DYNAMIC ADAPTION OF MEDIA ACCESS CONTROL OF IEEE 802.11 WLAN

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Abstract: IEEE 802.11 Specifics the most famous family of WLANs. Media access control technique. It is use two basic mode of operation Distributed Coordinating Function (DCF) and Point Coordinating Function (PCF). Both PCF and DCF mode of IEEE 802.11 do not perform equally well under all traffic scenarios. Their behavior varies depending upon current network size and traffic load. It is useful to use the DCF mode for low traffic and small network size, and the PCF mode for high traffic loads and to reduce contention in large size network. In this thesis, we have designed three protocols to dynamically adapt IEEE 802.11 MAC under varying load. One of them is designed to dynamically switch between either modes. Our Dynamic Switching Protocol (DSP) observes network traffic to decide switching point and switches dynamically to suit current traffic load and network size. PRRS is our second contribution that aims to reduce polling overheads. A major drawback of polling scheme in PCF, is their inefficiency when only a small number of nodes have data to send. Unsuccessful polling attempts causes unnecessary delays for station with data. We have presented network monitoring based scheme that replaces simple Round Robin scheduling in PCF with our Priority Round Robin Scheduling (PRRS). Result shows considerable increase in throughput especially when small fraction of node has data to transmit. In addition, we have presented the need to dynamically adapt various configuration parameters in both PCF and DCF. Statically configured values results in degraded performance under varying scenarios .We have showed the performance variation of PCF with PRRS by using different CFP repetition intervals. Our proposed CFP repetition interval adaption algorithm dynamically adjust the value of CFP repetition interval, depending upon last CFP usage

I. INTRODUCTION

Why IEEE 802.11 WLAN

IEEE 802.11 standard is one of the prominent wireless local area network standards being adopted as a mature technology. The success of the IEEE 802.11 standard has resulted in the easy availability of commercial hardware and a proliferation of wireless network deployment, in wireless LANs as well as in mobile ad hoc networks. Although IEEE 802.11 is not designed for multihop ad hoc networks, the easy availability has made it, most chosen MAC.

Need for Specialized Wireless MAC

Existing MAC schemes from wired networks like, CSMA/CD are not directly applicable to wireless medium. In CSMA/CD sender senses the medium to see if it is free. If medium is busy, the sender waits until it is free. If the medium is free, sender starts transmitting data and also continues to listen into the medium. It stops transmission as soon as it detects collision and sends a jam signal. In wired medium, this works because more or less the same signal strength can be assumed all over the wire. If collision occurs somewhere in the wire, everybody will notice it. This assumption gets invalidated in wireless medium, as the signal strength decreases proportionally to the square of distance to the sender. In wireless medium, sender may apply carrier sense and detect an idle medium. Thus, the sender starts sending, but a collision happens at the receiver due to a second sender. Second sender may or may not be audible to first sender. Hence the sender detects no collision, assumes that data has been transmitted without errors, but actually a collision might have destroyed the data at the receiver. Besides that, wireless devices are half duplex and battery operated. They are unable to listen to the channel for collision while transmitting data.

Hidden and Exposed Node Problem

The transmission range of stations in wireless network is limited by the transmission power, therefore, all the station in a LAN cannot listen to each other. This gives rise to hidden node and exposed node problem. Consider a scenario shown in Figure . Transmission range of A reaches B, but not C. The transmission range of C reaches B, but not A. Finally, the transmission range of B reaches both A and C.

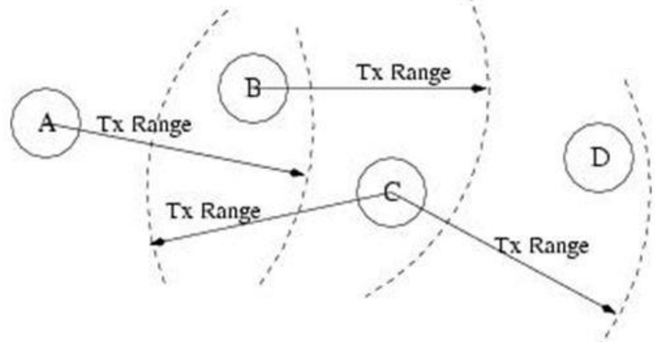


Figure : Hidden and Exposed Node Scenario

Hence C can listen to B but not A. A start sending to B, C does not hear this transmission, and also wants to send something to B. C senses the medium, medium appears to be free and it starts sending. Hence collision occurs at B. A cannot detect this collision and continues with its transmission. A and C are hidden to each other. This problem is termed as Hidden Node problem. Hidden terminals cause collision, and Exposed terminals suffer unnecessary delays. Consider the situation that B sends something to A and C wants to transmit data to D. D is not in transmission or interference range of A and B. C senses the medium and finds it busy. Thus, C postpone its transmission. But as A is

outside the interference range of C, waiting is not necessary. Collision at B due to C's transmission does not matter as it is too weak to propagate to A. This termed as Exposed Node problem.
Node C is exposed to B.

Challenges in Wireless LANs

Many different and sometimes competing design goals have to be taken into account for WLANs to ensure their commercial success.

