stations. The PC sends poll requests to only those pollable stations.

3. Polling list management

The PCF access mode uses a polling scheme to allocate the channel among uplink and downlink traffic streams during the contention free (CF) period. This section initially discusses the need for this polling to employ some form of fair queueing (FQ) and reviews some of the existing centralized and distributed FQ schemes, identifying the problem of implementing them on 802.11 WLANs. The distributed deficit round robin scheme[13] and the proposed scheduler will be discussed in Sections 3.1 and 3.2.

The scheduler running at the PC may use non-limited scheduling policies such as first-come first-serve (FCFS) or deadline-ordered scheduling disciplines [6] to handle the centralized queues (downlink streams). However these algorithms can suffer from unfairness due to the fact that the sources which generate lengthy packets at a higher rate, can easily block the channel for some time. In contrast , the limited service discipline algorithms which serve the queues up to a certain limit in each visit to the queue avoid blocking of the transmission channel by a particular flow for a long time.

The FQ service discipline [5] can be considered as a limited service discipline. The primary goal of the FQ is to serve queues in proportion to some predetermined service share independent of the queueing load. The round robin service discipline gives all the queues an equal share of bandwidth if the average packet size over the duration of a flow is the same for all flows[12]. However that is not the case for multimedia networks carrying a heterogeneous traffic.

Demers et al.[5] devised an algorithm for more general packet networks assuming a fluid-flow traffic model. An improved version of this algorithm was proposed using a simulated fluid flow model to eliminate the implementation limitations of the original scheme. The self-clock fair queueing (SCFQ)scheme[7] was proposed to reduce the computational complexity of the fluid flow model by assigning a timestamp on each arriving packet.

A simple modification to the round robin scheduling, “Deficit Round Robin” (DRR**)** was proposed in [15]. In this scheme, each queue i waiting for service has a state variable called *deficit counter* (DC_i). If the length of the next packet in the queue i is less than the DC_i, then queue i is allowed to send out its packet. It is clear that the scheduler has *a priori* knowledge of the next packet in the queue. After the transmission if there are no more packets in queue i, the state variable DC_i is reset to zero. If there are more packets waiting in queue i, DC_i is decremented by L_i, the length of the packet transmitted. After that the scheduler checks whether

DC_i is still greater than the length of the next packet; if so, the above procedure is repeated. Otherwise scheduler moves to the next station in the list stopping service to queue *i*. That means if the length of the next packet waiting for service in the queue is greater than the DC_i , it has to wait until enough credit is accumulated on DC_i before getting the service. At the start of subsequent rounds, DC_i is incremented by a specific service share (quantum).

In a centralized queueing system the scheduler has full access to the complete state of the queues. However in wireless networks the uplink traffic flows are decentralized (localized to the MS rather than at the PC) and the scheduler does not have direct access to the state of these distributed queues. Therefore none of the above FQ schemes can be directly used to schedule the uplink traffic flows in wireless networks.

The polling schemes investigated in [2][1][9] for multiplexing heterogeneous traffic in WLAN, come under the non-limited service discipline class. Schemes like R-Aloha[4] and PRMA [8]based on peak rate reservation and fixed frame length may result under utilization of network resources if the peak-to-average rate ratios are high.

A distributed version of SCFQ [10], Fully Gated Limited (FGL) [11] and non-uniform FGL [11] schemes addressed the issue of fair distribution of bandwidth among uplink traffic streams in the expense of exchanging information explicitly.

As mentioned earlier the existing schemes either suffer from unfairness or require continuous exchange of information explicitly either using a separate signalling channel or using extra control packets. As the IEEE 802.11 MAC protocol does not support exchanging additional information these schemes cannot be used at the PC to schedule uplink traffic during the CF period. One may think of using the standard round robin scheme that would work with the 802.11 MAC protocol rules. We recall the problem associated with standard round robin scheme to schedule traffic streams having varying average packet length. Our work in this paper mainly focuses a scheduler based on a distributed FQ scheme that can be used for uplink traffic scheduling in 802.11 MAC protocol based WLAN carrying heterogeneous mix of delay sensitive traffic. The scheme we examined is a distributed form of the DRR scheme which is described in Section 3.1.

