BACHELOR OF SCIENCE IN COMPUTER SCIENCE AND ENGINEERING

Predictive Channel Access in High Bandwidth Wireless LANs

By

Sami Kabir and Munasir Mahtab Priom

Supervised By

Dr. Muhammad Mahbub Alam

Department of Computer Science and Engineering (CSE)
Islamic University of Technology (IUT)
Organisation of Islamic Cooperation (OIC)
Dhaka, Bangladesh

September, 2012

Predictive Channel Access in High Bandwidth Wireless LANs

By

Sami Kabir
Student No: 084440

And

Munasir Mahtab Priom
Student No: 084443

Supervised By

Dr. Muhammad Mahbub Alam

A Thesis submitted to the Department of Computer Science and Engineering (CSE)
In partial Fulfillment of the Requirements for the award of the Degree of Bachelor of Science in Computer Science and Engineering (B.Sc. CSE)

Department of Computer Science and Engineering (CSE)
Islamic University of Technology (IUT)
Organization of Islamic Cooperation (OIC)
Dhaka, Bangladesh

September, 2012

RECOMMENDATION OF THE BOARD EXAMINERS

The thesis titled "**Predictive Channel Access for High Bandwidth Wireless LANs**" submitted by Sami Kabir (St. ID No. 084440) and Munasir Mahtab Priom (St. ID. No: 084443) of academic year 2011-2012 has been found satisfactory and is accepted as a partial fulfillment of the requirement for the degree of Bachelor of Science in Computer Science and Engineering on 15/09/2012.

1. ___________________________________ Chairman
Dr. Muhammad Mahbub Alam (Supervisor)
Associate Professor
Department of Computer Science and Engineering
Islamic University of Technology (IUT) , Board Bazar, Gazipur- 1704

2. ___________________________________ Member
Prof. Dr. Md. Abdul Mottalib (Ex-officio)
Professor and Head
Department of Computer Science and Engineering
Islamic University of Technology (IUT) , Board Bazar, Gazipur- 1704

DECLARATION OF CANDIDATE

This is to certify that the work presented in this thesis entitled “**Predictive Channel Access for High Bandwidth Wireless LANs**” is the outcome of the analysis and investigation carried out by the candidates under the supervision of **Dr. Muhammad Mahbub Alam** in the department of Computer Science and Engineering (CSE), IUT, Gazipur, Bangladesh. It is also declared that neither of this thesis nor any part of this thesis has been submitted anywhere else for any degree or diploma. Information derived from the published and unpublished work of others has been acknowledged in the text and a list of references is given.

Sami Kabir
Student No: 084440
Academic Year: 2011-2012
September, 2012.

Munasir Mahtab Priom
Student No: 084443
Academic Year: 2011-2012
September, 2012.

Dedicated to our parents and Dr. Muhammad Mahbub Alam for their incessant support, guidance and stimulation

ABSTRACT

Modern technologies are increasing the Physical Layer (PHY) Data Transmission Rate in Wireless LANs from hundreds of Mbps in current 802.11n to over Gbps[2]. But overhead of MAC such as channel access and ACKs have restricted the proportionate improvement in terms of data throughput efficiency. The efficiency of WLANs has deteriorated from over 80% at 1 Mbps to under 10% at 1 Gbps [1]. It happens due to the allocation of the channel as a single resource at a time in conventional MAC protocol. In high data rate WLAN, the channel is divided into several subchannels based on PHY data rate and frame size so that multiple stations can contend for and use the subchannels based on the condition of their local queues simultaneously leading to improvement of throughput and general efficiency[2]

In this paper, we propose Predictive Channel Access (PCA), a new system which constitutes two novel techniques for more efficient handling of media access by using the OFDM based PHY architecture. First, PCA uses Beacon Message which carries some fixed parameters to coordinate

subchannel access. Second, the Access Point (AP) has a second antenna, called the listening antenna which facilitates the simultaneous uplink and downlink between AP and stations ensuring enhanced fairness among all nodes.

Index Terms — MAC Protocols, OFDM, Algorithms, Random Number, Beacon, Listening Antenna.

Acknowledgments

First of all, we express our heartiest gratitude to Almighty Allah for the blessings he has bestowed upon us which has finally enabled us to complete this B.Sc Final Year Thesis.

Several people have contributed to the successful completion of this thesis work. My profound felicitation goes to all of them. But I must acknowledge the role of few of them who have played a vigorous role towards the intended result of this academic dissertation.

We would like to express deep gratitude to our thesis supervisor Dr. Muhammad Mahbub Alam, Associate Professor, CSE Department, IUT for his abled guidance and continuous support throughout this whole work. Dr. Mahbub taught us how to do research, carry forward with this, stay motivated and finally come up with an effective output. Without his supervision, this work would never reach the competition.

Our special thanks go to Prof. Dr. M.A. Mottalib, Head and Professor, CSE Department, IUT for his consistent direction, encouragement and feedback which prompted us to remain focused and go ahead with this research work.

Last but not the least; we would like to acknowledge the helpful guidance, suggestion and comment from time to time by Mr. Ashraf Alam Khan, Lecturer, CSE Department, IUT. Specially, during the simulation work, he cooperated with us intensely. We also recognize the effective advices throughout the whole work by Mr. Md. Sakhawat Hossen, Assistant Professor, CSE Department, IUT. May Allah reward all of you.

Table of Contents

List of Figures

Chapter 1

INTRODUCTION

Modern communication technologies are steadily advancing the physical layer (PHY) data rates in wireless local area networks (WLANs). For example, the latest ratified 802.11n standard has boosted data rates to 600Mbps. This capacity growth is achieved primarily through wider channel bandwidths and advanced PHY techniques like MIMO (Multiple- Input Multiple-Output).

However, the data throughput efficiency the ratio between the network throughput and the PHY data rate degrades rapidly as the PHY data rate increases due to the design of the current 802.11 medium access control (MAC) protocol. For example, given that most IP packets have a maximal transmit unit (MTU) size around 1500 bytes, the efficiency ratio in an 802.11n network at 300Mbps is only 20%. That is, the 300Mbps data rate can sustain an actual throughput of only 60Mbps.

The fundamental reason for this inefficiency is that the current MAC allocates the entire channel to one station as a single resource. This allocation strategy can become too coarse-grained when the channel width increases or PHY data rate increases. Even if a sender has a small amount of data to send, it still needs to contend for the entire channel. Such contention resolution time is there- fore an overhead to the channel time used for data. Unfortunately, this overhead cannot easily be reduced due to constraints of current electronics and physical laws. As a result, the higher the PHY data rate, the lower the throughput efficiency will become.

One way to improve the MAC efficiency is to extend the useful channel time for data transmissions by sending larger frames. Indeed, IEEE 802.11n allows frame aggregation, i.e., sending multiple frames together in one contention period. However, when the PHY data rate increases, the aggregated frame size needs to in- crease as well: achieving an efficiency of 80% in a 300Mbps net- work would require frames to be as large as 23KB. This larger aggregated frame means longer delays as the sender must wait to collect enough frames before actual transmission, resulting in adverse effects to TCP, real-time applications like VoIP and video conferencing, and even Web browsing that involves chatty protocols or short lived sessions.

To improve WLAN efficiency, FICA[FICA] reduces the channel width and create more channels, where the channel width is commensurate with PHY data rate and typical frame size. Multiple stations can then contend for and use these smaller channels simultaneously according to their traffic demands, thereby amortizing MAC coordination and increasing overall efficiency. But this method has the overhead of MRTS/ M-CTS and less fairness which we have overcome in this paper.

Orthogonal Frequency Division Multiplexing (OFDM) is a PHY layer technology that can eliminate the need to have guard bands, if the frequency and width of subchannels are strategically picked and transmission on each subchannel is synchronized in a way to become orthogonal, and hence noninterfering, to one another.

