On the Effectiveness of High-Speed WLAN Standards for Long Distance Communication

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Abstract— **Long-distance WiFi networks are a cost-effective means for providing Internet connectivity in developing regions. In these regions, providing support for real-time applications is considered an important requirement. Unlike prior works, this paper studies the effectiveness of features (e.g., frame aggregation and channel bonding) of 802.11n/ac in improving the performance of long-distance WiFi links as well as their ability to support real-time applications. Towards this end, we established a 7.1 km link using commodity 802.11n equipment. Our results yielded a throughput of up to 36 Mbps by only changing 802.11 parameter values. In addition, we show that our setup also meets the delay and jitter requirements of real-time applications.**

I. Introduction

Long-distance WiFi is a promising low-cost solution for providing Internet connectivity to remote areas in developing regions [1], [2]. As a result, long-distance WiFi has seen several deployments around the world [3], [4]. Several important applications (e.g., tele-medicine, distance-education) in these deployments are based on real-time video conferencing.

To support such applications, prior works have identified several limitations (e.g., channel under-utilization, highly variable packet loss rates) of 802.11a/b/g standards over long distances and proposed solutions to address them. Raman et al. [2] proposed 2P, a TDMA-style protocol with synchronous transmissions, that aimed at addressing inter-link interference. WiLDNet [3] builds on 2P by making additional changes in the 802.11 standard to further improve system utilization and robustness to packet losses. Utpal et al. [5] presented a study of long-distance WiFi using 802.11n and focussed on providing high throughput for backhaul connectivity in the context of wireless sensor networks. They reported a peak throughput of 40.8 Mbps on a 1.8 km link. Thus, prior works either consider earlier standards (e.g., 802.11a/b/g) and require changes to the 802.11 protocol or focus on non-real time communication over relatively shorter distances (e.g., see [5]).

Recent and upcoming high-speed WLAN standards (such as 802.11n and 802.11ac, respectively) provide support for MIMO (Multiple Input Multiple Output), wider channels via channel bonding, and introduce MAC layer enhancements (e.g., frame aggregation and block acknowledgements) that can allow setting up of robust and higher throughput long-distance links without requiring stronger signal strength than under 802.11a/b/g. In this work, we ask, "*Can we achieve similar or better performance with 802.11n/ac compared to customized solutions and support real-time applications (such as video conferencing) without requiring changes to the 802.11 protocol?*". Towards this end, we carried out initial experiments on a 7.1 km WiFi link (see Figure 1) using commodity off-the-shelf 802.11n equipment.

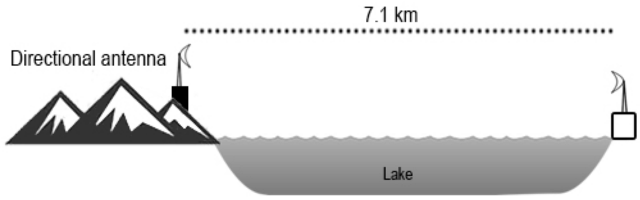


Fig. 1. Long-distance WiFi setup.

We consider several 802.11n features (e.g., frame aggregation, channel bonding, transmit modes) and metrics (e.g., throughput, inter-frame delays, frame retries) for our evaluation. Our initial results suggest that features in 802.11n can be leveraged for building robust and high throughput long-distance links. We found that 802.11n frame aggregation can effectively overcome low channel utilization observed in earlier standards over long-distance links. In particular, we observed a peak throughput of 36 Mbps and an average throughput of 27 Mbps in our experiments on a 7.1 km link. In addition, we found 80% of inter-frame[1] delays to be less than 5 ms across several bit rates, thus suggesting that delay and jitter constraints of real-time applications can potentially be met using off-the-shelf hardware. Altogether, we make three main contributions in this work: (1) We conduct detailed experiments to study the impact of several 802.11n features on the performance of a long-distance WiFi link of 7.1km, (2) We study the impact of rate control algorithms, and (3) We conduct analysis of the throughput and delay characteristics of using 802.11n.

II. Experimental Study

All experiments were conducted in Namal College, Punjab, Pakistan. The access point (AP) was placed on a rooftop while the client was located on a hillside (see Figure 1). The terrain between the AP and the client was relatively flat with a lake in the middle. The client's altitude was $\approx$55 m higher than the AP and there were no obstructions in the Fresnel zone [1].

Experimental Platform: We use a Core 2 Duo desktop with PCI based TP-Link 802.11n card containing Atheros AR9260 chipset as the client and a Ubiquiti Litestation LS-SR71 with

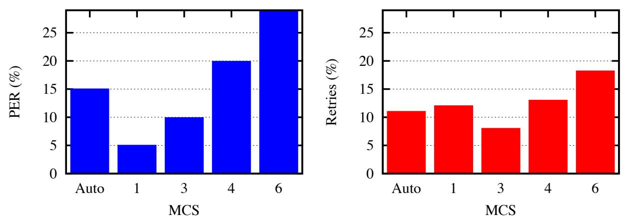
[1]Note that this is the delay between aggregate frames (or A-MPDUs containing multiple MPDUs) at the MAC layer. The inter-MPDU delays would be smaller.

