Comparison of performance analysis of 802.11a, 802.11b and 802.11g standard

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Abstract Wireless local area networks (WLANs) based on the IEEE 802.11 standards has been successfully deployed in a variety of home, office and corporate environments and available in various flavors like 802.11a/b/g. In this paper in-depth analysis of the throughput performance and bandwidth efficiency of 802.11a standard has been investigated and compared for CSMA/CA and RTS/CTS schemes. In this paper, an analytical model based on theoretical analysis has been used to predict the throughput performance in IEEE 802.11a**,** 802.11b and 802.11g WLANs and further extended to predict the throughput performance taking into account the effect of channel conditions (FER). Results have been obtained using Matlab software which shows a superior throughput performance for 802.11a as compared to 802.11b/g using the same OFDM technology is employed for both the standards. Variation of throughput as a function of MSDU for the CSMA/CA and RTS/CTS for standard 802.11a, 802.11b and 802.11g reveals that throughput for CSMA/CA is greater than RTS/CTS scheme for same data rate. It has also been observed that considering physical condition i.e. FER in this case, throughput for 802.11a/b/g standards decreases with increasing FER when data rate is kept constant.

1. INTRODUCTION

The WLAN market is now in the early stages of what seems to be mass adoption. In this market we see several technologies competing each other with different operating characteristics such as modulation type, data throughput, and frequency bandwidth.

A first, very important family of standards that needs to be mentioned is the IEEE 802.11 group developing wireless LAN standards, it includes task groups called 802.11b,a,g working on amendments.

The standard is similar in most respects to the IEEE 802.3 Ethernet standard. Specifically, the 802.11 standard addresses:

- Functions required for an 802.11 compliant device to operate either in a peer-to-peer fashion or integrated with an existing wired LAN
- Operation of the 802.11 device within possibly overlapping 802.11 wireless LANs
- The mobility of this device between multiple wireless LANs
- MAC level access control and data delivery services to allow upper layers of the 802.11 network
- Several physical layer signaling techniques and interfaces
- Privacy and security of user data being transferred over the wireless media

Maximum throughput performance of IEEE 802.11b was previously studied by other researchers [1].The main contribution of this thesis is the exact calculation of the theoretical maximum throughput for 802.11 networks, for a variety of technologies (802.11, 802.11b, 802.11g) and data rates. This paper also gives the comparison of throughput and bandwidth efficiency of 802.11a, 802.11b and 802.11g standard with RTS/CTS and CSMA/CA.

This paper is structured as follows. Section II provides an overview of the IEEE 802.11 standard and summarizes the basic throughput prediction model for IEEE 802.11a,802.11b and 802.11g WLANs to predict the throughput performance given the MAC scheme, basic data rate and frame size. Section III provides the Analysis of bandwidth efficiency. Section IV provides Throughput analysis of IEEE 802.11 considering frame error rate. Section V gives the results .Sections concludes the study and proposes some future work.

2. THROUGHPUT ANALYSIS

The maximum throughput is defined as the maximum number of MAC Layer Service Data Units (MSDUs) that are transmitted in a unit time. I have considered the MAC layer throughput comparison of three standards (802.11a, 802.11b and 802.11g). Each MSDU carries additional overhead at MAC and Physical layer such as PHY preambles and MAC headers, control frames, inter-frame spacing and back-off time in case of IEEE 802.11. In IEEE 802.11, the overhead is transmitted at control rate. In this thesis calculation considers all the assumptions defined in [2], i.e. there are no collisions in case of IEEE 802.11, the transmission is error free and at least one station has always a packet to send. The following section present numerical calculations to derive the maximum throughput of IEEE 802.11.

Table (3.1) Characteristics of the various physical layers in the IEEE 802.11 Standard

Characteristics	802.11a	802.11b	802.11g
Frequency	5Ghz	2.4Ghz	2.4Ghz
Rate(Mbps)	6,9,12,18,24,36,48,54	1,2,5.5,11	1,2,5.5,6,9,11,12,18,24,36,48,54
Modulation	BPSK,QPSK,16QAM,64QAM (OFDM)	DBPSK,DQPSK,CCK (DSS,IR and FH)	BPSK,DBPSK,QPSK,DQPSK, CCK 16QAM,64QAM(OFDM and DSSS)
FEC Rate	1/2,2/3,3/4	NA	1/2,2/3,3/4
Basic Rate	6Mbps	1 or 2Mbps	1,2 or 6 Mbps

Table 3.2. IEEE 802.11a PHY Characteristics

Parameters	***802.11a***	***Comments***
Aslottime	*9 usec*	*Slot time*
ADIFSTime	*34 usec*	*DIFS time*
ASIFSTime	*16 usec*	*SIFS time*
ACWmin	*15*	*Min contention window size in unit of a Slot Time*
tPLCPPreamble	*16 usec*	*PLCP Preamble duration*
tPLCPHeader	*4 usec*	*PLCP header duration (except the SERVICE field in case of 802.11a)*
Tsymbol	*4 usec*	*OFDM symbol interval*

