Multipacket Reception for Multiple Antenna Systems in IEEE802.11n-over- Fiber Network

Ali M. Alsahlany, Haider M. AlSabbagh, *Member, IEEE,* and Saod A. Alseyab

Abstract — **This paper investigates performance of the medium access control (MAC) protocol in MPR/IEEE 802.11n over fiber network. A closed-form expression for the maximum throughput is derived. Based on the presented model effects of the number of antennas used by remote antenna units (RAUs), fiber propagation delay and network size on the performance of MAC is analyzed and illustrated. The achieved results show that this system is considerably capable to increase throughput more than the physical layer (PHY) data rate. All results are presented for two state of channels; ideal and error-prone.**

Keywords — **MPR, 802.11n, ROF, MAC, RTS/CTS.**

I. Introduction

Recently, Multiple input multiple output (MIMO) technology using multiple antennas at both ends of a communication link have received a particular attention because of the potential capability to deal with capacity and quality issues in communication systems [1]. Radio over fiber (RoF) technology is a promising approach that allows efficient remote antenna units (RAUs) to connect to a central station (CS) unit via optical fiber links. RoF networks have numerous benefits in perspective of centralization of signal processing such as modulation, demodulation, multiplexing, de-multiplexing, handover, and protocol transformation. Also, have transmission links (fiber optic) benefits such as low attenuation, reliability, high bandwidth and interference tolerance [2].

A considerable efforts have been conducted to investigate possibility of incorporation MIMO technology of the new standard of wireless local area network (WLAN) (i.e IEEE 802.11n) into RoF technology [3-6]. This integration may result even more improvements in perspective of coverage and throughput with respect to employing a single input single output (SISO) technique when incorporated with RoF technology. The maximum improvement of throughput added by MIMO technology for conventional IEEE802.11n or with RoF network cannot exceed the physical layer data rates [3, 7-8].

A multi packet reception (MPR) technique [9] is one of the most promising future technologies for WLAN to realize a throughput exceeds the limits of the exchange data rate for the physical layer [10-12]. This technique depends on improvements in the physical (PHY) and the medium access control (MAC) layers. A new MPR technique PHY-layer, which enables distributed spatial multiplexing gain, is based on the IEEE 802.11n PHY-layer. To support such reception technique a new MAC is needed. The channel access mechanism in IEE8022.11n MAC uses carrier sense multiple accesses with collision avoidance (CSMA/CA) [13]. The collision of packets occurs when more than one station transmits their packets at the same time. With MPR technique, it is possible for a receiver to detect multiple packets simultaneously without causing collisions.

Most studies analyze performance of the MPR technique has been presented for the conventional WLAN [9, 12, 14-15]. This paper presents a study for the MAC-layer throughput performance for IEEE802.11n over RoF network when MPR is used. The achieved results indicate that the maximum throughput increases roughly linear with number of antennas and is not limited by the PYH layer data rates.

The paper is outlined as follows. Section II is devoted to explain the MPR/IEEE 802.11 MAC protocol within the context of hybrid optical wireless systems. Throughput performance of MPR/IEEE802.11n over fiber networks using RTS/CTS mechanism, in both channel case ideal and error-prone channels given in section III and the conclusions are drawn to section IV.

II. MPR-MAC Protocol

In this section performance of the MAC protocol for MPR in RoF network is analyzed. Details of the MPR MAC protocol and PHY implementation are based on the Ref [16] after extension it to support the RoF networks. The proposed protocol uses the IEEE 802.11 distributed coordinate function (DCF) with four way handshake mechanism to access the channel. Figure 1 shows the central station (CS) associated with a set of wireless terminal units (WTUs) across single mode optical fiber. Each RAU is working to coverage a single cell with an n associated client stations. Each RAU has the ability to receive up to M ($M \geq 1$) packets simultaneously. Where M is the number of antennas used at each RAU.

Figure 2 illustrates transmitting packets with using RTS/CTS mechanism. The station starts with transmitting a first packet of RTS frame to the CS across the RAU. In the MPR-MAC model, when multiple stations transmit RTS frames at the same time, the CS can successfully detect all the RTS frames if and only if the number of RTSs is no larger than M, which is one of the highlighted features to serve numerous users simultaneously with using such system. This is unlike that with conventional system which one user can be served at each time and collisions may be take place when more than one user try to access the channel simultaneously. When the number of transmitting stations exceeds M, collisions occur and the CS cannot decode any of the RTSs. The stations retransmit their RTS frames after a backoff time period according to the original IEEE 802.11 protocol.