• Global operation: WLAN products should sell in all countries, therefore, many national and international frequency regulations have to be considered.
• Low Power: Devices communicating via a WLAN are typically also wireless devices running on battery power. Hence, WLAN must implement special power saving modes and power management functions.
• License-free operation: LAN operators do not want to apply for a special license in order to be able to use the product. Thus, the equipment must operate in a license-free band, such as the 2.4 GHz ISM band.
• Bandwidth: Bandwidth is the one of the most scarce resource in wireless networks. The available bandwidth in wireless networks is far less than the wired links.
• Link Errors: Channel fading and interference cause link errors and these errors may sometimes be very severe.
• Robust transmission technology: Compared to wired counterparts, WLANs operate under difficult conditions. If they use radio transmission, many other electrical devices may interfere.
• Simplified spontaneous co-operation: To be useful in practice, WLANs should not require complicated setup routines but should operate spontaneously after power up. Otherwise these LANs would not be useful for supporting e.g., ad hoc meetings, etc.
• Easy to use: LANs should not require complex management but rather work on a plug-and-play basis.
• Protection of investment: A lot of money has already been invested into wired LANs. Hence new WLANs must protect this investment by being inter operable with the existing networks.
• Safety and security: Most important concern is of safety and security. WLANs should be safe to operate, especially regarding low radiation. Furthermore, no users should be able to read personal data during transmission i.e., encryption mechanism should be integrated. The network should also take into account user privacy.
• Transparency for application: Existing applications should continue to run over WLANs. The fact of wireless access and mobility should be hidden if not relevant.

IEEE 802.11 standard

IEEE 802.11 MAC features two mode of operations: Distributed Coordinating Function (DCF) and Point Coordinating Function (PCF). DCF is CSMA/CA based random access protocol that uses random backoff to avoid collision. It uses RTS/CTS exchange mechanism to reserve channel when packet size is above the RTS threshold. It reduces the hidden terminal effect (section 1.2.1). PCF provide centralized scheduled access to channel. It comprises of chain of contention free period (CFP) and contention period (CP). DCF rules are followed in the CP. In the CFP point coordinator (PC) polls the node one by one and grant access to channel. New stations that need to get enrolled in poll list, send request in CP.

Problem Statement

Our work aims at optimizing overall performance of IEEE 802.11 MAC. Although we have tried to keep solution robust enough to suit different traffic scenarios, our main focus is on traffic directed towards a central node. Both DCF and PCF do not perform well under all load regime. Each has its own pros and cons depending upon different load condition. When only small number of nodes have data to transmit PCF incurs polling overheads, and at high load DCF performance degrades. We think there is need to dynamically adapt IEEE 802.11 MAC under varying load, such that coexistence of both the modes can be exploited. Besides that, performance of DCF and PCF depends highly upon their various configuration parameters. Studies shows that good values of these configuration parameters depend upon network load. Statically configured values result in degraded throughput under varying load. So there is need to dynamically adapt these values. We have proposed learning based protocol to reduce polling overheads in PCF and to dynamically adapt configuration parameters. To exploit better half of both PCF and DCF, we have proposed a protocol to dynamically switch between two modes.

II. SCOPE AND PURPOSE OF IEEE 802.11 STANDARD

The scope of this standard is to develop a medium access control (MAC) and physical layer (PHY) specification for wireless connectivity for fixed, portable, and moving stations within a local area. The purpose of this standard is to provide wireless connectivity to automatic machinery, equipment, or stations that require rapid deployment, which may be portable or hand-held, or which may be mounted on moving vehicles within a local area. This standard also offers regulatory bodies a means of standardizing access to one or more frequency bands for the purpose of local area communication. Primary goal of the standard was the specification of a simple and robust WLAN which offers time-bounded and asynchronous services. Furthermore, the MAC layer should be able to operate with the multiple physical layers, each of which exhibits a different medium sense and transmission characteristic. Candidates for physical layers were infrared and spread spectrum radio transmission techniques. Additionally features of the WLAN should include the support of the power management, the handling of hidden nodes, and the ability to operate worldwide.

System Architecture

The basic service set (BSS) is the fundamental building block of the IEEE 802.11 architecture. A BSS is defined as a group of stations that are under the direct control of a single coordination function (i.e., a DCF or PCF) which is defined below. The geographical area covered by the BSS is known as the basic service area (BSA), which is analogous to a cell in a cellular communications network. Conceptually, all stations in a BSS can communicate directly with all other stations in a BSS. However, transmission medium degradations due to multipath fading, or interference from nearby BSSs reusing the same physical-layer characteristics (e.g., frequency and spreading code, or hopping pattern), can cause some stations to appear hidden from other stations. An ad hoc network is a deliberate grouping of stations into a single BSS for the purposes of internetworked communications without the aid of an infrastructure network. Figure is an illustration of an independent BSS (IBSS), which is the formal name of an ad hoc network in the IEEE 802.11 standard. Any station can establish a direct communications session with any other station in the BSS, without the requirement of channeling all traffic through a centralized access point (AP).