In our work, we present the PCA, a novel system based on OFDM that enables more optimal subchannel access and fairness in a high data rate WLAN. PCA introduces two key techniques to address the aforementioned challenges:

- PCA proposes the use of Beacon Message by AP which carries some parameters to coordinate the subchannel access.

- PCA employs a listening antenna for AP so that uplink and downlink can happen simultaneously between AP and stations leading to fair interleaving between uplink and downlink and increased fairness among all nodes.

In summary, this paper makes the following contributions. (1) We describe and examine the issue of current MAC protocols in the context of high-speed WLANs, and argue that this issue can be resolved by prediction based backoff and channel access. (2) We design PCA, a protocol that enables subchannel random access in an efficient manner in WLANs. To the best of our knowledge, PCA is the first system that enables prediction based channel access in WLANs.

Chapter 2

Background and Related Works

2.1 Inefficiency of current WLANs:

State-of-the-art MAC protocols in wireless LANs manage the whole channel (e.g., 20/40 MHz width) as a single resource. The MAC protocol arbitrates access among multiple potential senders and selects one as the winner, which then consumes the whole channel resource to transmit. If multiple senders transmit at the same time, collisions may happen and receivers will likely fail to decode the transmissions.

Current 802.11 WLANs use carrier sensing multiple access with collision avoidance (CSMA/CA) for their MAC protocol. When the channel is busy, all contending nodes wait until the channel becomes free. The MAC employs a random backoff scheme to avoid having multiple nodes transmitting simultaneously. Each node will randomly choose a number b within a contention window [0;CW), and wait for b time slots before it starts transmitting. If a node detects a transmission detected its backoff period, it will freeze the backoff counter until the channel is free again. If two nodes randomly choose the same backoff time, their transmissions will eventually collide. A collision is usually detected by a missing acknowledgement (ACK) from the receiver. When a collision is detected, a sender will double its contention window CW according to the binary exponential backoff (BEB) algorithm to further reduce the collision probability for the next transmission.

Figure 2.1 illustrates the channel access timing diagram of the 802.11 MAC. Figure 2.1(a) is the basic access method and Figure 2.1(b) shows channel access with the optional RTS/CTS handshake to handle hidden terminals. The Short Inter-frame Space (SIFS) is the shortest time interval required for a receiver to return a message to a sender. It is determined by Equation 1, where trfdelay is the delay incurred to transfer digital signals from the RF antenna to the processing unit, tproc is the time needed for the processing unit to operate on the incoming signals, and tTxRx is the time needed for the RF front-end to switch from receiving mode to transmitting. Normally, SIFS is about 10 to 16 micro seconds. The Distributed Interframe Space (DIFS) is determined based on SIFS and the backoff slot time, as shown in Equation 2. DIFS is defined to support priorities in CSMA/CA and should be larger than SIFS. The backoff slot time is critical. It is the minimal time needed for a node to sense the channel condition and acquire the channel. Slot time is determined by Equation 3, where tcca is the time for a node to measure the channel energy to decide the channel status and tprop is the time for the radio signal to reach the maximal distance of the network.

$$tsifs = trfdelay + tproc + tTxRx \qquad (1)$$

$$tdifs = tsifs + 2{:}tslot \qquad (2)$$

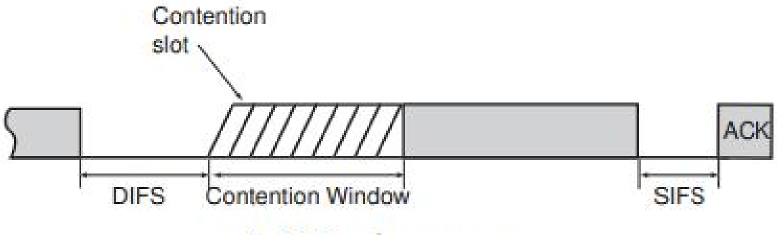
$$tslot = tcca + tTxRx + tprop + tproc \qquad (3)$$

Using these values, we can build a simple analytical model to compute the efficiency ratio for CSMA/CA. Since a node chooses a random number uniformly from the contention window [0,CW), the expected number of backoff slots is W = CW/2 . Equation 4 gives the efficiency ratio for the basic access of CSMA/CA:

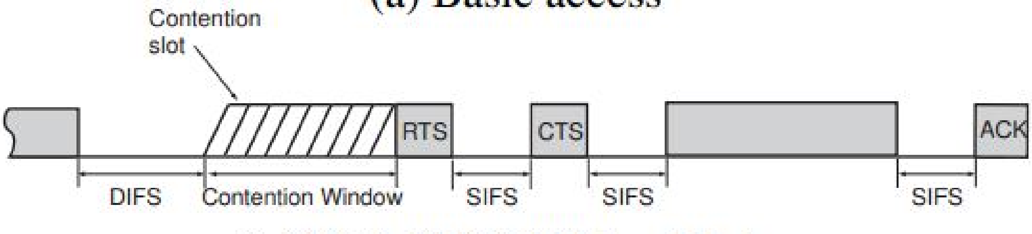
$$U = tdata$$

$$tslot{:}W + tdifs + tpreamble + tsifs + tack + tdata \qquad (4)$$

where tdata is the time used for data transmission, tpreamble is the time used to transmit per-frame training training symbol and tack is the time used for the ack frame. Only tdata is used for transmitting application data, while all other times are overheads. Some overheads are constrained by physical laws and current constraints in state-of-the-art radio electronics. For example, it is not possible to redice tprop less than 1 micro second to cover a network with a radius of a few hundreds of meters. It is also difficult to reduce TxRx since the RF circuit requires a few microseconds to settle down for sending or receiving. Others are needed for the correct operation of the protocol. For example, we need training symbols for reliable estimation of the wireless channel for each frame, thus preamble is essential. The average backoff slots, denoted by W, reflect the ability of CSMA/CA to avoid collisions. Thus, to work well in normal network settings, we need a reasonably large W. ACKs are also needed to detect collisions and other losses, thus in general we do not want to remove tack. Table 1 outlines some timing parameters defined in 802.11. They remain similar across the different standards of 802.11a/g/n except for the preamble; since 802.11n uses MIMO, it requires more training symbols in its preamble.



(a) Basic access



(b) With RTS/CTS handshake

Figure 2.1: Illustration of CSMA/CA access method

Therefore, when the PHY data rate increases, only tdata will be reduced proportionally, while the other parameters remain largely unchanged. As a consequence, the efficiency ratio U decreases inversely proportionally. Figure 2 illustrates such a phenomenon: the efficiency quickly decreases from 60% at 54 Mbps (802.11 a/g) to less than 10% at 1 Gbps (future 802.11 ac/ad).

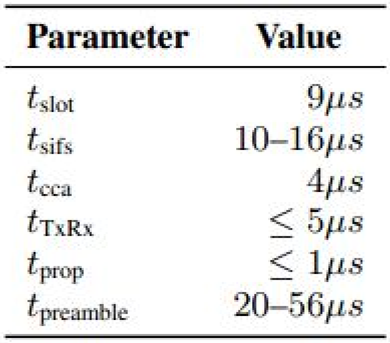
Transmitting larger frames will improve the efficiency ratio, but such a frame-aggregation approach has practical limitations. Moreover, in Fine-grained channel access the whole channel is divided into smaller subchannels so that different nodes can access different subchannels simultaneously. But frequent use of M-RTS and M-CTS by this method increases overhead and reduces fairness among the nodes.

So, PCA will be a better system where M-RTS/M-CTS overhead has been eliminated and 2-antenna AP enhances fairness among the nodes.