3.1 Distributed Deficit Round Robin scheme

In the Distributed Deficit Round Robin (DDRR) scheme[13], each connection that is admitted into the polling list at the PC is assigned a state variable called the Deficit Counter (*DC*). Note that these *DC*s are entirely managed by the scheduler running at the PC and are available at the PC. If the value of the DC_i is positive then the scheduler allows the i^{th} queue to send a packet from its priority buffer. Note that in the DDRR scheme packet is transmitted first and then “paid off” for the consumed bandwidth, rather than saving enough credit prior to the packet transmission as in the DRR scheme. This difference between the DRR and DDRR schemes is illustrated in Figure 2. The DRR service discipline does not give services to the i^{th} queue until the value of DC_i is greater than or equal to X, length of the next packet waiting for service in the i^{th} queue. Whereas the DDRR scheme allows the i^{th} queue to transmit its packet as soon as its DC_i is positive. Once the transmission is completed DC_i is decremented by L_i, where L_i is the length of the transmitted packet. If DC_i is still positive the scheduler repeats the above procedure. If DC_i is negative the scheduler does not send a poll request to the i^{th} queue and then the scheduler moves to the next entry in the polling list. Therefore servicing this i^{th} queue will be backlogged to the next DDRR cycle. Note that several DDRR cycles can happen within one CF cycle period. The basic idea behind this approach is to keep the stations which have seized a large fraction of bandwidth in their previous transmissions away for a while giving the chance to other stations to send their uplink traffic. At the start of subsequent rounds, DC_i is incremented by a specific service share (quantum). The pseudo code for the DDRR algorithm is given in the Appendix.

Figure 3 illustrates how the transmission of packets in the i^{th} queue is scheduled according to the DDRR scheme. In Figure 3, rectangles on the left side represents the length of the packets waiting at a mobile station for service after becoming associated with the PC and rectangles on the right side represent the corresponding deficit counter maintained by the PC. In the first round, the i^{th} queue transmits the first two frames in the queue. After that DC_i goes negative and the i^{th} queue is not granted permission to transmit during second round. By the third round i^{th} queue has “paid off” for the previous packets it transmitted and is allowed to continue its transmission in this round.

