Performance of MAC- IEEE802.11n-Over-Fiber Network in Presence of Errors in the Transmitting Channel

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ABSTRACT

An analytical model is presented to evaluate the MAC-protocol performance of the IEEE802.11n-over–fiber network with taking into account probability of error occurring in the transmitting channel. The results show that the data throughput with using RTS/CTS or basic access mechanism is suppressed with increasing amount of errors in the transmitting channel over all the range of fiber delay as well as it is very sensitive to the number of stations and packet length. And utilizing the RTS/CTS mechanism shows higher immunity than basic access mechanism when the network is utilized by high number of users and errors in transmission channel is relatively high.

أداء الماك (MAC) في بروتوكول IEEE 802.11n للشبكات اللاسلكية المحلية المرتبطة مع الليف الضوئي بوجود أخطاء في قناة الإرسال

الخلاصة

النموذج التحليلي المقدم هو موديل رياضي لتقيم أداء برتوكول ال ماك (MAC) IEEE 802.11n للشبكات اللاسلكية المحلية المحمولة على الليف الضوئي مع الاخذ بنظر الاعتبار احتمالية الأخطاء التي قد تحصل في قناة الإرسال. النتائج المستحصلة تبين انه عند استخدام ميكانيكية الوصول الثنائية (Basic access) أو الرباعية (RTS/CTS) فان نسبة عدد الحزم المرسلة (Throughput) تنخفض مع زيادة الأخطاء في قناة الارسال على طول مدى زمن التأخر في الليف الضوئي بالإضافة إلى ذلك فان نسبة عدد هذه الحزم المرسلة تكون حساسة جدا لعدد المستخدمين وحجم الحزمة. كذلك ان استخدام ميكانيكية الوصول الرباعية أظهرت مناعة أعلى من ميكانيكية الوصول الثنائية عندما يتم استخدم الشبكة من قبل عدد كبير من المستخدمين و قناة الإرسال ذات نسبة خطأ عالية نسبيا.

INTRODUCTION

In order to meet modern ever increasing user bandwidth and mobility demands, a wireless network based on radio over fiber (RoF) technology has been suggested as a promising solution [1]. In this network wireless signal is transmitted over optical fiber between the central site (CS) and remote antenna units (RAUs), and the RAUs serve as access points for mobile terminal units (WTUs) as illustrated in Fig.1. In such system, the majority components are kept away in the CS where most of the signal routing, processing and resource management are carried out. At RAU, only a simple optical/electrical conversion is implemented. The feasibility of the above architecture for wireless local area network (WLAN) over fiber optic has been demonstrated in Ref. [2-4].

In WLAN [5], the management of communications between various stations is performing by the Medium Access Control layer (MAC). The MAC 802.11n standard supports two schemes based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) to access the shared wireless medium. The default one is a two-way handshaking mechanism called basic access method. The positive MAC acknowledgement (ACK) is transmitted by the destination station to confirm the successful packet transmission. The other optional one is a four-way handshaking mechanism. In this case, the involved stations, i.e. stations activating the Request To Send (RTS) and the Clear To Send (CTS) packets, have the power to control the use of the medium between them. This scheme attempts to reserve the shared medium for the time duration needed to transfer the actual data frame prior to its transmission. During this period, all stations in the reserved area are restricted from transmission even though the channel is idle.

The distributed nature of the IEEE 802.11 medium-access-control (MAC) protocol makes it less tolerant to the insertion of a delay from an optical fiber link. There are numerous studies have investigated this effect [4] [6-8]. They show that the network throughput degrade by varying the length of the fiber. In addition, the maximum fiber length that can be inserted in 802.11 WLAN is limited by the Acknowledgement (ACK) and Clear to Send (CTS) timeout parameters depending on the access mode used. Another issue related to the IEEE 802.11 MAC is the hidden node problem; a simulation study in Ref. [9] has concluded that the RTS/CTS mechanism is beneficial in WLAN over fiber networks in the presence of hidden nodes. In recent our studies [10], the transport of Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) traffic over a fiber-fed IEEE 802.11n network. It has been concluded that the increase fiber delay degrades the TCP performance more than the UDP performance. However, most of these studies were performed for the IEEE 802.11 by assuming ideal channel.

