NOVEL CROSS-LAYER SIMULATION PLATFORM TO INCLUDE REALISTIC CHANNEL MODELING IN SYSTEM SIMULATIONS

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ABSTRACT

Up to date wireless local access network (WLAN) simulation platform development efforts have concentrated either on the physical (PHY) layer or the medium access control (MAC) layer. The obtained performance is thus biased in that one layer has more weight than the other. On the other hand, an all-inclusive simulator based on the actual platforms could be too much resource consuming. Simulator architectures are indeed tailor-made for one of the layers and thus not convenient for the other. That is why we propose a new IEEE 802.11n/ac multi-user simulation platform with reduced complexity. This platform is composed of an all inclusive PHY layer module and an elaborated MAC layer module working in a symbiotic manner. Both PHY and MAC layers being finely represented, an accurate modeling of reality is made possible. This PHY+MAC simulation platform can thus be an interesting tool for testing PHY-MAC cross-layer solutions for WLANs.

KEYWORDS

Cross-layer, hidden stations, IEEE 802.11n/ac, realistic channel modeling, simulation platform

1. INTRODUCTION

In the wireless local access network (WLAN) context, physical (PHY) layer or medium access control (MAC) layer performance evaluations can either use link-level or system-level simulations, depending on the layer to study in depth. Elaborated PHY layer simulators, notably including very fine channel models, consider at least one of the following assumptions if not all: full queues [1], oversimplified contention [2], or perfect channel state information feedback [3]. This kind of simulator is based on a "PHY-centric" study. Ptolemy II [4] and COSSAP [5] are such simulators. On the other hand, complex MAC layer simulators allow fine simulation of contention access and queue refilling, which is done according to application layer needs. But the PHY model these "MAC-centric" simulators use is oversimplified considering the complexity of the wireless channel. The latter is often modeled using either graph model [6, 7], ON/OFF model [8], or information-theoretic model [9]. Some models even use lookup tables (LUT) to enable simple link-to-system mapping technique (like packet error rate, PER, to signal-to-noise ratio, SNR, correspondence tables [10]). Sometimes more sophisticated techniques are used (bit error rate, BER, per block of subcarriers [11]). But in all cases the PHY layer has been simplified. NS3 [12] (or its previous version NS2 [10]) and Opnet [13] are such simulators. Therefore in both types of simulators, i.e. either PHY-centric or MAC-centric, one

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of the layers has been reduced in complexity, somewhat biasing the behavior of the global system.

However, building an all-inclusive and exhaustive simulator would be too complex of a solution. The specifications and characteristics of each layer being very different, a common ground might be more than difficult to find. All the while, the use of such simulators can be very beneficial, especially when studying phenomena requiring an accurate and realistic modeling of PHY and MAC layer mechanisms.

That is why we propose a new multiple user simulation platform composed of two parts working in a symbiotic manner. Each part finely characterizes the corresponding layer. The incorporation of an all inclusive IEEE 802.11n/ac [14, 15] PHY layer, containing a realistic channel model, and an elaborated IEEE 802.11n/ac MAC layer results in an accurate modeling of reality. PHY layer simulations are very time consuming because of channel tap computations. Consequently the simulation platform performs these simulations only when necessary. Such a knowledgeable mix of detailed PHY simulations and LUTs enables optimization with regards to time and computational resource consumption. In [16] a similar approach was used for 3GPP LTE-Advanced. Wi-Fi and cellular systems are quite different though. In Wi-Fi the access strategy is distributed and the data transmission channel is also used for signaling. An IEEE 802.11 specific simulator has to be used for Wi-Fi performance analysis studies. In [17] however, the authors have modeled both PHY and MAC layers of the IEEE 802.11a [18]. This simulator is very well done but does not comprehend either IEEE 802.11ac, or IEEE 802.11n enhancements, thus restricting its use to single antenna Wi-Fi standards.

We will firstly present the proposed simulator structure and detail the characteristics of the PHY chain, dynamic channel modeling, and MAC section. Then we will validate our simulation model through a well-known MAC functionality, data aggregation. A modified version of NS2 using LUTs serves as reference. Finally, the advantages of using such a model will be shown through a hidden node [19] scenario.

2. PROPOSED NOVEL SIMULATOR STRUCTURE

2.1. Presentation

The principle that served as a basis for the elaboration of the simulator is the following: develop a MAC simulation module which interfaces with a PHY simulation module in a symbiotic manner. Indeed, in order to have a complete PHY-MAC simulator, it might be tempting to expand a PHY-exhaustive simulator to somehow faithfully comprehend the MAC layer, or the other way around. But this first sight solution implies a considerable increase in complexity. One of the layers' tailor-made simulator architecture has to be distorted so as to accommodate for the other layer. Therefore we propose to have two separate functions that interact only when necessary and exchange pre-processed information. We have an "OSI-like" structure, but with enhanced and completely dynamic interaction.