2.1 Throughput analysis of IEEE 802.11 for ideal channel

In IEEE802.11, data frames and control frames are transmitted at different rates. In case of CSMA/CA, the station transmits if the channel is free for Distributed Inter-frame Spacing period (DIFS). Short Inter-frame Spacing (SIFS) framing is used to separate transmission belong to a single dialog. Each frame in IEEE 802.11 is composed of additional delay created by inter-frame spacing and back off period. In case of RTS/CTS, the transmission cycle contains 3 SIFS period in addition to RTS and CTS frames. The maximum throughput of IEEE 802.11 is presented in [3], where the upper throughput limit of IEEE 802.11a and IEEE 802.11b is derived. However, the derivation ignores RTS/CTS mechanism. The RTS/CTS mechanism is considered in [4], where the throughput is analyzed for payload size of 4000 bytes but the propagation delay is ignored. My throughput calculation of IEEE 802.11 is based on the formulas given in [4] and [3], with a slight modification by the addition of propagation delay in case of RTS/CTS mechanism. From the developed analytical model I have predicted the throughput performance in IEEE 802.11a, 802.11b and 802.11g WLANs and presented the comparative analysis of three standards in terms of throughput and bandwidth efficiency.

The maximum throughput TMT is calculated as the ratio of MSDU size x to the transmission delay per MSDU size and is given by:

$$TMT = (8 \times x)/Delay \qquad (1)$$

Where

x = MSDU

Where the total delay per MSDU depends on which MAC scheme is used in the transmission.

For CSMA/CA MAC scheme, a transmission cycle composes of the following phases that are repeated over time: (1) DIFS deferral phase; (2) Back off (BO)/contention; (3) Data (or MPDU) transmission phase; (4) SIFS deferral phase; and (5) ACK transmission phase. Therefore, the delay per MSDU can be calculated as:

$$TDIFS + TBO + TDATA + TSIFS + TACK \qquad (2)$$

For RTS/CTS MAC scheme, a transmission cycle composes of the following phases that are repeated over time: (1) DIFS deferral phase; (2) BO (Back off)/contention; (3) RTS transmission phase; (4) SIFS deferral phase; (5) CTS transmission phase; (6) SIFS deferral phase; (7) Data (or MPDU) transmission phase; (8) SIFS deferral phase; and (9) ACK transmission phase. Therefore, the total delay per MSDU for RTS/CTS MAC scheme can be calculated as:

$$TDIFS+TBO+TRTS+TSIFS+TCTS+TSIFS+TDATA+TSIFS+TACK+2\,\Gamma \qquad (3)$$

The values of each fixed delays specified in IEEE 802.11 standard are shown in table 1.

The data transmission time can be calculated as in equation

$$TDATA = TPLCPheader + TPLCPPreamble + MPDU/Data\ rate \qquad (4)$$

The PLCP preamble and header parameters are always transmitted at 1 Mbps, regardless of the data transmission rate. Hence they are treated as constant value (192 μsec for long preamble PLCP) in the calculation. In this study, it is assumed that there is no collision in the network, therefore the BO time would be randomly selected between [0, CWmin]. The equation of BO time is given as:

$$Back\ off\ Time = Random() \times aSlotTime \qquad (5)$$

Where Random () = pseudorandom integer drawn from a uniform distribution over the interval [0, CWmin]. aSlotTime = value of corresponding PHY characteristics, which is 20μs in this case. Assuming that BO is randomly distributed from [0, CWmin], it will give an expected average value of CWmin/2.

The value of BO would then be:

BO = 31/2* 20µs= 310µs (6)

Summing up all the fixed delays specified by the standard in a transmission cycle, the saturation throughput of an IEEE 802.11 data frame can be evaluated for both schemes as follows.

For CSMA/CA MAC scheme:

TMT=MSDU*8/ (TDIFS+ TBO + TDATA + TSIFS+ TACK) (7)

For RTS/CTS MAC scheme:

TMT=MSDU*8/(TDIFS+TBO+TRTS+TSIFS+TCTS+TSIFS +TDATA+TSIFS+TACK+2г) (8)

2.2 Analysis of bandwidth efficiency

As a measure of spectral utilization, we define bandwidth efficiency ε:

ε = TMT/R (9)

2.3 Throughput analysis of IEEE 802.11 considering frame error rate

First, the probability of bit error in Differential Binary Phase Shift Keying (DBPSK) can be expressed as

$BER = ½ \exp^{-E_b / N_0}$ (10)

Eb/No can be related to SNR as:

$E_b /N_0 = S/N \times B_T/R$ (11)

Where B_T is the signal bandwidth; R is the transmission data rate. Obviously, the error performance of a modulation scheme varies with different SNR values. The frame error rate in a channel can be expressed in terms of BER as:

$FER = 1-(1-BER)^{8L}$ (12)

Where 8L here is the frame size in bits.

