Delay Bound Analysis for Hybrid Network of IEEE 802.11n HT-Mixed Format WLAN over Fiber

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***Abstract*— This paper presents the result of delay bound parameter analysis for hybrid network of IEEE 802.11n Wireless Local Area Network (WLAN) and optical fiber. This networks use several modulation and coding schemes (MCS) with HT-mixed format and distributed coordination function (DCF) access method for data transmission. ACK Timeout and CTS Timeout protocols engineering utilizing short interframe space (SIFS) time interval is used to determine the length of optical fiber extension. This extents the optical fiber lengths 5.96 km for certain condition. In addition, basic access MCS 27–40 MHz scenario produced the lowest delay and highest data rate. These results may support the implementation of big data and cloud computing flexibility.**

***Index Terms*— Delay bound; Hybrid network; WLAN; Optical fiber.**

I. INTRODUCTION

Big data has become trend in all life sectors. One of the big data traffic generator is Internet of Things (IoT). It has two aspects of information dissemination, which are Delay Tolerant Network (DTN) and Opportunistic Network (ON) [1]. Big data access will be smooth if supported by a cloud computing infrastructure which consists of heterogeneous networks. This heterogeneous networks include wireless: WiFi, 3G/4G/5G, WiMAX and wired: fiber optic network, etc.

Combination of cellular network and optical fiber has been widely discussed in the technological context of Radio over Fiber (RoF), as in [2]. WLAN over Fiber (WiLANoF) as part of RoF is a nomadic network using IEEE standard family, such as 802.11a, 802.11b, 802.11e, and 802.11g, as has been discussed in [3] [4] [5] [6]. The main idea behind this combination of wireless and optical fiber is to gain the flexibility that wireless network could provide and the large bandwidth (BW) owned by optical fiber network. This network is expected to be able to accommodate cloud computing and big data needs.

In reality, traffic on WiLANoF hybrid network only uses one transmission opportunity (TXOP) in a time with maximum rate of 54 Mbps [7]. Thus, it needs long transmission time for big data queue. To overcome that problem, this paper proposes the usage of new WLAN IEEE 802.11n standard on WiLANoF.

This standard offers 10 times higher data rate compared with the previous standard by utilizing Multiple Input Multiple Output (MIMO) technique. This standard does not offer Quality of Service (QoS) guarantee. However, using a non-QoS network to support big data is not a problem, since in reality, the traffic peak among data center is dominated by background and non-interactive traffic [8].

For analysis, this paper uses a deterministic approach on various access schemes to gain maximum extension of optical fiber that applies HT-Mixed 802.11n format on single Base Station Subsystem (BSS). The format is used in order to achieve backward compatibility with 802.11n.

II. WLAN SYSTEM

New hybrid WLAN standard is implemented to the system model based on factors as follow.

A. IEEE 802.11n

IEEE 802.11n technology applies High Throughput-Orthogonal Frequency Division Multiplexing (HT-OFDM) scheme via MIMO technique. The main scenarios of MIMO are spatial multiplexing by sending different data frame for each spatial stream, and diversity by duplicating data frame on entire stream. Number of antennas determines delay. In this case, maximum number of antenna is four.

IEEE 802.11n technology could apply equal modulation or unequal modulation techniques for each antenna [9]. Modulation technique is represented by MCS value which affects data rate level. This study applies MCS equal modulation 16-QAM rate ½, which is a modulation modus with Guard Interval (GI) 800 ns and Short Guard Interval (SGI) 400 ns. Related parameters are shown on Table 1.

B. Frame Format

The update of HT-OFDM 802.11n frame format is to minimize overhead. There are three new types of frame formats in 802.11n, namely non-HT, HT-Mixed Format (HT-MF), and HT-Greenfield (HT-GF) formats. Non-HT format is identical to Extended Rate Physical-OFDM (ERP-OFDM) format. HT-MF consists of non-HT preamble and HT preamble. In detail, non-HT preamble consists of Legacy-Short Training Field (L-STF), Legacy-Long Training Field (L-LTF), and Legacy-Signaling (L-SIG). Meanwhile, HT preamble is subdivided into HT-STF, HT-LTF, and HT-SIG. As for HT-GF, it only consists of HT preamble and does not have the ability of backward compatibility. Non-HT and HT-MF formats are mandatory, while the HT-GF is optional [10]. However, HT-MF frame structure which is depicted in Figure 1 is the most widely applied [12].

