International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 06 | June 2019 www.irjet.net p-ISSN: 2395-0072

DYNAMIC ADAPTION OF DCF AND PCF MODE OF IEEE 802.11 WLAN

Zainab Kamal Khan[1], Ravi Prakash Singh[2], Raj Kumar Yadav[3]

[1]Research Scholar, Dept. of Computer science & Engineering, Suyash Institute of Information Technology, Gorakhpur, U.P., India
[2]Head of Department, VIET, Gorakhpur, U.P., India
[3]Assistant Professor, Dept. of Computer science & Engineering, Institute of Engineering & Technology, Gorakhpur, U.P., India

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Abstract - *IEEE 802.11 specifies the most famous family of WLANs. It features 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. An unsuccessful polling attempt 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 algorithms dynamically adjust the value of CFP repetition interval, depending upon last CFP usage.

Key Words: IEEE 802.11, WLANs, DCF, PCF, PRRS, Dynamic Switching Protocol.

1. INTRODUCTION

Wireless computing is a rapidly emerging technology providing users with network connectivity without being tethered off of a wired network. Wireless local area networks (WLANs), like their wired counterparts, are being developed to provide high bandwidth to users in a limited geographical area. WLANs are being studied as an alternative to the high installation and maintenance costs incurred by traditional additions, deletions, and changes experienced in wired LAN infrastructures. Physical and environmental necessity is another driving factor in favour of WLANs.

The operational environment may not accommodate a wired network, or the network may be temporary and operational for a very short time, making the installation of a wired network impractical. Examples where this is true include ad hoc networking needs such as conference registration centres, campus classrooms, emergency relief centres, and tactical military environments. However, to meet these objectives, the wireless community faces certain challenges and constraints that are not imposed on their wired counterparts.

1.1 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.

1.2 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.

1.3 Challenges in Wireless LANs

- 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.

1.4 IEEE 802.11 standard

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 net-works. 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.

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 back off 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.

2. MAC SUBLAYER IN IEEE 802.11

The IEEE standard 802.11 specifies the most famous family of WLANs in which many products are already available. Standard belongs to the group of 802.x LAN standards, e.g., 802.3 Ethernet or 802.5 Token Ring. This means that the standard specifies the physical and medium access layer adapted to the special requirements of wireless LANs, but offers the same interface as the others to higher layers to maintain interoperability.

2.1 Scope and Purpose of IEEE 802.11 standard

[1] 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.

[2] 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.

[3] 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.

2.2 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 2.1 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).

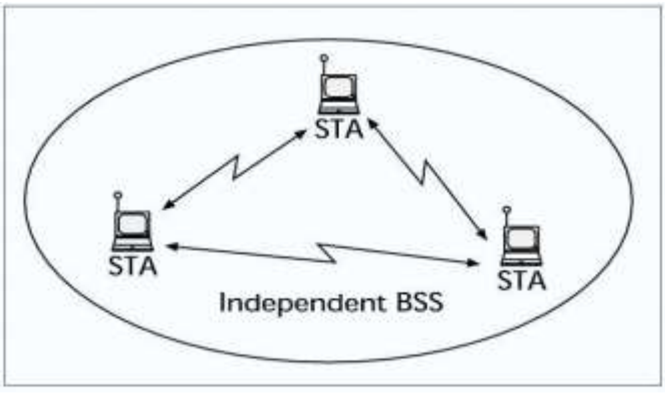

Figure 2.1: Sketch of an ad hoc network

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 2.2 illustrates a simple ESS developed with two BSSs, a DS, and a portal access to a wired LAN.