2.2 Orthogonal Frequency Division Multiplexing:

OFDM has become increasingly popular in modern wireless communications. It has been embraced by many existing wireless standards like IEEE 802.11 a/g/n, WiMax and 3GPP LTE. Cognitive radio technologies also mainly rely on OFDM to use non-contiguous spectrum bands for communication [19].

OFDM divides a spectrum band into many small and partially overlapping signal-carrying frequency bands called subcarriers. The subcarrier frequencies are chosen so that they are orthogonal to one another, meaning that cross-talk between subcarriers sums up to zero even though they are overlapping (Figure 3). OFDM can therefore pack subcarriers tightly together without inter-carrier interference, eliminating the need to have guard bands.



Parameter	Value
t_{slot}	$9\mu s$
t_{sifs}	$10\text{–}16\mu s$
t_{cca}	$4\mu s$
t_{TxRx}	$\leq 5\mu s$
t_{prop}	$\leq 1\mu s$
t_{preamble}	$20\text{–}56\mu s$

Table 1: Timing parameters of 802.11.

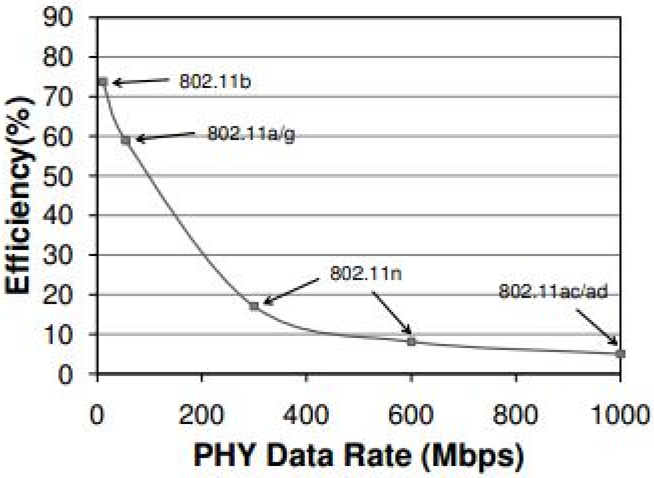
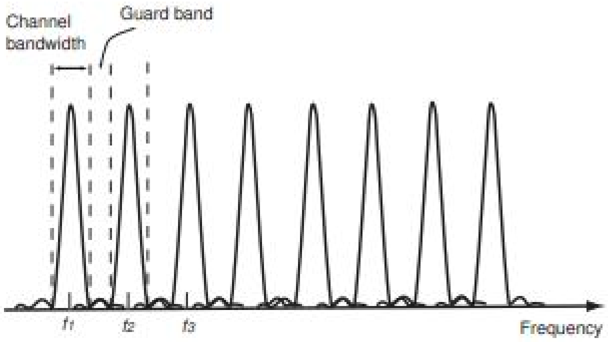


Figure 2.2: Inefficiency of 802.11 MAC at high data rates with a typical Ethernet MTU (1500B)

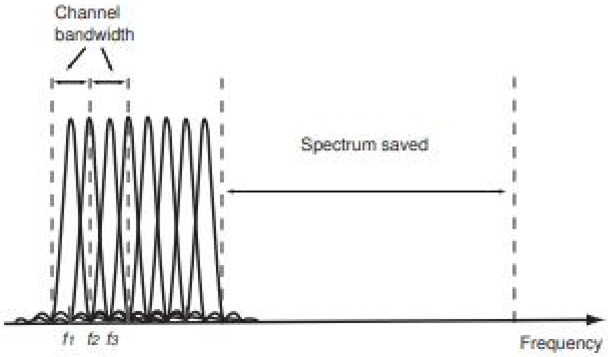
When OFDM is used as a multi-access technology where multiple stations share the same channel, symbol timing alignment will be a critical issue. As shown in Figure 4(a), if OFDM symbols from two nodes misalign, the receiver may not be able to pick up an FFT window containing the same samples across all senders. Orthogonality will be lost and signals from both nodes will cause mutual interference. To ensure perfect symbol alignment, a multi-access technology called OFDMA has been proposed for OFDM cellular networks like WiMAX and LTE. OFDMA requires all mobile stations to maintain tight timing synchronization with the cellular base station (usu-ally hundreds of nanoseconds). It requires a complex ranging scheme to measure the propagation delay and fine tune each mobile stations timing offset at the sample level granularity. OFDM further has a built-in robustness mechanism called thecyclic-prefix (CP) to guard against symbol misalignment due to multipath echoes. Each OFDM symbol is prefixed with a copy of the symbols tailing samples so that the receiver can still find a proper FFT window as long as the misalignment is within a CP length (Figure 4(b)). CP is intrinsic to any OFDM system; in 802.11, the CP-to-symbol length ratio is 1:4 (0.8 micro seconds to 3.2 micro seconds)

2.3 Fine-grained Channel Access in WLAN

In Fine-grained channel access, to improve throughput efficiency in a high-data-rate WLAN, the channel width is divided into appropriately sized sub-channels commensurate with the PHY data rate and typical frame size, and further use OFDM on the whole channel to avoid wasting bandwidth on guard bands. The fundamental challenge with this approach is coordinating random access among multiple distributed and asynchronous nodes in a WLAN (potentially with multiple APs), without resorting to cellular-style tight timing synchro-nization. Because coordination in a WLAN is distributed and decentralized in nature, it is impractical to have OFDMA-style global time synchronization. Not only would it introduce a great deal of system complexity, it would also likely require new hardware functionality beyond the current or emerging 802.11 standards. Further, OFDMA does not support random access and hence cannot be used directly in a WLAN. Instead, we should use existing 802.11 coordination mechanisms, such as carrier-sensing and broadcast, to establish a rough symbol alignment among concurrent senders. We can leverage OFDMs intrinsic CP mechanism and lengthen it to suit the alignment scale, and further use a longer symbol length to maintain the same CPto- symbol ratio. This approach calls for a new OFDM architecture specially designed for distributed coordination.



(a) Normal frequency division multiplexing



(b) OFDM

Figure 2.3: OFDM gains higher spectrum efficiency

Having a longer symbol length, however, does have a negative impact that makes a conventional time-domain backoff scheme very inefficient. For example, if we can only guarantee a 10 micro-seconds symbol alignment under current 802.11 coordination schemes, we will need a 40 microseconds symbol length to keep the same guard-time overhead ratio. The reserved time slot for backoff, which has to be at least one OFDM symbol in length, will now increase proportionally. This raises another technical challenge: we need a new efficient MAC contention mechanism and a new backoff scheme. All these are necessary conditions for fine-grained channel access in high data rate WLANs.

