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A Comparison Throughput of CSMA/CA RTS CTS Protocol for IEEE 802.11a/b/g WLAN Standards

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Abstract- **This research, we propose performance analysis of CSMA/CA RTS CTS protocol for wireless local area networks. The theoretical throughput and delay parameters are studied in our system model using each based times transmission frames. Three standards of wireless local area networks are referred to IEEE802.11a, IEEE802.11b and IEEE802.11g respectively. Throughput and delay are studied when MAC service data units (MSDU) are changed in data link layer. Finally, we compare the performance of CSMA/CA RTS CTS protocol which referred three standards of IEEE802.11a/b/g wireless local area network.**

Index Term- **CSMA/CA RTS CTS, MSDU, IEEE802.11a, IEEE802.11b, IEEE802.11g, DSSS, FHSS, OFDM, WLAN.**

I. INTRODUCTION

Presently, the IEEE802.11 standards use the terms Physical Layer and Data Link Layer to name the lowest two layers of the ISO/OSI reference model. In this model the connection layer is further sub-divided: access control is provided by Medium Access Control (MAC) and Logical Link Control (LLC).In this division, the Physical Medium Dependent (PMD) sub layer is responsible for modulation and encoding, whereas the Physical Layer Convergence Protocol (PLCP) provides a normal PHY interface, no matter what medium is involved. In particular, PLCP also supplies the Clear Channel Assignment signal (CCA) which shows the medium's current state. In addition to monitoring signals, this CCA signal is also used to prevent collision due to noise from microwave ovens. The MAC and PHY layers in IEEE802.11 are shown in Fig.1.[1][2]

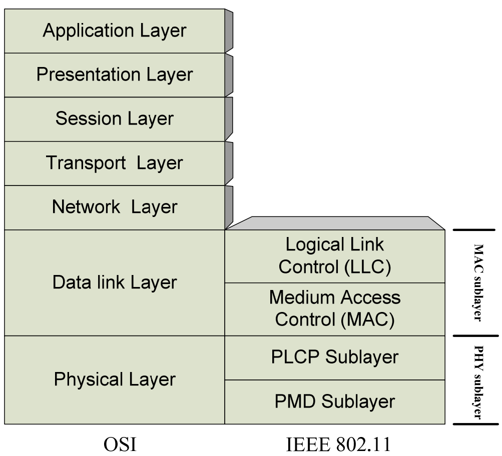

Fig. 1 MAC and PHY layers in IEEE802.11

The first wireless LAN standard IEEE802.11 was approved and supported speeds up to 2 Mbps. Today's WLAN (Wireless local area network) products operate inside a collection of frequencies, know as a frequency band: 2.4 GHz for IEEE802.11b/g and 5 GHz for IEEE802.11a. The speeds are increased to 54 Mbps using orthogonal frequency division multiplexing (OFDM) modulation technique technology. The IEEE802.11a is a physical layer standard for WLAN in the 5 GHz radio band. It specifies eight available radio channels. Maximum link rate of 54 Mbps per channel that high data throughput and greater number of channels give better protection against possible interference from neighboring access points. The IEEE802.11b is a physical layer standard for WLAN in the 2.4 GHz radio band. It specifies three available radio channels. Maximum link rate of 11 Mbps per channel that installations may suffer from speed restrictions in the future as the number of active users are increased. The limit of three radio channels may cause interference from neighboring access points. The IEEE802.11g is a physical layer standard for WLAN in the 2.4 GHz and 5 GHZ band. It specifies three available radio channels. The maximum link rate is 54 Mbps per channel and the IEEE802.11g uses OFDM modulation. The trade-off with IEEE802.11g is in a lower capacity, versus IEEE802.11a, to serve a large number of high-speed WLAN users. The OFDM modulations allow for higher speed but the total available bandwidth in the 2.4 GHz frequency band remains the same because IEEE802.11g is still restricted to three channels in the 2.4 GHz band, unlike the eight that are available in the 5 GHz band. The total characteristic of IEEE802.11a/b/g WLAN standards are shown in table I. [3] [4]

II. THE CSMA/CA RTS CTS PROTOCOL

The IEEE802.11 standard specifies both the MAC layer and PHY layer. MAC layer offers two different types of service channel technique: a contention free service provided by the Distribute Coordination Function (DCF), and a contention – free service implemented by the Point Coordination Function (PCF). This service types are made available on top of a variety of physical layers. Specifically, three different technologies have been specified in the standard: Infrared (IF), Frequency Hopping Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS). The DCF provides the basic access method of the IEEE802.11a/b/g MAC protocol and is based on a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme.