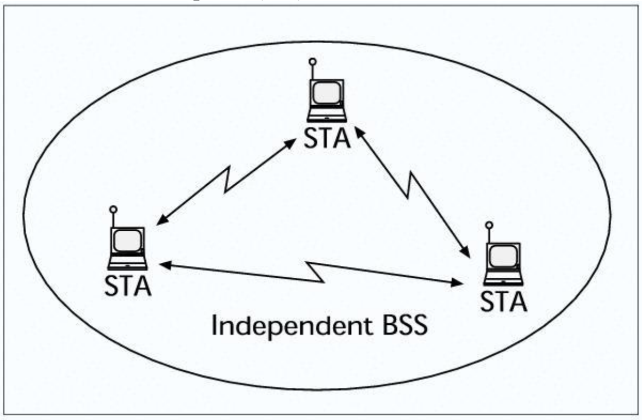


Figure: Sketch of an ad hoc network

In contrast to the ad hoc network, infrastructure networks are established to provide wireless users with specific services and range extension. Infrastructure networks in the context of IEEE 802.11 are established using APs. The AP is analogous to the base station in a cellular communications network. The AP supports range extension by providing the integration points necessary for network connectivity between multiple BSSs, thus forming an extended service set (ESS). The ESS has the appearance of one large BSS to the logical link control (LLC) sublayer of each station (STA). The ESS consists of multiple BSSs that are integrated together using a common distribution system (DS). The DS can be thought of as a backbone network that is responsible for MAC-level transport of MAC service data units (MSDUs). The DS, as specified by IEEE 802.11, is implementation independent. Therefore, the DS could be a wired IEEE 802.3 Ethernet LAN, IEEE 802.4 token bus LAN, IEEE 802.5 token ring LAN, fiber distributed data interface (FDDI) metropolitan area network (MAN), or another IEEE 802.11 wireless medium. Note that while the DS could physically be the same transmission medium as the BSS, they are logically different, because the DS is solely used as a transport backbone to transfer packets between different BSSs in the ESS. An ESS can also provide gateway access for wireless users into a wired network such as the Internet. This is accomplished via a device known as a portal. The portal is a logical entity that specifies the integration point on the DS where the IEEE 802.11 network integrates with a non-IEEE 802.11 network. If the network is an IEEE 802.X, the portal incorporates functions which are analogous to a bridge; that is, it provides range extension and the translation between different frame formats. Figure illustrates a simple ESS developed with two BSSs, a DS, and a portal access to a wired LAN.