Referring to Figure 1, in the HT-MF format, the preamble length depends to the number of HT-LTF field. HT-LTF consists of Data LTF (HT-DLTF) and Extended LTF (HT-ELTF). HT-DLTF acts as demodulation process, while HT-ELTF is used as extra spatial stream. The maximum number of HT-LTF field is K = 5 [10], which mathematically expressed as:

$$N_{HT-LTF} = N_{HT-DLTF} + N_{HT-ELTF} \leq 5 \quad (1)$$

HT-LTF field as the maximum number of HT-Data field is inseparable from the amount of space-time-stream N_{STS} and extension-spatial-stream N_{ESS}, which defined as:

$$N_{ESS} + N_{STS} \leq 4 \quad (2)$$

C. Distributed Coordination Function

WLAN communication between the Access Point (AP) and station (STA) uses distributed coordination function (DCF) protocol. Each STA could access the medium independently and do not recognize each other. Each STA has equal opportunity to sense the medium according to contention window (CW) which is generated using back-off procedure.

In DCF there are two access methods, namely Basic Access (BA) or 2-ways handshake, and Request to Send/Clear to Send (RTS/CTS), otherwise known as the 4-ways handshake. Referring to BA method in Figure 2, when a STA senses medium and found it idle, STA has to wait for Distributed Interframe Space (DIFS) to ensure the channel is idle. After it is confirmed idle, STA is allowed to send data. Then, the transmitting STA waits for a Short Interframe Space (SIFS) to obtain data condition report in the form of acknowledgement (ACK) frame from the receiving STA. For the case a channel is not confirmed idle, the sent data frame will be considered failed or damaged and need to be resent.

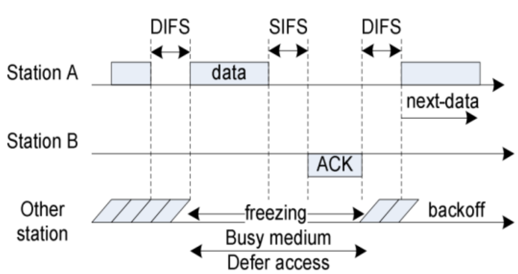

Figure 2: Basic access mechanism, adapted from [10]

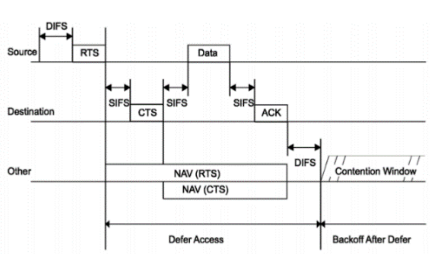

Figure 3: RTS/CTS and NAV mechanism, adapted from [10]

The weakness of BA method mentioned above is its less capability to handle collision in hidden node region. Based on this reason, RTS/CTS method was developed [4]. Shown in Figure 4, RTS/CTS access method adds RTS control frame after DIFS and adds CTS frame after SIFS. This is to ensure the channel is idle before the data frame and ACK frame are sent. If one STA has occupied a channel, then other STA will initiate Network Allocation Vector (NAV), which is started from the last RTS frame until the last ACK frame. The end of NAV is simultaneous to the end of ACK delivery, which indicates that the frame transfer process has been completed and initiates the next CW.

