Accuracy of Simulation of Wireless Technology Using MATLAB and NS-3

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***Abstract*---Performance predictions of wireless IEEE 802.11 specifications have been obtained using two well-known simulators - MATLAB and Network Simulator 3 (NS-3). Benchmarking was done by comparison to laboratory performance measured practically using an experimental method based on technical features claiming to contribute to higher bandwidth. The findings show that both simulators' predictions match the specifications at zero line-of-sight between transmitter and host. Technical features were confirmed to broadly increased data rates approximately to specification. However, accuracy of the simulators was inversely correlated with propagation distance. In certain cases, the claim of higher bandwidth by the latest amendment was not borne out in practice over distances greater than 10m. In conclusion, NS-3 was more often better correlated with measured values than MATLAB. In future, better software modelling of ray tracing and beam forming, physical techniques employed in cellular simulators that better model propagation effects would be expected to improve accuracy.**

Keywords-WIFI, Wireless technology, MATLAB, NS-3.

I. INTRODUCTION

The IEEE 802.11 standard is the de-facto solution for wireless network access. Previous workers have considered discrepancies between theoretical and physical performance under various conditions [1]-[3].

Little work has investigated variance between theoretical, practical and simulated performance measurements. With such practical variances being observed, the possibility of a similar discrepancy with the predictions of 802.11 simulations arises. The lack of research into these variances thus draws into question the validity of simulated performance measurements and hence the indicated benefits of any proposed enhancements demonstrated through simulations. The IEEE standard features an evolving series of enhancements each of which is defined within the specification amendments with the effect on the performance theoretically attainable. To evaluate the effectiveness of proposed enhancements, several academics have utilized simulation software [4]-[6]. The results of simulations are interpreted as an indication of the improvements attainable in practical applications.

The 802.11n amendment, published in 2009 and ratified in IEEE 802.11-2012 [7], specifies a number of enhancements to improve on throughput, range and reliability. Physical layer (PHY) enhancements include advanced modulation techniques, utilization of Multiple-Input Multiple-Output (MIMO) antennas, wider channels and operation in the 2.4GHz or optional 5GHz frequency bands. Medium Access Control (MAC) layer enhancements consist of frame aggregation and block acknowledgements to increase MAC layer efficiency.

The 802.11ac amendment was published in 2013 and ratified in IEEE 802.11-2016 [8]. It specifies PHY layer enhancements for 5GHz exclusivity, increased number of MIMO streams, Multi-user MIMO, wider channels and further advancements to modulation techniques. The MAC layer enhancements build on previous frame aggregation techniques.

The structure of the paper is as follows. Section 1 is the Introduction. Section 2 is a discussion of the selection of a method and the design choices made. Section 3 is an analysis of the findings. Section 4 is the evaluation and draws conclusions. Finally, section 5 is a list of the references.

II. METHOD

Innovative features in 802.11 amendments were identified - modulation, convolutional coding, channel widths, guard intervals, MIMO, spatial streams, beam-forming, frame aggregation and block acknowledgements. Each innovation is responsible for a notable increase in PHY or MAC level data rates. Additionally the medium-specific variables of Signal to Noise Ratio (SNR) and obstructions must be accounted for. Each experiment must isolate an individual variable as best as possible within the environment in which the experiments are performed, the conditions under which the experiment is conducted and the measure of performance. Then repeated in MATLAB and NS-3 simulation, the results collated into datasets. Experiments measured the downstream data rate from access point to client, over distinct distances.

NS-3 [9] and MATLAB [10] were used for simulations. NS-3 is an open-source real-time network simulator, supporting numerous technologies e.g. Ethernet, Wi-Fi, Worldwide Interoperability for Microwave Access (WiMAX), Long Term Evolution (LTE) and 5G. MATLAB supports a variety of technologies using ’Toolboxes’.

In order to simulate the 802.11 specification and physical layer communication effects (attenuation, noise, interference etc.) in MATLAB, two add-on packages were used, viz., Communications System Toolbox for Radio Frequency (RF) modelling and Wireless Local Area Network (WLAN) System Toolbox for modeling the 802.11 MAC and PHY layers.

