Performance study of Wireless-Optical 802.11 Network using TCP and UDP Packet Transmission

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Abstract: In this paper the MAC-performance of an optically distributed IEEE 802.11 network using TCP and UDP transmission is mathematically analysed and the results are verified by Network Simulator (NS-2). In wireless-optical 802.11 networks radio frequency signals are distributed from a central location to remote antenna sites for mobile and fixed users. Our study takes into account both the Basic and RTS/CTS methods (i.e. the current DCF access mechanisms) using various TCP and UDP packet sizes over different length of fibre. The results show that the performance of the system increases as the data packets grow in size.

1. Introduction

Hybrid wireless-optical access networks are a promising architecture for future access networks [1]. In such systems the Remote Antenna Unit (RAU) is very compact and the radio channel assignment is performed at a centralised location away from the remote unit. The majority of the base station components are positioned at a central location where the signal processing is carried out. Figure 1 illustrates this design, where the main unit, i.e. the Access Point, and its antenna are separated and connected together by an optical fibre link. This results in a less complex and more compact RAU [2].

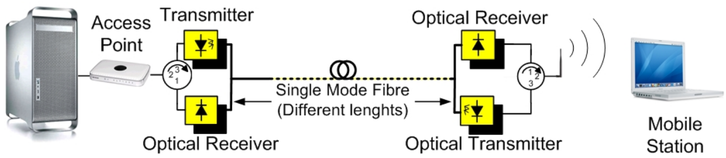

Figure 1: Wireless-Optical 802.11 Architecture

The applicability of deploying optical fibre into the IEEE 802.11 architecture has been shown in [3]. We evaluate the MAC performance of the above RoF system, in terms of the throughput, by varying the TCP and UDP data packet sizes. In addition, we consider two different length of fibre in our investigation. These two values are chosen to match the timeout values used within the experimental work of [4].

2. Overview of the IEEE 802.11 MAC Protocol

The Medium Access Control Layer (MAC) manages communications between various stations and its functionality is common between 802.11a/b/g standards. In this paper we follow the parameters of the popular IEEE 802.11b standard, which supports up to 11 Mbps data rate. The 802.11 MAC supports two schemes (the Basic and RTS/CTS methods), which are based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) to access the shared wireless medium.

After a successful transmission, when using the Basic mode, illustrated in Figure 2, , the destination station waits for a Short Inter-frame Space (SIFS) interval and then sends an Acknowledgement packet (MAC ACK) to confirm the correct reception of data [5]. The same procedure is applied when the 'ack' (TCP acknowledgement packet) is sent back to the source station, to provide confirmation of the successful reception of data at the TCP layer. Note, unlike TCP, UDP does not guarantee reliability and hence data packets do not get acknowledged at UDP level.

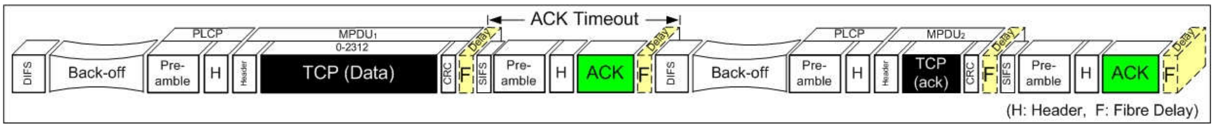

Figure 2: The Basic Access Method in an optically distributed 802.11 Network using TCP transmission

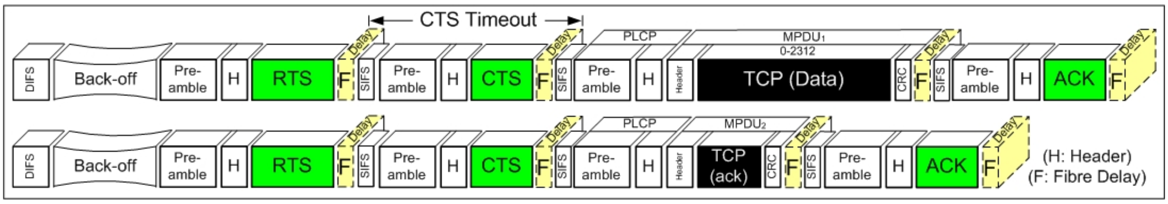

Figure 3: The RTS/CTS Mechanism in an optically distributed 802.11 Network using TCP transmission

In the second method, illustrated in Figure 3, the 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 data frame prior to the transmission [6] [7].

According to Figure 2 and Figure 3, each packet is associated with an optical fibre delay when traverses through the fibre. This delay is more evident in the RTS/CTS method than the Basic mode due to the higher number of overhead packets being involved.