III. WLAN over Fiber Modelling

This modelling uses 802.11n standard for AP and STA over one BSS which is combined with optical fiber. This network combination connects Central Unit (CU) and Remote Access Unit (RAU), as illustrated on Figure 4. The upstream and downstream devices are assumed to be separated spatially. In the downstream direction, signal from the server and 802.11n AP modulates LASER which acts as optical signals conversion. The optical fiber as transmission medium conveys the optical signals to a photodiode, which is assigned to convert the optical signals into electrical signals. The converted signals then feed the AP. Further transmission processes are using MIMO multi antenna techniques toward 802.11n STA in RAU side. The same process applies to the opposite direction.

IV. Delay Bound WiLANoF

In this paper, the delay bound parameter includes device to-device that means the LASER transmitter in CU up to receiver devices in 802.11n STA. The total transmission delay that occurs is influenced by the parameters of optical transceivers, optical fiber, and air propagation time, as defined by the following equations [3] [4]:

$$T_D = 2\ (T_{opt} + t_f + \tau) \quad (3)$$

$$t_f = \frac{n_{eff} L_f}{c} \quad (4)$$

The definitions of symbols are T_D for total propagation delay time (s), T_{opt} is optical transceiver delay time (s), T_f is optical fiber delay time (s), τ is air propagation delay time (s), η_{eff} is effective refractive index of optical fiber core, L_f is length of optical fiber (m), and c is the speed of light in vacuum (3×10^8 m/s).

The optical transceiver and the optical fiber delay have considerable influence to the delay [3]. By simulating BA access and RTS/CTS method in WiLANoF, which is utilizing SIFS duration and using Equation (3) - (4), the optical fiber extension is obtained. The extension of optical fiber was only 660 m. This optical fiber length is too short for general application in optical fiber access network.

The delay bound calculation involves parameter of data frame length, encoding, and guard interval. The data frame transmission delay, which uses Binary Convolutional Code (BCC) encoding in the HT-MF format, are described below [10].

$$T_{D_{Data-GI}} = T_{LEG\_PREAMBLE} + T_{L_{SIG}} + T_{HT\_PREAMBLE} + T_{HT\_SIG} + T_{SYM} \times N_{SYM} + 0 \quad (5)$$

$$T_{D_{Data-SGI}} = T_{LEG\_PREAMBLE} + T_{L_{SIG}} + T_{HT\_PREAMBLE} + T_{HT\_SIG} + T_{SYM} \times Ceiling\left(\frac{T_{SYMS} \times N_{SYM}}{T_{SYM}}\right) + 0 \quad (6)$$

where [10]:

$$T_{LEG\_PREAMBLE} = T_{L-STF} + T_{L-LTF} \quad (7)$$

$$T_{HT\_PREAMBLE} = T_{HT-STF} + T_{HT-LTF1} + (N_{LTF} - 1) T_{HT-LTFs} \quad (8)$$

$$N_{SYM} = m_{STBC} \left\lceil \frac{8.length + 16 + 6.N_{ES}}{m_{STBC} \ . \ N_{DBPS}} \right\rceil \quad (9)$$

The definition of all variables on Equation (5) - (9) are shown in Table 2. The total delay bound of BA and RTS/CTS are corresponding to Figure 2 and Figure 3, which are defined as follows [5].

$$D_{BA} = T_{D_{DATA}} + T_{D_{ACK}} + T_D + T_{DIFS} + T_{SIFS} + \overline{CW} \quad (10)$$

$$D_{RTS/CTS} = T_{D_{DATA}} + T_{D_{ACK}} + T_{D_{RTS}} + T_{D_{CTS}} + 2T_D + T_{DIFS} + 3T_{SIFS} + \overline{CW} \quad (11)$$

where:

$$\overline{CW} = \frac{CW_{min} T_{slot}}{2} \quad (12)$$

The limit of propagation delay that can be tolerated by WLAN depends on the parameters of ACK Timeout and CTS Timeout [3] [4]. ACK Timeout is used for BA access method, while CTS Timeout is used for RTS/CTS [10].