TABLE I
Summarize the IEEE802.11 WLAN standards [3] [4] [5]

Standards	IEEE802.11a	IEEE802.11b	IEEE802.11g
Available Bandwidth	300 MHz	83.5 MHz	83.5 MHz
Unlicensed Frequency of Operation	5.15-5.35 GHz 5.425-5.675 GHz 5.725-5.825 GHz OFDM	2.4-2.4835 GHz DSSS	2.4-2.4835 GHz DSSS, OFDM
Data Rate per Channel	54, 48, 36, 24, 18, 12, 9, 6 Mbps	11, 5.5, 2, 1 Mbps	54, 36, 33, 24, 22, 12, 11, 9, 6, 5.5, 2, 1 Mbps
Modulation Type	BPSK (6, 9 Mbps) QPSK (12, 18 Mbps) 16-QAM (24, 36 Mbps) 16-QAM (48, 54 Mbps)	DQPSK/CCK (11, 5.5 Mbps) DQPSK(2 Mbps) DBPSK(1Mbps)	OFDM/CCK (6, 9, 12, 18, 24, 36, 48, 54) OFDM (6, 9, 12, 18, 24, 36, 48, 54) DQPSK/CCK (22, 33, 11, 5.5 Mbps) DQPSK(2 Mbps) DBPSK(2 Mbps)
Compatibility	Wi-Fi (5 GHz)	Wi-Fi	Wi-Fi at 11Mbps and below
Access	CSMA/CA	CSMA/CA	CSMA/CA

The PCF is implemented on top of the DCF and is based on a polling scheme. It uses a point coordinator that cyclically polls stations, giving them the opportunity to transmit. In this research, we propose only the DCF service mode. The CSMA/CA is the channel mechanism used by most wireless LANs in the Industrial Scientific and Medical (ISM) band. The basic principle of CSMA is to listen before talk and the contention. This is an asynchronous message passing mechanism (connectionless), delivering a best effort service, and no bandwidth and latency guarantee. CSMA is fundamentally different from the channel access mechanism used by cellular phone system (i.e., TDMA: Time Division Multiple Access). CSMA/CA is derived from the channel access mechanism CSMA/CD (Carrier Sense Multiple Access with Collision Detection) employed by Ethernet. However, collision waste valuable transmission capacity, so rather than the collision detection (CD) used in Ethernet, CSMA/CA uses collision avoidance. Collision avoidance (CA); on a wire, the transceiver has the ability to listen while transmitting and so to detect collisions (with a wire all transmissions have approximately the same strength). But, even if a radio could listen on the channel while transmitting, the strength of its own transmissions would mask all other signals on the air. Thus, the protocol can not directly detect collision like with Ethernet and only tries to avoid them. In CSMA/CA protocol technique; there are two schemes for accessing channel as Basic CSMA/CA protocol (Two-way handshaking) and CSMA/CA RTS CTS protocol (Four-way handshaking). In the basic CSMA/CA scheme (see Fig. 2), a node having a packet ready to transmit, senses the medium first. If the medium is idle for a period of DIFS (Distribute Inter Frame Space) duration, then the node transmits its packet. Otherwise, the node initiates a back-off. When the packet is received successfully, the receiving node sends an acknowledgement (ACK) to the sending node after a short Inter Frame Space (IFS). ACK is necessary as the sender cannot determine if a packet has been successfully received by listening to its own transmission.

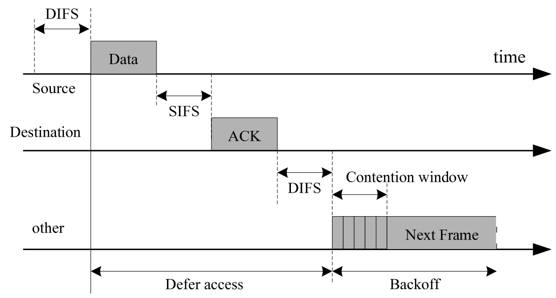

Fig.2 The Basic CSMA/CA with ACK mechanism

In the Basic CSMA/CA with ACK scheme, the wireless medium characteristics generate complex phenomena such as the hidden station and the exposed station problems. Fig. 3 shows a typical "hidden station" scenario.