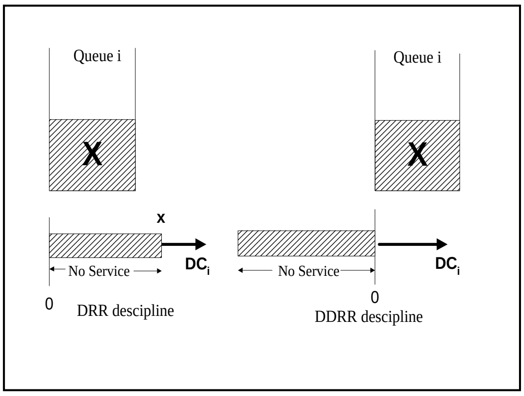

Figure 2: DRR and DDRR Schemes servicing policy

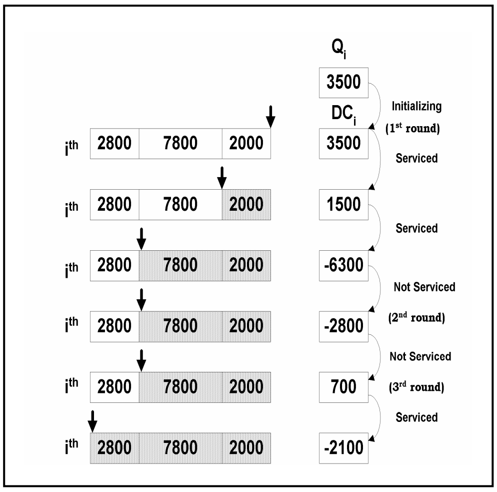

Figure 3: Distributed Deficit Round-robin scheme

3.2 Combined strategy for uplink and downlink traffic scheduling

Usually an 802.11 WLAN carries traffic in both the uplink and downlink directions. Therefore the scheduler operating at the PC must schedule both uplink and downlink traffic so as to distribute the bandwidth fairly among all the uplink and downlink traffic flows. In such an overall scheduling scheme, if the scheduler can send poll requests to the stations integrated with downlink data packets, it is possible to increase the unified transmission efficiency. The IEEE 802.11 standard supports this by allowing the MAC layer to integrate several frames during the contention free transmission period. As described in Section 2 it is possible for an active downlink flow to exist while the corresponding uplink flow is inactive. Therefore the scheduler will have to schedule uplink and downlink traffic flows either simultaneously or independently.

In the original DDRR scheme, if the DC_i is positive, the scheduler sends polls to the i^{th} uplink stream until the DC_i goes negative. The “more data” bit field in the 802.11 MAC header can be used to minimize polling of empty uplink streams. The pseudo code is in the Appendix. If the more data bit field of the previous response is set then the scheduler performs the algorithm as described in Section 3.1. However if the more data bit field is reset and if the corresponding *DC* value is still positive then the scheduler resets the *DC* to zero. In addition to that the proposed scheduler deactivates this empty queue for the rest of the CFP. If an entry becomes inactive it will be reactivated either on arrival of a packet from the corresponding downlink stream or in the following CF cycle. If all entries become inactive, the CFP is terminated. This adaptively allocates more bandwidth to asynchronous traffic if delay sensitive traffic is light.

4. Simulation Description

A WLAN carrying a mixture of real-time traffic (voice and video) and non real-time asynchronous traffic was simulated with two scheduling schemes. The first scheme, DDRR/DRR combined scheme which we call hereafter as DDRR scheme described in Section 3.2 was investigated to explore the characteristics behaviour of this scheme and to evaluate its performance. The standard round robin scheme considering the “more data” bit field information which we call hereafter as RR scheme was examined to compare with DDRR scheme. Section 4.1 describes the traffic models used and Section 4.2 presents system parameters.

4.1 Traffic Models

Voice traffic: The voice source is modelled using an ON/OFF process. The amount of time sitting in the “talking” state(ON) or “silent” state(OFF) is exponentially distributed. When the source is in the talking state it periodically generates fixed size voice packets. We selected the CF repetition period identical to the inter-arrival time of these periodic voice packets.

Video traffic: As a video traffic source we used the MPEG-I traffic traces available at the FTP site *ftp-info3.informatik.uni-wuerzburg.de/pub/MPEG/* [14]. A video traffic source generates frames at a constant rate over its active period. The length of the video frame can be very large compared to the maximum length of the Mac Protocol Data Unit (MPDU) defined in the standard. These packets are segmented into constant size packets and sent to the MAC layer as a packet burst.

Data traffic: The presence of asynchronous traffic in an 802.11 based network results in transmission during the contention based period. The transmissions during the contention period may delay the start time of CF cycles. Since this is common in most practical situations, we used asynchronous data terminals to generate asynchronous traffic. The data traffic is generated using multiple stations. Both packet length distribution and data frame inter arrival time distribution form a negative exponential distribution.

4.2 System parameters

We used the default figures [17] for all the DCF and the PCF related attributes, which are not specified in this paper. Tables 1 to 3 show the important user specified parameters. The contention free repetition interval (20 ms) is partitioned into a 15 ms CF period and a 5 ms contention period. This partition size is sufficient to transmit a maximum size MPDU during the contention based transmission period.