$$ACK_{Timeout} = T_{SIFS} + T_{Slot} + T_{PRSD} \quad (13)$$

$$CTS_{Timeout} = T_{SIFS} + T_{Slot} + T_{PRSD} \quad (14)$$

By calculating the intervals of ACK Timeout and CTS Timeout in accordance to parameters stated in Table 2 and Equations (13) - (14), it is obtained that the maximum delay is 0.063 ms. Therefore, the calculation of the optical fiber extension and device-to-device delays do not exceed the maximum delay limit. Citing the results in paper [3], the optical transceiver delay T_{opt} is assumed to be 1.6 µs, and the refractive index of core $\eta_{eff} = 1.5$. These values then substituted into the Equation (3) - (4). Figure 5 shows a graph of the optical fiber extension length to be 5.96 km for air propagation time $\tau = 0.1\mu s$ and 5.88 km for $\tau = 0.5\mu s$. Thus, the maximum length of optical fiber extension is 5.96 km. Based on these results, parameter $\tau = 0.1\mu s$ is used for further calculation and analysis.

The maximum length limit of optical fiber extension is then used to determine the delay bound with the assumsion of $N_{HT-LTF} = 4$ for data and extended LTF. Then, by substituting the parameter values indicated in Table 2 into Equation (5) - (12) for the data frame lengths of 1500 bytes, the total delay for data transmission is obtained, as indicated by Table 3.

V. RESULTS AND DISCUSSION

Coverage range of 802.11n AP is equal to a picocell, which is about 200 m [13]. Although using Industrial Science and Medical (ISM) frequency, which is identical to 802.11b/g, the implementation of the MIMO in 802.11n AP has created more cluster area ranges. The area and number of clusters are more dependent to the rate of MCS rather than the power of AP. In order to continue the analysis, a reference number of air propagation delay is needed, using symbol τ and expressed as $\tau << 1\mu s$ in Table 2. From Figure 5, the assumptions used are $\tau = 0.1\mu s$ and $\tau = 0.5\mu s$, which gives the maximum length of optical fiber extension 5.96 km and 5.88 km, respectively. These lengths of optical fiber extension are shorter compared to [3] [4], because the duration of PHY-RX-START-Delay in 802.11n only 33 µs. If the extension of optical fiber is extended beyond the upper limit, the delay will also exceed the limit. It is interpreted as a failure to send data to STA in RAU. Further action is to request resending data. In turn, the accumulation of failure for sending data causes the network throughput deteriorate.

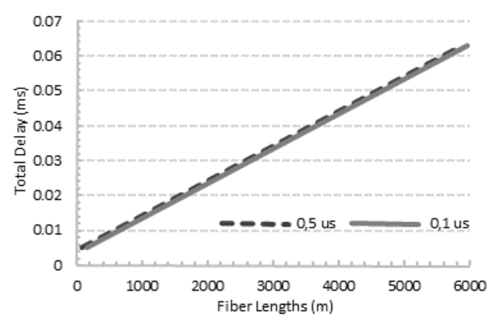

Figure 5: Maximum optical fiber length with air propagation time variance

The next parameter to be defined is the delay bound for BA and RTS/CTS methods. The calculation result of transmission delay on data and control frames from Equation (5) – (9) is substituted into Equation (10) – (11), in which the corresponding parameter values are stated on Table 2. Equation (10) is used to calculate the delay bound for BA method, while Equation (11) is for RTS/CTS. The calculation results of delay bound are shown in Figure 6 - 9. Figure 6 and 7 show the delay bound for evaluating number of spatial streams and BW. Figure 8 describes evaluation of BA and RTS/CTS access methods and Figure 9 displays evaluation result of guard interval to delay bound.