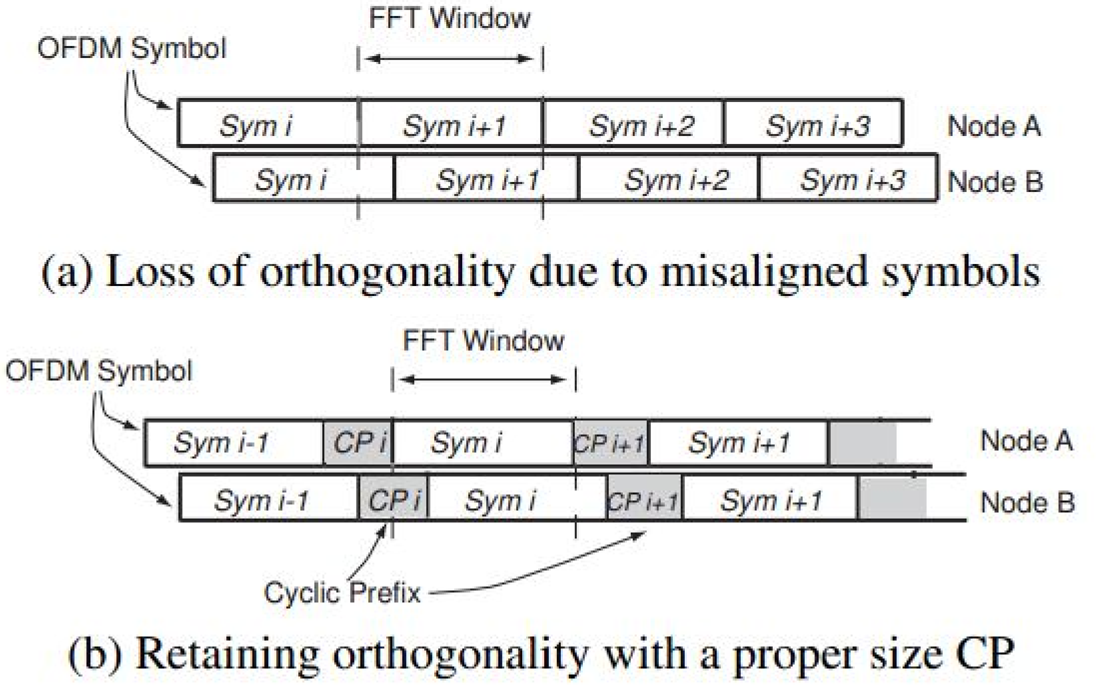


Figure 2.4: Misaligned OFDM transmission

2.4 FICA

FICA is a cross-layer design that enables fine-grained channel access in high-rate wide-band WLANs. It is based on OFDM and divides a wide-band channel into a set of orthogonal subchannels, which different nodes can contend for individually.

Figure 5 illustrates the basic uplink media access scheme for FICA. In this example, the channel is divided into four subchannels and each subchannel contains a number of sub-carriers. FICA follows the basic scheme of CSMA. A new transmission opportunity appears only when channel is idle. Then, all stations try to contend for different subchannels after the channel is idle for a certain amount of time (DIFS). At this time, all nodes will transmit a special RTS sig-nal simultaneously. This RTS signal is a specially-designed OFDM symbol, called Multi-tone RTS in which each node embeds its contention information in a set of subcarriers for each subchannel it intends to access. All M-RTS signals are resolved at the AP, and the AP will broadcast the contention results in a corresponding M-CTS OFDM signaling symbol. Then, only the nodes assigned subchannels will use them for data transmissions; note that a node may contend for multiple subchannels based on its instantaneous traffic demands. The AP will then generate an acknowledgement on each subchannel where a data frame has been successfully decoded.

In downlink transmissions, the AP will initiate an M-RTS signal and receiving stations may return an M-CTS. However, since FICA does not use random time backoff, it needs to separate uplink and downlink transmissions; otherwise, collisions would happen under bi-directional traffic. FICA does so by assigning different DIFS times to uplink and downlink transmissions. In PCA, we propose a new mechanism which allows this bidirectional traffic by adding a listening antenna to the AP. It also guarantees more fairness among nodes than FICA.

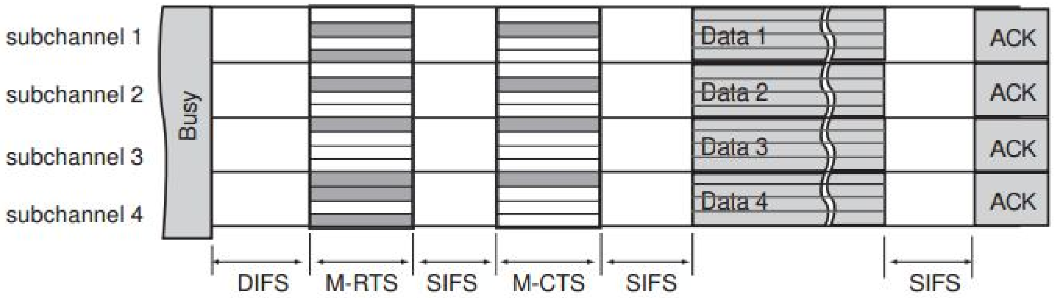


Figure 2.5: FICA uplink media access with four subchannels per channel

2.5 Related Works

The application of OFDM for multiple accesses in WLANs is limited. In [3], Rahua, et al. developed FARA that implements downlink OFDMA in a WLAN and per-subcarrier rate adaptation. But, since there is only one transmitter (the AP), symbol alignment is not an issue. OFDM has been used as a simple form of concurrent channel access. Nodes may modulate one bit of ACK information on different subcarriers after receiving a broadcast frame. FICA [2] is another PHY/MAC frame-work for WLANs that enables data communication over fine grained subchannels to improve overall network efficiency.

Physical layer signaling, usually with Binary Amplitude Modulation, has been used previously to assist MAC proto-cols. In many systems, busy tones are used to indicate channel occupancy to mitigate the hidden terminal problem. FICA similarly shares the idea with SMACK and MCBC to apply PHY signaling based on simple BAM modulation, but FICA has the broader goal of enabling fine-grained channel access in high data rate WLANs.

Coordination using broadcast in local area networks has been previously exploited for time synchronization in reference-broadcasting synchronization, which provides microsecond-level synchronization precision. Microsecond-level coordination accuracy is practical in WLANs.

There is extensive work in the literature to improve 802.11 MAC performance by fine-tuning the backoff scheme. But these approaches still consider the channel as one resource unit where only one radio can work on one channel at a time. Multi-channel MAC protocols have been studied to improve wireless network performance by using more orthogonal channels that are separated by guard bands. FICA[2] uses OFDM to create a fine-grained structure (i.e., subchannels) for multi-access inside a wide-band channel without guard bands. Thus, a FICA node can adjust the portion of the spectrum it accesses based on its traffic demands, while other nodes can use the remaining spectrum simultaneously. This property shares some similarity to the adaptive channel width. FICA is complementary to that work by providing a concrete means for adaptive fine-grained subchannel access in WLANs. But a limitation of FICA is the overhead of M-RTS/M-CTS and less fairness which have been addressed perfectly by our proposed PCA.

The inefficiency of the 802.11 MAC has also been discussed before for supporting VoIP traffic. A TDMA approach is used to reduce the contention overhead for CSMA in 802.11. In this paper, we argue that the inefficiency of 802.11 MAC is a fundamental bottleneck as the PHY data rate increases for all traffic, not just VoIP traffic. We further argue that this inefficiency issue should be resolved by enabling predictive channel access.

Chapter 3

Predictive Channel Access for High Bandwidth Wireless LANs

3.1 PCA

PCA brings a big improvement over FICA. PCA discards the use of M-RTS/M-CTS in FICA. In PCA, the AP sends a Bea-con Message to all the stations after every certain interval. This Beacon Message contains some fixed parameters which all the stations receive.