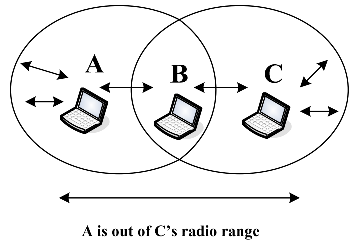

Fig. 3 Hidden Station problem

In figure 3, we assume that station B is in the transmitting rang of both A and C, but A and C can not hear each other. Let us also assume that A is transmitting to B. if C has a frame to be transmitted to B, according to the DFC protocol, it senses the medium and find it free because it is not able to hear A's transmissions. Therefore, it starts transmitting the frame but this transmission will results in a collision at the destination station B. the hidden station problem can be alleviated by extending the basic mechanism by a virtual carrier sensing mechanism that is based on two control frames: Request To Sense (RTS) and Clear To Sense (CTS), respectively. This mechanism can see in Fig. 4 and Fig. 5.

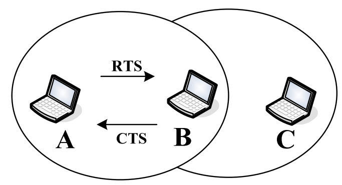

Fig. 4 RTS and CTS scheme for avoid hidden station problem

According to this mechanism, before transmitting a data frame, the source station sends a short control frame, named RTS, to the receiving station announcing the upcoming frame transmission. Upon receiving the RTS frame, the destination station replies by a CTS frame to indicate that it is ready to receive the data frame.

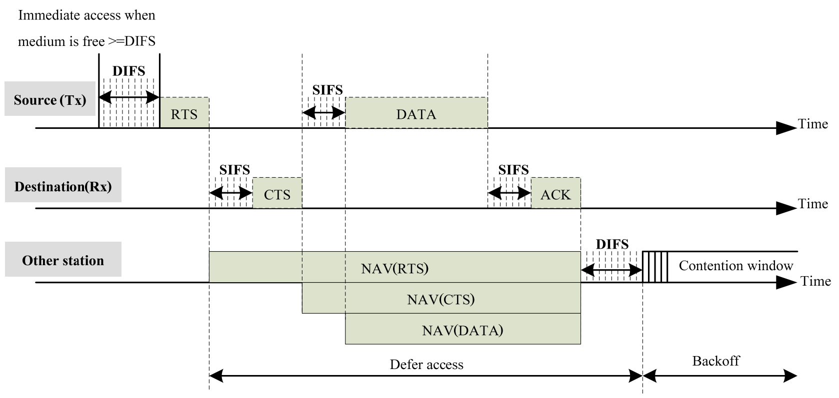

Fig. 5 The CSMA/CA with RTS CTS Protocol frame exchange

Both the RTS and CTS frames contain the total duration of the transmission, i.e., the overall time interval needed to transmit the data frame and the related ACK. This information can be read by any station within the transmission range of either the source or the destination station. Such a station uses this information to set up a time called Network Allocation Vector (NAV). While the NAV timer is greater than zero the station must refrain from accessing the wireless medium. By using the RTS and CTS mechanism, station may become aware of transmissions from hidden station and on how long the channel will be used for these transmissions. The RTS and CTS scheme are very useful when the number of contending nodes is large or the offered load is high because the probability of collision is much high in such a system. The use of RTS and CTS scheme can also greatly improve the performance by reducing the collision duration. In Distribute Coordination Function mode, we use an exponential back-off scheme to determine the random back-off timing. The back-off time is determined by:

$$T_{Backoff} = 2^m \times CW_{\min} \times T_{SLOT} \quad (1)$$

$$CW_{\max} = 2^m CW_{\min} \rightarrow 2^m = \frac{CW_{\max}}{CW_{\min}} \rightarrow m = \log_2\left(\frac{CW_{\max}}{CW_{\min}}\right) \quad (2)$$

Where $m =$ Maximum back-off stage or the numbers of retransmission

$CW_{\min} =$ Minimum Contention Window size

$CW_{\max} =$ Maximum Contention Window size

III. THEORITICAL MAXIMUM THROUGHPUT AND DELAY OF CSMA/CA RTS CTS PROTOCOL

Figure 6 shows the data flow between the protocols layers on the transmission side. The MAC as well as the Physical Layer Convergence Protocol (PLCP) provides a transmission service to the next higher layer. On the MAC side, the MAC Service Data Units (MSDU) is filled with data coming from the Logical Link Control (LLC). A complete MAC frame with header and Frame Check Sequence (FCS) is known as MAC Protocol Data Unit (MPDU) on the MAC side and will be fed into the PLCP Service Data Unit (PSDU) on the PLCP side. The full frame to be transmitted by the Physical Medium Dependent layer (PMD) is again know as PLCP Protocol Data Unit (PPDU)