In this paper, throughput of IEEE 802.11n over fiber networks using different MAC mechanisms for UDP transmission is investigated with considering the errors appearing in the transmission channel.

The paper is outlined as follows: Section 2 is devoted to explain the used model. Numerical results are analyzed in Section 3 and then our conclusions are drawn to Section 4.

MATHEMATICAL MODELING

In this section, a model is presented to investigate the maximum achievable throughput of the RTS/CTS mechanism for the IEEE 802.11n-over-fiber network and 2-way mode. It is taken into account probability of error which may occur in the transmitting channel. Then, a comparison between performances with using of these modes is offered. Then, number of users and fiber delay on the overall performance is investigated.

Error-Prone Channel

Influence of error in the transmitting channel may be included through considering the parameter α as discussed in [11].
In the case of employing basic access mechanism [11]:

$$\alpha = 1 - (1 - BER)^{L} \qquad .....(1)$$

Where $L = 2PLCP + ACK + DATA$. In the case of using RTS/CTS mechanism [11]:

$$\alpha = 1 - (1 - BER)^{4PLCP} * (1 - BER)^{RTS} * (1 - BER)^{CTS} * (1 - BER)^{ACK} * (1 - BER)^{DATA} \qquad ......(2)$$

Packet Transmission Probability

Our analysis assumes that the network consists of n contending stations and that each station has always a packet available for transmission. The probability of a station to transmit a packet in a randomly chosen slot time is [10]:

$$\sigma = \frac{1 - p^{m+1}}{1 - p} . b_{0,0} \qquad .....(3)$$

Where

$$b_{0,0} = \frac{2(1 - 2p)(1 - p)}{(1 - 2p)(W + 1) + pW(1 - (2p)^{m})} \qquad ......(4)$$

σ Does not depend on the type of the mechanism adapted by a station: basic access or RTS/CTS mechanism. Instead, it depends on the number of the backoff stages m, and the conditional collision probability p. To find the value of p it is necessary to know the probability p that a transmitted packet encounters a collision, which means, at least one of the n - 1 remaining stations transmits in a time. So for error prone channel case, the probability that each packet collides after launched into the channel, the conditional collision probability, is [11]:

$$p = 1 - (1 - \sigma)^{n-1}(1 - \alpha) \qquad ......(5)$$

Maximum Throughput Analysis

Let ***Th*** be the normalized system throughput, defined as the fraction of time the channel is used to successfully transmit payload bits. To compute ***Th***, an analysis for what can happen in a randomly chosen slot time. P_{tr} be the probability that there is at least one transmission in the considered slot time. Since stations contend on the channel, and each transmits with probability σ, then [11]

$$P_{tr} = 1 - (1 - \sigma)^{n} \qquad .....(6)$$

The probability P_s that a transmission occurring on the channel is successful is given by the probability that exactly one station transmits on the channel, conditioned on the fact that at least one station transmits, i.e. [10]

$$P_s = \frac{n\sigma\,.(1-\sigma)^{n-1}(1-\alpha)}{P_{tr}} = \frac{n\sigma\,.(1-\sigma)^{n-1}(1-\alpha)}{1-(1-\sigma)^n} \qquad \dots\dots(7)$$

Then the throughput can be calculated as [10]:

$$Th = [\,P_s\,.P_{tr}\,.E_{[Packet]}]/[(1-P_{tr})\delta + P_s\,.P_{tr}.T_{success}^{Operational_{mode}} + (1-P_s)\,.$$

$$P_{tr}.T_{Failur}^{Operational_{mode}}] \qquad \dots\dots(8)$$

The average of data packet payload size in bits is $E_{[Packet]}$. A successful transmission in a Slot Time (δ) occurs with the probability of P_sP_{tr}. The average time the wireless channel is sensed busy because of a successful transmission $T_{success}^{Operational\_mode}$ and because of an unsuccessful transmission $T_{Failur}^{Operational\_mode}$ depends on the operational mode, i.e., the mechanism and the type of packet traffic used by the system.

