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Channel Bonding Effects of the IEEE802.11n Standard on the WLANs Performance

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Abstract

The evolution of wireless communication technologies has led to the widespread adoption of Wireless Local Area Networks (WLANs). IEEE 802.11n provides many enhancements in physical and MAC layers such as (channel bonding(CB), Multiple Input/Output (MIMO), frame aggregation and block acknowledgment) to achieve higher throughput and improved reliability. As a result, CB is a key technique for enhancing the performance of wireless network. It is frequently used in various fields, such as workplace networks and live streaming. This research paper focuses on analyzing the effect of channel bonding on the performance of the IEEE802.11n WLANs, especially in two terms (throughput and delay). By using the OPNET (Riverbed) Modular version 17.5, five various number of nodes (5, 10, 15, 18 and 30 nodes) uniform topologies are modeled and simulated to investigate the WLANs performance for various MIMO up to 4 SS. Simulation outcomes indicated that applying of CB enhanced both delay and velocity performance. Specifically, in the scenarios (30 nodes), for MIMO (4×4) spatial streams, the average throughput value for channel bonding is (157.28 Mbps) compared to (87.41 Mbps) for no-channel bonding, and the average delay value for channel bonding is (0.0476 Sec) compared to (0.06762 Sec) for no-channel bonding. The enhancement values in the performance of WLANs are 42% and 79.9% for latency and throughput (velocity), respectively.

Keywords: Bandwidth, Channel Bonding, IEEE802.11n, MI-MO, OPNET(v.17.5), WLANs.

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Introduction

Over the past few years, the wireless local area network (WLAN) has rapidly transformed, becoming an integral part of our daily routines. Among the most widely adopted wireless technologies, Wireless-Fidelity (Wi-Fi), compliant with the IEEE802.11 WLAN standard, has effectively addressed the increasing demand from users for diverse services [1]. Consequently, the 802.11 standard has developed from IEEE802.11g/b/a to 802.11n to offer a high-throughput (HT) that is increasingly crucial [2]. The IEEE 802.11n standard implemented numerous enhancements to both the physical (PHY) and media access control (MAC) layers of the IEEE802.11 protocol [3]. 802.11n provides a data rate of up to (600Mbps), compared to (54 Mbps) in 802.11a/g [4]. These improvements have enhanced WLAN performance in terms of speed (throughput), coverage, and reliability [3, 5]. 802.11n PHY layer enhancements include Multiple-input Multiple-Output (MIMO) spatial streams, channel bonding (CB), several Modulation and Coding Schemes (MCS), and Short Guard Interval (SGI) [2, 6]. The MAC layer is improved by including the block Acknowledgement (BA) and frame aggregation to reduce MAC overhead [7, 8, 9]. Channel bonding scheme is one important technique of the 802.11n standard that increases channel bandwidth by merging multiple 20MHz channels to create wider channel bandwidth (40 MHz) [3, 10]. In this paper, the IEEE802.11n performance is analyzed and investigated for Channel Bonding (CB) by using the Riverbed (OPNET) modeler (v17.5). This research paper is organized as follows: The related work in 2nd Section. In 3rd Section, the Materials and Method (including 802.11ac primary features, theoretical performance, and parameters with modeled network scenarios) are described. In Section 4, the simulation result of throughput and delay for channel bonding and MIMO are described. Finally, the concluded part is given in Section 5.

Literature Review

Many research papers have investigated channel bonding(CB) and its related challenges, along with its impact on the performance of wireless local area networks (WLANs). Optimal Wireless LAN performance can be achieved by carefully choosing factors such as the data buffer size and fragmentation threshold [11, 12].