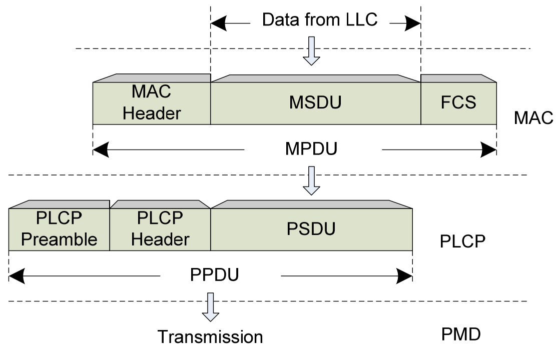

Fig. 6 Data encapsulation procedure in MAC and PLCP

To calculate Theoretical Maximum Throughput (TMT) and Delay of CSMA/CA RTS CTS protocol, we are used the timing diagram of a successful packets transmission for difference MAC Service Data Units (MSDU) in MAC layer. The CSMA/CA RTS CTS frame format (timing) is shown in Fig. 7 and our system model is defined under the following assumptions:

- Bit error rate (BER) is zero.
- Point Coordination Function (PCF) mode is not used.
- No packet loss occurs due to buffer overflow at the receiving node
- There are no losses due to collision.
- The MAC layer does not use fragmentation.
- Each station always immediately has a packet available for transmission (saturation conditions)
- Path loss, multi-path fading and capture effect are not consider

The basic equation for modeling throughput is:

$$Throughput_{802.11a/b/g} = \frac{Payload}{Delay} = \frac{T_{MSDU(size)}}{T_{Delay\ per\ MSDU(size)}} \quad (3)$$

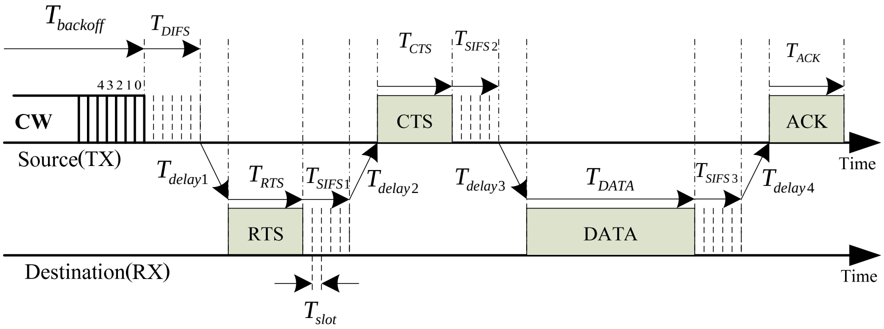

Fig. 7 Timing diagram of successful data transmission for CSMA/CA RTS CTS protocol

The payload at MAC layer is MSDU (MAC Service Data Unit). The MSDU includes all the overheads (header, trailer) of above layer and is treated as the payload at MAC layer for our calculations. As we have assumed that there is no collision in the network, therefore the back-off time of contention windows in system model would be fixed. The propagation delay (T_{delay}) equals 1 μs (we assumed that the distant between transmitter to receiver equals 300 m and speed of radio waves in air channel equal $3x10^8$ m/s). From Fig. 7, the total delay per MSDU of CSMA/CA RTS CTS protocol is calculated as:

$$T_{Delay\ per\ MSDU} = \begin{array}{l} T_{RTS} + 3T_{SIFS} + 4T_{delay} + T_{CTS} + T_{MSDU(size)} \\ + T_{ACK} + T_{DIFS} + T_{Backoff} \end{array} \quad (4)$$