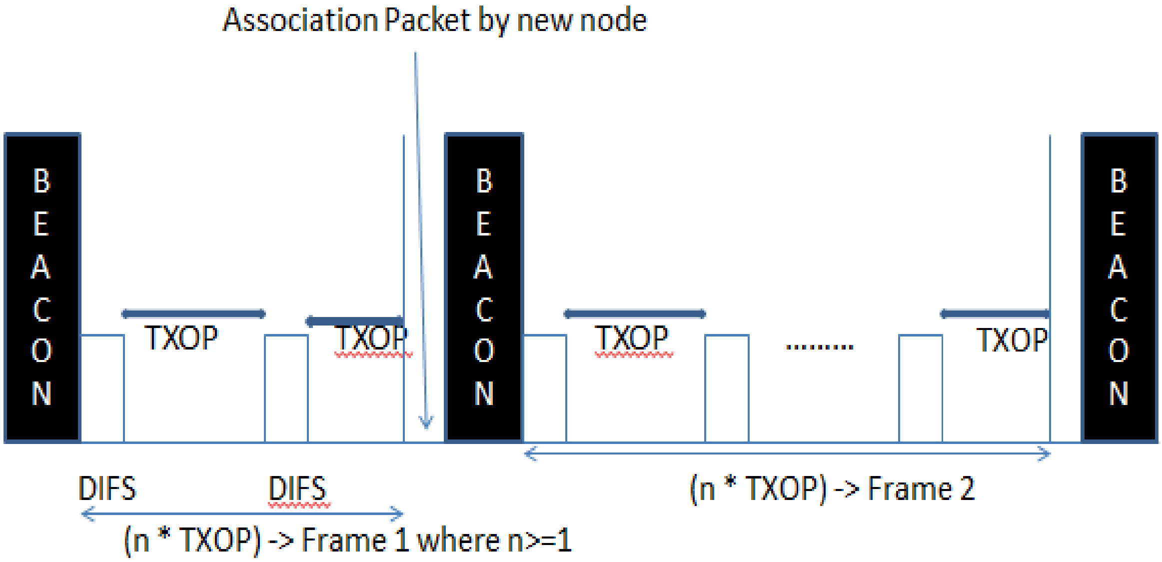


Figure 3.1: Predective Channel Access(PCA)

Upon reception of these fixed parameters, all the stations which have data to send generate a random number based on those fixed parameters and a common algorithm. As each station knows all other stations' parameters and algorithm they have used to generate their random numbers, every station knows the random value generated by other stations. Then the station which has chosen the lowest value will start transmit-ting its data. The winning station can also send multiple data packets as long as it satisfies the Transmission Opportunity (TXOP) parameter. Upon completion of the sending of data by the winning station, the station which has chosen the second lowest value will start transmitting its data after waiting for PIFS time. Every station knows all other stations' node ID. So if two stations choose the same random number at the same time, then the station whose node ID is lesser will be the winner and start sending data.

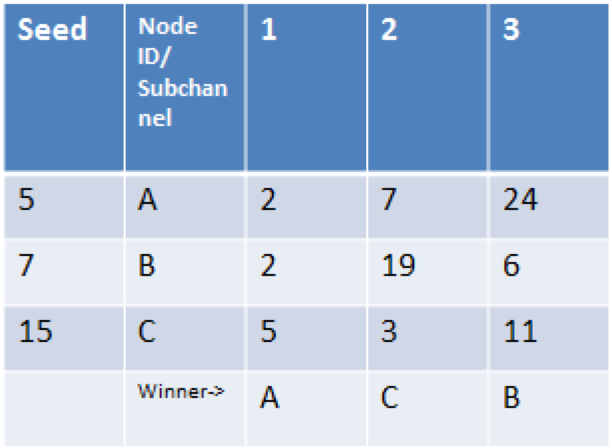
In PCA, a certain number of subchannels are reserved for downlink so that no stations contend for those subchannels for uplink. Its objective is to ensure bidirectional traffic avoiding collision. The Beacon Message contains the number of subchannels which are reserved for uplink. After receiving these beacon messages, all the stations know the numbers of those reserved subchannels and then they refrain themselves from contending for those subchannels.

If a node finishes transmission before TXOP and it has further data, it can send in remaining time. Different cases have different solution. If a new node joins and the TXOP not over and media idle for more than DIFS than New node sends association packet to AP. If the number of new node is more than one than new node sends association packet to AP before next Beacon.

3.2 Linear Congruential Generator

To choose the subchannel we applied the LCG(Linear Congruential Generator) method. The steps of this algorithm are following:

```
$n * m$ matrix where $n$ = rows and $m$ = columns
$P_{ij}$ = backoff value for node i for channel j
    for a specific value of j
        for all values of i
    if $P_{ij}$ is the min for 1 value of i,
        node i wins
    else if $P_{ij}$ is min for more than 1 value of i
        lesser node ID wins
```



Seed	Node ID/ Subchannel	1	2	3
5	A	2	7	24
7	B	2	19	6
15	C	5	3	11
	Winner->	A	C	B

Figure 3.2: LCG method

In PCA, the stations will have only one antenna but the Aps will have a second antenna for listening purpose. While uplink is going on between the AP and a station, by dint of the listening antenna, the AP can also initiate downlink transmission towards the intended stations using those reserved subchannels for downlink. In this way, PCA maintains simultaneous uplink and downlink while ensuring fairness among the nodes. PCA also reduces the amount of idle time of a node by facilitating bi-directional traffic.

Figure 3.3: PCA assumptions

3.3 Key Points of PCA

We end the description of PCA with a few additional points of consideration.

- PCA also enables an opportunity to exploit Multi-user diversity in WLANs. When a node chooses subchannels to access, it may also consider the quality of each subchannel. Moreover, heterogeneous modulation methods can be applied to different subchannels to match the conditions on that specific channel band. There is already much research on resource allocation for multi-user diversity in both single and multi-channel cases and applying these ideas in a distributed system like PCA remains interesting open challenges.

- It is also possible for PCA to coexist with current 802.11. Since PCA is still based on CSMA, PCA nodes will defer if they sense a transmission of 802.11 nodes and vice versa.

- Finally, we note that the mechanisms designed in PCA may unlikely be applicable in cellular networks because coverage of a cellular base station is large (e.g., a few kilometers). Thus, the propagation time is large as well, at least an order of magnitude larger than that in a WLAN. Consequently, even using broadcasting the synchronization accuracy is too coarse (e.g., several tens of microseconds). Current OFDM based WWANs already employ a relative long cyclic prefix (4.69 micro seconds) and FFT period (66.67 micro seconds) to handle a large delay spread due to multi-path fading in the wide area. A low-precision synchronization method in OFDMA will further enlarge the symbol FFT size, adding substantial engineering complexity to control frequency offsets and undermining the ability to handle Doppler effects in a mobile environment.

What if Beacon Message isn’t received by all nodes:-

A Beacon Message is broadcast at the beginning of a beacon interval. If this beacon isn’t received by few nodes due to channel error or communication failure, those nodes’ common table will not be consistent with the other nodes which have received the Beacon Message. So, a collision is likely to occur in this case as more than one node may attempt to transmit packet simultaneously in the same sub channel. It happens due to the fact that two nodes may find themselves the contention winner of the same sub channel at the same time because two nodes have distinct values in the common table on grounds of beacon message broadcast failure.

Still, the collision probability and overall collision impact is lower in PCA than 802.11 and FICA.

Chapter 4

Simulation and Performance evaluation

We implemented an event-based simulator (ns-2.34) to study the performance of PCA large-scale wireless networks and to compare its performance with 802.11n and FICA. The simulator can model both the CSMA MAC and an OFDM PHY that supports multiple sub channels. We study the performance primarily under a single AP network with varying number of stations. We assume only collisions will cause frame reception failures, and thus we focus on the performance of the MAC design. We also focus on only the uplink transmissions (the downlink behavior in this setting is analogous), and we apply various traffic patterns in a wide 40MHz channel with high data rates. For 802.11n, we also simulate MAC Service Data Units (MSDU) aggregation, the most efficient aggregation method defined in 802.11n[4].

For PCA, we use the same value of *t*sifs and *t*difs as in 802.11. The preamble in PCA requires three OFDM symbols for single and 2x MIMO and four for 4x MIMO. Using the three-symbol preamble as an example, *t*preamble = 46.8 *micro-seconds*, and counting another OFDM symbol for the ACK, *i.e.*, *t*ack = 15.6 *micro-seconds*, the subtotal peraccess MAC overhead of PCA is 157.8 *micro-seconds*. Note that although PCA uses the M-RTS/M-CTS handshake, the overhead is comparable to that of 802.11 (160 *micro seconds with minimal contention window)* due to the use of the PHY signaling mechanism.