MATLAB simulations used an 802.11ac simulation script [15]. Ten simulations were scripted, five for 802.11n and five for 802.11ac. The channel model within the simulation was configured to replicate the RF environment as closely as possible. All configured parameters were equal for both High Throughput (HT) and Very High Throughput (VHT) simulations.

MATLAB was used with wlanTGacChannel and wlanTGnChannel objects configured with a delay profile of Model-D. The model was found to be the most representative of the practical results recorded. The key factor in this decision was the breakpoint distance of 10 meters i.e. Line Of Sight (LOS) transmission for ⩽ 10m and Non Line Of Sight (NLOS) for > 10m, produced results to most closely match those observed.

The carrier frequency was set to channel 44, 5.20GHz. Noise was introduced through the Adds White Gaussian Noise (AWGN) Channel object, with the initial signal to noise ratio being set to 97dB. The simulation was configured to take into account path loss and shadowing RF propagation effects.

NS-3 simulations used scripts modified for HT [16] and VHT [17]. Six scripts were created - three for 802.11n and three for 802.11ac. Each script calculated the data rate achieved at each distance for all parameter combinations, with each script doing so for 1, 2 or 3 spatial streams.

NS-3 provides a variety and ever growing number of wireless propagation models. Each is built around a unique set of equations and up to seven may be chained to produce a single complex propagation model. A number of models were evaluated for suitability. Based on the results of each, and considering recommendations towards path loss models for this use case by [18], the decision was made to implement the Log Distance Propagation Model alongside the Nakagami Propagation Loss Model.

The key disadvantage to these models, however, was the lack of accounting for complex RF effects, such as shadowing. Thus a degree of variance was expected in the results. Chaining the Shadowing Loss propagation model resulted in an unrealistic simulation of wireless performance, with a greater degradation of signal quality over distance being exhibited. Hence the shadowing loss propagation model was not implemented. In order to model shadowing loss to some degree, the Random Propagation Loss Model was implemented using a random integer between 0 and 5. The result was a random signal loss between 0 and 5dBm. For configuration of the propagation model, the logarithmic power was set to 3.00. Due to constraints imposed by the execution time of each simulation, it was not possible to evaluate powers to a greater precision than 0.25.

As shown in Table 1, measurements and simulations were made using a range of tools. Directional data rate was measured Access Point (AP) to client using a constant stream of uniformly formatted packets and frames. The Internet Performance Working Group (IPERF) [11] network benchmarking tool was chosen as it supports User Datagram Protocol (UDP), packet loss, logging and streaming.

For the monitoring of noise and SNR, SDRSharp (SDR#) [12] for Windows was chosen for basic functionality and simplistic interface of SDR#. For accurate identification of the received signal strength (dBm) the inSSIDer [13] tool was chosen. Combined, these tools provide the necessary measurements to monitor local RF conditions using the Software Defined Radio (SDR).

TABLE 1. SUMMARY OF TOOLS FOR PRACTICAL MEASUREMENTS AND SIMULATIONS.

Software	Usage	Description
IPERF	Practical	UDP Datagram generation
SDR#	Practical	Spectral Analysis
inSSIDer	Practical	Identify Signal Strength
WLAN Toolbox	Simulation	MATLAB simulation
Comms Toolbox	Simulation	MATLAB RF simulation

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The infrastructure in Figure 1 consists of the Cisco Aironet 2702i with 2504 WLAN controller. A TP-Link T9UH adapter provided support for up to 3x3:3 MIMO. As a result of access point and network adapter limitations, the experiments were limited to a maximum of 3x3:3 MIMO and 80MHz channel widths. For spectral analysis the HackRF SDR was chosen for 20MHz bandwidth and ⩽ 6GHz tuning range [14]. All equipment was switched through the C3650-24PS switch in order to provide a 1Gbps link.

