Abstract: This paper mainly focuses on the throughput enhancement of legacy IEEE 802.11 MAC protocol. The two parameters, throughput and QoS are now main challenge for multimedia applications in wireless networks. Throughput parameter are very poor as compare with PHY data rate, even data rate goes infinite high. After certain PHY data rate, throughput are almost independent of data rate when data packets are fixed size. This is only due to large amount overhead adding with every data packets. So overhead reduction is the best solution to enhance the throughput for future communications. In this paper, I discussed two important overhead reduction mechanisms, which sufficiently improve the throughput performance. One is frame aggregation and another is block acknowledgement scheme. In performance analysis graph of both schemes, shows that the throughput performance are below 100 Mbps. But industries are seeking higher data rate for multimedia applications. i.e more than 100 Mbps. So it is easy make a comment that the above two important components are not sufficient enough for IEEE 802.11n individually. To fulfil the throughput performance of IEEE 802.11n, I proposed a new MAC mechanism. The new Frame Aggregation and Block Acknowledgement (FABA) MAC mechanism is the collecting of some features of above two important components, which improve the throughput performance as our desire. In this research work I also simulate the FABA scheme, which shows the throughput performance more than 160 Mbps when the number of burst within TXOP duration is 5 and PHY data rate 600 Mbps.

I. Introduction

Today Wireless Local Area Network (WLAN) is widely used in home, office everywhere instead of wired network. Cost benefit, mobility, high data rate, flexibility of use, standardization, and interoperability makes it more popular. Now there are lots of versions of IEEE 802.11 are available in market due to lower cost and easy deployment. Such as 802.11b and 802.11a, it supports data transmission rates of up to 11 and 54 Mbps; respectively. The basic Medium Access Control (MAC) mechanism of 802.11 is called Distributed Coordination Function (DCF). DCF is based on distributed channel access and employs Carrier Sense Multiple Access (CSMA) protocol for the medium access. Another Optional IEEE 802.11 access mechanism, called Point Coordination Function (PCF), based on centrally controlled access mechanism. Now a day many wireless devices manufacturer of the 802.11 use DCF. In very little area PCF is hardly implemented this complex design access mechanism. In multimedia applications such as audio/video streaming, teleconferencing, Internet telephony and interactive games demands more data rates. Industry is seeking Higher Data Rates (HRD’s) over 100 Mbps for IEEE 802.11a extension [3], which is undergoing discussions in IEEE 802.11 meetings. Throughput enhancement of the legacy IEEE 802.11 is the important issue for future wireless devices. Thus, a lot of research works have been carried out to enhance the throughput of IEEE 802.11 MAC protocols for wireless network. MAC protocol is not sufficient enough though the physical layer (PHY) data rate is significantly high. This is due mainly to the large overheads composed of medium access control (MAC) header, PHY preamble/header, backoff time, acknowledgement (ACK) transmission and some inter-frame spaces (IFs) [4]. So we have to reduce MAC overhead of the legacy IEEE 802.11 for better throughput. A new MAC schemes is proposed in the paper and also evaluate the performance using simulation of this new proposed MAC schemes. In the section 2, I discuss the Distributed Coordination Function (DCF), in the section 3, I discuss FABA schemes and finally I analysis the performance of FABA schemes using simulation, which is coded in Matlab 7.1 simulation software. Here it is important to mention that the FABA scheme is implemented in EDCA of legacy IEEE802.11e.
II. Distributed Coordination Function (DCF)
The 802.11 MAC layer provides functionality to allow reliable data delivery for the upper layers over the wireless PHY media. The data delivery of DCF itself is totally based on an asynchronous, best-effort, connectionless delivery of MAC layer data. The Guarantee less, best effort and connectionless data delivery is provided by IEEE 802.11 MAC layer. Distributed Coordination Function (DCF) is the basic access mechanism of 802.11, which is based on Carrier Sense Multiple Access (CSMA). CSMA operates as like listen-before-talk, i.e, before transmitting a frame to wireless media STA must sense the media. If the media is free at least for short time called DCF Inter Frame Space (DIFS) time period then the STA can access the media and can transmits data. During this time period of transmission other STAs must wait until medium becomes idle again at least for DIFS time period.