978-1-4799-3088-3/14/$31.00 ©2014 IEEE

Channel Width	Throughput (Mbps)	Retries (%)	Jitter (msec)
10 MHz	14.95	3	3.1
20 MHz	24.5	5	6.6
40 MHz	26.4	8	2.47

TABLE I

IMPACT OF CHANNEL WIDTH ON THROUGHPUT AND FRAME RETRIES.



(a) (b)

Fig. 2. PER and A-MPDU retries as a function of the MCS values. Note that 'Auto' refers to the default bit rate adaptation algorithm used in ath9k.

Atheros AR9160 2.4/5 GHz MIMO chipset as the AP. The AP runs OpenWRT (Attitude Adjustment 12.09) while the client makes use of Ubuntu 12.04 with Linux kernel 3.3.7. Both chipsets allow data rates up to 130 Mbps and 300 Mbps for 20 MHz and 40 MHz channels respectively. The AP and the client have 2 spatial streams with an antenna configuration of 2x2. Both use ath9k; an open source driver for 802.11n. Each wireless node is connected to a directional 2x2 MIMO antenna (TL-ANT2424B), where the each antenna element is vertically polarized. The 2.4 GHz MIMO antennas have a 24 dBi gain and 10 degree vertical and 14 degree horizontal beamwidth. While carrying out experiments, we set our AP on Channel 1. We found that the link RSSI varied between -63dBm to -57dBm. We observed that two other nodes were operating on partially overlapping channels.

III. Evaluation Results

We vary the channel width and the MCS (Modulation and Coding Scheme) index values and study their impact on throughput, packet error rate (PER), frame retries, and inter-frame delays. In all the experiments, frame aggregation and block acknowledgments were enabled. The ACK timeout value was increased to avoid spurious timeouts. Note that ath9k restricts every A-MPDU to have an air time (which includes DIFS, SIFS, and the ACK timeout value) of up to 4 msec. This restriction is due to the regulatory requirement from 802.11j. As a result, in our experiments, we found most A-MPDUs to have a length of 4 or less. In indoor settings, however, we observed A-MPDUs of length 12 or more for the same MCS value [6]. We used iperf to generate traffic over UDP and the application sending rate was chosen to saturate the WiFi link.

Impact of Channel Width/Channel Bonding: Table I shows the impact of using 10 MHz, 20 MHz, and 40 MHz channels on throughput, A-MPDU (aggregate frame) retries, and jitter. Observe that as the channel width increases, the throughput also increases, however, the frame retries also increase. This happens because increasing the channel width decreases the power/hertz, which increases PER for the same distance, thus causing more frame retries. Interestingly, we find that this doesn't necessarily translate into higher jitter because in wider channels, higher bit rates are often used.

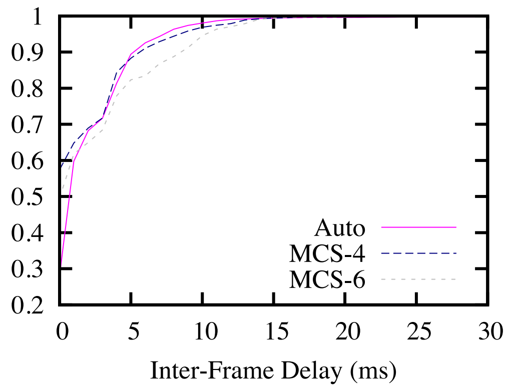


Fig. 3. Impact of MCS values on inter-frame delays.

Impact of MCS Index: Figures 2(a) and 2(b) show the PER and the percentage of A-MPDUs experiencing retries as a function of the MCS index (as well as for the default rate control algorithm in ath9k). Observe that PER increases with the MCS index as it corresponds to using a higher bit rate. Figure 3 shows the CDF of inter-frame delays for different MCS values. Observe that 80% of inter-frame delays are less than 5 ms and less than 5% of delays were longer than 10 ms. These longer inter-frame delays can be avoided by reducing the frame retry limit. Note that the MCS values we used take advantage of spatial diversity, thereby transmitting the same signal over multiple antennas simultaneously, which improves reception. We tried higher MCS indexes that support spatial multiplexing (e.g., 11 and 14) but their PER was very high.

IV. Conclusion and Future Work

We presented an initial study of the performance of 802.11n over a 7.1 km link. We investigated the impact of various features such as channel bonding, MCS values, and frame aggregation on enabling high performance especially for real-time applications. Our results show that 802.11n can potentially be leveraged for setting up high throughput and low jitter long-distance links. In the future, we plan to evaluate the performance of various real-time applications (e.g., video conferencing, VoIP). In addition, we plan to design a system that dynamically tunes various protocol parameters based on the requirements of different applications.

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