Authors in [13] compared throughput results when channel bonding was applied with and without frame aggregation. Channel bonding outperforms frame aggregation in their simulations. Additionally, the results demonstrate that the throughput reaches 116.44 Mbps with channel bonding in MCS 7, which is higher than the throughput of 110.60 Mbps achieved with aggregation and channel bonding, as the distance rises. In [12], the authors utilized a range of commercially accessible equipment to conduct experimental measurements on the efficiency of IEEE802.11n. The throughput is an efficiency metric that demonstrates notable enhancements compared to IEEE 802.11g, particularly when frame aggregation and block acknowledgment (BA) are enabled for both TCP and UDP traffic in each downlink and uplink. In reference, the authors investigates the impact of various protective methods on the IEEE802.11n networks performance in the existence of legacy nodes. In the authors presented channel bonding with aggregation to improve the WLANs performance, and their results showed that aggregation with channel bonding outperforms by 15% and 20%, respectively. In reference, the authors evolved a mathematically model to examine the efficiency of channel bonding(CB), their findings revealed that CB is efficient when secondary channels are available, but it should be deactivate when conflict from other legacy nodes attains a certain threshold in the secondary channels. In reference, the authors assessed the physical layer (PHY) performance of the IEEE802.11n standard using a 4 MIMO spatial stream (SS) at various STBC rates, employing 64-QAM modulation. In the authors take into account the elements that influence the channel state and the IEEE802.11n WLAN performance. They present a network sensor that can identify collision situations that impact channel selection and network efficiency.

Method and Materials

IEEE 802.11n (HT-WLAN) Primary Features

MIMO and Frame Aggregation

The physical layer (MIMO) antenna communication technology of IEEE 802.11n enhances spectrum efficiency and increases throughput by suppot up to 4 MIMO antenna systems [6]. The MIMO antenna system at the IEEE802.11n Physical layer utilizes three processing approaches to enhance the performance of WLAN: (i) ‘Spatial-Division-Multiplexing’ (SDM), also known as ‘space multiplexing’, is a technique that enables simultaneous transmission and reception of numerous signals for high-speed data transfer (which is used in this research paper), the basic configuration of this technique is illustrated in figure 1. (ii) ‘Space-Time-Block-Coding’ (STBC), also known as

space diversity, is a technique used to improve the reliability or range of transmission over fading channels. (iii) 'Low-Density-Parity-Check' (LDPC) channel coding aims to enhance the coding gains for MIMO-OFDM communication and achieve high data rate (throughput) demands while increasing resistance to signal interference .

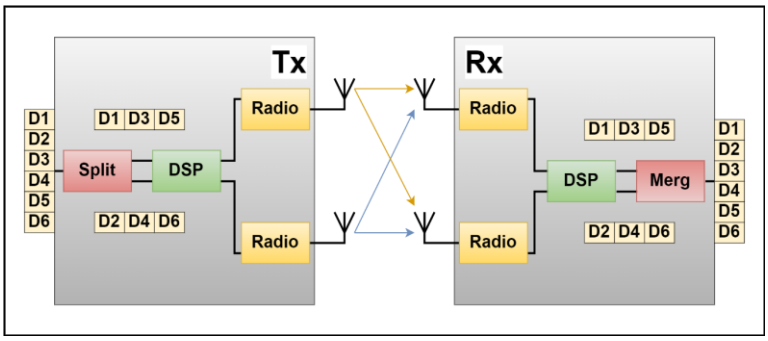


Fig. 1: MIMO-SDM Technique

The MAC layer can be improved by implementing two-level frame aggregation mechanisms, the 1st level (AMSDU) with a max size of 7935 bytes and the 2nd level (AMPDU) with a max size of 65535 bytes. These mechanisms address the issue of huge aggregation by selectively retransmitting just the frames that include errors, as illustrated in Figure 2(a). The MAC layer incorporates block acknowledgment as well. The recipient transmits a block acknowledgment to verify that each frame was correctly received. Frames can be broadcast without acknowledging every unicast frame, as illustrated in Figure 2(b) [7, 8].