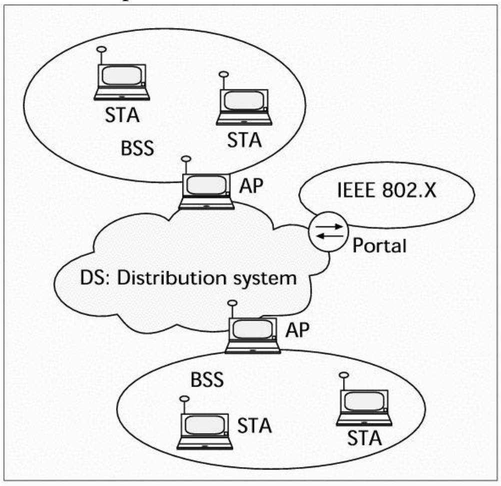


Figure : Sketch of an infrastructure network

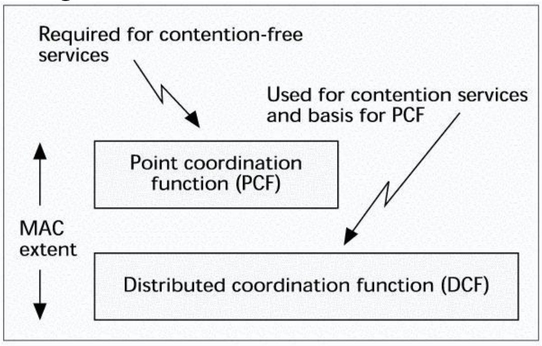


Figure : MAC Architecture

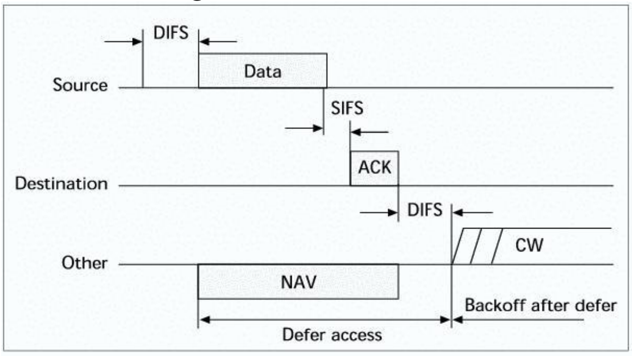


Figure : Transmission of an MPDU without RTS/CTS

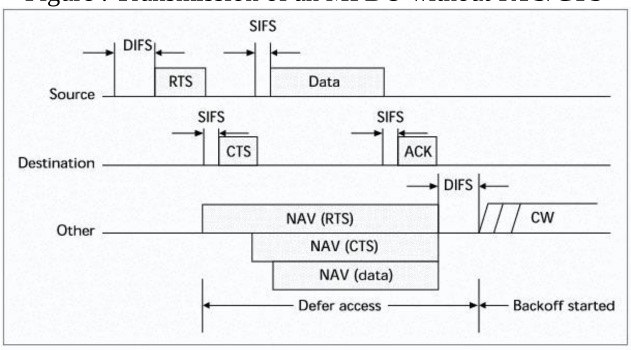


Figure : Transmission of an MPDU using RTS/CTS

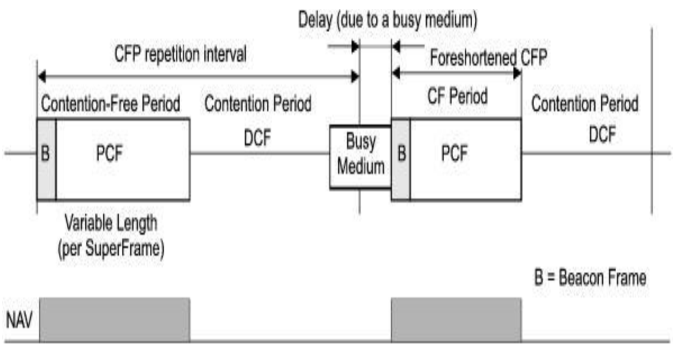


Figure : Super frame CFP/CP alternation

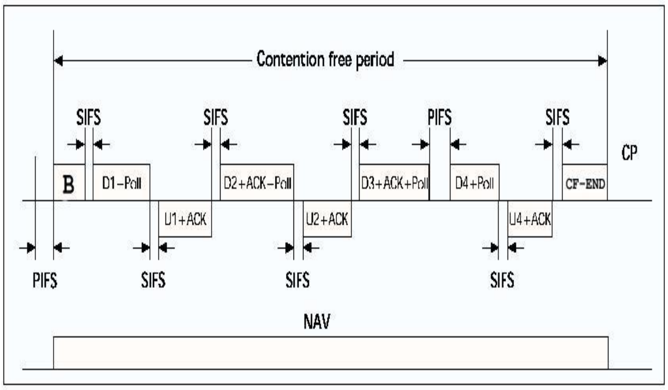


Figure : PCF PC-to-station frame transmission

III. NEED FOR SWITCHING BETWEEN PCF AND DCF

The DCF mode of IEEE 802.11 exerts a CSMA/CA approach, which is in fact a 1-persistent random access protocol with delay. Random access protocol works satisfactorily as long as network size is limited. Here by network size we mean number of node that have pending data in BSS, i.e. in transmission range of central node. Load is defined as total bits transmitted by all stations in BSS per second. As network expands, competition for accessing shared wireless channel increases. This results in throughput degradation and more delay because of more collision and increased time spent for negotiating channel access. We need ordered way to schedule the channel access at high loads. IEEE 802.11 provide another more organized way to grant channel access called PCF. But better management always poses some overheads that become prominent under low load scenarios. Similar story appears here. DCF whose performance degrades at high load and in big size network, provide lesser delays at low load. On counter side, scheduled MAC like PCF with centralized control better utilize resources at high load and in large network. But when few nodes have data to send PCF perform worse than DCF because of scheduling overhead in PCF). Graph shown in figure presents goodput and delay at different load. PCF starts with slightly high delay, but it remains low and constant up to 80% goodput. In DCF beyond 60% load the delay increases exponentially. We think dynamic switching between them will increase the channel capacity and offer lower delays.

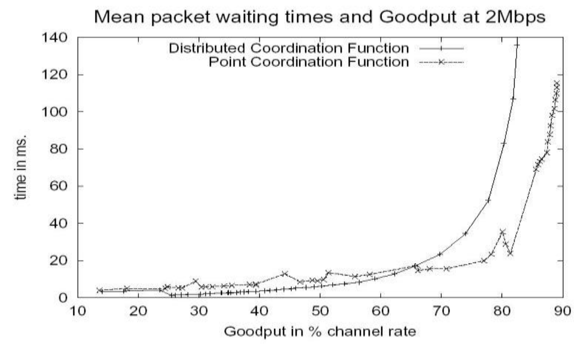


Figure : Comparison of mean packet waiting and goodput between DCF and PCF at 2 Mbps. 15 Nodes,1 PC and 1500 bytes packet size.

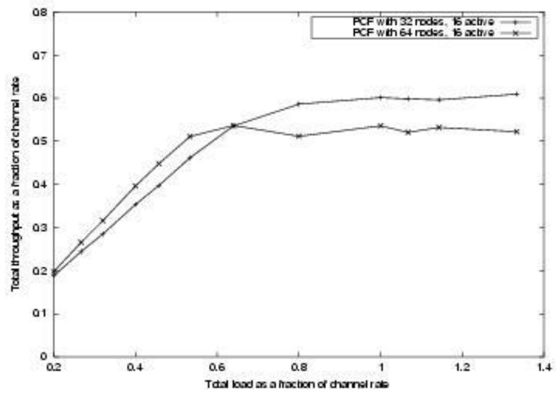


Figure : Effect of polling overhead on network throughput

Parameter	Symbol	Value
SIFS Interval	SIFS	10μs
Channel B/w	bw	2Mbps
CF-Poll size	SizePoll	20 bytes
Ack Size	SizeAck	14 bytes
Null Frame Size	SizeNull	34 bytes
Time to send poll	TPoll	SizePoll × 8/bw
Time to send Null Frame	TNull	SizeNull × 8/bw
Time to send Data	TData	Psize × 8/bw
Time to send Ack	TAck	SizeAck × 8/bw

Table1: 802.11b Default parameters

Percentage of active Nodes

		12.5%	25%	50%	75%
Packet size in bytes	300	52.37%	32.03%	13.57%	4.97%
	500	41.77%	23.51%	9.29%	3.29%
	1000	27.74%	13.97%	5.19%	1.78%
	1500	20.76%	10.09%	3.60%	1.22%

Table : Percentage polling overheads with active nodes percentage 10,25, 50, and 75 and packet size (bytes) 300,500,100,and 1500

Solution Overview

We have only modified the PC functionality, rest nodes work as usual. At present network monitoring layer does very simple job of classifying nodes as active node and passive node on the basis of observed traffic. Figure shows solution model at PC. We start with explaining Priority Round Robin Scheduling (PRRS) that aims to reduce polling overheads. PRRS replaces simple round robin scheduling in PCF with priority round robin scheduling. On observing results of PRRS, we design a protocol to further enhanced its performance by dynamically adapting CFP repetition interval. We have discussed CFP adaption algorithm after showing the simulation results of PRRS, in chapter 6.1. Dynamic Switching Protocol (DSP) is our next proposed protocol that aims at exploiting coexistence power of PCF and DCF and merges better half of both modes. We have suggested various criteria to decide switching point for dynamically switching between two modes PCF and DCF.

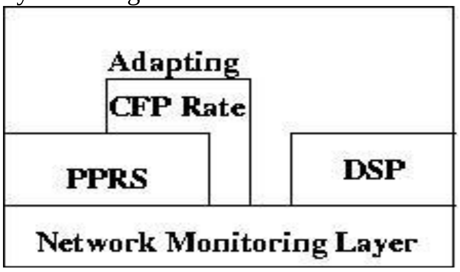


Figure: Solution model at PC

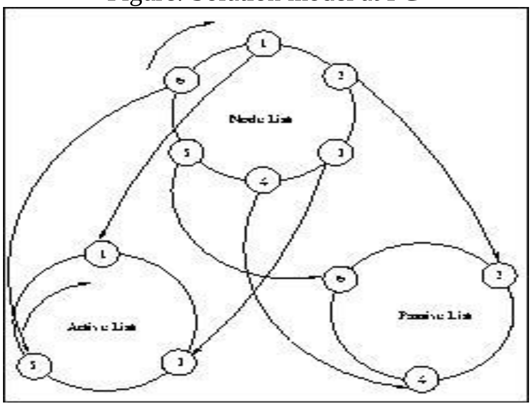


Figure : Example of stations/nodes in Active and Passive list. The order is imposed by the Node list.