3. Performance Evaluation

A mathematical model was created to examine the effect of different TCP and UDP packet sizes on the performance of the Wireless-Optical Broadband System (WOBAN). All the parameters used in the model are given in Table 1. Equation (2) calculates the throughput of the system.

$$Throughput = \frac{Ps.E[Packets]}{Ps.T_{success}^{Operational\_Mode} + Pc.T_{failure}^{Operational\_Mode}} = \frac{\sum_{i=1}^{N} Ps.Packet(i) \Big/ N}{Ps.T_{success}^{Operational\_Mode} + (1-Ps).T_{failure}^{Operational\_Mode}} \qquad \textbf{(2)}$$

RTS/CTS Mode:

$$T_{Success}^{RTS-TCP}(i) = 2DIFS + 2\overline{CW}(i) + 8T_{PLCP} + 2T_{RTS} + 2T_{CTS} + 2T_{ACK} + 6SIFS + T_{MPDU_1} + T_{MPDU_2} + 8\tau + 8\delta$$

$$T_{Success}^{RTS-UDP}(i) = DIFS + \overline{CW}(i) + 4T_{PLCP} + T_{RTS} + T_{CTS} + T_{ACK} + 3SIFS + T_{MPDU_1} + 4\tau + 4\delta$$

$$T_{failure}^{RTS}(i) = DIFS + CW(i) + T_{PLCP} + T_{RTS} + CTS\_Timeout + \tau + \delta$$

Basic Mode:

$$T_{Success}^{Basic-TCP}(i) = 2DIFS + 2\overline{CW}(i) + 4T_{PLCP} + 2T_{ACK} + 2SIFS + T_{MPDU_1} + T_{MPDU_2} + 4\tau + 4\delta$$

$$T_{Success}^{Basic-UDP}(i) = DIFS + \overline{CW}(i) + 2T_{PLCP} + T_{ACK} + SIFS + T_{MPDU_1} + 2\tau + 2\delta$$

$$T_{Failure}^{Basic}(i) = DIFS + \overline{CW}(i) + T_{PLCP} + T_{MPDU_1} + ACK\_Timeout + \delta + \tau$$

Where, the average value for the Backoff Window is calculated in equation (3).

$$\overline{CW}(i) = \begin{cases} \frac{2^i.(CW_{min}+1)-1}{2} \times Slot\_Time & 0 \le i < 6 \\ \frac{CW_{max}}{2} \times Slot\_Time & i \ge 6 \end{cases} \qquad (i \text{ is the number of unsuccessful attempts}) \qquad \textbf{(3)}$$

Equation (2) and (3) assumes *Packet(1) = Packet(i) = Packet(N)* $= L_{MSDU_1}$. $T_{success}$ is the total time that it takes for a data frame to be successfully received at the receiver, whereas $T_{failure}$ is the time that is wasted when the transmission fails. P_S is the probability of a successful transmission and P_C is the probability of a failure (or collision).

Table 1 – Parameters used

Slot_Time	*20* μs
SIFS (Short Inter-frame Space)	*10* μs
DIFS = (2.Slot_Time+SIFS)	*50* μs
PLCP Preamble & Header	*24 bytes*
MAC Header & CRC	*34 bytes*
(Data rate, Control rate)	*(11,1) Mbps*
RTS	*20 bytes*
$P_C = 1 - P_S$	*0*
CTS or ACK	*14 bytes*
Air propagation delay (δ)	*<* $1 \mu s$
Fibre propagation delay (τ)	$1\mu s \equiv 194.80 m$
$(CW_{\min}, CW_{\max})$	*(31, 1023)*
L_{MPDU_2} *(ack data packet)*	*84 bytes*
L_{MSDU_1} *(Data packet - MAC overhead)*	*100 – 2312 bytes*

To verify the theoretical work presented in this paper, we have also simulated the effect of various TCP and UDP data packet sizes using the popular network simulator, NS-2. In simulation a delay module has been inserted in the wireless channel. The delay module postpones every packet that goes through the channel for a fibre delay. The fibre delay is specified for two different lengths of fibre, i.e. 8.2km and 13.2km. The data packet length is kept constant in each simulation (100, 500, 1000, 1500, 2000, 2312 bytes). Each data point is the average of 5 simulation runs. Note, unlike our analysis, there are 5-7% of data packets being transmitted concurrently with one set of RTS, CTS and ACK packets in NS-2. This has a slight increasing effect on the throughput of NS-2 compared to the theoretical analysis.