PHY medium capacity	10 Mbps
Number of Data stations	10
Mean Aggregate Asynchronous data load	2 Mbps
CFP repetition interval	20 ms
CFP_Max_Duration	15 ms

Table 1: MAC and PHY channel configuring attributes

Voice source rate	64 Kbps
Voice frame duration	20 ms
Maximum speech delay	32 ms
Mean ON state duration	1.0 sec.
Mean OFF state duration	1.35 sec.
Voice Quantum size	2208 bits

Table 2: Attributes of a voice source

Video source rate	25 frames/sec.
Average Video frame length	15599 bits
Video frame duration	40 ms
Maximum Video Delay	100 ms
Video Quantum size	16524 bits

Table 3: Attributes of a video source

5. Simulation Results

We set up a single cell infrastructure WLAN with three different types of terminals. These data, voice and video terminals generate a heterogeneous mix of traffic according to the traffic models described in Section 4.1. The number of data stations was fixed to 10 and these 10 data stations generate asynchronous data traffic at an aggregate rate of 2Mbps. In our simulations we model the physical channel as an error free channel. Each simulation run simulates 80,000 CF cycles. We ignore the results of initial warm-up period of 5,000 cycles.

Figures 4,5, and 6 show the contention free (CF) cycle length as a function of the contention free cycle number for different load conditions under DDRR scheme. The term "load" here refers CF traffic transmitted under the PCF rules. For the three cases presented in Figures 4,5 and 6 the network was subjected to following conditions:

	Case 1 (Presented in Figure 4)	Case 2 (Presented in Figure 5)	Case 3 (Presented in Figure 6)
Number of voice sources	6	16	32
Number of video sources	1	2	4
Total delay sensitive traffic load normalized to CFP capacity, G_{CFP}	0.155	0.357	0.642

It is clear that the scheduler detects the level of the contention free traffic load using the more data bit field and terminates the CF cycle earlier than the specified nominal value when the offered delay sensitive load is less resulting more bandwidth is available for contention traffic. Figure 7 reports the average CF cycle length on increasing number of video connections for a given voice load under DDRR scheme. A voice or a video connection refers to full a duplex connection. Figure 8 shows the impact of adaptive nature of the DDRR scheme on asynchronous traffic transmitted during the contention period.

Figures 9 and 10 illustrate the percentage of voice MPDU loss as a function of the number of video connections for given number of voice connections. This can be seen more clearly in Figures 11. From these graphs, it can be seen that the DDRR scheme achieves better voice MPDU loss ratio than RR scheme. This due to the fact that the scheduler can limit the number of bits that can be transmitted by a connection under DDRR scheme. This prevents video streams from seizing a larger portion of bandwidth than the specified service share. Such a restriction cannot be imposed in RR scheme.

Figure 12 shows the number of full duplex voice and video connections that can be supported by a 10 Mbps 802.11 WLAN satisfying the following QoS measures.

- 99% of the voice MPDUs must be transmitted with voice packet delay less than 32 ms
- 99% of the video MPDUs must be transmitted with video packet delay less than 100 ms

The "packet delay" in either case refers to the access delay which is the sum the MAC delay and the queueing delay in the local queue. Note that packets are discarded from the network as the packet lifetime expires. The DDRR scheme is better than RR scheme in terms of number of voice and video connections that can be accommodated in a 10Mbps 802.11 based WLAN. According to the results we obtained it is possible to achieve up to 20% more voice connections for a given number of video connections under DDRR scheme

6. *Conclusion*

In this paper we have discussed a novel fair queueing scheduler for the point coordinator of the IEEE 802.11 based wireless networks to schedule traffic flow during the contention free period. Specifically we examined a distributed fair queueing algorithm based on the deficit round robin scheme for uplink traffic scheduling together with it centralized counterpart. Simulation results showed that a scheduler based on the distributed deficit round robin and deficit round robin schemes outperforms the scheduler based on round robin scheme. We have shown that it is possible to achieve up to 20% more voice connections under the distributed deficit round robin/deficit round robin scheduling scheme we presented in this paper.

We have effectively used the "more data" bit filed included in the 802.11 medium access control frame header to detect the empty uplink traffic flows and then use that to dynamically vary the contention free access period at the point coordinator. This will avoid the reservation of bandwidth for contention free period unnecessarily.