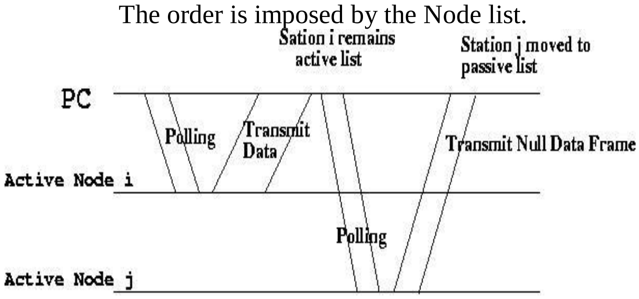


Figure : Transmission sequence and list updating in CFP

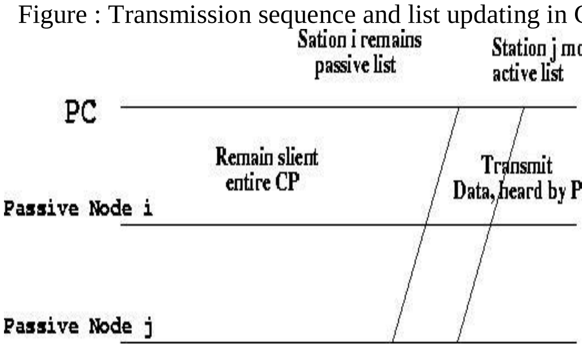


Figure : Transmission sequence and list updation in CP

IV. SIMULATION RESULTS

Our simulations are done using the public domain network simulator NS-2 (2.1b8)[3]. Support for wireless simulations in ns was added as a part of the CMU Monarch project . Support for the PCF mode of IEEE 802.11 already exists. PCF patch added by Lindgren, et. simulates only limited PCF features. We have simply extended some feature of existing PCF patch like:

- We added the support for Null data frame that need to be sent in response to poll, if station have no pending data. Previously it was resolved via poll timed out at PC.
- We added support for sending broadcast packet in CFP. Existing implementation simply drops such packet in CFP

Support for association, deassociation and reassociation still have not been added. Presently nodes need to be associated through tcl script. Since we assume nodes remain in range of PC all the time, therefore static association simply serves our purpose.

Simulation Setup

Our studies are confined to a single cell of radius 240m, slight less than the transmission range of central coordinator. Conceptually every station in region can communicate di-rectly with central node. However, transmission medium degradations due to multipath fading, or interference from nearby BSSs reusing the same physical-layer characteristics can cause some stations to appear hidden from other stations. In our simulations we are working with only one BSS, a clean channel without errors and fading effects etc., so all stations can indeed communicate directly with PC. We have used the default values for all the physical and MAC layer parameters. The number of stations other than PC in circular cell is varied from 8 to 64 asynchronous data user. Nodes are placed randomly around PC. All our runs are averaged over ten such random placements. At stations, we attached a cbr source that simulates arrival of frames for transmission at constant rate. Packet size is kept constant at 500 bytes for most simulations, except when throughput is studied as a function of packet size. The choice of 500 bytes as a packet size worth studying is motivated by the fact that we consider messaging applications to be appropriate for wireless networks.

Parameter	Value
Transmission Power	281.8mW
Transmission Range	250m
Slot Time	20μs
SIFS	10μs
Channel Bandwidth	2Mbps
Number of Stations	Varied from 8 to 64
Central Coordinator	1
Packet Size	500 bytes
RTS/CTS threshold	250 bytes
Fragmentation threshold	2346 bytes
CW _Min	31
CW _Max	1024
CFP repetition interval	Varied from 50 to 400 TUs
Time Unit (TU)	1024μs

Table : Simulation Parameters

V. SIMULATION RESULTS OF PRRS

We simulated PRRS for 300 seconds using different traffic loads and network size. Nodes placement is total random. In all simulations for PRRS, we have changed the sources dynamically. Consider graph in figure , we have three different set of 8 sources. Source nodes of each set send packets for 100 seconds. All 8 cbr sources start and end at same time.

Throughput

We define throughput as the total number of bits per second passed up from the MAC sublayer at each destination. Then we present it as a fraction of channel bandwidth. So the throughput what we measure here is actually the goodput, because control frames, management frames, routing packets, header size, etc. are not counted. Similarly, we offered load as the average number of bits per second of actual data offered to the MAC sublayer at each source. It is then represented as a fraction of channel bandwidth. Figure shows PRRS result with 25% node active and total 32 nodes in BSS. Highest throughput achieved by PRRS is 0.637534 × 2000000 = 1275068 bps and with RRS is 0.585006×2000000 = 1170012 bps. Around 10% increase in goodput is achieved. Considering the same ratio of active nodes and total nodes, with 64 nodes (figure Throughput difference is highest when offered load is 80%. Throughput achieved by PCF with RRS at 80% offered load is 0.511695 × 2000000 = 1023390 bps and by PCF with PRRS is 0.592234 × 2000000 = 1184460 bps. Throughput improved by 15.7% approximately.