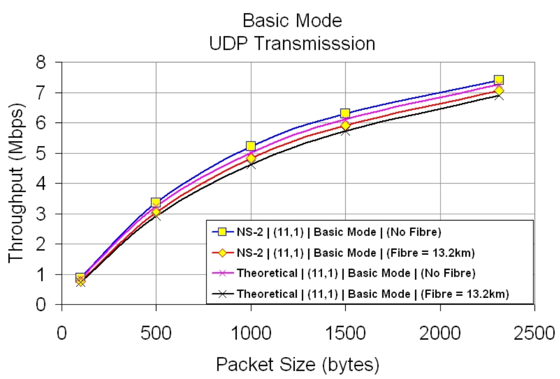

Figure 2: UDP transmission - Basic mode

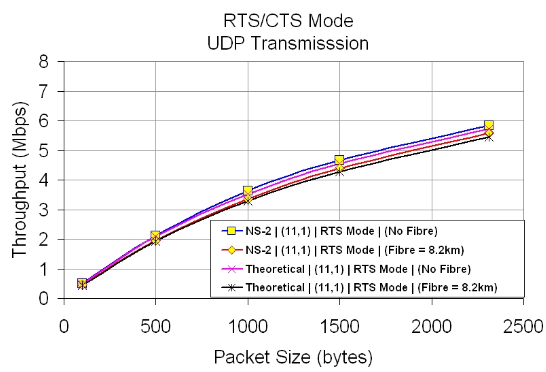

Figure 3: UDP transmission – RTS/CTS mode

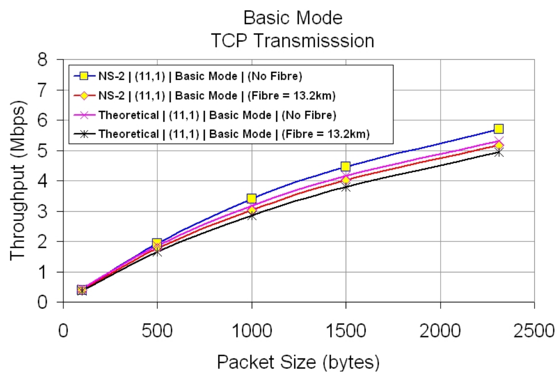

Figure 4: TCP transmission - Basic mode

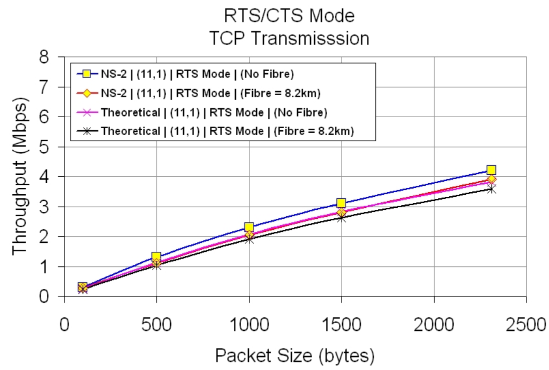

Figure 5: TCP transmission – RTS/CTS mode

Figure 2 shows the throughput of UDP transmission over the Basic access mode. The performance of an 11Mbps system (according to NS-2) reaches around 7.4Mbps with zero fibre length and packet size of 2312 bytes (which is the maximum allowable MAC payload). However, the performance is decreased to 7Mbps when 13.2km of fibre is employed (with the same packet length). For the case of having a packet size of 1000 bytes the throughput decreases to 5.22Mbps (no fibre in the system) and 4.82Mbps (13.2km fibre). Comparing Figure 2 with Figure 3 shows that the rate of the throughput increase is less when using the RTS/CTS mode due to extra overhead packets. As an example, the throughput in the RTS/CTS mode is 5.83Mbps when the packet size is 2312 bytes and no fibre is used in the system. This value is decreased to 5.5Mbps when 8.2km of fibre is deployed.

In TCP packet transmission (Figures 4 and 5) the performance is decreased comparing to UDP transmission. The reason for this is due to fact that, unlike UDP, TCP data packets get acknowledged at the TCP layer. For instance, the TCP throughput over the Basic mode is 5.7Mbps (no fibre and packet size of 2312) compared to 5.1Mbps when 13.2km of fibre is available.

4. Conclusions

The effect of different UDP and TCP packet sizes on the performance of a hybrid wireless-optical IEEE 802.11 network is investigated by means of theoretical analysis. To verify the results, simulations have been carried out using the modified NS-2 IEEE 802.11 model. The results show that the system's throughput increases as the data packet grows in terms of size. However, as the length of the fibre was increased the performance decreased. It was also realised that the maximum throughput in the RTS-CTS mode was lower than the Basic Access method due to the involvement of more overhead packets. Finally, due to the TCP acknowledgement packet the UDP performance in terms of the throughput was higher than the TCP packet transmission.

References

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