Figure.2 shows the relationship among three IFS SIFS is the inter frame space (IFS) between the data frame from sender and ACK frame from receiver. As we mention above SIFS is smaller than DIFS duration, so no data frame from other stations will access the medium before ACK frame. The second shortest IFS is PIFS which is used by AP in Point Coordination Function (PCF) as we mention earlier. PCF is optional polling based access mechanism of IEEE 802.11 that’s poll stations individually which is centrally controlled. In PCF, PC/AP is given priority over ordinary stations such that PIFS is lower duration than DIFS time period. The values of IFS are depending on the underlying Physical layer (PHY) condition and it is the multiple of slots time. Slots time is derived from propagation delay, transmission delay, and other physical dependent parameters [11]. PIFS is equal to SIFS plus one slot time and DIFS is equal to PIFS plus one slot time. Mathematically SIFS<PIFS<DIFS. If SIFS is equal to 7 slots time, then PIFS is equal to (7+1)=8 slots time and DIFS is equal to (8+1)=9 slots time. Carrier sensing is done by the stations, which want to communicate with the other station. The IEEE 802.11 MAC specifies both physical and virtual carrier sensing as a means to avoid collisions. While physical carrier sensing is done through signal measurement, virtual carrier sensing is done using the Network Allocation Vector (NAV).

Note that data frames can be transmitted at any data rate but control frames including ACK frame must be operated at predefined rate of Basic Services Set (BSS) so that all stations within the same network understood the same control rate. For example, if the basic rate set is defined by the BSS is {12Mbps, 24Mbps, 36Mbps} and data rate is 28 Mbps then the ACK frame transfer rate will be 24 Mbps. Now for IEEE 802.11a parameter set which is mentioned above table 1, the transmission time of data frame or MAC Protocol Data Unit (MPDU) with L byte payload

\[ T_{\text{data}} = t\text{PLCP preamble} + t\text{PLCP SIGNAL} + \left( \frac{28 + (16 + 6) / 8 + L}{BpS(m)} \right) * t\text{Symbol} \]

and

\[ T_{\text{ACK}} = t\text{PLCP preamble} + t\text{PLCP SIGNAL} + \left( \frac{30.75 + L}{BpS(n)} \right) * t\text{Symbol} \]

where BpS(m) and BpS(n) represent byte per symbol rate of data frame and ACK frame respectively. So the number of bytes in a symbol BpS (m) = m/2

Where m is the PHY data rate in Mbps.

If the data frames are transmitted at m Mbps in PHY and ACK frame are transmitted at n Mbps then the throughput performance of the system can be calculated as follows:

\[ T_{\text{throughput}}(m, n) = \frac{8 * L}{t\text{DIFS} + t\text{Backoff}(i) + t\text{data} + t\text{SIFS} + T_{\text{ACK}}} \]

Here (i-1)th retransmission attempt of random backoff time is defined as follows:

\[ t\text{Backoff}(i) = \min \left[ \frac{2^{i-1} \cdot (C W \min + 1) - 1, C W \ max}{2} \right] * t\text{SlotTime} \]

Random back off delay is the unit of slot time and this random integer is picked up from a uniform distribution of the interval [0,CW] where CW is the current contention window size. The initial contention window size is C Wmin and maximum contention window size is C Wmax. But in this case CW is always in C Wmin.
Because there is only one active sender and only one active receiver station is in BSS.

**III. Frame Aggregation and Block Acknowledgement (FABA) schemes.**

Firstly I try to figure out the throughput of Burst Transmission and Acknowledgement (BTA) mechanism with above following assumptions. Let \( L_r = 22 \) denote the size of the burst acknowledgement request (BurstAckReq) in bytes and \( L_a = 56 \) denote the size of the burst acknowledgement (BurstAck) in bytes according to IEEE 802.11e. \( T_r \) denote the time required to transmit the burst acknowledgement request frame, \( T_a \) denote the time required to transmit the burst acknowledgement frame then we have following equation for Maximum Throughput (MT)

\[
MT = \frac{8L_{\text{data}} \cdot Nb}{T_{\text{po}} + Nb \cdot T_{\text{data}} + Tr + Ta + Tsifs(Nb + 2)}
\]

and

Minimum Delay (MD)

\[
MD = T_{\text{data}} + Tsifs
\]

Where \( T_{\text{po}} \) and \( Nb \) denote that the time required transmitting contention free poll (CF-Poll) and number of bursts respectively.

