11axHDWLANsSim validation report (v0.1)

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1 Introduction

The purpose of this report is to provide some examples of the validations carried out for the IEEE 802.11ax `11axHDWLANsSim` simulator. In order to assess the accuracy of the simulator, we compare the results obtained through three alternative tools: Bianchi's analytical model, the SFCTMN framework, and the Network Simulator 3 (NS3). It is important to notice that each of the mentioned alternative tools have their drawbacks in terms of scenario restrictions and in some cases we have not been able to test the same scenario through each of them. For instance, Bianchi's modeling considers only fully overlapping networks, SFCTMN does not capture backoff collisions ant is very computationally expensive when the number of WLANs grows (from 10 on), and most novel features like Dynamic Channel Bonding (DCB) are not implemented in NS3 up to this date. Nonetheless, we have managed to reproduce the results of some scenarios in each of the tools.

2 Evaluation setup

The value of the parameters considered in the simulations are shown in Table 1. Regarding the path loss, we use the dual-slope log-distance model for 5.25 GHz indoor environments in room-corridor condition [1]. Specifically, the path loss in dB experienced at a distance d is defined by

$$\mathrm{PL}(d) = \begin{cases} 53.2{+}25.8\log_{10}(d) & \text{if } d \leq d_1 \text{ m} \\ 56.4{+}29.1\log_{10}(d) & \text{otherwise} \end{cases}, \tag{1}$$

where $d_1 = 9$ m is the break point distance.

The MCS index used for each possible channel bandwidth (i.e., 20, 40, 80 or 160 MHz) was the highest allowed according to the power power budget established between the WLANs and their corresponding STA/s and the minimum sensitivity required by the MCSs. As stated by the 11ax amendment, the number of transmitted bits per OFDM symbol used in the data transmissions is given by the channel bandwidth and the MCS parameters, i.e., $r = Y_{\text{sc}}Y_{\text{m}}Y_{\text{c}}V_{\text{s}}$, where Y_{sc} is the number of data sub-carriers, Y_{m} is the number of bits in a modulation symbol, Y_{c} is the coding rate, and $V_{\text{s}} = 1$ is the number of single user spatial streams (note that we only consider one stream per transmission).

The number of data sub-carriers depends on the transmission channel bandwidth. Specifically, Y_{sc} can be 234, 468, 980 or 1960 for 20, 40, 80, and 160 MHz, respectively. For instance, the data

Table 1: Parameters considered in the presented scenarios.

Parameter	**Description**	**Value**
f_c	Central frequency	5.25 GHz
$\|c\|$	Basic channel bandwidth	20 MHz
L_D	Frame size	12000 bits
N_a	No. of frames in an A-MPDU	64
CW_{min}	Min. contention window	16
m	No. of backoff stages	5
MCS	11ax MCS index	0 - 11
η	MCS's packet error rate	0.1
CCA	CCA threshold	-82 dBm
P_{tx}	Transmission power	15 dBm
G_{tx}	Transmitting gain	0 dB
G_{rx}	Reception gain	0 dB
$PL(d)$	Path loss	see (1)
ℓ	Channel bonding loss factor	3 dB
CE	Capture effect threshold	20 dB
N	Background noise level	-95 dBm
T_e	Empty backoff slot duration	9 μs
T_{SIFS}	SIFS duration	16 μs
T_{DIFS}	DIFS duration	34 μs
T_{PIFS}	PIFS duration	25 μs
$T_{PHY\text{-}leg}$	Legacy preamble	20 μs
$T_{PHY\text{-}HE\text{-}SU}$	HE single-user preamble	164 μs
σ_{leg}	Legacy OFDM symbol duration	4 μs
σ	11ax OFDM symbol duration	16 μs
L_{BACK}	Length of a block ACK	432 bits
L_{RTS}	Length of an RTS packet	160 bits
L_{CTS}	Length of a CTS packet	112 bits
L_{SF}	Length of service field	16 bits
L_{MD}	Length of MPDU delimiter	32 bits
L_{MH}	Length of MAC header	320 bits
L_{TB}	Length of tail bits	18 bits