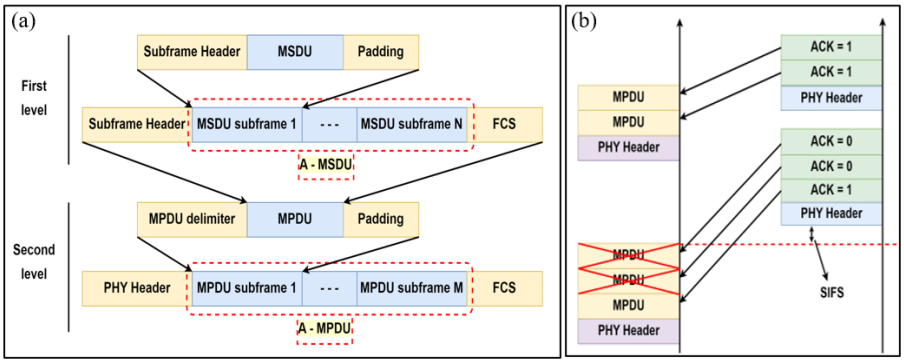


Fig. 2: (a) Frame Aggregation Levels. (b) BA with Aggregation

Channel Bonding

Channel bonding in 802.11n networks creates a wider channel bandwidth by merging two neighboring channel bandwidths (20MHz) to create a channel bandwidth of (40MHz), as shown in figure 3. The increased channel capacity allows for better data transmission rates and enhanced network performance, especially in low-interference environments [6, 10]. The 2.4 GHz frequency spectrum contains 3 nonoverlapping 20MHz channels. The 5 GHz frequency band has 12 nonoverlapping 40 MHz channels and 24 nonoverlapping 20MHz channels [2, 3].

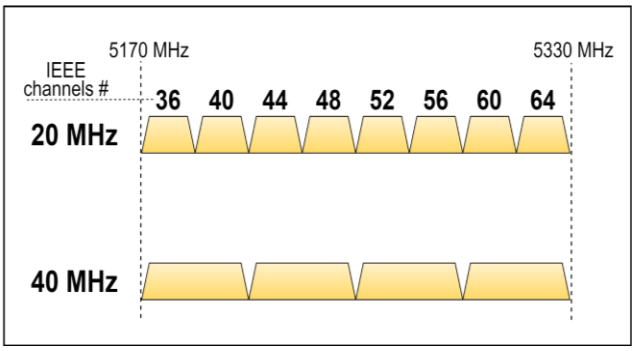


Fig. 3: Channel Bonding of 802.11n [10]

IEEE 802.11n Theoretical Performance

The theoretical max throughput (transfer velocity) and delay time (latency), as shown in table 1 can be determined by formulas (1) and (2), which are provided .

$$Throughput_{(bits/sec)} = \frac{N_{DS} \times N_{SS} \times N_{Bits\ per\ symbol} \times CR}{T_{OFDM}} \quad (1)$$

$$Delay_{(second)} = \frac{Max\ A-MPDU\ Length}{Max\ DR} \quad (2)$$

Where: N_{DS} is Data subcarriers (52 and 108 for 20 and 40MHz), N_{SS} is MIMO Spatial stream (SS) number (1 to 4), N_{BPS} is number of symbol Bits (6 for 64-QAM), T_{OFDM} is the time of OFDM symbol (3.6 µs), Max A−MPDU is the 2nd aggregation level (65535 bytes), and CR is the coding rate (5/6).

Table 1: Theoretical (throughput in Mbps) and (latency in Sec).

Channel BW / MIMO SS	20 MHz		40 MHz	
	Throughput	Delay	Throughput	Delay
1x1 SS	72.2	0.00726	150	0.00349
2x2 SS	144.4	0.00363	300	0.00174
4x4 SS	288.8	0.00181	600	0.00087

Modeled Network Scenarios

Five scenarios (uniformly distributed) with various number of nodes (5, 10, 15, 18 and 30 nodes) are considered to evaluate the (HT-WLAN) based on IEEE802.11n as illustrated in Figure 4.