According to paper [3] for the BTA mechanism, a theoretical throughput upper limit (TUL_BTA) and a theoretical delay lower limit (DLL_BTA) exist. The TUL_BTA and DLL_BTA are independent of data rate (even data rate goes infinitely high). TUL_BTA and DLL_BTA are define as follows

\[
TUL_{\text{BTA}} = \frac{8L_{\text{data}} \cdot Nb}{(Nb + 3)(Tp + T_{\text{phys}}) + Tsifs(Nb + 2)}
\]

and

\[
DLL_{\text{BTA}} = Tsifs
\]

For the sake of simplicity I assume that all bursts are equal in length and the data rate and control rate are equal. Figure 6 shows the Theoretical Upper Limit (TUL) using BTA schemes.

In this FABA scheme, I pay attention to improve the throughput performance of wireless LAN by reducing MAC overheads. To ensure the QoS, I use EDCA part of legacy IEEE 802.11e. Both the frame aggregation and block acknowledgement (BA) are popular schemes for reducing MAC and PHY layer overheads. To achieve higher throughput for IEEE 802.11n standard, I combine the above two popular components in my proposed FABA schemes. To describe the mechanism, I will consider three phases of FABA scheme. Firstly frame aggregation phase, secondly channel access phase then finally block acknowledgement phase. In frame aggregation, multiple small frames aggregate into a single MAC frame up to threshold value. The threshold value can be found from Channel State Information (CSI).

There are four possible ways of aggregation mechanisms: A-MSDU, A-MPDU, A-PPDU, and PPDU bursting. They belong to different levels: MSDU aggregation is between LLC (Logical Link Control) and MAC, MPDU aggregation is between MAC and PHY, and PPDU aggregation and PPDU bursting are at PHY [10]. The task of frame aggregation can be made simpler if it performs above the MAC SAP. Even without any change of hardware, it can be implemented. It is possible to implement by changing only devices driver. Above MAC SAP, we can aggregate multiple IP packets into a single chunk, and send it to the MAC as a single frame or more exactly MAC Service Data Unit (MSDU). Therefore, the MAC layer can deal with the aggregated frame as a normal MSDU [4]. From IEEE statistic it can be seen that over 70% of packets are small, under 128 bytes. It is about 15 % packets are over 1024 bytes. So small size packets are dominating over big size packets and degrade the performance of total system throughput. In frame aggregation phase, it is obviously increase the throughput performance because of greatly reduces PHY and MAC overhead. In access to the wireless media phase, I consider the EDCA backoff procedure of IEEE 802.11e standard to ensure the QoS. By adopting this mechanism, the aggregated frames will have the same destination address and same level of QoS priority. First small frames are aggregated above MAC-SAP, which has same destination address and same level of QoS priority then this aggregated frame contend for the backoff period[4]. The duration of the backoff period are vary in according to AC of EDCA mechanism because of the arbitration inter frame spacing (AIFS), is different for each AC.[4]. In below figure 2 shows the total FABA mechanism.

![Figure: 2 Frame aggregation and Block Acknowledgement (FABA) Schemes.](image)

Each AC content its backoff duration as like individuals STA, which is competing with each other’s and access channel. In IEEE 802.11e, there is a mechanism, burst transmission, provided for STA to transmit a number of frames in a TXOP. While it provides an approach to save the contention time of each frame, there are still overheads in each transmitting frame [5]. Transmitting longer frames may have a better throughput than transmitting shorter frames, adopting the concatenation mechanism; the system can achieve the throughput of transmitting longer frames. Another overhead the contention time of each frame will remove using burst transmission mechanism. But an important overhead, like acknowledgement overhead should be removed. So do that Block Acknowledgement mechanism is introduced in FABA scheme. In TXOP duration, multiple frame can
transmit with single backoff period. When all frames transmitted, a special frame called BurstAckReq frame (BAR) frame transmitted to the receiver so that let the receiver knows burst transmission is ended and acknowledgement should be sent to the transmitter via BurstAck (BA). One is immediate acknowledgement and another is delayed acknowledgement. Due to short delay and jitter, it is appreciated immediate block acknowledgement schemes in some multimedia applications such as VoIP. On the other hand, delayed block acknowledgement is preferred in some multimedia applications if throughput is more important than delay and jitter. However in both case, overhead is greatly reduced and consequently improvement of throughput is high. Both BurstAckReq (BAR) and BurstAck (BA) frame are transmitted at the same rate used for data transmissions.