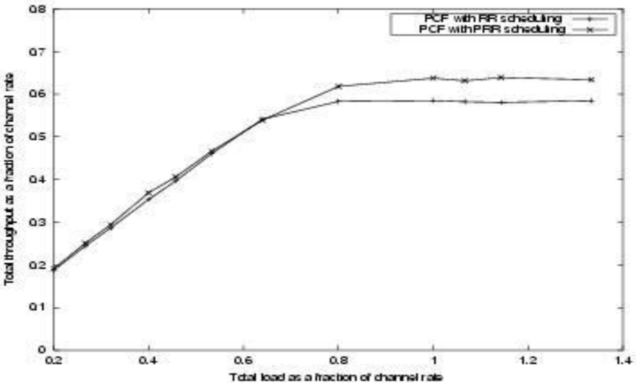


Figure : Throughput Comparison between PCF with PRRS and non optimized PCF with RRS. Total node =32 and 25% active node

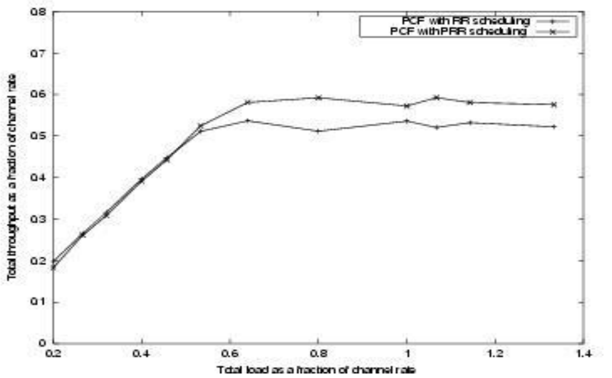
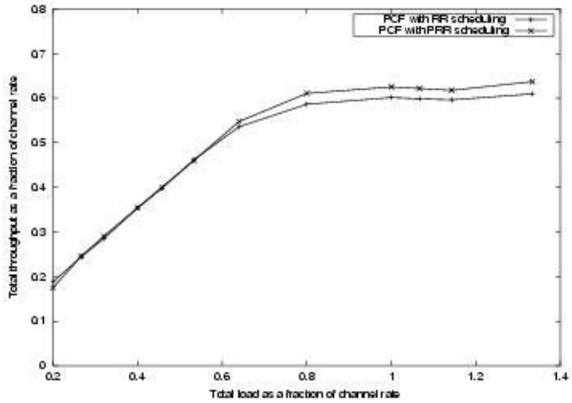
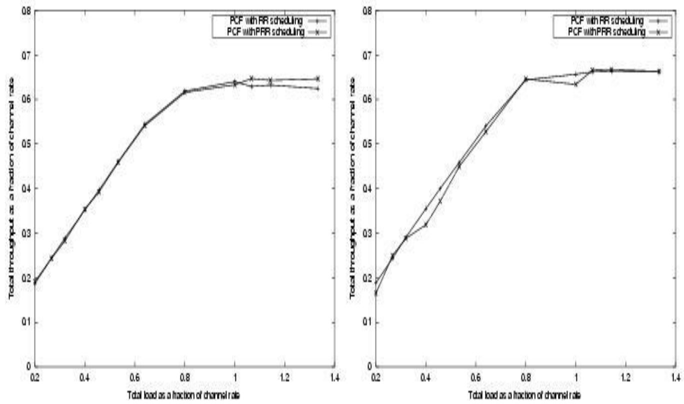


Figure : Throughput Comparison between PCF with PRRS and non optimized PCF with RRS. Total node =64 and 25% active node

Figure shows the throughput comparison with 32 nodes and among them 50% 75%100% active. As number of active nodes increases throughput difference decreases. Figure shows the throughput comparison with 64 nodes and among them 50% and 75% active.

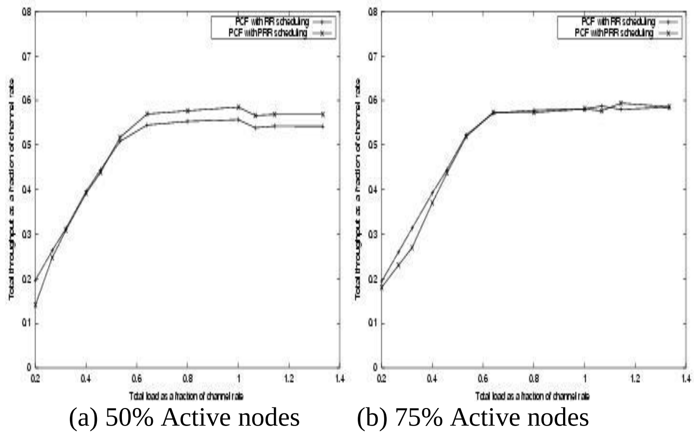


(a) 50% Active nodes



(b) 75% Active nodes (c) 100% Active nodes

Figure : Throughput comparison of PRRS against non optimized PCF with 32 nodes



(a) 50% Active nodes (b) 75% Active nodes

Figure : Throughput comparison of PRRS against non optimized PCF with 64 nodes

Delay

Delay here is measured as end to end delay at agent layer. We have used DSDV as a routing protocol. Since DSDV is proactive and our runs are limited to single hop and do not involves mobility, so routing overhead can be assumed to be constant. Hence measurement of agent layer end to end delay is justifiable and it can be said that differences are significantly due to MAC performance.