rate provided by MCS 11 in a 20 MHz transmission is $s = (234 \times 10 \times 5/6 \times 1)\sigma^{-1} = 121.9$ Mbps. However, control frames are transmitted in legacy mode using the basic rate $r_{leg} = 24$ bits per OFDM symbol of MCS 0, corresponding to $s_{leg} = 6$ Mbps since the legacy OFDM symbol duration σ_{leg} must be considered. With such parameters we can define the duration of the different packets transmissions, and the duration of a successful and collision transmission accordingly:

$$
\begin{aligned}
T_{RTS} &= T_{PHY\text{-}leg} + \left\lceil \frac{L_{SF} + L_{RTS} + L_{TB}}{r_{leg}} \right\rceil \sigma_{leg}, \\
T_{CTS} &= T_{PHY\text{-}leg} + \left\lceil \frac{L_{SF} + L_{CTS} + L_{TB}}{r_{leg}} \right\rceil \sigma_{leg}, \\
T_{DATA} &= T_{PHY\text{-}HE\text{-}SU} + \\
&\quad + \left\lceil \frac{L_{SF} + N_a(L_{MD} + L_{MH} + L_D) + L_{TB}}{r} \right\rceil \sigma, \\
T_{BACK} &= T_{PHY\text{-}leg} + \left\lceil \frac{L_{SF} + L_{BACK} + L_{TB}}{r_{leg}} \right\rceil \sigma_{leg}.
\end{aligned}
$$

3 Scenarios

The PHY and MAC parameters of the scenarios below are the ones presented in Section 2 (e.g., central frequency $f_c = 5.25$ GHz, floor noise $N = -95$ dBm, capture effect $CE = 20$ dB, etc.). Only saturated downlink traffic is considered and the RTS/CTS mechanism is activated. The results gathered by the simulators (NS3 and `11axHDWLANsSim`) are averaged considering 100 simulations of 30 seconds and 1 simulation of 1000 seconds, respectively.

3.1 Simple scenarios

In order to properly validate the distributed coordination function (DCF) operation implemented in `11axHDWLANsSim`, we start with a couple of simple scenario containing a single WLAN, where all the devices (an AP and STA/s) are within communication range. The STA/s are separated 2.83 m from the AP as shown in Figure 1a and 1b. We also considered no aggregation, i.e., just one data packet is transmitted per transmission opportunity (TXOP). Results are shown in Table 2 and 3, respectively. As expected, the same aggregate throughput is achieved when the AP randomly selects the downlink destination between two STAs (STA_1 and STA_2) in a deployment like the one considered. Regarding the results provided by each of the tools, we can see that the expected throughput is the same when using Bianchi's model, SFCTMN or *11axHDWLANsSim*. The slight differences with respect NS3 are due to the beaconing system implemented by the AP that we do not consider in the other tools.

(a) Single WLAN with 1 STA.

(b) Single WLAN with 2 STAs.

Figure 1: Scenarios with a single WLAN.

Table 2: Throughput [Mbps] for a single WLAN with 1 STA and transmission rate 108 Mbps.

Node	Bianchi	SFCTMN	NS3	`11axHDWLANsSim`
AP	26.87	26.87	25.28	26.87

Table 3: Throughput [Mbps] for a single WLAN with 2 STAs and transmission rate 108 Mbps.

Node	Bianchi	SFCTMN	NS3	`11axHDWLANsSim`
AP $\rightarrow$ STA_1	13.43	13.43	12.64	13.43
AP $\rightarrow$ STA_2	13.43	13.43	12.64	13.43
AP	26.87	26.87	25.28	26.87

In order to assess the accuracy of `11axHDWLANsSim` for larger WLAN networks, we can use Bianchi's model. In Table 4 we compare the results obtained by the mentioned tools for different scenarios. Note that we also consider adaptive contention windows with m backoff stages. That is, the backoff is computed by $\text{BO} = [0, \text{CW} - 1]$, where $\text{CW} = 2^b\ \text{CW}_{\text{min}}$, for $b = 0, 1, ..., m$ increased by one or reset to 0 when a timeout or an ACK occurs, respectively. All the scenarios considered fully overlapping WLANs composed of 1 AP and 1 STA. Only downlink traffic was considered in single-channel (20 MHz) and maximum MCS (i.e. 1024 QAM 5/6) without packet aggregation. The RTS/CTS mechanism was activated in Komondor and implicitly consider in the transmission time overheads for Bianchi. Results in Komondor correspond to 1,000 s simulation time.