From reference [1] [2] [3] and [4], we can find the transmission times for T_{RTS} , T_{CTS} , $T_{DATA\ or\ MSDU(size)}$ and T_{ACK} as follows:

$$T_{RTS\ 802.11a} = T_{Preamble} + T_{Signal} + T_{SYM}\left(\frac{L_{Service} + L_{Tail} + 8L_{RTS}}{N_{DBPS}}\right) \quad (5)$$

$$\begin{aligned} T_{CTS\ 802.11a} = T_{ACK\ 802.11a} &= T_{Preamble} + T_{Signal} \\ &+ T_{SYM}\left(\frac{L_{Service} + L_{Tail} + 8L_{ACK}}{N_{DBPS}}\right) \end{aligned} \quad (6)$$

$$\begin{aligned} T_{MSDU\ 802.11a} &= T_{Preamble} + T_{Signal} \\ &+ T_{SYM}\left(\frac{L_{Service} + L_{Tail} + 8(L_{MAC} + MSDU)}{Data\ rate}\right) \end{aligned} \quad (7)$$

$$T_{RTS\ 802.11b} = T_{Preamble} + T_{PLCPheader} + \frac{8L_{RTS}}{RTS\ rate} \quad (8)$$

$$\begin{aligned} T_{CTS\ 802.11b} = T_{ACK\ 802.11b} &= T_{Preamble} + T_{PLCPheader} \\ &+ \frac{8L_{ACK}}{ACK\ rate} \end{aligned} \quad (9)$$

$$T_{MSDU\ 802.11b} = T_{Preamble} + T_{PLCPheader} + \frac{8(L_{MAC} + MSDU)}{Data\ rate} \quad (10)$$

$$\begin{aligned} T_{CTS\ 802.11g} = T_{ACK\ 802.11g} &= T_{Preamble} + T_{Signal} \\ &+ T_{SYM}\left(\frac{L_{Service} + L_{Tail} + 8L_{ACK}}{N_{DBPS}}\right) + T_{EX} \end{aligned} \quad (11)$$

$$T_{RTS\ 802.11g} = T_{Preamble} + T_{Signal} + T_{SYM}\left(\frac{L_{Service} + L_{Tail} + 8L_{RTS}}{N_{DBPS}}\right) \quad (12)$$

$$\begin{aligned} T_{MSDU\ 802.11g} &= T_{Preamble} + T_{Signal} \\ &+ T_{SYM}\left(\frac{L_{Service} + L_{Tail} + 8(L_{MAC} + MSDU)}{Data\ rate}\right) + T_{EX} \end{aligned} \quad (13)$$

We can summarize the parameters value of IEEE802.11a/b/g for CSMA/CA RTS CTS protocol in table II [5] [6] [7]

Table II
System parameters in IEEE802.11a/b/g

Parameters	IEEE802.11a	IEEE802.11b	IEEE802.11g
T_{SIFS}	$16\mu S$	$10\mu S$	$10\mu S$
T_{DIFS}	$34\mu S$	$50\mu S$	$28\mu S$
T_{SLOT}	$9\mu S$	$20\mu S$	$9\mu S$
$T_{PLCP\ header}$	$16\mu S$	$48\mu S$	-
$T_{Preamble}$	$16\mu S$	$144\mu S$	$16\mu S$
T_{SYM}	$4\mu S$	-	$4\mu S$
T_{Signal}	$4\mu S$	-	$4\mu S$
T_{EX}	-	-	$6\mu S$
L_{RTS}	-	20 *bytes*	-
L_{MAC}	34 *bytes*	34 *bytes*	34 *bytes*
$L_{Service}$	16 *bits*	-	16 *bits*
L_{Tail}	6 *bits*	-	6 *bits*
L_{ACK}	14 *bytes*	14 *bytes*	14 *bytes*

The time spent while a packet travels from one node to another. Each time of packet frame is measured in microseconds. The notations are defined as follows and will be used calculation throughput in this research: [6] [7] [8]

T_{SLOT} = Slot time in μs

T_{SIFS} = SIFS time in μs

T_{DIFS} = DIFS time in μs

T_{ACK} = ACK transmission time in μs

$T_{DATA\ or\ MSDU(size)}$ = Transmission time for the payload in μs

T_{RTS} = RTS time in μs

T_{CTS} = CTS Transmission time in μs

$T_{Preamble}$ = Transmission time of the physical preamble in μs

T_{NDBPS} = Number of data bits per OFDM symbol

T_{EX} = Signal extension in μs

$T_{PLCPheader}$ = Transmission time of PLCP header in μs

T_{SYM} = Transmission time for a symbol in μs

L_{ACK} = ACK size in bytes

L_{DATA} = Payload size in bytes

L_{RTS} = RTS size in bytes

L_{CTS} = CTS size in bytes

MSDU = MAC Service Data Units in bytes

$T_{backoff}$ = Back off time of contention windows in μs

N_{DBPS} = 24, 48, 96 and 216 for OFDM-6, OFDM-12, OFDM-24, and OFDM-54, respectively