If the basic access method is used over the fiber, illustrated in Fig.2-a, the following equations are obtained:

$$T_{success}^{bassic} = \{DIFS + 2(T_{PLCP} + F + a) + T_{ACK} + SIFS + T_{DATA}\} \qquad \dots\dots(9)$$

$$T_{Failure}^{bassic} = \{DIFS + T_{PLCP} + ACK_{Timeout} + 2F + T_{DATA}\} \qquad \dots\dots(10)$$

Figure 2-b depicts the case of employing the RTS/CTS mode and the following equations obtained:

$$T_{success}^{RTS} = \{DIFS + 4(T_{PLCP} + F + a) + T_{RTS} + T_{CTS} + T_{ACK} + 3SIFS + T_{DATA}\} \qquad \dots\dots(11)$$

$$T_{Failure}^{RTS} = \{DIFS + T_{PLCP} + T_{RTS} + CTS_{Timeout} + 2F\} \qquad \dots\dots(12)$$

ANALYSES FOR THE ACHIEVED RESULTS

The values of parameters used to obtain numerical results, are specified for the IEEE 802.11n PHY and MAC layer as given in Table (1). The values of the ACK $_{Timeout}$ and CTS $_{Timeout}$ are not specified in the standard, and they have been set equal to 87.074 µs. This numerical value has been chosen as it is sufficiently long to contain a SIFS, the ACK transmission and a round trip delay for air and optical fiber. The refractive index for optical fiber is 1.5.

Table (1): Numerical Parameters [10]

Slot-time (δ)	***9 μs***
SIFS	***16 μs***
DIFS	***34 μs***
PLCP Preamble & Header	***24 μs***
MAC Hader & FCS	***40 byte***
Data rate	***144.44 / 300Mbps***
Basic rate	***54 Mbps***
Control rate	***6 Mpbs***
Payload E [P]	***8000 bits***
CTS & ACK	***14 bytes***
RTS	***20 bytes***
Air propagation delay (α)	***1 μs***
Fiber propagation delay (F)	***1 μs = 194.8 m***
W (min Window size)	**15**
$ACK_{Timeout}$ ***or*** $CTS_{Timeout}$	***(42.074+2δ) μs***

Figure 3 shows the throughput in the network as the expected fiber delay for real time applications with excellent services [12] with adopting RTC/CTS and basic access. The results are considered for three different channel states: Ideal, BER = 10^{-4} and 10^{-5}. It can be clearly seen that throughput decreases gradually with increasing fiber length and more sharp decrease when the ACK or CTS Timeout expires. The $ACK_{timeout}$ and $CTS_{timeout}$ have been chosen equal to allow the insertion of the same fiber length, regardless of the mode. In additional, Fig.3 shows that the throughputs are sensitive to channel state where throughput decreases as BER increase. This difference is due to the effect of the parameter α on conditional collision probability, which could be much sensible at higher level of BERs.

Typical analytical throughput versus BER is shown in Fig. 4 with fiber delay of 22.24 μs (i.e., 4.3 km, which corresponding to achieve ACK, $CTS_{Timeout}$ = 87.074μs). The curves in the figure correspond to the throughput with payload size configured as 2000, 5000 and 8000 bits. From the achieved results, it is observed that the throughput level is decreasing with increasing errors in the channel over all the payload size value. Fig.(3) and (4) are given for one transmitting node.

Figure (5) shows throughput in a network as the expected load changes from 1–100 stations, for a fiber delay of 22.24 μs (i.e., 4.3 km) for different BER with using RTC/CTS, and basic access modes. It can be clearly seen that level of throughput is better with using RTS/CTS than basic access in the high load area and when errors in transmission channel is relatively high. Specifically, for the 22.24 μs delay and BER = 10^{-4}, when the number of contending stations in the network is more than 50, the RTS/CTS mechanism should be used to maximizes the throughput.