Appendix

This appendix describes the generic distributed deficit round robin scheme algorithm together with the changes required for IEEE 802.11 based wireless MAC protocol. Steps shown in italics correspond to the additions required for implementing the distributed deficit round robin scheme to the 802.11 MAC protocol.

Algorithm:

<u>Attaching module</u>: On the arrival of an association or re-association request from terminal *i* in the wireless network or a packet from the backbone network, the corresponding deficit counter is initialized to DC_i = Quantum $(\text{type})_i$, where type is either voice or video.

<u>Polling module:</u>

```
Set i to ActiveNode
WHILE ((SchedulingList is not empty) AND (CF remaining time < CF_MAX_Duration) AND (All the entries are not inactive))
        $DC_i=DC_i+Q_i$;
        Set MoreDataBit;
        WHILE (($DC_i>0$) AND (MoreDataBit))
              Send a poll request to terminal i;
              Receive packet p;
              $DC_i=DC_i$- length of the packet p;
              Read MoreDataBit from p;
        END-While
        $DC_i=0$;
        Make the $i^{th}$ entry inactive;
        i=i+1;
END-WHILE
```

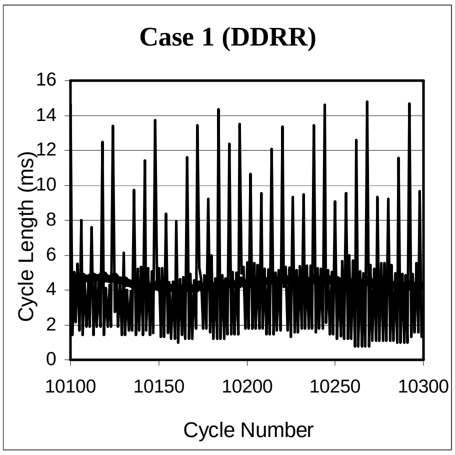

Figure 4 : CF cycle length distribution under Low level of delay sensitive load

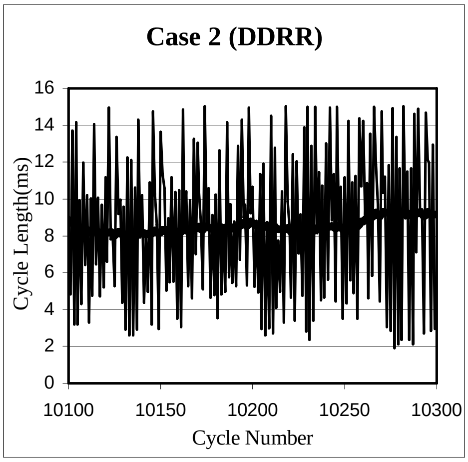

Figure 5 : CF cycle length distribution under medium level of delay sensitive load

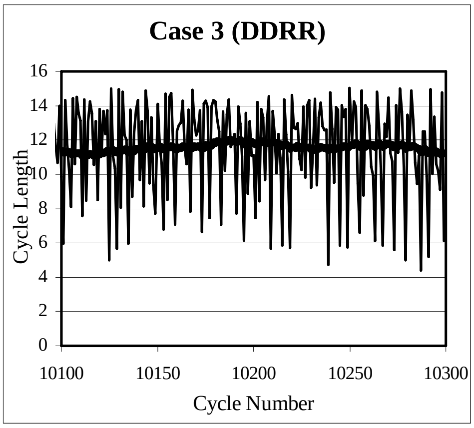

Figure 6 : CF cycle length distribution under High level of delay sensitive load

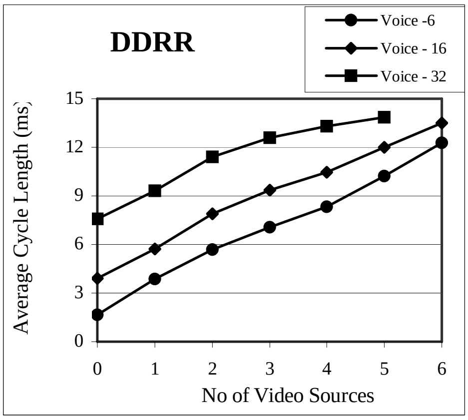

Figure 7 : Average CF cycle length versus number of active video connections for given number of voice connections under DDRR scheme