Furthermore, the FER for an L-bytes long data frame taking into account of MAC mechanism is derived:

FER^m (data_L) = 1-(1-FER^1 (24)) × (1-FER^m (28 + L))

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Where m = 1, 2, 3 and 4 is the PHY mode representing 1, 2, 5.5 and 11 Mbps transmission rate in IEEE 802.11b, respectively; FER1 (24) is the probability of error of the PLCP preamble/header transmitted using PHY mode 1; FER m (28+L) is the probability of error of the MPDU including the MAC overhead.

An ACK frame is transmitted at the rate equals to or lower than the data frame rate, and is 14 bytes long, which is usually much shorter than the data frame. Therefore, the error probability of the ACK frame is very low compared to the error probability of the data frame, and hence ignored in the calculation here.

The network throughput accounting for the channel errors is defined as:

$Throughput_{actual}$ = No. of frames sent (1-FER)/ Total Time Delay (14)

Where FER is the frame error rate due to the channel error and the unit for the throughput is frame per second.

And Total Time Delay = No. of frames sent * Delay per second. (15)

Hence, the network throughput can be converted into bits per second (bps) by multiplying the frame length and the actual throughput becomes:

$Throughput_{actual} = 8L\times(1-FER)/$ Delay per MSDU

$= Throughput_{max}\times(1-FER)$ (16)

Where $Throughput_{max}$ is the maximum throughput for ideal channel condition.

3 RESULTS AND DISCUSSION

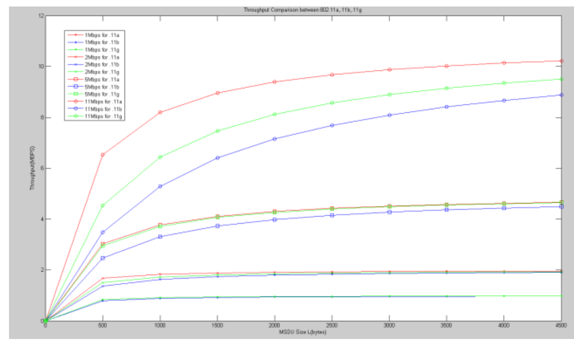

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Fig (4.1) Throughput comparison between 802.11a, 802.11b and 802.11g

On plotting Throughput/MSDU graph (fig 4.1) for various standards that are 802.11a, 802.11b and 802.11g, the following results are observed:

1. For lower data rates for the standards 802.11a, 802.11b and 802.11g, the difference in throughput is negligible i.e. for data rates 1Mbps and 2Mbps the curves are very close to overlapping having very minor differences in between. Hence at low data rates all the three standards behave identically.
2. Now, as the data rates has been raised from 1 - 2Mbps to 5MBps the observations are that When basic data rate is 6 Mbps, MSDU is 1500 bytes the throughput for standard 802.11a is 4.1051, for standard 802.11b throughput is 3.7253 and for standard 802.11g throughput is 4.0634 which makes it obvious that throughout for standard 802.11a and 802.11g is greater that for standard 802.11b by performed values. The difference in throughput for standard 802.11a and 802.11g is almost negligible as these curves are very close to overlapping. Hence as the data rate increases standard 802.11a. 802.11g becomes better than standard 802.11b giving more throughput for same data rates and MSDU.
3. Now as the data rate is further increased from 5Mbps to 11Mbps the observations are that when basic data rate is 6 Mbps, MSDU is 1500 bytes the throughput for standard 802.11a is 8.9589, for standard 802.11b

is 6.3984 and for 802.11g is 7.465. From results it is clear i.e. with increasing data rates the difference in throughput of standard 802.11a, 802.11g increases from the standard 802.11b.as throughput for standard 802.11a and 802.11g rises sharply and almost linearly with data rate for lower value of MSDU and saturates at higher value of MSDU for same data rate whereas for standard 802.11b the rise in throughput is not so sharp but sluggish and it saturates at higher MSDU than 80.11a and 80.11g.Also the difference in throughput of standard 802.11a and 802.11g is noticeable with increasing data rate, with standard 80.11a found to best by giving higher throughput for same MSDU & data rate than other two standards i.e 802.11b & 802.11g, followed by standard 802.11g and in last the standard 802.11b with lowest throughput at same data rate and MSDU.

It is also observed that by keeping data rate constant the same throughput can be attained by varying MSDU. For same data rate of 11Mbps the throughput of 6.3984 is obtained in the standard i.e. 802.11a, 802.11g, 802.11b by having MSDU size 500, 1000 and 15000 respectively. Hence data makes it clear that for obtaining same throughput at same data rate, MSDU for standard 80.11a is minimum and that for standard 802.11b is maximum .MSDU for standard 80.11g lies in between standard 802.11a and 802.11g for having same throughput at same data rate.