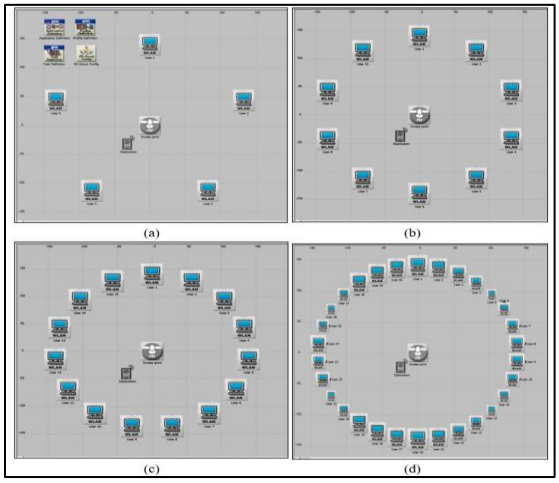


Fig. 4: Simulation Scenarios of WLANs (a)5, (b) 10, (c) 15, and (d) 30 Nodes

The proposed scenarios by using the OPNET modeler are executed with the parameters for simulation as illustrated in Table 2.

Table 2: The Factors Values

Factors	Values
Physical characteristics and channel BW	802.11n, 5 GHz (20 and 40 MHz)
Modulation and coding scheme /Coding rate	64 – QAM / 5/6
MIMO spatial streams (SS)	1×1, 2×2 and 4×4
Guard interval (ns)	400
Transmit power (Watt)	0.1
Buffer length	1024000 (bits)
Data rate	600 and 288.8 (Mbps)
length of packet	2048 (bytes)
Power threshold packets receiving (dbm)	-95
Cwmin and CWmax	15 and 1023
Slot time, SIFS and DIFS (µs)	9, 10 and 28
A-MSDU and AMPDU aggregation (bytes)	7935 and 65535
RTS-threshold (bytes)	(512/None) and (enabled CTS)
Files information (bytes)	High load
Voice type and Video type	(G.711 e. s.) and (30 frame/sec - 352x240 pixel)
Simulation time	10 second

Result and Discussion

The performance of WLAN has been investigated in two metrics (Throughput) and (Delay) as shown in Figures (5, 6 & 7) and (8, 9 & 10), respectively. Various MIMO number (1, 2 and 4) spatial streams and two-channel BW (20MHz and 40MHz) are considered in the investigation process of the IEEE802.11n performance.

Throughput

Figures 5, 6 and 7(a,b) illustrate the variations in throughput between different MIMO antenna systems (1x1, 2x2 and 4x4) spatial streams for channel Bandwidths (20MHz and 40MHz) respectively. The relationship between the throughput and the number of MIMO antenna systems is evident: as the number of streams rises, the throughput also increases. Nevertheless, as the number of nodes increases, the data rate (throughput) diminishes. This occurs because a greater number of data packets are being transmitted through router (accesspoint), which in turn raises the likelihood of congestion, collisions, and ultimately packet loss. The throughput performance for 1x1 MIMO spatial stream (SS) and when applied channel bonding (i.e., 40 MHz), the average throughput values are (116.44, 94.1, 74.2, 67.58, and 49.39 Mbps), compared to channel BW 20 MHz throughput values (59.4, 47.9, 37.8, 43.338, and 25.1 Mbps) for 5, 10, 15, 18, and 30 nodes number scenarios, respectively. While for 4x4 MIMO spatial stream (SS) and when applied channel bonding, the average throughput values are (377.29, 326.19, 230.54, 208.64, and 157.28 Mbps), compared to channel BW 20 MHz throughput values (201.08, 168.15, 132.13, 117.82, and 87.41 Mbps) for 5, 10, 15, 18, and 30 nodes number scenarios, respectively.