Table 3
Units for Magnetic Properties

MCS Schemes	D_{BA} (ms)		$D_{RTS/CTS}$ (ms)	
	GI	SGI	GI	SGI
MCS 3, 16-QAM, 1/2, N_{SS} 1, 20 MHz	0.841	0.797	1.036	0.992
MCS 11, 16-QAM, 1/2, N_{SS} 2, 20 MHz	0.609	0.589	0.804	0.784
MCS 19, 16-QAM, 1/2, N_{SS} 3, 20 MHz	0.537	0.521	0.732	0.716
MCS 27,16-QAM, 1/2, N_{SS} 4, 20 MHz	0.489	0.481	0.676	0.668
MCS 3, 16-QAM, 1/2, N_{SS} 1, 40 MHz	0.601	0.581	0.796	0.776
MCS 11, 16-QAM, 1/2, N_{SS} 2, 40 MHz	0.489	0.481	0.684	0.676
MCS 19, 16-QAM, 1/2, N_{SS} 3, 40 MHz	0.457	0.449	0.652	0.644
MCS 27, 16-QAM, 1/2, N_{SS} 4, 40 MHz	0.429	0.425	0.616	0.612

Referring to Figure 6 and Figure 7, it appears BW 20 MHz, BW 40 MHz and number of spatial streams affect the delay bound generally. The analysis is described as follow. First analysis, BW 20 MHz was observed to produce higher delay bound compared to BW 40 MHz. It is expected as BW 20 MHz has less number of subcarrier. Thus, it makes fewer amounts of data that can be transmitted. Meanwhile, BW 40 MHz has more subcarriers, which can influence data rate achievement up to twice than BW 20 MHz. The greater data rate is generated, the delay decreases. The second analysis, delay bound which is generated by using BA and RTS/CTS methods show the similar results. Observed, the more number of spatial streams, the lower its delay bound. This is because the increasing number of spatial streams will increase the number of data bits per OFDM symbol (N_{DBPS}) that can be sent through each stream. As a result, the volume of data bits sent is getting bigger and the delay bound obtained decreases.

Figure 8 shows delay bound for BA and RTS/CTS. It shows that the values and acceleration rate of delay bound for RTS/CTS is greater than that for BA. This is because protocol procedure of RTS/CTS consists of several steps, as shown in Figure 4. Each of these steps has delay allocation. Thus, the total delay bound of RTS/CTS is greater than that for BA. Even though RTS/CTS has a great delay, this is a kind of tradeoff because it could eliminate hidden node effects on ad hoc network that cannot be overcome by BA [4].

In the OFDM system, each data packet is sent through an antenna, and it is inserted a guard interval time to prevent inter-symbol-interference (ISI) and inter-carrier-interference (ICI) while being processed in the receiver [14]. The 802.11n standard offers two choices of guard interval, which are GI = 800 ns and SGI = 400 ns. The graphs in Figure 9 shows the delay bound for GI is higher than that for SGI. The cause is the interval symbol (Tsym) as time function of guard interval plus Discrete Fourier Transform (DFT) for GI is greater than that for SGI. This resulted the delay bound for GI becomes greater. In addition, considering delay bound values in Table 3, it shows that significant delay differences between GI and SGI occurred in BW 20 MHz, either for BA or RTS/CTS scheme, are greater than BW 40 MHz. The cause is bits capacity for one symbol on BW 20 MHz is smaller and even almost a half of BW 40 MHz, accordingly it produces more symbols (N_{SYM}) and results in the higher delays.

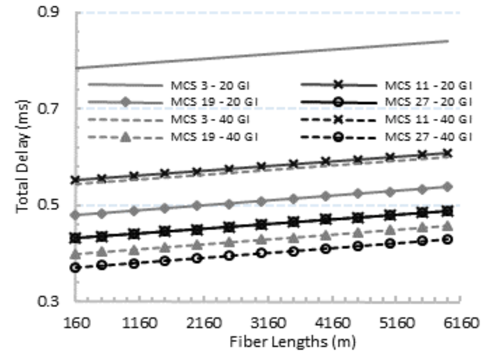

Figure 6: Delay bound evaluation for bandwidth and number of spatial streams on BA method at GI, BW 20 MHz