We note that results match really well. In fact, only for a very small amount of WLANs (e.g., $M = 2$) and high number of backoff stages (e.g., $m = 6$) the differences could be considered significant. The main reason of such differences is the probability of a WLAN of experiencing large periods of time transmitting without freezing the backoff because of the high contention windows potentially reached by the others. We guess that letting the simulator running very large simulations, these results will get even closer.

3.2 Complex scenarios

Once the single-channel and fully overlapping have been validated, we now consider more complex scenarios implementing DCB and non-fully overlapping deployments. To that aim, since neither

Table 4: Komondor validation using Bianchi's model.

Configuration			Bianchi			`11axHDWLANsSim`		
M	m	CWmin	EB [slots]	p_c	Γ [Mbps]	EB [slots]	p_c	Γ [Mbps]
1	0	2	0.50	0.00000	20.851	0.50	0.00000	20.851
	0	16	7.50	0.00000	18.794	7.50	0.00000	18.793
	6	2	0.50	0.00000	20.851	0.50	0.00000	20.851
	6	16	7.50	0.00000	18.794	7.50	0.00000	18.793
2	0	2	0.50	0.66667	8.149	0.50	0.66687	8.148
	0	16	7.50	0.11765	9.746	7.50	0.11776	9.746
	6	2	1.70	0.37084	9.574	1.77	0.18046	10.098
	6	16	8.56	0.10462	9.692	8.56	0.11106	9.678
4	0	2	0.50	0.96296	1.471	0.50	0.96297	1.471
	0	16	7.50	0.31305	4.812	7.50	0.31326	4.811
	6	2	3.72	0.51024	4.562	3.85	0.38318	4.794
	6	16	10.91	0.23133	4.844	10.97	0.23465	4.838
8	0	2	0.50	0.99954	0.022	0.50	0.99956	0.022
	0	16	7.50	0.58361	2.207	7.50	0.58366	2.207
	6	2	6.92	0.61120	2.174	7.12	0.54652	2.250
	6	16	15.75	0.35016	2.381	15.86	0.34740	2.383
16	0	2	0.50	1.00000	0.000	0.50	1.00000	0.000
	0	16	7.50	0.84702	0.832	7.50	0.84705	0.832
	6	2	11.95	0.70036	1.023	12.26	0.66856	1.046
	6	16	24.51	0.45115	1.162	24.57	0.44653	1.164
32	0	2	0.50	1.00000	0.000	0.50	1.00000	0.000
	0	16	7.50	0.97935	0.152	7.50	0.97933	0.152
	6	2	19.70	0.78457	0.467	20.10	0.77098	0.474
	6	16	39.34	0.54070	0.563	39.42	0.53564	0.564

Bianchi's model nor NS3 can be used because of their constraints in spatial settings and DCB, respectively, we make use of SFCTMN and `11axHDWLANsSim` to validate them altogether.