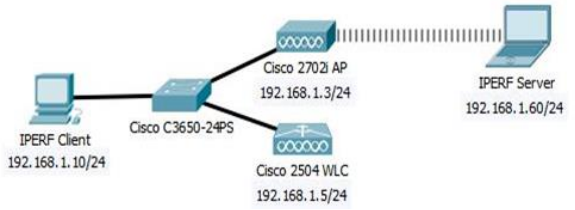

Fig. 1. Wireless Network Infrastructure for Practical Measurements

III. FINDINGS

A. Modulation Schemes

Practical measurements matched theoretical and simulated increases in data rates because of increases in Orthogonal Frequency-Division Multiplexing (OFDM) symbol density. HT and VHT exhibited in data rate variations of 3.5% and 9.6% respectively over four distances. NS-3 consistently predicted optimistic data rates with 35%, 22% and 14.5% average over prediction for Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK) and 16-Quadrature Amplitude Modulation (QAM). For VHT, performance did not match that predicted for larger distances. Both simulations suggest logarithmic compared to observed linear performance due to pessimistic channel modelling or environmental effects producing gains. NS-3 showed minimal variation between predicted and measured performance with a 0% and 6% variation.

B. Spatial Streams

Theoretical data rates were not exhibited in reality. The improvement in data rate over lesser numbers of spatial streams decreased. In the case of VHT, the data rates for 2 and 3 spatial streams decreased below that of 1 spatial stream at 10 and 15 meters.

For HT, MATLAB correctly predicted the degradation of performance for 1 spatial stream across all distances. However, for 3 spatial streams the prediction was not representative of reality. For VHT, whilst the prediction for the degradation of performance over distance was pessimistic, the simulation did correctly predict that beyond 10 meters, 1 spatial stream would retain the data rate such that it would exceed the data rates of both 2 and 3 spatial streams. The predictions were, in general, not indicative of the true performance. NS-3 was noted to be the most accurate at predicting HT performance over all distances, especially for 1 and 2 spatial streams. It correctly predicted that over all four distances the performance of the increased number of spatial streams would not degrade below that of the lower numbers of spatial streams. For VHT however, NS-3 did not correctly predict the performance across all measured distances. Overall, the key observation from the measurements and predictions was that existing simulation models do not accurately portray the true performance of 802.11 standards when taking spatial multiplexing (spatial streams) into consideration.

The practical measurements showed that the theoretical increases in data rates, attributed to increases in channel width, held true. For HT, the data rate increased by 66Mbps for 20MHz compared to 40MHz. For VHT, the data rate increased by 90Mbps and 188 Mbps for 20MHz to 40MHz and 40MHz to 80MHz channels. Note that the data rate more than doubled in all cases. This effect was not expected. A possible cause for such an effect may have been cross-channel interference reductions as bandwidth increased, due to dynamic channel assignment taking effect at remote access points. It should also be noted that the decrease in data rate at 5 and 10 meters for VHT 20MHz was experienced across all 10 measurements at each distance. As the experiments were performed in an environment containing other wireless transmitters (APs, Devices etc.) this decrease may be attributed to interference from said transmitters at the time of the measurements being taken. This would explain why the effect was not measured across the 40MHz and 80MHz measurements. NS-3 and MATLAB were shown to produce realistic performance predictions, modelling both the data rate and performance over distance successfully for each channel width. As previously discussed, NS-3 was unable to successfully model transient environmental effects. Additionally, for both HT and VHT, the predicted performance degradation was again overly pessimistic for both simulations. Unlike previous experiments, this degradation did occur correctly between the 10 and 15 meter distances, however not to the degree predicted.

C. Guard Intervals

The practical measurements found for HT and VHT respectively a 10% and 9.5% increase in data rates when changing from 800ns guard intervals to 400ns. This closely matched the theoretical increase of 11.1% stated within the 802.11 specification.

Additionally, for VHT, the long guard interval was shown to exceed the performance of the short guard interval as the signal quality degraded. This matched theory as longer guard intervals are expected to improve performance due to additional time for reflected signals to disperse prior to transmission.

NS-3 predictions closely matched measurements for HT with a maximum variance of 20Mbps being observed. For VHT, NS-3 did not correctly model reduced data rates at 0 meters, nor the sharp decrease observed between 5m and 10m. However, for the 5m and 15m measurements, predictions for the long guard interval varied by only 5.7% and 1.6%.

MATLAB predictions were somewhat inaccurate. For HT, a sharp performance reduction was incorrectly predicted, occurring beyond 9 meters. However, the increase in data rate of 11.1% was correctly predicted. For VHT, whilst the model was overly pessimistic, it did correctly predict a sharp performance reduction between 5m and 10m. It did not predict the long guard interval overtaking the performance of the short guard interval.