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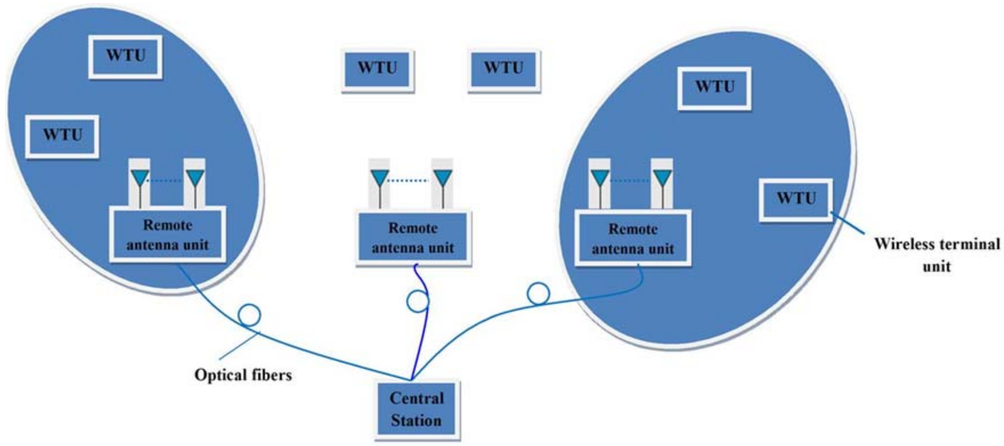

Fig. 1: Simplified MPR and RoF link.

When the CS detects the RTSs successfully, it responds after an SIFS period, with a CTS frame that grants transmission permissions to all the requesting stations. Then, the transmitting stations start transmitting DATA frames after an SIFS, and the CS acknowledge the reception of the DATA frames by an ACK frame. Unlike that stated in the previous analyses for MPR-MAC, where the extra propagation delays of fiber link are not considered. Each packet in the transmission is associated with a fiber delay (F) which should be taken into account and be added as extra delay besides the air propagation delay (A) when setting the CTS timeout and ACK timeout. Otherwise, the timeout could be exceeded due to the fiber delay in which case the number of retransmissions increases and consequently the performance degrades significantly. This can even lead to a complete network shutdown.

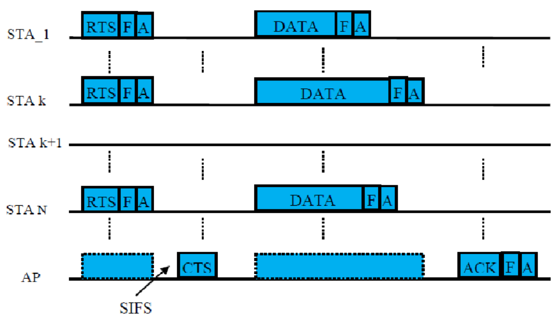

Fig. 2: Time line example for the MPR MAC.

III. THROUGHPUT OF ROF NETWORK WITH MPR

Throughput is one of the most important measurement parameters which are required to evaluate performance of communication systems. This section is conducted to investigate the saturation throughput of a WLAN over fiber network using MPR technique. Here saturation throughput meant that all stations (STAs) always have data are ready to be transmitted. The calculations take into account effects number of packets received simultaneously (i.e., number of antenna at RAU), as well as, network size (i.e., number of stations) over different lengths of fibers.

Suppose there are n STAs contending for channel access, and each transmits with probability τ in a given slot time. Let P_{tr} be the probability that there is at least one transmission in the slot time. Then

$$P_{tr} = 1-(1-\tau)^n \quad (1)$$

The conditional probability P_{s1} that a single-packet transmission is successful is given by the probability that only one STA transmits, conditioning on the fact that there is at least one transmission,

$$P_{s1} = \frac{n\tau(1-\tau)^{n-1}}{P_{tr}} \quad (2)$$

Generally, let P_{sk} be the probability that a k-packet simultaneous transmission is successful. It is given by the probability that k STAs transmit, conditioning on the fact that there is at least one transmission,

$$P_{sk} = \frac{\binom{n}{k}\tau^k(1-\tau)^{n-k}}{P_{tr}} \quad (3)$$

We define the throughput Th to be the ratio of average payload bits which are transmitted successfully in a time slot and the duration of the time slot. Therefore,

$$Th = \frac{\sum_{k=1}^{M} k\, P_{sk}\, P_{tr} E[L]}{(1-P_{tr})\sigma + \sum_{k=1}^{M} P_{sk} P_{tr} T_{sk} + P_{tr}(1-P_s) P_{tr} T_c} \quad (4)$$

where $E[L]$ is the average payload length in bits, $T_{success}^{RTS/CTS}$ is the average slot time spent when there are successful k-packet transmissions, $T_{Failur}^{RTS/CTS}$ is the average slot time when there are collisions, and

$$P_s = \sum_{k=1}^{M} P_{sk} \quad (5)$$

is the conditional probability of successful transmissions in a busy time slot (σ).