CONCLUSIONS

In this paper the performance of IEEE 802.11n over fiber network is analyzed. The computations have taken into consideration influence of fiber delay, the error level in the utilizing transmission channel, payload size, type of the transmission channel mechanism, and the size of the network. The achieved results demonstrating that there is a tradeoff between the throughput and fiber length in both DCF's mechanisms (i.e. RTS/CTS and basic access). And, for the networks using basic access and RTS/CTS mechanism, the throughput is suppressed with increasing amount of errors in the transmission channel over all the available range of the fiber delay, payload size as well as it is sensitive to the size of the network.

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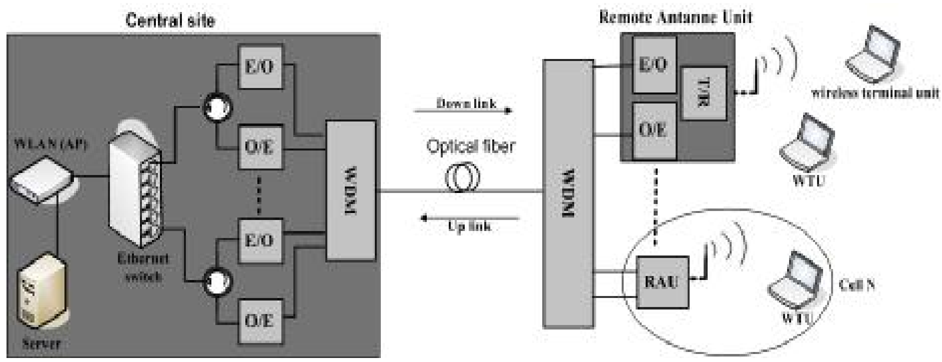
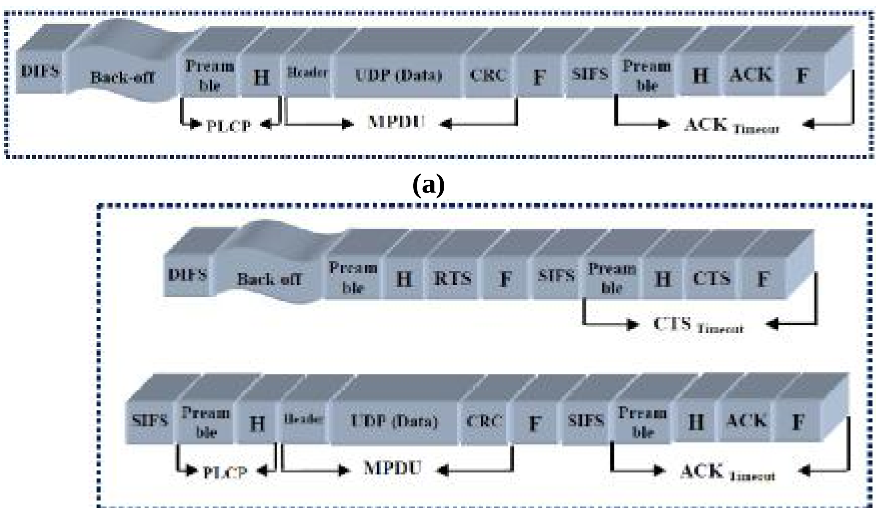


Figure (1) Block diagram for a WLAN over fiber network.



(b)

Figure (2): Packet exchange of RTS/CTS and basic access method when UDP traffic is used within a hybrid optical-wireless 802.11 networks. (a) UDP traffic over RTS/CTS mechanism. (b) UDP traffic over RTS/CTS mechanism [10].