Thus, to achieve an efficiency ratio of 80%, we need 40 DATA OFDM symbols. For different PHY data rates, frame sizes for the same efficiency correspond to a size of 400/800/1600 bytes at 145/290/580Mbps, respectively. We use these sizes as a rule of thumb for FICA nodes to fragment upper layer frames and send each fragment on one subchannel. The simulation parameters are summarized below.

Traffic	UDP
Number of Subchannels	4
Beacon Interval	0.20 sec
Packet Size	1500 bytes
RTS/CTS exchange	Disabled
Backoff Timer	Disabled
PHY Data Rate	150 Mbps
No of Nodes	10
Experiment lasted for	300 sec

No Aggregation:-

In this scenario, we first disable the frame aggregation of 802.11n as a lower bound. Figure 4.1 shows the throughput efficiency of 802.11n, FICA and PCA. The scenario simulates ten concurrent nodes where each node where each node transmits UDP traffic corresponding to the 1/10th of the PHY data rate with a frame size of 1500 bytes. As expected, with a 1500-byte frame, current 802.11 a/g rates only provide around a 50% efficiency ratio, and this ratio decreases rapidly with the increase of the PHY data rate. However, by enabling Predictive Channel Access, PCA can gain a much higher efficiency ratio than both 802.11 and FICA. This benefit is because different stations can access different sub- channels simultaneously. Thus the per-access MAC overhead is amortized among all concurrent nodes. Also, we find that PCA has slightly better performance than FICA. As we will see in subsequent experiments, PCA consistently performs better. We hypothesize that this is because PCA adjusts *channel contention* much smoother compared to FICA. However, a deep analysis on the optimal frequency-domain backoff strategy remains future work. This scenario is the worst case for 802.11n. We show this case to demonstrate how significant the MAC overhead can be at high PHY data rates, and that techniques like PCA or frame aggregation are indeed necessary for efficiency.

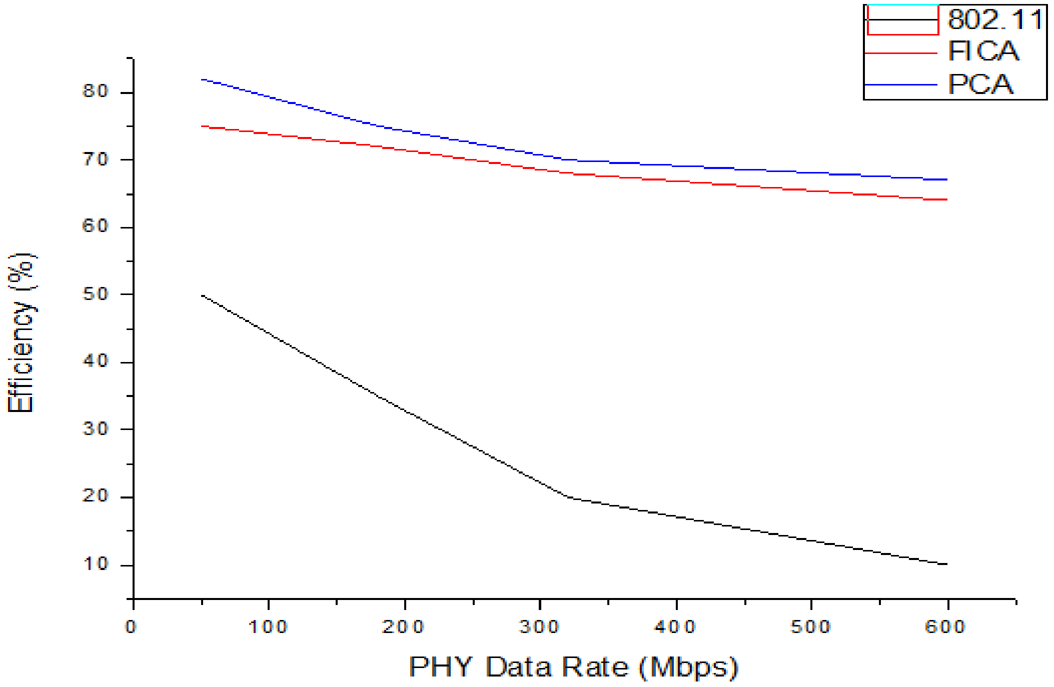


Figure 4.1 : Efficiency ratio of 802.11 and FICA with differen PHY data rates. No frame aggregation is enabled.

Full Aggregation:

Here, we show the best case of 802.11n with frame aggregation. In this experiment, all nodes are saturated so that the frame aggregation can work most efficiently. Figure 4.2 shows throughput efficiency with different numbers of contending nodes at two PHY data rates, 150Mbps and 600Mbps, respectively. In both cases, the efficiency of 802.11n has been significantly improved due to frame aggregation. Since all nodes are saturated, the aggregation level is very high: 12 frames (or 18KB) on average. FICA still has slightly better performance than 802.11n even in this case, though, because FICA has slightly fewer collisions compared to 802.11n. To understand why, consider the operation of frequency domain contention. When there are many stations contending for a subchannel, if two stations happen to pick up the same subcarrier to send their signals, it does not necessarily result in a collision. A collision occurs only when the collided subcarrier is also chosen as the winner as nodes contend for subchannels. In the next contention period, all stations will pick a different random number again. This situation is unlike time-domain backoff used in 802.11: when two stations pick the same backoff slots they will eventually collide with each other.

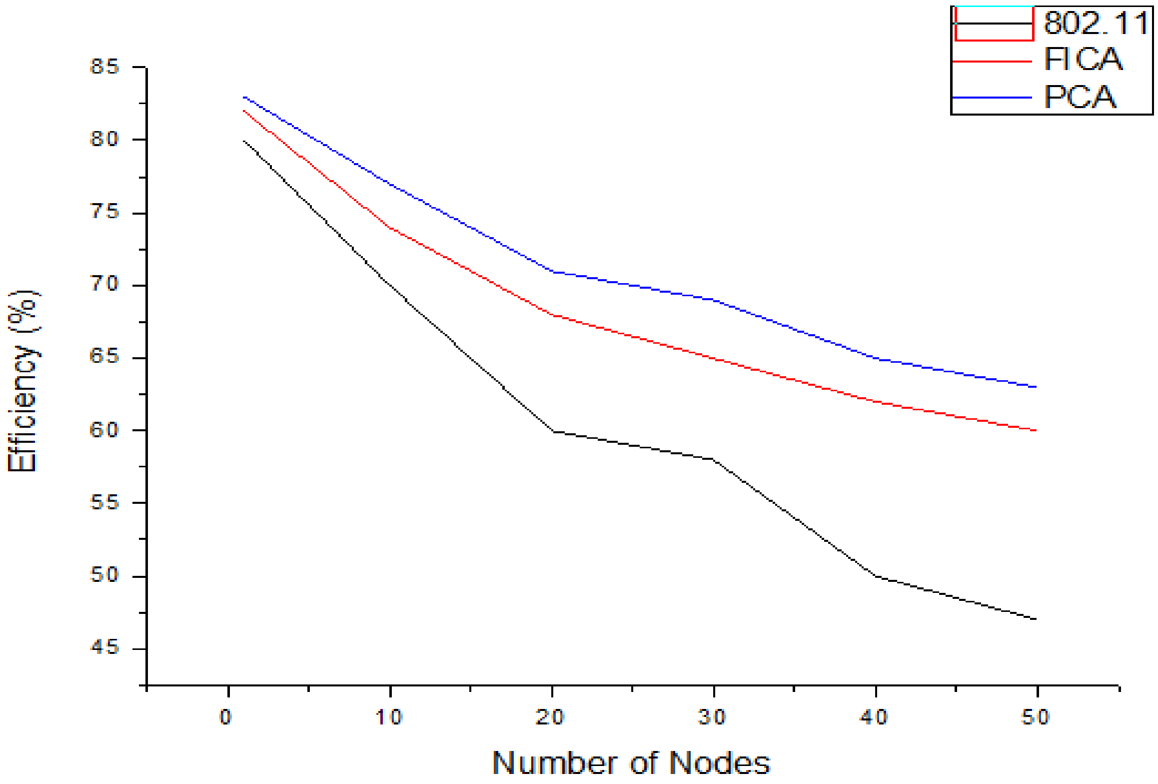


Figure 4.2: Efficiency ratio of 802.11, FICA and PCA with varying number of nodes at PHY Data Rate 150 Mbps

<u>Collision:-</u>

FICA has less collision probability compared to 802.11 a/g due to FICA’s fine-grained channel access mechanism. However, PCA has even lesser collision probability than both FICA and 802.11. Assuming that the Beacon message sent by the AP at the beginning of every Beacon Interval is received by all the concerned nodes correctly and the common table is updated consistently by all those nodes, it may be shown in Figure 4.3 that the collision probability at PCA is always 0 (zero) irrespective of the number of nodes.