IV. Algorithm for FABA schemes.
In this section, I try to summarize the total FABA mechanism with the help of pseudo code. Before doing that I assume some basic assumption for this scheme. There is only one active station within the radio range. So all frames have the same source and destination address. Here fragment_thresh is a predefine value according to channel state information (CSI). In contention phase, I consider EDCA mechanism to evaluate block acknowledgement procedure.

Aggregation Phase:
Initialisation, i=0; aggre_frame=0;
while(aggre_frame< fragment_thresh)
    if(frame[i]+aggre_frame < fragment_thresh and have same level priority of QoS )
        aggre_frame= aggre_frame+frame[i]
        i=i+1;
    do
Contention Phase:
According to QoS priority level
Select AC (Access Category)
switch ( QoS priority level)
case AC0: AIFS [AC0];
cwindow(); break;
case AC1: AIFS [AC1];
cwindow(); break;
case AC2: AIFS [AC2];
cwindow(); break;
case AC3: AIFS [AC3];
cwindow();
Block Acknowledgement Phase:
if (Immediate acknowledgement)
    after SIFS duration block acknowledge for current aggregate frame;
if (delayed acknowledgement)
    after transmitting all bursts within TXOP block acknowledgement for whole bursts.

V. Necessary Assumptions
For the calculation of maximum theoretical throughput and evaluate the performance of legacy IEEE 802.11 and enhanced FABA schemes, I will consider the following assumptions there is only one active station in the radio range. No other station within the BSS, all packets have the same source and destination address. Packets are always available in the buffer queue. The channel is always error free (i.e ideal). So there are no collisions during transmission. All packets are small enough that no fragmentation will be allowed (i.e packets are smaller than the fragmentation threshold).

VI. Performance Evaluation
With above necessary assumptions the following frame aggregation schemes, BTA schemes and FABA schemes are simulated. The results of the simulation are enlisted below.

![Payload vs Throughput at different PHY data rate using frame aggregation schemes.](image1)

![PHY data rate vs Throughput at different payload in byte using frame aggregation schemes.](image2)
Here I simulate some proposed schemes and also simulate a new MAC enhancement scheme. To simulate those I first consider some assumptions in the section V. In figure 3, figure 4, figure 5 and figure 6, I noticed that the throughput performance of block acknowledgement scheme and frame aggregation scheme are much better than the legacy existing MAC protocols. From figure 4, another observation is that the throughput performance is independent with PHY data rate. Especially small packet sizes are more suffer than the bigger packets size. For example, 100, 500 and 1000 byte payloads are independent at 100, 600 and 700 Mbps data rate respectively. However those above two schemes are not sufficient enough for multimedia applications. Those both two schemes provide below 100 Mbps throughput. But industries are seeking above 100 Mbps. Here I proposed a new MAC enhancement scheme is called FABA, which is able to provide throughput as sufficient enough for multimedia applications. Figure 7 and figure 8 shows the simulation of FABA scheme. Figure 7 shows the PHY data rate versus Throughput of FABA scheme and figure 8 shows PHY data rate versus throughput at different number of burst within TXOP duration.

VII Future work

There are several important areas for future work. This research work is only based on the best-case scenario. i.e only I try to figure out the theoretical maximum throughput. So it is needed to more study on saturation case scenario, when the large number of stations are involved. I consider EDCA schemes to evaluate block acknowledgement schemes in our FABA scheme. But in our simulation I consider only one AC. So QoS study in combination with throughput may be another great issue for IEEE 802.11n. Here I consider the channel is error free i.e always ideal and I take 2304 byte as fragmentation threshold for performance evaluation. But in reality channel is always error porn. So there is a big issue that how the fragmentation threshold depend on channel quality or channel condition (CSI). Frame aggregation
should be in proper layer due to QoS ensures. Here frame aggregation is considering only when the source and destination address are same for all packets. If the source and destination address are different then the aggregation schemes need further studied to find out the proper aggregation layer.

References