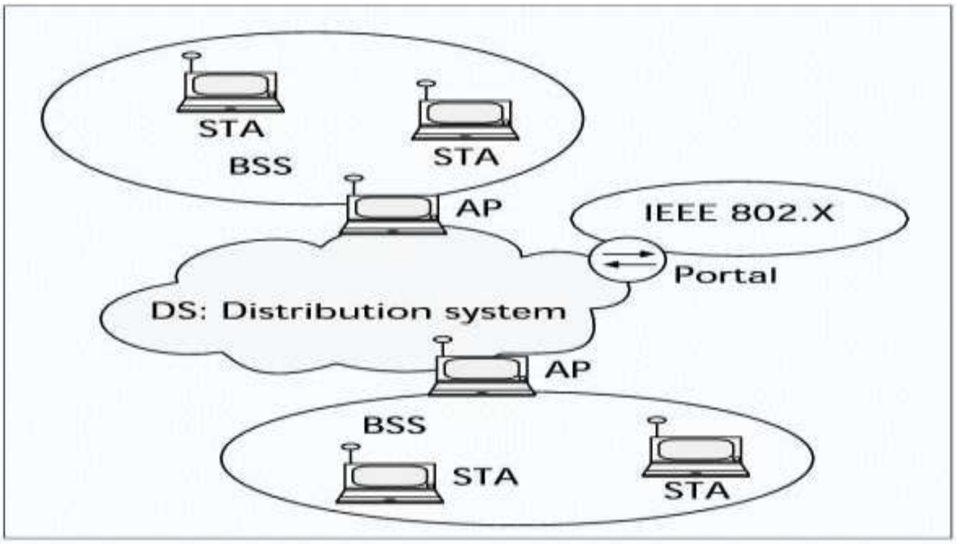

Figure 2.2: Sketch of an infrastructure network

3. PROBLEM ANALYSIS AND RELATED WORK

In this work we have focused on three problem areas that lead to performance degradation in IEEE 802.11 WLAN. One major problem with PCF that gets highlighted when small fractions of associated and pollable nodes in BSS are sending data, and rest are silent. This results in significant polling overheads that wastes the scare channel band-width. Second problem area is to define protocol for dynamic switching between two modes. Mean packet delays can be reduced by having DCF when less nodes have pending data and PCF otherwise. Third problem area is statically configured configuration parameters of PCF and DCF. Depending on the network configuration, the standard can operate far from the theoretical throughput limits.

3.1 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 has 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 provides 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 (section 3.2). Graph ∗ shown in figure 3.1 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.

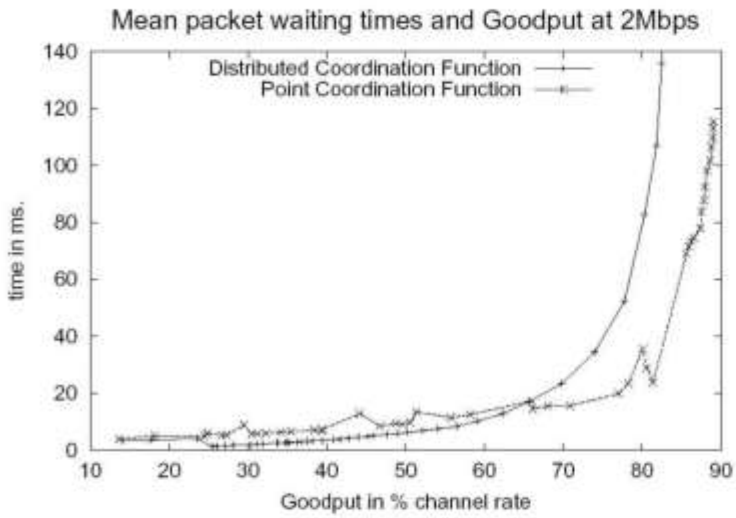

Figure 3.1: Comparison of mean packet waiting and goodput between DCF and PCF at 2 Mbps. 15 Nodes,1 PC and 1500 bytes packet size.