with taking RTS and CTS packet length into account the average slot time be as:

$$T_{sk} = RTS + SIFS + \delta + F + CTS + SIFS + \delta + F + H + \frac{E[L_k^*]}{R} + SIFS + \delta + F + ACK + DIFS + \delta + F \quad (6)$$

$$T_c = RTS + DIFS + \delta + F \quad (7)$$

Where F is the fiber propagation delay; δ is the air propagation delay; $H = PHY_{(header)} + MAC_{(header)}$ is the total overhead time to transmit the packet headers; $E[L_k^*]$ is the average length (in bits) of the longest payload involved in a k-packet simultaneous transmission; and R is the data rate for payload transmission. We assume that all packets have the same fixed length, i.e., the average length

$E[L_k^*]= E[L] =L$ ($1\leq k \leq M$) and $T_{sk} =T_s$, where L and T_s are constants.

It is clear from (4) that *Th* is a function of τ. Therefore, the optimal value of τ, which maximizes *Th*, can be obtained by solving the equation $dTh\ /d\tau\ =\ 0$.

As shown in [17], analysis of the Markov chain model leads to the following two equations:

$$\tau = \frac{2(1-2p)}{(1-2p)(W+1)+pW(1-(2p)^m)} \tag{8}$$

And

$$p = 1 - \sum_{k=0}^{M-1} \binom{n-1}{k} \tau^k . (1-\tau)^{n-1-k} \tag{9}$$

In the above, p is the conditional collision probability, W is the minimum contention window size, and m is the maximum backoff stage. Let us consider the analyses for two cases:

A. Ideal Channel

Let us consider the channel with ignoring all types of errors to evaluate performance of the proposed MPR/IEEE 802.11n over fiber network. In this case – ideal channel –is investigated here for comparison purpose to measure amount of improvements with employing the system in practical environment. Results in Fig. 3 represent the maximum throughput of MPR for different values of *M*. Assuming the fiber delay = 22.4µs (i.e. fiber length = 4.3km) and the number of active stations n = 50, and other parameters as listed in Table I. Figure 3 shows that the maximum throughput increases roughly linear with *M* and is not limited by the physical layer data rates. In other words, maximum throughput is infinitely scalable with *M*, when only the MAC protocol is taken into account.

TABLE 1: THE PARAMETER VALUES.

Slot-time (σ)	9
SIFS (Short Inter-frame space	16
DIFS = (2Slot-Time+SIFS)	34
PLCP Preamble & Header	24
MAC Hader	40 byte
Data rate	144.44 Mbps
Basic rate	54 Mbps
Control rate	6Mpbs
Payload E [P]	8000 bits
CTS & ACK	14bytes
RTS	20bytes
Air propagation delay (δ)	1
Fiber propagation delay (F)	1µs = 194.8m
W (min Window size)	15
ACK_Timeout or CTS_Timeout	(42.074+2δ) µs

Figure 4 illustrates variation of the maximum throughput with fiber propagation delay for various *M*. Amount of the throughput decreases gradually with increasing fiber propagation delay and sharply decreases when the $CTS_{timeout}$ expires. The $CTS_{timeout}$ have been chosen equal to allow the insertion fiber length to go up to 4.3 km. Increasing the $CTS_{timeout}$ allows the system to wait longer in order to receive the CTS packets. Also, Fig.4 shows that the throughputs are sensitive to *M* where throughput increases as *M* increase. This difference is due to increased number of packets are received simultaneously at the RAU.

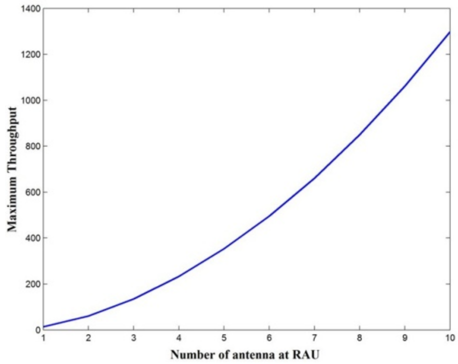

Fig.3: Maximum throughput of MPR/IEEE 802.11n over fiber as a function of *M* when the RTS/CTS method is used for fiber delay 22.4µs and number of active stations n = 50.

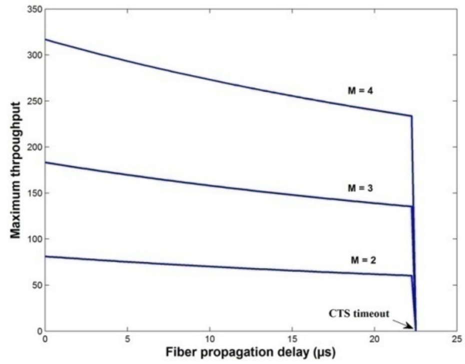

Fig.4: Variation of throughput with fiber delay when the RTS/CTS method is used and number of active stations n = 50.