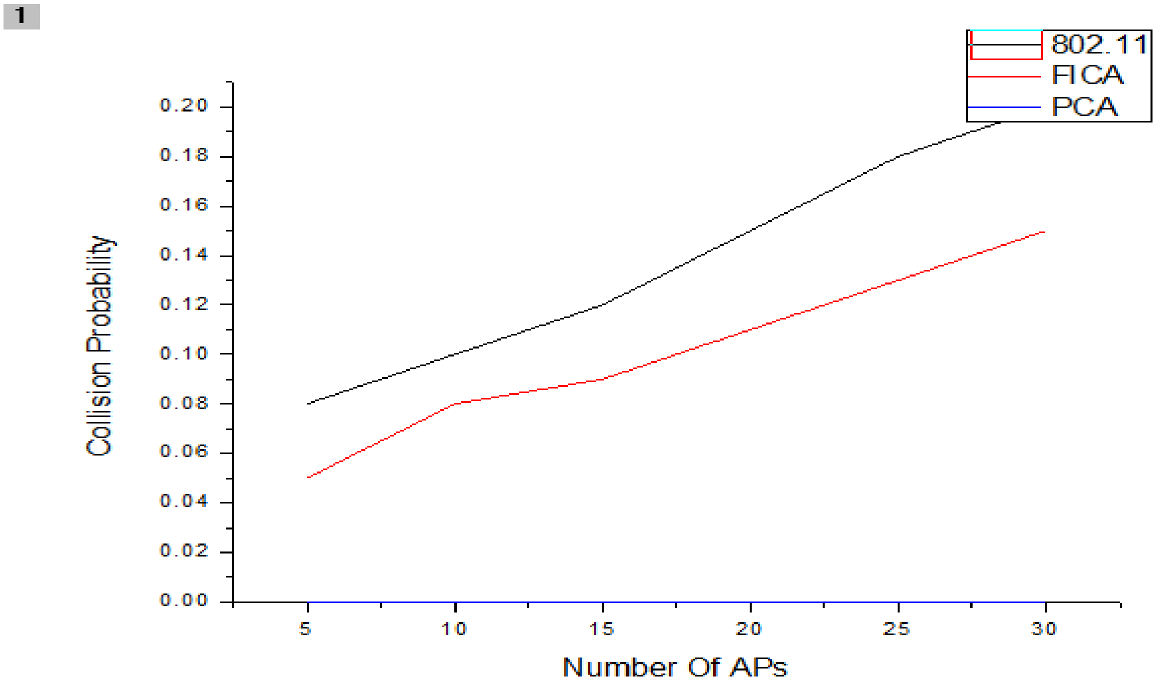


Figure 4.3: Collision Probability of 802.11, FICA and PCA with varying number of APs

Demodulation Performance :-

In this experiment, we compare the demodulation performance of FICA, where multiple nodes are allowed to simultaneously access different subchannels, to the conventional WLAN, where only a single node can access the whole channel. We have one FICA station access only the odd-numbered subchannels and another FICA station access only the even-numbered subchannels. Thus, these two stations maximally interleave their subchannels and should be more sensitive to mutual inter-subchannel interference if there is any. We fix the position of the AP and two stations and adjust the transmission power to get different signal-to-noise-ratios (SNR). For each SNR setting, we evaluate four different modulation schemes. We schedule the transmissions in the following way. For each transmission power setting, we let two stations access the channel simultaneously using FICA first, and then immediately one station transmits alone. Since these two transmissions are back-to-back, we assume their channel conditions should be similar. For each power setting, we send 1400 frames. Each frame is 400 bytes and uses one subchannel.

We use the classic bit-error-rate (BER) to SNR plot to illustrate the demodulation performance. The BER value shown is measured before the Viterbi decoder; after Viterbi, most of the errors are corrected. Clearly, all curves are very close to each other, including the high rate modulations like 64QAM which are very sensitive to interference. Thus, we conclude that with FICA different nodes can transmit on different subchannels simultaneously without interfering with each other.

The OFDM PHY was incorporated into the single-channel mac-802_11.cc in the following way.

A single channel was used and different channel id was used for different nodes. When the channel delivers the packet to the nodes, it checks the channel id of the receiving mac. If the sending and receiving channels are same, only then, the channel sends the packet upward.

Step 1: maintaining channel id for the MAC layer, and to set it from the TCL script.

A. Mac.h

1. Following variables have been added from different class

   ```
   int channelIndex_;      //current channel
   int maxChannel_;        //maximum channels
   MobileNode* node_;

   public:           //setters and getters for the variables
   inline int& channelIndex(){
   return channelIndex_;
   }

   inline int& maxChannel(){
   return maxChannel_;
   }
   ```

B. mac-802_11.h

1. Add a function to change the channel index.

   ```
   void setChannelIndex(int ind);
   ```

C. mac-802_11.cc

1. Initialize the variables declared in mac.h (in the constructor)

   ```
   channelIndex_=0;
   maxChannel_ = 4;
   ```

2. Define the function setChannelIndex(int)

   ```
   void Mac802_11 :: setChannelIndex(int ind)
   {
           if(ind>maxChannel()){
                   printf(“invalid channelIndex\n”);
   ```

```
                return;
        }
        channelIndex() = ind; //set the channel
}
```

3. Since above functions need to access the node class, we need to create a link from the mac layer to the node class. The following codes have been added in the command function of mac-802_11.cc . if structure with 3 arguments have been used.

```
} else if(strcmp (argv[1], “my-node”) == 0){
  node_ = (Mobienode*) TclObject :: lookup(argv[2]);
  Return TCL_OK;
}
```

4. To set the channel from the TCL script, the following code has been added in command function.

```
} else if(strcmp(argv[1], “current_channel”) == 0) {
  setChannelIndex(atoi(argv[2]));
  return TCL_OK;
}
```

D. ns-mobilenode.tcl

1. channel changing also requires to change the base station. When an interface is added, the mac module passes the node information by calling the command function of mac. For this, one statement has been added in this file. At the beginning of the Mac layer code, at about line-477

```
$mac my-node $self
```

2. to set the channel from the TCL script, needs to add the following function

```
Node/MobileNode instproc set_channel {args} {
        $self instvar mac_
        eval $mac_(0) current_channel $args
}
```

Step 2: Filtering packets based on the channel of the sender and receiver

A. packet.h
   1. needs to add the channel index of each index of each transmitted packet by the mac layer. Therefore, we add a variable at the common header.
      a. Variable has been declared

```
int channelNo_;
```

      b. Setter and getter have been added for this

```
Inline int& channelNo(){
        return channelNo_;
}
```

B. mac-802_11.cc
   1. each node has been allowed to add the channel index of the transmitting node to every packet.
      a. The following code in the transmit function has been added.

```
ch -> channelNo() = channelIndex();
```

      b. Variable ch has been defined at the beginning of the function

```
Hdr_cmn* ch = HDR_CMN(p);
```

C. channel.cc

It filters the packet while delivering them to the neighbors.