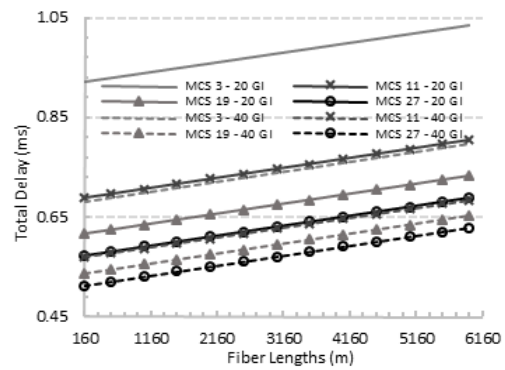

Figure 7: Delay bound evaluation for bandwidth and number of spatial streams on RTS/CTS method at GI, BW 20 MHz

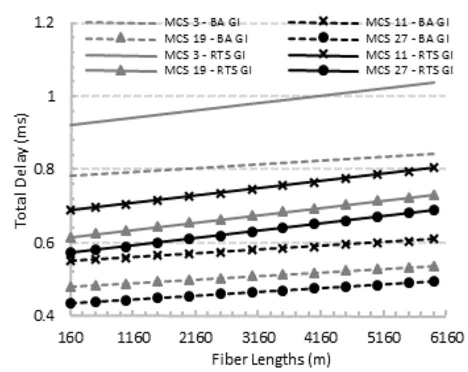

Figure 8: Delay bound for BA and RTS/CTS method, BW 20 MHz, GI

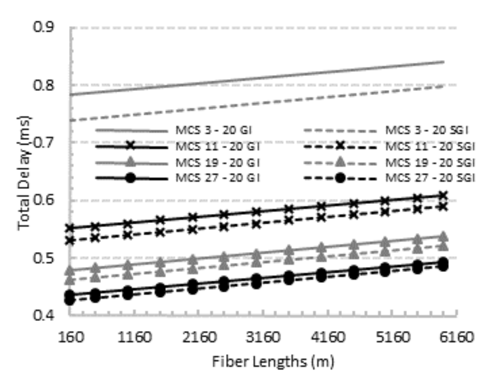

Figure 9: Delay bound for various guard interval on BA method at BW 20 MHz

Observing the delay bound graphs in Figure 6 - 9, it is shown that MCS 3 - 20 MHz produces the greatest delay bound and a significant difference delay when compared with other MCS schemes. The cause is MCS 3-20 MHz utilizes only one spatial stream within limited BW 20 MHz. As a result, MCS 3-20 MHz is only able to send a minimum number of bits per symbol. This greatly affects the delay bound.

VI. CONCLUSION

This paper has analyzed various contributors about delay bound device-to-device on hybrid network IEEE 802.11n HT-Mixed Format WLAN over Fiber using deterministic approach. The results of the analysis are shortly as follows. The maximum length of optical fiber extension is 5.96 km with τ = 0.1 μs involving ACK Timeout and CTS Timeout parameters. When the extension of optical fiber exceeds the maximum limit, it causes the network throughput decreases. In general, the parameters which contribute to a great value of delay bound is BW-20 MHz with minimal number of subcarriers, minimal number of spatial streams, RTS/CTS access protocol, and large guard intervals. The opposite situation, has the lowest delay bound but achieves the highest data rate by MCS 27-40 MHz.

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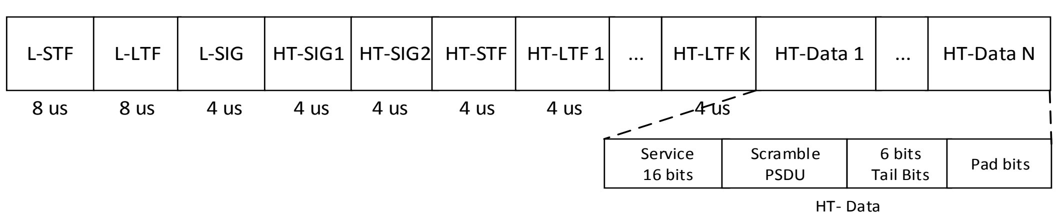

Figure 1: HT-mixed frame format [10]