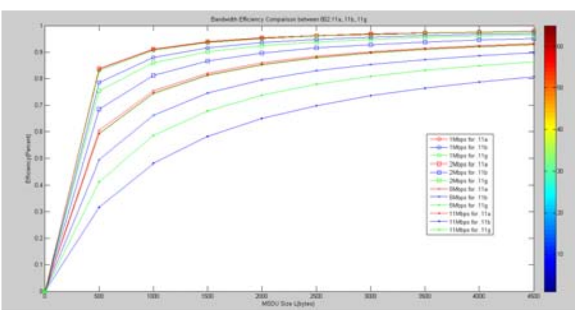


Fig (4.2) Bandwidth Efficiency comparison between 802.11a, 802.11b and 802.11g

Fig.4.8 shows the bandwidth efficiency for different standards i.e. 802.11a, 802.11b and 802.11g. From the graph following results are observed:

1. From the bandwidth curves, it is observed that bandwidth efficiency increases as MSDU size is increased.
2. For 5Mbps, MSDU 1500 bytes the bandwidth efficiency for standard 802.11a is 82%, for 802.11b is 75% and for 802.11g is 81%. For 11Mbps, MSDU 1500 bytes the bandwidth efficiency for standard 802.11a is 81%, for 802.11b is 58% and for 802.11g is 68%.Hence the data shows the efficiency of standard 802.11a is greater than standard 802.11g which is greater than standard 802.11b at all data rates. Also with the increase in data rates the bandwidth efficiency decreases for all the three standards.

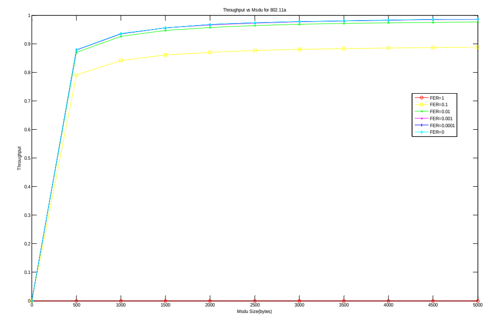
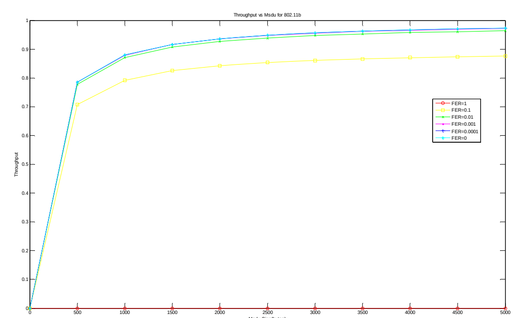


Fig (4.3) Throughput vs MSDU size considering FER for 802.11a



Throughput vs MSDU size considering FER for 802.11b

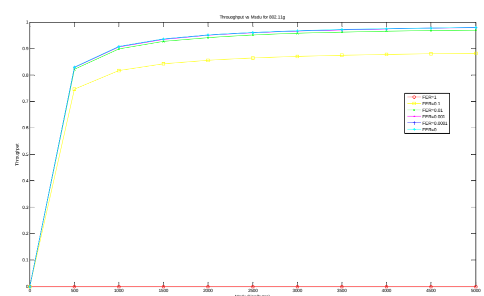


Fig (4.5) Throughput vs. MSDU size considering FER for 802.11g

The graph plotted for Throughput vs. MSDU size based on analytical throughput model considering physical conditions fig(4.3),fig(4.4.)and (4.4) shows that throughput of 802.11a/b/g decreases as the FER increases.

4. Conclusion This thesis presents the calculation of the theoretical maximum throughput of 802.11 networks. To broaden the applicability of the results, variation of throughput as a function of MSDU for the CSMA/CA and RTS/CTS has been studied. Theoretical results have been obtained for 802.11a, 802.11b and 802.11g and detailed comparison of these three standards using various data rates and MSDU size has been carried out.

Variation of throughput as a function of MSDU for the CSMA/CA and RTS/CTS for standard 802.11a, 802.11b and 802.11g reveals that throughput for CSMA/CA is greater than RTS/CTS scheme for same data rate. Further on comparing the three standards it was observed that 802.11a provides higher throughput than 802.11g and 802.11b. Investigation also reveals that the observed throughput for 802.11a/b/g standards decreases as FER increases for a constant data rate.

In future work, the throughput performance for multi-user multi-hop scenario can be investigated for physical model rather than the protocol model. Also the information from this analysis can be combined Network layer information to improve throughput performance at the higher layers.

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