Figure 5 illustrates the throughput in the network as the number of user increases from 10–100 stations, for different packet receptions: M = 2, 3, 4. It is shown that for small values of *M* the throughput decreases gradually when number of user increases. This is due to increasing number of collisions as number of users getting higher which yields that number of reaching packets to the destination is low.

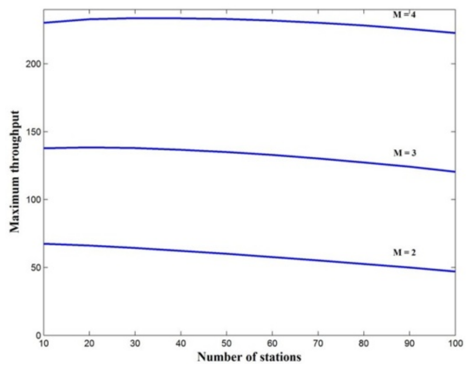

Fig.5: Variation of throughput with number of user when the RTS/CTS method is used for fiber delay 22.4µs.

B. Error- Prone Channel

Influence of error in the transmitting channel may be included through considering the parameter *pc* as introduced in Ref [18]. We modify and extend it to consider MPR/IEEE802.11n over fiber systems.

In the case of RTS/CTS mechanism:

$$P_c = 1 - *(1-BER)^{RTS} * (1-BER)^{CTS} * (1-BER)^{ACK} * (1-BER)^{DATA} \tag{10}$$

So for error prone channel case, the probability that a k-packet simultaneous transmission is successful, it is given by

$$P_{sk} = \frac{\binom{n}{k}\tau^k(1-\tau)^{n-k}(1-P_c)}{P_{tr}} \quad (11)$$

Which is proportional to amount of error in the channel via P_c .

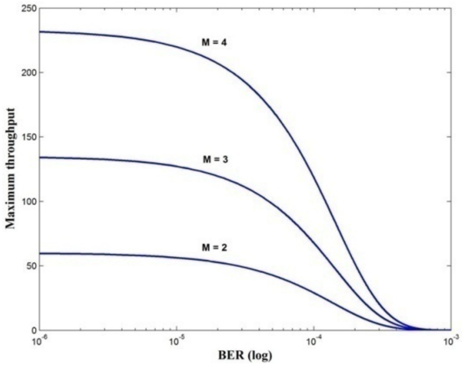

Fig. 6: Throughput versus BER with different M and fiber delay = 22.24µs.

The impact of BER on maximum throughput is shown in Fig.6 for $M = 2$, 3 and 4. When a BER increases in the used channel from10^{-6} to 10^{-3}, the maximum throughput degrades to almost zero over all M values when amount of the error exceed around 10^{-4}. This effect is due to influence of the parameter Pc on probability successful k-packet simultaneous transmission (P_{sk}).

Figure 7 shows the RTC/CTS throughput in a network as the fiber delay changes, for two different channel states: BER= 10^{-4} and 10^{-5}. The throughput decreases gradually with increasing fiber length and sharply decreases when the $CTS_{Timeout}$ expires. In addition, Fig.7 shows that the throughput is sensitive to channel state where throughput decreases as amount of BER increases.

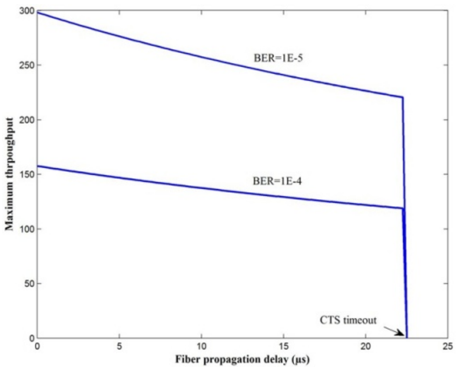

Fig. 7: Variation of throughput with fiber delay when RTS/CTS is used for different BER and $M = 4$.

IV. CONCLUSION

This paper presents analyses for the performance of MPR/IEEE802.11n over fiber network that allows for more than one antenna (i.e. M antenna) to be used by the RAU and then k-packets to be simultaneously transmitted without collision. Analytical expressions have been derived for this system and have analyzed the variation of maximum throughput with respect to M. Besides influence of M the analyses have taken into consideration influence of fiber propagation delay and number of stations. The achieved results are considered for two channel states, namely, ideal and practical cases. With using an ideal channel, the results demonstrating that the maximum throughput increases roughly linear with M. And, the throughput decreases gradually with increasing fiber propagation delay and number of active stations.

On the other side, with employing an error-prone channel, the throughput is suppressed with increasing amount of errors in the transmission channel over all the available range of the fiber propagation delay, as well as it is very sensitive to M.

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