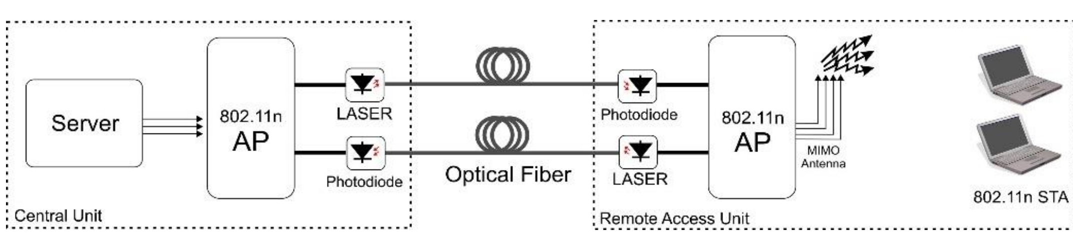

Figure 4: Hybrid network model for WiLANoF 802.11n [6]

Table 1
MCS parameter on IEEE 802.11n [10]

MCS Index	Modulation	R	BW (MHz)	N_{BPSCS} (i_{ss})	N_{CBPS}	N_{DBPS}	N_{SS}	N_{ES}	Data rate (Mbps) GI	SGI
3	16-QAM	1/2	20	4	208	104	1	1	26	28.9
11	16-QAM	1/2	20	4	416	208	2	1	52	57.8
19	16-QAM	1/2	20	4	624	312	3	1	78	86.7
27	16-QAM	1/2	20	4	832	416	4	1	104	115.6
3	16-QAM	1/2	40	4	432	216	1	1	54	60
11	16-QAM	1/2	40	4	864	432	2	1	108	120
19	16-QAM	1/2	40	4	1296	648	3	1	162	180
27	16-QAM	1/2	40	4	1728	864	4	1	216	240

notes:
R - Coding Rate

N_{CBPS}-Number of coded bits/OFDM symbol

N_{DBPS}-Number of data bits/OFDM symbol

N_{SS} - Number of spatial stream
N_{ES} - Number of extended stream
BW - Bandwidth

Table 2
IEEE 802.11n parameters [10]

Symbol	Description	Value	Unit	Symbol	Description	Value	Unit
T_{slot}	A slot time	2.4 GHz=20 5 GHz=9	µs	T_{GI}	Guard interval duration	0.8	µs
τ	Air propagation time	<< 1	µs	T_{SGI}	Short guard interval duration	0.4	µs
L_{RTS}	Length of RTS frame	20	byte	$T_{L\text{-}STF}$	Non-HT short training sequence duration	8	µs
L_{CTS}	Length of CTS frame	14	byte	$T_{L\text{-}LTF}$	Non-HT long training sequence duration	8	µs
L_{ACK}	Length of ACK frame	14	byte	T_{SYM}	Symbol interval	4	µs
$L_{H\text{-}MAC}$	Length of MAC header frame	28	byte	T_{SYMS}	Short GI symbol interval	3.6	µs
T_{SIFS}	SIFS time	2.4 GHz=10 5 GHz = 16	µs	$T_{L\text{-}SIG}$	Non-HT SIGNAL field duration	4	µs
T_{DFT}	IDFT/DFT processing time	3.2	µs	$T_{HT\text{-}SIG}$	HT SIGNAL field duration	8	µs
T_{RTT}	RX-TX turn around time	< 2	µs	$T_{HT\text{-}STF}$	HT short training field duration	4	µs
T_{PHYP}	Transmission time of PHY preamble	16	µs	$T_{HT\text{-}LTF1}$	The first HT long training field duration	4	µs
T_{PHYH}	Transmisson time of PHY header	4	µs	$T_{HT\text{-}LTFs}$	The second and next HT long training field duration	4	µs
T_{PRSD}	aPHY-RX-START-Delay	33	µs	T_{DIFS}	DIFS time	50	µs
CW_{min}	Minimum contention window size	15	slot	N_{DBPS}	Number of data bits per OFDM symbol	variable	-

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