3.2.1 Dynamic channel bonding

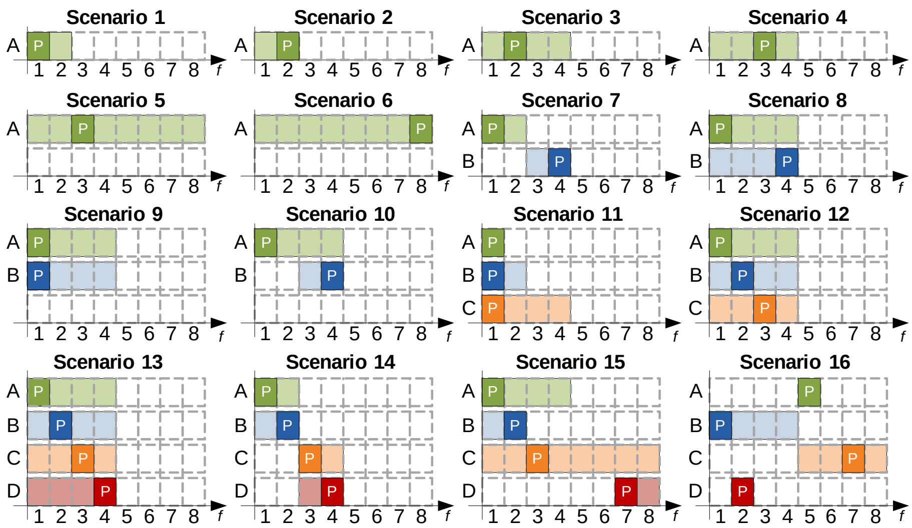
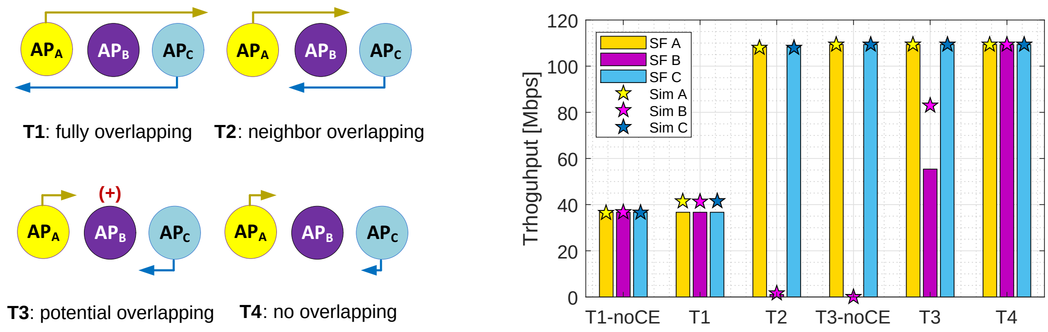


Figure 2: DCB channel allocation scenarios.

First, we consider the the scenarios in Figure 2 to assess the accuracy of the tools when DCB is implemented. Note that up to 4 WLANs and up to 8 basic channels of 20 MHz are now considered. Letter "P" denotes the primary channel and the colored ranges represent the available channel of each WLAN. For instance, in Scenario 10, WLAN A can transmit in channels 1 (20 MHz), 1 and 2 (40 MHz) or 1 to 4 (80 MHz), and WLAN B can transmit in channels 3 (20 MHz) or 3 and 4 (40 MHz). In Table 5, the corresponding results are shown for the both tools. Similarly to previous scenarios, only fully overlapping WLANs composed of 1 AP and 1 STA are considered. Downlink



(a) Topologies.

(b) Average throughput.

Figure 3: Yellow and blue arrows indicate the carrier sense range of WLANs A and C, respectively. The carrier sense range of WLAN B is not displayed. *T3-noCE* refers to topology *T3* when B does not accomplish the capture effect condition whenever A, B and C are active. SF and Sim refer to the values obtained through SFCTMN and `11axHDWLANsSim`.

traffic is considered too but now bonded channels are allowed following the AM DCB policy. The maximum MCS (i.e. 1024 QAM 5/6) and now we consider packet aggregation $N_a = 64$. RTS/CTS mechanism was activated in Komondor and implicitly consider in the transmission time overheads for Bianchi and SFCTMN. Results in Komondor correspond to 1,000 s simulation time. The backoff is computed by $\text{BO} = [0, \text{CW} - 1]$, where $\text{CW} = 2^b\ \text{CW}_{\text{min}}$, for $b = 0$. Note that slotted backoff collision may occur in `11axHDWLANsSim` while it is not the case for SFCTMN. Throughput is expressed in Mbps.

We note that results match almost completely. However, in those scenarios when collisions may occur, the simulator provides better accuracy since SFCTMN is not able to capture them. Nonetheless, in terms of throughput, the differences between both tools is pretty small, which allows us to analyze different DCB policies with appropriate certainty.

Table 5: SFCTMN validation with 11axHDWLANsSim.