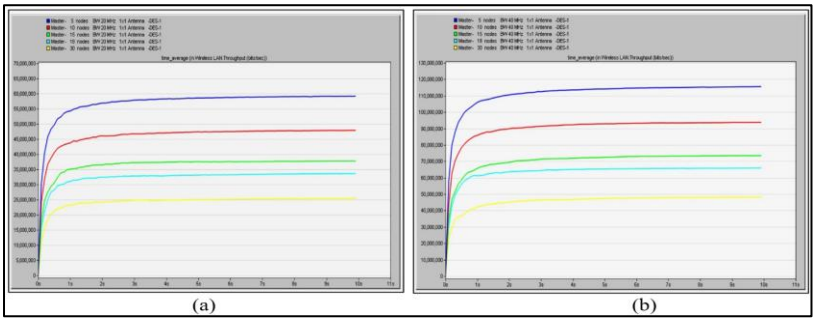


Fig. 5: Average Throughput for 1×1 MIMO Antenna Systems: (a) 20MHz, (b) Channel Bonding 40MHz

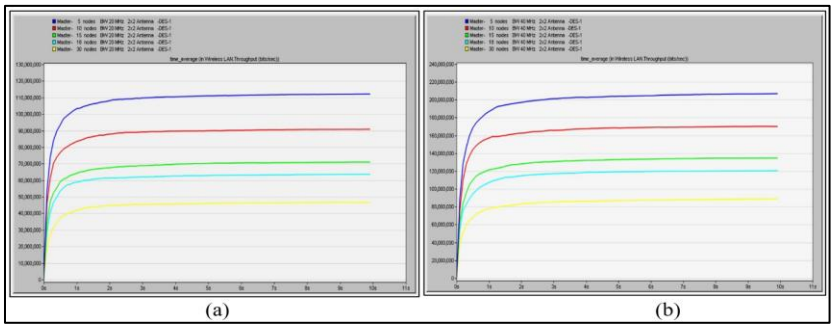


Fig. 6: Average Throughput for 2×2 MIMO Antenna Systems: (a) 20MHz, (b) Channel Bonding 40MHz

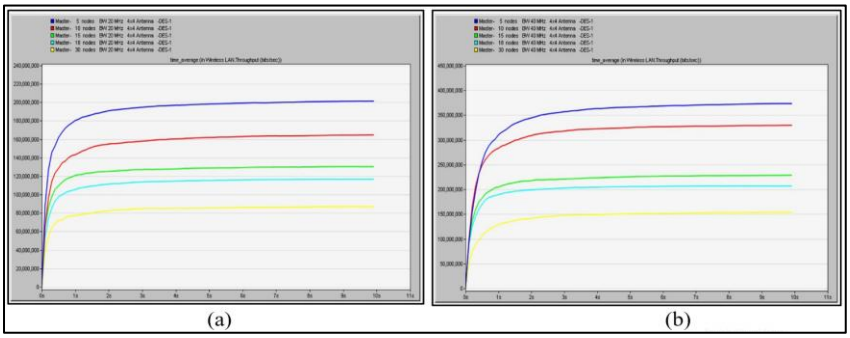


Fig. 7: Average Throughput for 4×4 MIMO Antenna Systems: (a) 20MHz, (b) Channel Bonding 40MHz

For various nodes number and different MIMO configurations, table3 illustrates the average throughput values (in Mbps) for channel BW 20MHz and channel bonding (i.e. 40MHz).

Table 3: Average Throughput Values (in Mbps)

Nodes	5		10		15		30	
SS	20MHz	Bonding	20MHz	Bonding	20MHz	Bonding	20MHz	Bonding
1x1	59.41	116.44	47.99	94.1	37.796	74.2	25.10	49.39
2x2	112.61	207	91.67	170.71	71.862	135.71	46.91	90.62
4x4	201.08	377.29	168.15	326.19	132.13	230.54	87.41	157.28