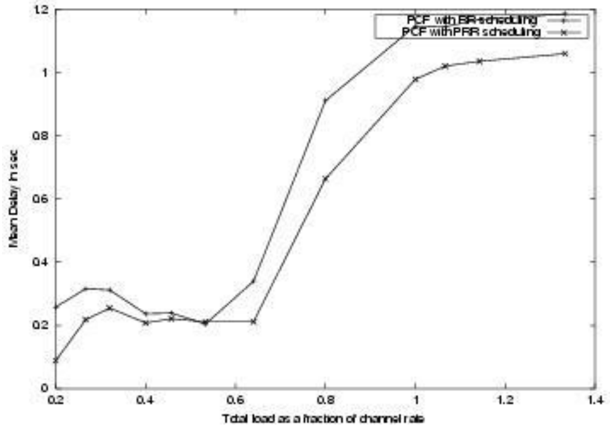
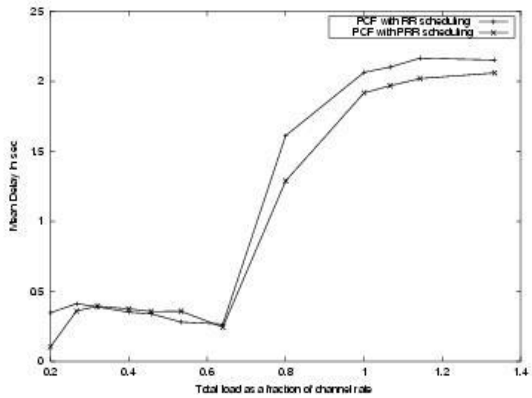
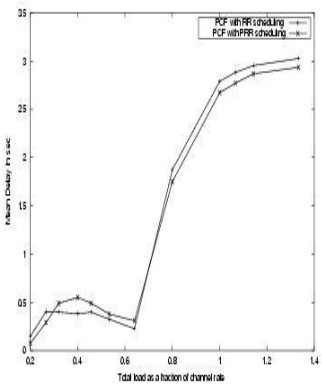


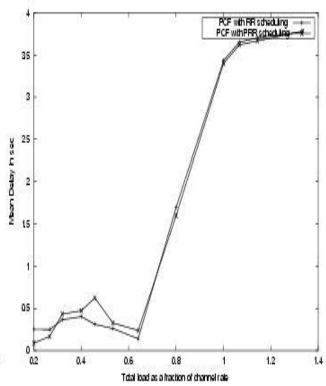
Figure : Average Delay comparison between PCF with PRRS and PCF with RRS. Total node =32 and 25% active node

Figure shows PRRS delay result with 25% node active and total 32 nodes in BSS. Mean delays have reduced as unsuccessful polling attempt has reduced. As a result, active nodes get next chance to transmit early. But if we observe delay graph (Figure) with 50%, 75%, and 100% nodes active, delay values for PRRS increases and also it becomes more than RRS at some points. We think reason behind this is the problem that we stated in section 4.4. Competent nodes may not be getting chance to send data in CP as result they are not added to poll list. This delays their chance to send till next CFP or CP. Figure 5.7 compares mean packet delays with 64 nodes and 25% and 50% nodes active.



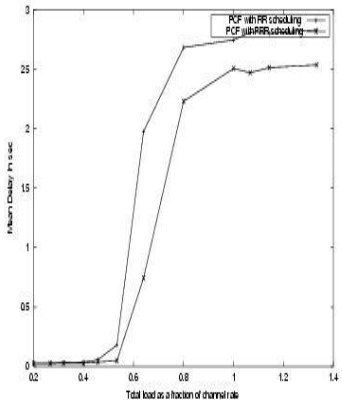
(a) 50% Active nodes

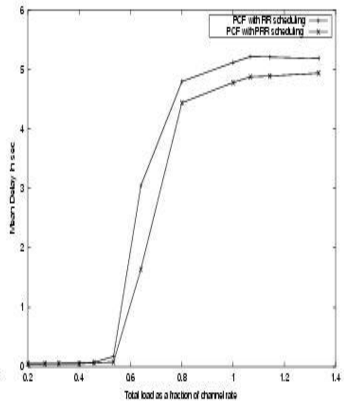




(b) 75% Active nodes (c) 100% Active nodes

Figure : Delay Graphs with 32 nodes and among them 50%, 75%, and 100% active.





(a) 25% Active nodes (b) 50% Active nodes

Figure : Delay Graphs with 64 nodes and among them 25% and 50% active

Simulation Results of DSP

We simulated DSP for 350 seconds. We changed the traffic pattern for DSP simulation. Previously all cbr connection starts and ends at same instant of time but now we have introduced 1ms time gap between starting time of cbr connections. We have placed nodes randomly and averaged the reading over 10 such random placements. Switching point used by us is:

- DCF till number of active nodes less than equal to 10.
- PCF when number of active nodes exceeds 10.

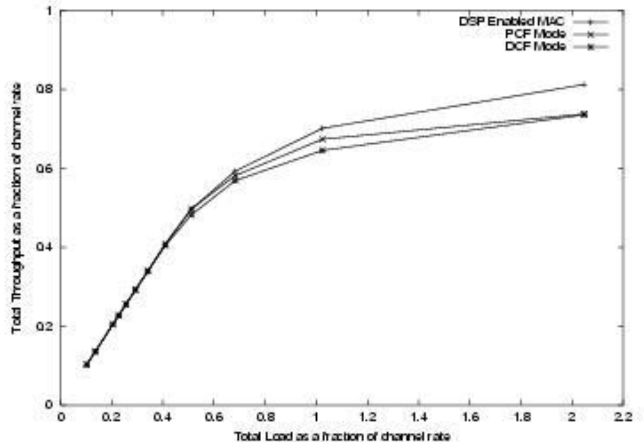


Figure : Throughput comparison of DSP with PCF and DCF

Graph shown in figure 5.8 shows the throughput comparison of DSP with PCF and DCF mode. We simulated with 16 nodes in BSS. Number of active nodes is varied form 4 to Traffic load is defined as

- From 0 to 50 sec, we have 4 cbr connections
- From 51 to 100 sec, we have 8 cbr connections
- From 101 to 150 sec, we have 12 cbr connections
- From 151 to 200 sec, we have 16 cbr connections
- From 201 to 250 sec, we have 11 cbr connections
- From 251 to 300 sec, we have 7 cbr connections
- From 301 to 351 sec, we have 4 cbr connections

On x-axis we have varied packet inter arrival time from 200 ms to 10 ms. Result shows the throughput improvements on using DSP. Graph in figure 5.9 shows the delay curve for DSP. DSP offers lower mean packet delays than both PCF and DCF.