1. First, extract the channel index of the sender. Beginning of sendUp function

```
int txmit_channel, recv_channel;
txmit_channel = hdr -> channelNo();
```

2. Then, after finding the affected nodes(neighbours), filter the packet from nodes using a different channel. At about line 378, before creating a new copy of the packet.

```
recv_channel = rnode -> mac_ -> channelIndex();
if(recv_channel != txmit_channel)
    continue;
```

D. ns-mobilenode.tcl

The channel class needs to know the channel index used by the nodes. It creates a list of neighboring nodes. Thus, each node needs to access its mac layer to get the channel index. We therefore create a link from each node to their mac layer.

1. Following command has been added in the add-interface procedure, just after the mac layer codes. At about Line-480

```
$self point-mac $mac
```

E. node.h

1. At the beginning, the following header file has been added.

```
#include “mac.h”
```

2. At the end, the following has been added

```
Mac* mac_;
```

F. mobilenode.cc

1. The following codes are executed by the above OTCL command

```
} else if (strcmp (argv[1], “point-mac”) ==0){

mac_ = (Mac*) TclObject :: lookup (argv[2]);
return TCL_OK;
}
```

To activate the Access Point (AP), the following if structure under the command function of mac-802_11.cc has been used.

```
if (strcmp(argv[1], "ap") == 0) {
                ap_addr = addr();
                bss_id_ = addr();
                infra_mode_ = 1;
                mhBeacon_.start((Random::random() % cw_) *
                                phymib_.getSlotTime());
                return TCL_OK;
        }
```

At about Line – 510 of ns-mobilenode.tcl , the following function has been added to activate a certain node as Access Point(AP).

```
Node/MobileNode instproc set_ap {args} {
$self instvar mac_;
eval $mac_(0) ap $args
}
```

To enable the Access Point (AP) to receive four packets simultaneously, “**rx_state**” variable of mac-802_11.cc has been changed to an array “**rx_state_AP[4]**” in terms of the node which has been set as the AP.

To serve the same purpose, four separate recv_timer_AP() functions have been created. For this, four additional RxTimer class have been declared in the mac-timers.h . In mac-timers.cc , handle() function was declared for each of those four new RxTimer classes.

In the example TCL script file, the following line has been added to set a specific node as AP.

$node(2) set_ap 2

In this code, node number 2 has been set as AP.

Chapter 5

CONCLUSION

5.1 Conclusion

In our works we addresses the inefficiency issue of MAC protocols in current WLANs as the PHY data rate increases. The fundamental reason of this inefficiency lies in the fact that the current MAC protocol allocates the entire wide-band channel as a single resource. Such allocation becomes too coarse-grained for general traffic demands as the channel width or the PHY data rate increases.

We argue that this inefficiency issue should be resolved using predictive channel access in high data rate WLANs. We present the design of PCA, a new design that enables predic-tive subchannel random access based on OFDM. First, FICA proposes incorporation of beacon messages to coordinate subchannel random access and reserve downlink subchannels. Second, PCA employs listening antenna in APs to ensure bi-directional traffic while avoiding collision. We have plan to go for detailed simulation to assess the performance of PCA in near future.

5.1 Future Work

Since MAC overhead reduction in WLAN is a challenging problem, there are a number of possibilities for future research works which can be extended from the work presented in this thesis.

The first is to study and experiment this work with different types of parameters. Simulating with multiple APs has been left as the work to be done in near future.

The second area of future work is to experiment the approaches presented in this thesis in a test-bed environment. It is often difficult to predict how a protocol or algorithm will work in a real hardware even with the most complex network simulator tool. However, the simulation studies are the effective ways to obtain a starting point for the test-bed experiment as simulation is always flexible and allow changing simulation parameters easily during the experiment to derive the optimum output.

Bibliography

[1] F. J. Z. Y. C. S. S. L. TAN, K. and Y. ZHANG, “Fine grained channel access in wireless lan,”SIGCOMM 2010.

[2] S. N. Souvik Sen, Romit Roy Choudhury, “Wifi-nano : Reclaiming wifi efficiency through 800ns slots,” MobiCom 2011.

[3] D. H. Rahul, F. Edalat and C. Sodini, “Frequency aware rate adaptation and mac protocols,”MobiCom 2009.

[4] IEEE standard for local and metropolitan area networks part 11; amendment 5: Enhancements for higher throughput. *IEEE Std 802.11n-2009*.

[5] IEEE standard for local and metropolitan area networks part 16: Air interface for fixed broadband wireless access systems. ANSI/IEEE Std 802.16-2004

[6] 3GPP TS 36.201-820:. Evolved universal terrestrial radio access (E-UTRA); long term evolution (LTE) physical layer; general description.

[7] R. Chandra, R. Mahajan, T. Moscibroda, R. Raghavendra, and P. Bahl. A case for adapting channel width in wireless networks. SIGCOMM Comput. Commun. Rev., 2008.

[8] A. Dutta, D. Saha, D. Grunwald, and D. Sicker. SMACK: a smart acknowledgment scheme for broadcast messages in wireless networks. In SIGCOMM ’09. , New York, NY, USA, 2009. ACM.

[9] Z. J. Haas and J. Deng. Dual busy tone multiple access (dbtma)-a multiple access control scheme for ad hoc networks. Communications, IEEE Transactions on , 50(6):975–985, 2002.

[10] Y. He, R. Yuan, J. Sun, and W. Gong. Semi-random backoff: Towards resource reservation for channel access in wireless lans. In ICNP , 2009.

[11] M. Heusse, F. Rousseau, R. Guillier, and A. Duda. Idle sense: an optimal access method for high throughput and fairness in rate diverse wireless lans. SITCOM Compute. Common. Rev., 35(4):121–132, 2005.

[12] B.-S. Kim, S. W. Kum, and R. L. Ekl. Ofdma-based reliable multicasting mac protocol for wlans. IEEE Transactions on Vehicular Technology, 57(5), 2008.

[13] X. Liu, E. K. P. Chong, and N. B. Shroff. Opportunistic transmission scheduling with resource-sharing constraints in wireless networks. IEEE Journal on Selected Areas in Communications , 19, October 2001.

[14] J. Mo, H.-S. So, and J. Walrand. Comparison of multichannel MAC protocols. Mobile Computing, IEEE Transactions on, 7(1):50–65, Jan. 2008.

[15] H. Rahul, N. Kushman, D. Katabi, C. Sodini, and F. Edalat. Learning to share: narrowband-friendly wideband networks. SIGCOMM Comput. Commun. Rev., 38(4):147–158, 2008.

[16] B. Roman, F. Stajano, I. Wassell, and D. Cottingham. Multi-carrier burst contention (MCBC): Scalable medium access control for wireless networks. In WCNC 08 , 2008.

[17] S. Shin and H. Schulzrinne. Experimental measurement of the capacity for voip traffic in IEEE 802.11 wlan. In Infocom 2007.

[18] K. Tan, J. Zhang, J. Fang, H. Liu, Y. Ye, S. Wang, Y. Zhang, H. Wu, W. Wang, and G. M. Voelker. Sora: High performance software radio using general purpose multi-core processors. In NSDI 2009 .

[19] Q. Tang, S. Gupta, and L. Schwiebert. BER performance analysis of an on-off keying based minimum energy coding for energy constrained wireless sensor applications. In ICC 2005 , 2005.

[20] P. Verkaik, Y. Agarwal, R. Gupta, and A. C. Snoeren. Softspeak: Making VoIP play well in existing 802.11 deployments. In NSDI , 2009.