Delay

Figures 8, 9 and 10(a,b) illustrate the variations in delay between different MIMO antenna systems (1x1, 2x2 and 4x4) spatial streams for channel bandwidths (20 and 40 MHz) respectively. The latency (delay) Lowers as the number of MIMO antenna systems rises. However, the latency rises with an increase in node number. The performance of delay for 1x1 MIMO spatial stream (SS) and when applied channel bonding (i.e., 40 MHz), the overall delay values are (0.02145, 0.0348, 0.06071, 0.06534, and 0.11119 Sec), compared to channel BW 20 MHz overall delay values (0.03118, 0.06232, 0.0967687, 0.10908, and 0.15167 Sec) for 5, 10, 15, 18, and 30 nodes number scenarios, respectively. While for 4x4 MIMO spatial stream (SS) and when applied channel bonding, the overall delay values are (0.00633, 0.00963, 0.02037, 0.02973, and 0.0476 sec), compared to channel BW 20 MHz overall delay values (0.00854, 0.02119, 0.04398, 0.05820, and 0.06762 sec) for 5, 10, 15, 18, and 30 nodes number scenarios, respectively.

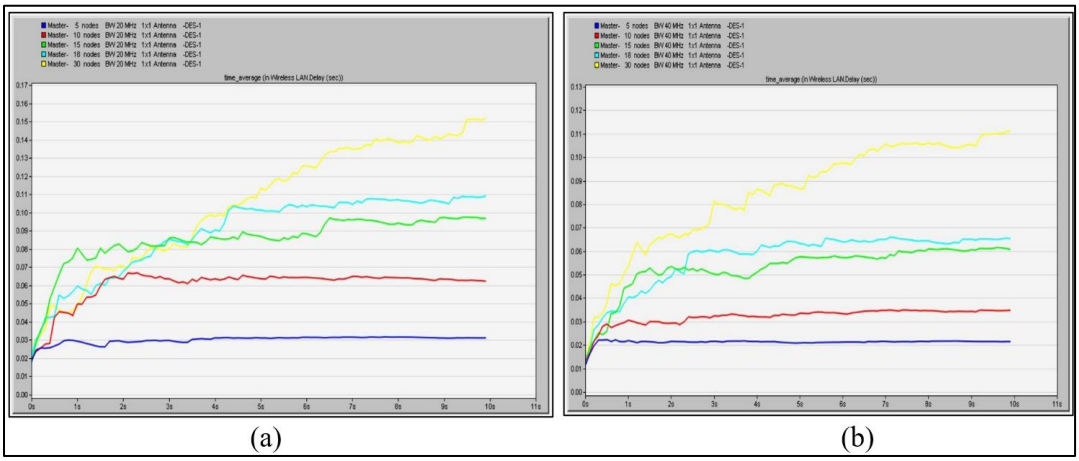


Fig. 8: Average Delay Performance for 1×1 MIMO Antenna Systems: (a) 20MHz, (b) Channel Bonding 40MHz

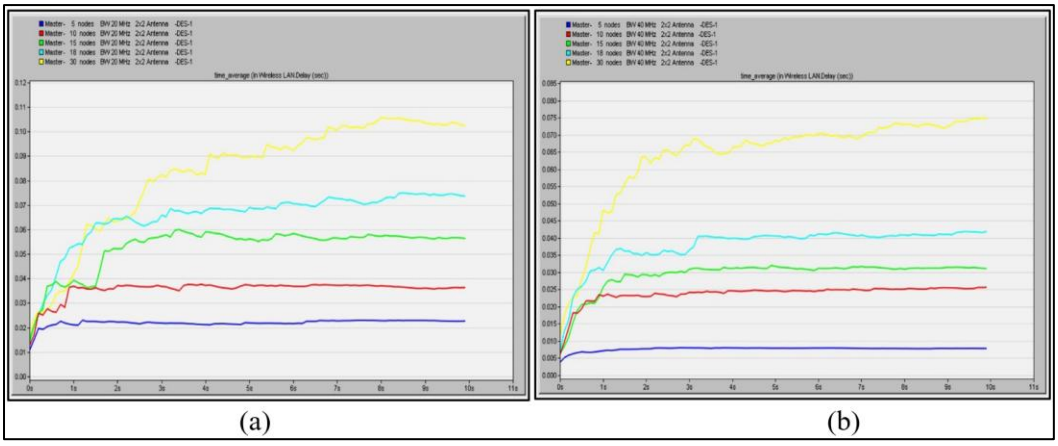


Fig. 9: Average Delay Performance for 2×2 MIMO Antenna Systems: (a) 20MHz, (b) Channel Bonding 40MHz