	11axHDWLANsSim					SFCTMN				
Scenario	p_c	Γ_A	Γ_B	Γ_C	Γ_D	p_c	Γ_A	Γ_B	Γ_C	Γ_D
0	0.00000	109.362	-	-	-	0	109.363	-	-	-
1	0.00000	203.469	-	-	-	0	203.471	-	-	-
2	0.00000	203.469	-	-	-	0	203.471	-	-	-
3	0.00000	369.487	-	-	-	0	369.497	-	-	-
4	0.00000	369.487	-	-	-	0	369.497	-	-	-
5	0.00000	586.048	-	-	-	0	586.036	-	-	-
6	0.00000	586.048	-	-	-	0	586.036	-	-	-
7	0.00000	203.469	203.469	-	-	0	203.471	203.471	-	-
8	0.11791	186.803	186.803	-	-	0	187.798	187.798	-	-
9	0.11791	186.803	186.803	-	-	0	187.798	187.798	-	-
10	0.00258	204.530	202.156	-	-	0	206.678	199.667	-	-
11	0.22007	59.828	60.110	60.150	-	0	60.280	60.280	60.280	-
12	0.22108	124.116	124.753	124.647	-	0	125.891	125.891	125.891	-
13	0.31365	93.222	93.119	92.690	93.135	0	94.680	94.680	94.680	94.680
14	0.11793	102.371	102.337	102.324	102.385	0	102.653	102.653	102.653	102.653
15	0.10565	123.369	152.961	123.242	203.013	0	105.079	197.825	105.079	203.429
16	0.00189	108.297	205.064	205.127	108.329	0	108.259	205.203	205.203	108.259

3.2.2 Spatial-flexible scenarios

Finally, for the validation of spatial-flexible scenarios, we refer to the cumulative interference and flow starvation scenario in [2], where authors present different topologies considering partially overlapping phenomena. Figure 2 collects the different topologies of the aforementioned scenario. In Table 6, we collect the results for each of the topologies. As state in [2], the main difference is given in topology T3 due to insensitivity property of CTMNs.

"(...) Such difference is caused by the insensitivity property of the CTMN. For instance, whenever the system is in state $s_6 = \mathrm{A}_1^1\mathrm{C}_1^1$ and A finishes its transmission (transiting to $s_4 = C_1^1$), B decreases its backoff accordingly while C is still active. In this case it is more probable to transit from s_4 to $s_7 = \mathrm{B}_1^1\mathrm{C}_1^1$ than to $s_6 = \mathrm{A}_1^1\mathrm{C}_1^1$ again because, in average, the remaining backoff counter of B will be smaller than the generated by A when finishing its transmission. This is in fact not considered by the CTMN, which assumes the same probability to transit from s_4 to s_6 than to s_7 because of the exponential distribution and the memoryless property."

Table 6: Spatial-flexible validation 11axHDWLANsSim.

	11axHDWLANsSim				SFCTMN			
Topology	p_c	Γ_A	Γ_B	Γ_C	p_c	Γ_A	Γ_B	Γ_C
T1-noCE	0.21968	36.467	36.564	36.684	0	36.689	36.689	36.689
T1	0.00000	41.520	41.466	41.225	0	36.689	36.689	36.689
T2	0.00000	108.334	1.195	108.313	0	108.331	1.041	108.331
T3	0.00000	109.366	82.996	109.362	0	109.363	55.382	109.363
T3-noCE	0.01726	109.366	0.000	109.363	0	109.363	0.002	109.363
T4	0.00000	109.359	109.365	109.365	0	109.363	109.363	109.363

References

[1] Ding Xu, Jianhua Zhang, Xinying Gao, Ping Zhang, and Yufei Wu. Indoor office propagation measurements and path loss models at 5.25 ghz. In *Vehicular Technology Conference, 2007. VTC-2007 Fall. 2007 IEEE 66th*, pages 844–848. IEEE, 2007.

[2] Sergio Barrachina-Munoz, Francesc Wilhelmi, and Boris Bellalta. Performance analysis of dynamic channel bonding in spatially distributed high density wlans. *arXiv preprint arXiv:1801.00594*, 2018.