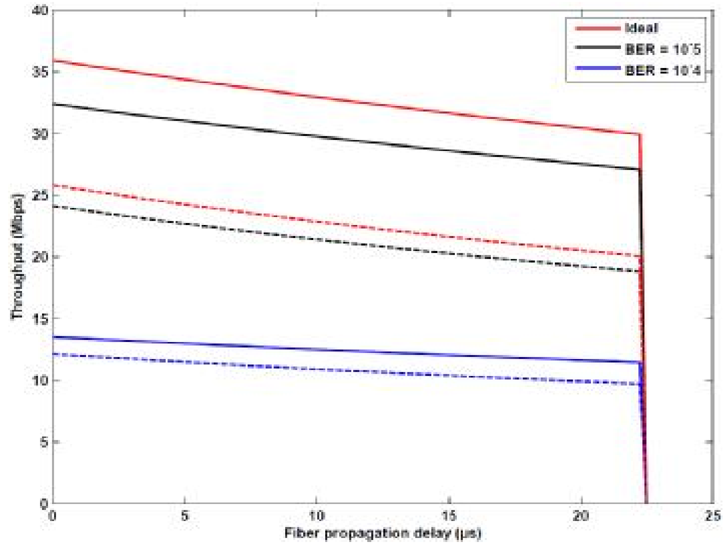


Figure (3): Variation of throughput with fiber delay for UDP Traffic when the basic access (represented by solid line), and RTS/CTS (represented by dashed line) method is Used for different BER.

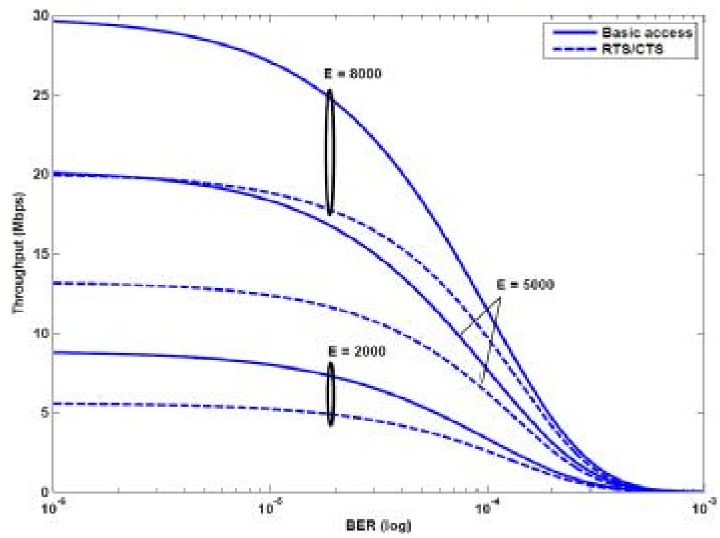


Figure (4): Throughput versus BER with different payload size and fiber delay = 22.24 µs.

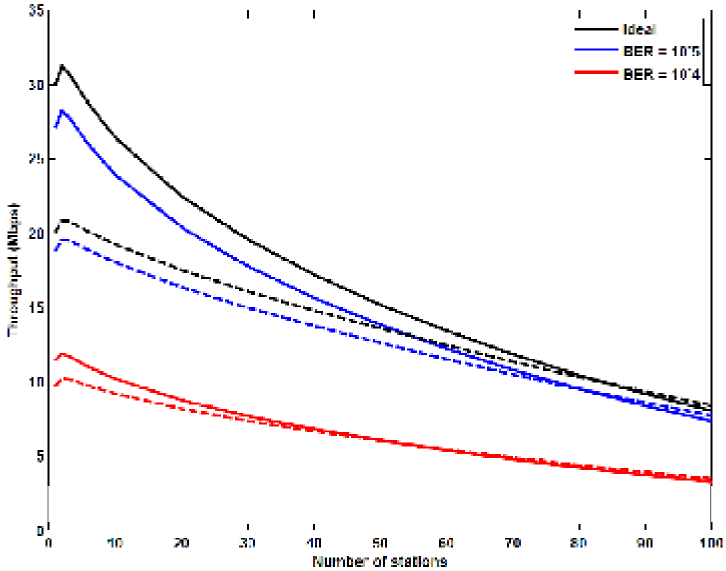


Figure (5): Variation of throughput with number of user for UDP traffic when the basic access (represented by solid line), and RTS/CTS (represented by dashed line) method is used for different BER and fiber delay = 22.24 µs.