D. *Coding Schemes*

Practical measurements showed that the specification data rate increases for HT and VHT occurred. For HT, each increase in the ratio of data bits to error-checking bits theoretically results in the data rate increasing by 15Mbps (Between 2/3, 3/4 and 5/6). The true increase was measured to be 13Mbps moving from 2/3 to 3/4 coding and 11Mbps from 3/4 to 5/6 coding. VHT on the other hand measured only an 11Mbps increase between 3/4 and 5/6, compared to the stated theoretical increase of 30Mbps. Unlike HT, VHT showed a tendency for the achieved data rates to converge as the distance increases. This was expected as higher coding schemes are intended to offer higher data rates at the cost of reliable data transfer. A lower coding rate is expected to achieve greater data rates than higher coding rates as a reduction in signal quality is observed.

The predictions made by the NS-3 simulator were noted to be a closer representation of the true performance than MATLAB. For HT, MATLAB matched the theoretical increases of 15Mbps as the coding scheme increased. NS-3 predicted a 12Mbps and 15Mbps increase from 2/3 to 3/4 and 3/4 to 5/6 respectively. Additionally, at 15 meters, NS-3 correctly predicted a minor convergence of each coding scheme, as was observed to a lesser degree in the lab. Similarly, NS-3 most accurately predicted the VHT measurements both in terms of the data rate and the reduction in data rate between 5 and 10 meters. It did not however correctly predict the leveling off between 10 and 15 meters, nor did MATLAB.

IV. DISCUSSION

The performance of 802.11n and 802.11ac was found to be lacking when compared to the data rates stated in the specification. This performance was unable to be accurately modeled in a number of experiments by the two simulators investigated. Specifically, the following findings were made:

When simulating 802.11ac (VHT), both NS-3 and MATLAB were found, in general, to accurately model the increases in data rates. For non-zero distances it was found that the accuracy of the predictions made reduced as the distance between the transmitter and receiver increased due to the simulators' RF model(s) (channel model). Models could not be calibrated with known measurements.

When simulating 802.11n (HT) both simulators were found to more closely reflect the performance measured in reality, across all four distances. However, at 15 meters, the greatest variances were observed. MATLAB was shown to be the least accurate model of performance, with prediction accuracy falling greatly after 10 meters. NS-3 on the other hand more accurately predicts both the measured data rates and the reduction in data rates over distance, excluding predictions for multiple spatial streams.

Of the technical features evaluated in this report, the simulation predictions for spatial multiplexing (MIMO) were found to substantially differ from those measured in reality. The models used for NS-3 and MATLAB were found to more accurately reflect the measurements of HT and VHT respectively, with substantial prediction inaccuracies being made by NS-3 and MATLAB for VHT and HT respectively. Similar to the other experiments conducted, the factor responsible for such variations was the implementation of the RF model.

In high SNR conditions, advanced technical features aimed at increasing data rates fulfilled their function. However, these features did not necessarily do so to the degree stated in the 802.11 standard. As distances increased, and SNR fell, the performance gains decreased, in some cases to a point where the attainable data rate fell below that of features with lower stated data rates.

V. CONCLUSION

It has been shown that MATLAB and NS-3 successfully modeled the technical features of the 802.11 specification. For both 802.11n and 802.11ac, both simulators successfully modeled the increases in data rate provided by increasing the efficiency or complexity of each technical feature. Performance over distance is modeled through channel models. The inaccurate implementation of the channel models contributed greatly to the inaccuracy of the predictions made.

Better monitoring is recommended. E.g., Ettus Research X300 [19] for 160MHz channel bandwidth, full 802.11ac capabilities and support for low-level configuration using C++, Python or GNU Radio.

In future, 5G cellular contains innovations to increase data rates to up to 20Gbps per user with frequencies between 30 and 100GHz under consideration, full duplex, beamforming, MIMO and pico-cells [20]. Development simulators are the Third Generation Partnership Project's 3GPP [21] and the Novel Millimeter-Wave Channel Simulator (NYUSIM) simulator, built by researchers at New York University [22].