IV. PERFORMANCE EVALUATION

The throughput of CSMA/CA RTS CTS for IEEE802.11a/b/g used equations (3) to (13) with the parameters in table II for simulation. Our numerical results show the throughput and delay when data speeds of MSDU are changed. Fig. 8 shows the throughput of IEEE802.11a using OFDM modulation technique and the contention window is fixed at 6 time slots. The data rates of MSDU change at 6, 12, 24 and 54 Mbps respectively. Fig. 9 shows the throughput of IEEE802.11b using DSSS modulation scheme and the contention window is fixed at 31 time slots. The data rates of MSDU change at 1, 2, 5.5 and 11 Mbps respectively. From fig. 8 and 9, we can see that the sizes of MSDU increase as the throughputs increase. The throughput of higher data rate saturates much later than the throughput of lower data rates. Figure 10 plots the throughput of CSMA/CA RTS CTS for IEEE802.11b by comparison performance between DSSS with FHSS scheme. From our results, the DSSS technique has performance better than the FHSS technique when we fixed data rate at 1 and 2 Mbps respectively. Figure 11 shows the throughput for IEEE802.11g by using OFDM technique also the contention windows are fixed at 6 time slots. On graph, we can see that the throughput of IEEE802.11g increasing to follow MSDU sizes, furthermore it is easy to see that the throughput is an increasing (decreasing) function of the data rate.