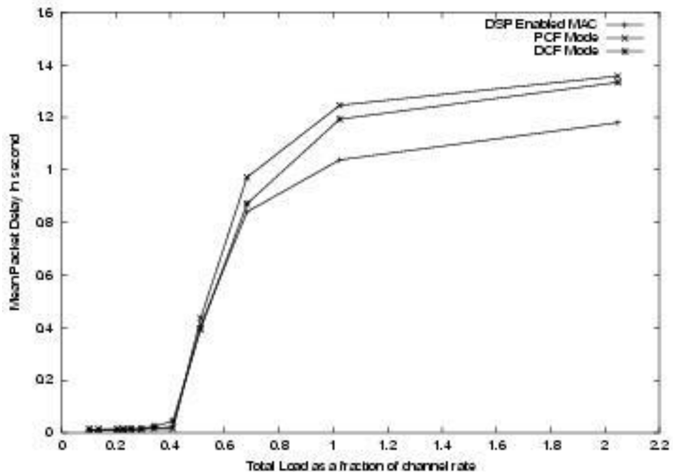


Figure 5.9: Delay comparison of DSP with PCF and DCF

Result Summary

PRRS shows better results than PCF with RRS, especially when less than 75% node have pending data to send. It suffers from higher delays when percentage of active nodes reaches 75% and more. We have discussed possible reason for this in section 4.4. DSP requires extensive experimentations. We have seen improvements in both throughput and mean delay. We have used different CFP repetition intervals, while experimenting with PRRS. We varied the parameter in accordance with number of nodes in network. In next chapter we will show effect of this parameter on PCF performance.

VI. CONCLUSION AND FUTURE RESEARCH

Conclusion

IEEE 802.11 MAC needs dynamic adaption to enhance its performance. Static con-figured MAC performance deviates a lot from achievable limit. We have suggested a network monitoring based approaches to approximate the network size and load and dynamically adapt MAC. Our approaches add very little overhead and strictly follows the standard, without demanding any change in existing frame for-mats and access procedures. The best thing about our approaches is that, they add just one additional network monitoring layer at access point (PC) and rest all stations functionality remain unchanged. PRRS that replaces simple round robin scheduling in PCF, significantly overcomes the efficiency of the polling schemes especially when small fraction of stations have data to transmit and when the traffic load is moderate. We have achieved around 10% to 15% improvement in throughput. By reducing unsuccessful polling attempts when few nodes in BSS have data to transmit, it reduces mean packet delays. This makes it more suitable for handling real time data and multimedia traffic. DSP that defines protocol for dynamic switching between PCF and DCF, opens a new door to exploit coexistence of DCF and PCF mode and to mix better half of both the modes. We have also provided various ways to approximate size and traffic load, for defining ideal switching point. Our idea of distributed DSP would increase the network capacity and enhance performance in an ad hoc networks.

We have showed the need for dynamic adaption of CFP repetition interval for en-suring both better throughput and the fairness. Around 10-20% throughput variation is observed by using different configuration. Our CFP Adaption protocol success-fully adapt CFP rate to suit current network load. CFP adapted PCF has achieved performance almost close to or even better than statically configured PCF.

REFERENCES

[1] Charles E. Perkins, Pravin Bhagwat, Highly dynamic Destination-Sequenced Distance-Vector routing (DSDV) for mobile computers, ACM SIGCOMM Computer Communication Review, v.24 n.4, p.234-244, Oct. 1994.

[2] Anders Lindgren and Andreas Almquist, Implementation of the PCF mode of IEEE 802.11 for the NS-2 Network Simulator, http://www.sm.luth.se/dug-dale/index/software.shtml

[3] The VINT project, NS notes and documentation, editors Kevin Fall and Kan-nan Varadhan, http://www.isi.edu/nsnam/ns

[4] Josh Broch, David A. Maltz David B. Johnson,Yih-Chun Hu and Jorjeta Jetcheva, A Performance Comparison of Multi-hop Wireless ad hoc Networking Routing Pro-tocols, Proceedings of Mobicom,October 1998.

[5] Shugong Xu, Tarek Saadawi Does IEEE 802.11 MAC Protocol Work Well in Multi-hop Wireless Ad Hoc Networks?, IEEE Communications Magazine, p.130-137, June 2001.

[6] Andreas Kopsel, Jean-Pierre Ebert, and Adam Wolisz, A Performance Comparison of Point and Distributed Coordination Function of an IEEE 802.11 WLAN in the presence of Real-Time Requirements, Proc. of 7th Intl. Workshop on Mobile Multi-media Communications (MoMuC2000), October 23-26, 2000.

[7] Leena Chandran-Wadia, Shruti M. and Sridhar Iyer. Throughput Performance of the Distributed and Point Coordination Functions of an IEEE 802.11 Wireless LAN , ICCC’2002, Aug. 11-4, Mumbai, India

[8] Brian P. Crowe, I. Widjaja, J. Kim, P. Sakai, IEEE 802.11 Wireless Local Area Networks, IEEE Communications Magazine, September 1997.

[9] Vaduvur Bharghavan, Alan Demers, Scott Shenker and Lixia Zhang. MACAW: a media access protocol for wireless LAN’s in Proc. ACM SIGCOMM ’94, pp. 212-25, London, UK, Aug. 31–Sept. 2, 1994.

[10] IEEE Std. 802.11, Wireless LAN Media Access Control (MAC) and Physical Layer (PHY) Specifications, 1999.

[11] I. Aad and C. Castelluccia. Differentiation mechanisms for IEEE 802.11 In Pro-ceedings of IEEE INFOCOM 01,Anchorage, Alaska, April 2001.

[12] Frederico Cal`ı, Marco Conti, and Enrico Gregori

Dynamic tuning of the IEEE protocol to achieve a theoretical throughput limit, IEEE /ACM Transactions on Networking, 8(6):785-799, 2000.