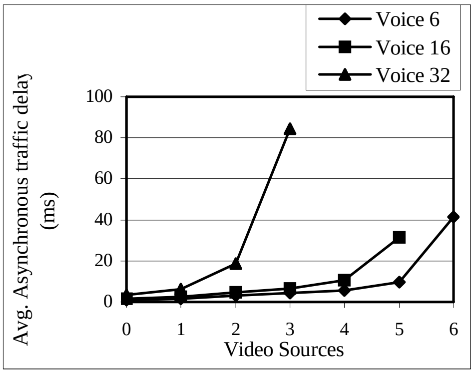

Figure 8: Average asynchronous traffic delay versus number of active video connections for given number of voice connections under DDRR scheme

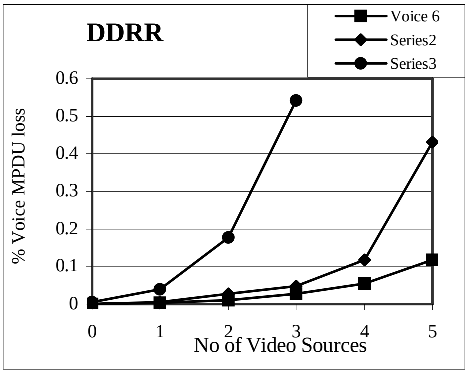

Figure 9: Percentage voice MPDU loss distribution under for DDRR scheme

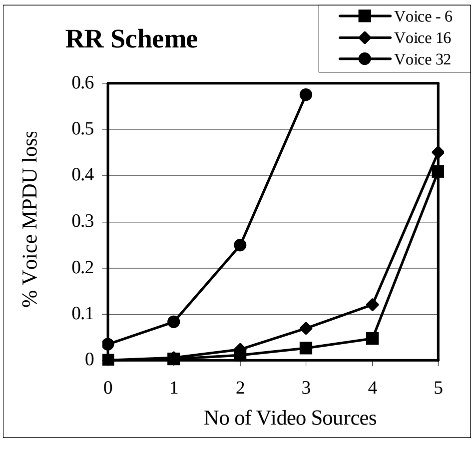

Figure 10 : Percentage voice MPDU loss distribution under RR scheme

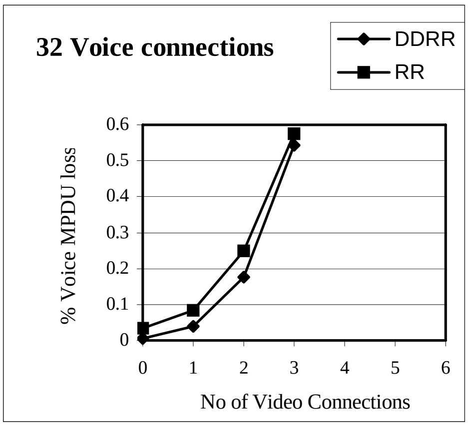

Figure 11 : Percentage voice MPDU loss distribution under RR scheme

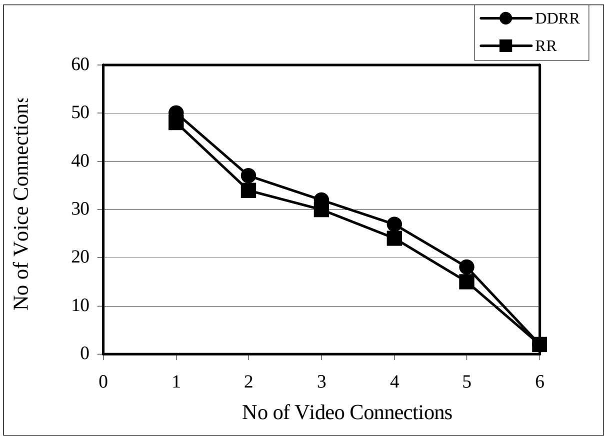

Figure 12 : Number of voice connections versus number of video connections that can be accommodated in an 802.11 based network under DDRR scheme and RR scheme

References

[1] K.C. Chen, C. H. Lee, “Group randomly addressed polling for multicell wireless data networks,” *ICC’ 92*, 1992, pp. 1025-31.