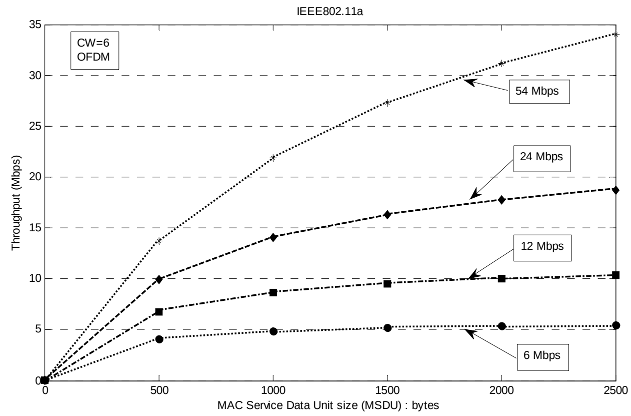

Fig. 8 Throughput of IEEE802.11a

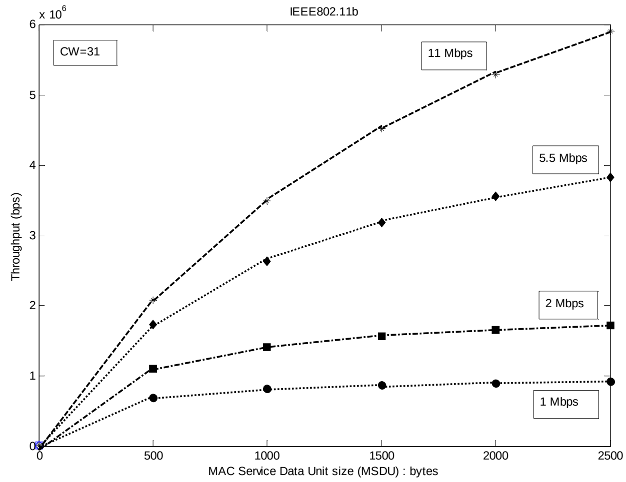

Fig. 9 Throughput of IEEE802.11b

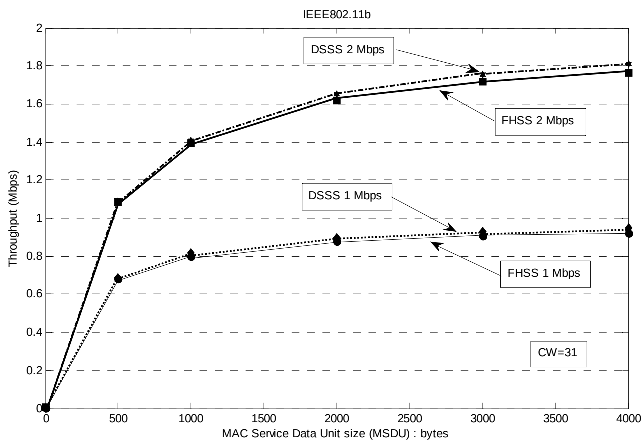

Fig. 10 Throughput of IEEE802.11b for DSSS and FHSS

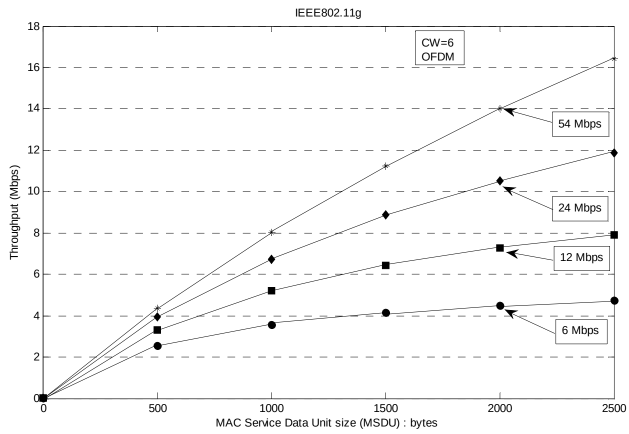

Fig. 11 Throughput of IEEE802.11g OFDM

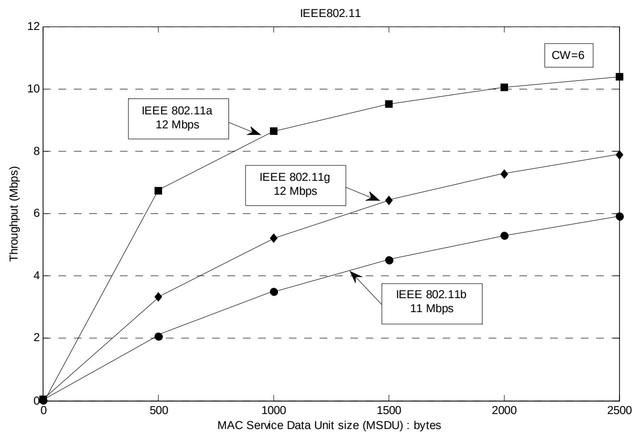

Fig. 12 Comparison Throughput of IEEE802.11a/b/g

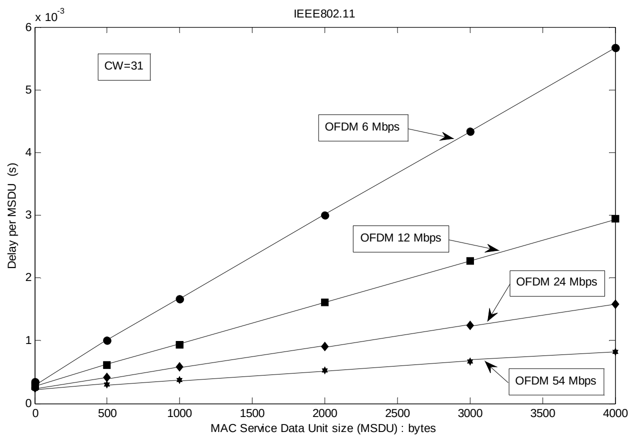

Fig. 13 Daley of IEEE802.11g

The throughput comparison of IEEE802.11a, IEEE802.11b and IEEE802.11g using CSMA/CA RTS CTS protocol is presented in Figure 12. In the figure, throughput of IEEE802.11a is batter than both IEEE802.11b and IEEE802.11g when we fixed data rate at 12 Mbps and contention windows at 6 time slots respectively; because, the IEEE802.11b and IEEE802.11g have header and inter frame space more than the IEEE802.11a.

Finally, we show the delay of IEEE802.11a when data rate and MSDU sizes are changed in figure 13. From the figure, we can see that the higher data rate has delay less than lower data rate.

V. CONCLUTION

In this paper, we present throughput analysis of CSMA/CA RTS CTS protocol which can completely solve the hidden terminal. The throughput and delay performance for IEEE802.11a/b/g standards for WLAN are considered. From our analytical results, we can see that the performance of IEEE802.11a is better than the both performance of IEEE802.11b and IEEE802.11g. The throughputs increase but the delay decrease when data rate is increased. If we neglected multi-path and fast fading channel, the performance of DSSS scheme is better than FHSS scheme for spread spectrum technology. In future work, the performance of CSMA/CA RTS CTS protocol in IEEE802.11a/b/g standards will be compared in teams of PER (Packet Error Rate) on interference, multi-path and fast fading channel.

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