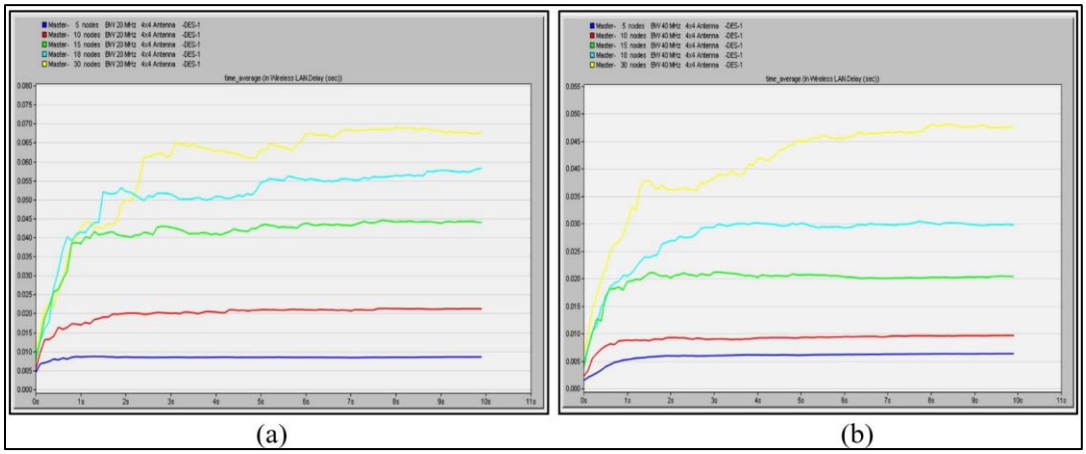


Fig. 10: Average Delay Performance for 4×4 MIMO Antenna Systems: (a) 20MHz, (b) Channel Bonding 40MHz

For various nodes number and different MIMO configurations, Table4 illustrates the overall latency values (in Sec) for channel BW 20MHz and channel bonding (i.e. 40MHz).

Table 4: Overall Latency Values (in Sec)

Nodes	5		10		15		30	
SS	20MHz	Bonding	20MHz	Bonding	20MHz	Bonding	20MHz	Bonding
1x1	0.03118	0.02144	0.06231	0.0348	0.09676	0.06071	0.15167	0.11119
2x2	0.0227	0.00781	0.03633	0.02568	0.05642	0.03106	0.10236	0.07474
4x4	0.00854	0.00632	0.02119	0.00963	0.04398	0.02037	0.06762	0.0476

Conclusions

In this paper, several node number scenarios (5, 10, 15, 18 and 30 nodes) are suggested for modeling and simulating Wireless LANs that are accordant with the IEEE802.11n standard. OPNET (Riverbed) Modeler v. 17.5 is utilized to evaluate and examine the performance efficiency of the IEEE802.11n standard-based WLANs for channel bonding. These scenarios employ extensive modeling processes to enhance network performance. The simulation results indicated that applying channel bonding(CB) improved throughput and delay performance. Specifically, in the scenarios (30 nodes), for MIMO (4×4) spatial streams, the average throughput value for channel bonding is (157.28 Mbps) compared to (87.41 Mbps) for no-channel bonding, and the average delay value for channel bonding is (0.0476 Sec) compared to (0.06762 Sec) for no-channel bonding. The enhancement values in the performance of WLANs are 79.9% and 42% for throughput and delay, respectively.

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