[2] K.C. Chen, C. H. Lee, “RAP – A novel medium access control protocol for wireless data networks,” *Proc IEEE Globecom ‘93*, 1993, Vol. 3, pp. 1713-17.

[3] B.P. Crow, I. Widjaja, J.G. Kim, P. Sakai, “Investigation of the IEEE 802.11 medium access control (MAC) sublayer functions,” *Proc. INFOCOM 97*, Apr. 1997, Kobe, Japan, pp.126-33.

[4] W. Crowther, R. Rettberg, D. Walden, S. Ornstein, F. Heart, “ A system for broadcast communication : Reservation – ALOHA,” *Proc. 6th Hawaii Int. Conf. Sys. Sci.*, 1973, pp. 596-603.

[5] A. Demers, S. Keshav, S. Shenker, “Analysis and simulation of a fair queueing algorithm,” *Proc. SIGCOMM 89*, Sept. 1989, Vol. 19, No. 4, pp.1-12.

[6] N.R. Figueira, J. Pasquale, “A schedulability condition for deadline-ordered service disciplines,” *IEEE/ACM Trans. Networking*, April 1997, Vol.5 No. 2, pp.232-44.

[7] S.J. Golestani, “A self-clocked fair queuing scheme for broadband applications,” *Proc. INFOCOM ’94*,1994,pp. 636-46.

[8] D.J. Goodman, S.X. Wei, “Efficiency of packet reservation multiple access,” *IEEE Trans. Vehic. Tech*., Feb. 1991, Vol. 40, No. 1, pp. 170-6.

[9] A. Hoffman, R. J. Haines, A.H. Aghvami, “Performance analysis of a token based MAC protocol with asymmetric polling strategy (“TOPO”) for indoor radio local area networks under channel outage conditions,” *ICC’ 94*, 1994, pp. 1306-11

[10] R. Kautz, A. Leon-Garcia, “A distributed self-clocked queueing architecture for wireless ATM networks,” *Proc PIMRC’97*, 1997, Vol. 1, pp. 189-93.

[11] N. Movahhedinia, G. Stamatelos, H.M. Hafez, “Polling-based multiple access for indoor broadband wireless systems”, *Proc. PIMRC 95*, 1995, Vol. 3, pp. 1052-6.

[12] J. Nagle, “On packet switches with infinite storage,” *IEEE Trans. Commun.*, Apr. 1987, vol. COM-35, no 4, pp.

[13] R.S. Ranasinghe, L.L.H. Andrew, D. Everitt, “Impact of polling strategy on capacity of 802.11 based wireless multimedia LANs,” *Accepted to ICON’’ 99* .

[14] O. Rose, “Statistical properties of MPEG video traffic and their impact on traffic modeling in ATM systems,” *Proc. 20th Annual Conf. Local Comp. Network*, Minneapolis, CA, Oct. 1995

[15] M. Shreedhar, G. Varghese, “Efficient fair queueing using deficit round robin,” *IEEE/ACM Trans. Networking*, 1996, Vol.4 No. 3, pp. 375-85.

[16] M.A. Visser, M. E. Zarki, “Voice and data transmission over an 802.11 wireless network”, *Proc. PIMRC 95*, Sep. 1995, Toronto, Canada, pp. 648-52.

[17] P802.11, Wireless medium access control (MAC) and physical layer (PHY) working group, IEEE 802.11 draft standard, “Wireless medium access control (MAC) and physical layer (PHY) specifications,” IEEE Stds. Dept., Jul. 1996, D5.