REFERENCES

[1] Y. Zeng, P. H. Pathak, and P. Mohapatra, "A first look at 802.11 ac in action: Energy efficiency and interference characterization," in Networking Conference, 2014 IFIP, 2014, pp. 1-9: IEEE.

[2] D. Newell, P. Davies, R. Wade, P. Decaux, and M. Shama, "Comparison of Theoretical and Practical Performances with 802.11 n and 802.11 ac Wireless Networking," in Advanced Information Networking and Applications Workshops (WAINA), 2017 31st International Conference on, 2017, pp. 710-715: IEEE.

[3] M. Darbyshire. "Practical Performance, Interference Effects of Wireless Networks ", Bournemouth University, 2017.

[4] Z. Machrouh and A. Najid, "Performance Analysis of IEEE802. 11ac DCF Enhancement for VHT with Frame Aggregation," International Journal of Recent Contributions from Engineering, Science & IT (iJES), vol. 4, no. 3, pp. 17-21, 2016.

[5] W. Zhengzhong, Z. Xianxin, Y. Wenge, and L. Zilin, "System level simulation modeling of Bluetooth voice and its interference," in Signal Processing, 2004. Proceedings ICSP'04. 2004 7th International Conference on, 2015, vol. 1, pp. 29-32: IEEE.

[6] N. V. Doohan, D. K. Mishra, and S. Tokekar, "Reliability analysis for wireless sensor networks considering environmental parameters using MATLAB," in Computational Intelligence, Communication Systems and Networks (CICSyN), 2011 Third International Conference on, 2011, pp. 99-102: IEEE.

[7] "IEEE Standard for Information technology--Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific requirements--Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications--Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz," IEEE Std 802.11ac(TM)-2013 (Amendment to IEEE Std 802.11-2012, as amended by IEEE Std 802.11ae-2012, IEEE Std 802.11aa-2012, and IEEE Std 802.11ad-2012), pp. 1-425, 2013.

[8] "IEEE Standard for Information technology--Telecommunications and information exchange between systems Local and metropolitan area networks--Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," IEEE Std 802.11-2016 (Revision of IEEE Std 802.11-2012), pp. 1-3534, 2016.

[9] NSF, "Network Simulator 3. 3.27 ", ed. Alexandria, Virginia: National Science Foundation, 2018a.

[10] MathWorks, "MATLAB. 2017a ", ed. Natick, Massachusetts, 2017.

[11] J. Dugan, S. Elliott, B. A. Mah, J. Poskanzer, and K. Prabhu, "IPERF3. 3.1.3 ", ed. iperf.fr: iKoula, 2016.

[12] AirSpy, "SDR#. revision 1651 ", ed, 2018.

[13] Metageek, "inSSIDer. 3.1.2.1 " 2016.

[14] M. Ossmann, D. Spill, T. Streetman, E. Wooton, J. Graves, and M. Mclaurin, (2016, 25 February 2018). HackRF One. Available: https://greatscottgadgets.com/hackrf/

[15] MathWorks, "Packet (Frame) Processing", Massachusetts, 2018.

[16] M. Banchi, HT Wi-Fi Network [ns-3 script], 2018, Available: https://goo.gl/NuZKKq

[17] S. Deronne, VHT Wi-Fi Network [ns-3 script], 2018, Available: https://goo.gl/koR2KG

[18] M. Stoffers and G. Riley, "Comparing the ns-3 propagation models," in Modeling, Analysis & Simulation of Computer and Telecommunication Systems (MASCOTS), 2012 IEEE 20th International Symposium on, 2012, pp. 61-67: IEEE.

[19] Ettus Research, (7 April 2018). USRP X300 Available: https://www.ettus.com/product/details/X300-KIT

[20] A. Nordrum and K. Clark, "Everything You Need to Know About 5G," IEEEE, 2017.

[21] 3GPP, "LTE; 5G; Study on channel model for frequency spectrum above 6 GHz ", Sophia Antipolis, France, 2017, Accessed on: 12 April 2018.

[22] S. Sun, G. R. MacCartney, and T. S. Rappaport, "A novel millimeter-wave channel simulator and applications for 5G wireless communications," in Communications (ICC), 2017 IEEE International Conference on, 2017, pp. 1-7: IEEE.