4. OPTIMIZING PCF MODE OF IEEE 802.11 MAC

4.1 Why PCF

In recent years there has been an increasing trend towards personal computers and workstations becoming portable and mobile. People need the same service quality as in wired network. Future demands support of voice and other real time traffic. We believe PCF will better satisfy the future needs. Existing studies shows the PCF ability to provide better quality of service and support of voice and real time traffic. Upcoming standard for QoS in IEEE 802.11 MAC, 802.11e [17] also justify our keen interest in optimizing PCF. Malathi, et. al [18] discuss the support of voice services via PCF mode. We are not focusing on QoS issues, support of voice and real time data, etc. We have proposed generalized improvement in PCF that we believe will enhance existing IEEE 802.11 mac.

4.2 Solution Overview

As we said earlier in section 3.5 our proposed solutions are based on a network monitoring layer. 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 4.1 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.

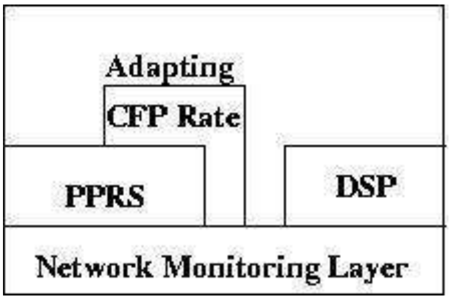

Figure 4.1: Solution model at PC

4.3 PRRS-Priority Round Robin Scheduling

Instead of simple Round Robin scheme, we now define priority scheduling that uses two priority class. All nodes in active list posses same priority. Hence we poll them in simple round robin fashion. Nodes in Passive list are assigned low priority. Our existing PRRS does not schedule them at all.

PRRS suffers from unbounded waiting time. Waiting time can be bounded to certain extent if we use service differentiation feature in CP. Amad et. al [11] have suggested a simple scheme for service differentiation in DCF, based on:

• Deferent backoff increase function

• Deferent DIFS interval

• Deferent maximum frame length

Deng, et. al [14] have also proposed simple scheme based on the shorter IFS and the shorter random backoff time. If station is not polled in CFP and has data to transmit then it could have priority access to channel. As a result, in CP station that want them to be placed in poll list would have always high priority to access channel than station already in poll list.

Alternative way to place upper bound on waiting time is to use Bilevel Feedback Scheduling (BFS) . All nodes in active list are polled in Round Robin fashion. Nodes in Passive list are not polled at all. But in each CFP period we increase the priority of nodes in passive list by threshold value and when their priority reaches the level of active list then they are shifted to active list. We could also have different increment rates for different nodes depending upon their recent activity. By having different increment rates for different nodes, we are actually converting BFS to Multilevel Feedback Scheduling (MFS). We need to decide appropriate threshold value that balances polling overhead and waiting time.

5. 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 [4].Support for the PCF mode of IEEE 802.11 already exists.

[2]. 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, dissociation 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.

5.1 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 directly 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 5.1: Simulation Parameters

5.2 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

6. Conclusions

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 network.

We have showed the need for dynamic adaption of CFP repetition interval for ensuring 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.

6.1. Future Research

Our current version of PRRS introduces slight more delays for some nodes, when number of active nodes * approaches total number of nodes. We need to implement service differentiation mechanism to priorities nodes that have not been polled in CFP, to send data packet in CP. There is need to explore alternative Bilevel feedback scheduling policy (Section 4.4). Whether Bilevel feedback scheduling is sufficient, when we need multiple feedback scheduling, how to adjust number of levels in feedback scheduling dynamically depending upon current traffic load and network size, etc., are still open for research and further experimentation.

Restricted version of DSP needs better approximation of traffic load to define switching point. We have suggested various alternatives for that, but there is need to extensively explore these options and do rigorous experiments. Designing the distributed version of DSP is a great challenge in itself. It requires robust protocol for clustering of nodes and PC selection. Many security related issues * need to be resolved for deploying distributed DSP.

CFP Adaption algorithm is just a first step towards dynamic adaption of configuration parameters. Algorithm needs to be refined further. Using the network monitoring layer, we need to design protocol for adapting other configuration parameters like minimum CW size, RTS/CTS threshold, etc.

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