2.1.1. PHY section with realistic channel modeling

As implied before, we have used a fine grained PHY simulator as a basis of our cross-layer simulator. This custom Ptolemy II-like [4] PHY tool uses C++ environment, which eases functional block manipulation. It has allowed us to build IEEE 802.11n [14] and IEEE 802.11ac [15] compliant transmit (Tx) and receive (Rx) chains. TGn [20] and TGac [21] channel model blocks, which are used in the standardization process, represent the most substantial portion of the PHY section. These blocks enable a faithful representation of channel variations through time for IEEE 802.11n and IEEE 802.11ac systems (resp.) in a multiple-input, multiple-output (MIMO) context.

2.1.2. MAC section

The NS3-like [12] MAC section deals with contention access, basic service set (BSS) management and control frame exchanges. Each frame is acknowledged if it is correctly received. The classical 802.11 contention access has also been extended to the IEEE 802.11e [22] quality of service (QoS) contention access and to the IEEE 802.11n packet aggregation. Multiple-user MIMO (MU-MIMO), as detailed in IEEE 802.11ac, is also implemented. In addition, rate adaptation algorithms, which are not specified in standards but are indispensable in any commercial product, are taken into account. It is also the case of MU-MIMO station selection algorithms, which will certainly be used in the IEEE 802.11ac standard. In short, we try to be as close as possible to realistic usage scenarios.

2.1.3. Interactions between the PHY and MAC sections

Once the transmitting station (STA) has been selected by the MAC section, information regarding the transmission (mainly MCS - Modulation and Coding Scheme - and data size) is handed over to the PHY section. The latter simulates transmission of information bits using the received parameters. Channel coding and modulation is done accordingly, followed by interaction with a fine grained channel, and a demodulation and decoding process to finish with. The PHY section then forwards the decoded bits, which will be checked through the included forward check sum (FCS), to the MAC section. Channel state information (CSI) can also be handed over, if necessary, to improve rate adaptation and MU-MIMO station selection. The two sections thus work sequentially and in an interdependent manner, so as to be sure to compass each layer’s characteristics.

2.2. Detailed PHY chain presentation

2.2.1. Global structure

The most time and computational resource consuming block in WLAN link-level simulators is the channel block. This is due to channel tap generation and matrix manipulations. But a fine grained channel block is critical when modeling channel evolutions. Therefore for an intelligent use of resources, we have two PHY layers. One consists of a complete Tx chain, channel, and Rx chain. This model is used for the transmission of data frames. The precise effects (benefits as well as handicaps) of the physical medium and Tx/Rx chains upon data transmission can thus be faithfully captured. The problem is that this process is time consuming. That is why we use another PHY model for control and management frames. This model is a simplified version of the first one. The success or failure of a frame is probabilistically determined based on LUTs (just like in some modified versions of NS2 and NS3). Control and management frames are normally sent using robust modulations. Therefore, compared to less robust 802.11n or 802.11ac data frames, there is greater margin for correct reception. The particularities of the PHY chain have less impact on the outcome than for data frame reception.

The resulting optimized architecture will allow a simulation that is as close as possible to reality while minimizing global computational complexity.

2.2.2. Parameters

Our chain is designed so as to be compliant to 802.11n and 802.11ac standards. It is also shared by all STAs of the currently simulated scenario. Consequently 802.11n and 802.11ac parameters can be tuned during the scenario setup. In addition, all the transmission parameters (number of antennas, MCS, etc.) are dynamically reconfigurable according to the characteristics of the selected pair of STAs and the current transmission rate. This modular structure enables to compass a wider scope of scenarios.

2.2.3. Dynamic reconfiguration

The PHY layer chain is common to all stations therefore it needs to be dynamically reconfigurable so as to meet the characteristics of each (e.g. number of antennas and data size). These are given over by the MAC section every time a STA has won access to the channel.

However, most PHY layer simulators (for e.g. Ptolemy II and COSSAP [5]) have functional blocks with static I/O FIFO sizes. The sizes of I/O FIFO buffers are set at the beginning of the simulation so as to fit a particular MCS. This is understandable considering that PHY layer simulations usually evaluate the performance of a single link, i.e. between a transmitter and a receiver. Having the same bridle in our fine grained PHY simulator while simulating multiple links, we built a “water pipe”-like (useful information + padding) structure for I/Os to workaround this flaw. At the beginning of the simulation, I/O FIFO sizes are set large enough so as to support the current simulation’s maximum useful information size. However this bypass structure should not be much resource consuming because processing is only limited to the useful information, padding being neglected. Dynamic reconfiguration is enabled despite static I/O FIFO sizes.

2.3. Dynamic channel modeling

2.3.1. Channel model

As indicated before, one of the elements that renders our PHY layer simulation faithful to reality is the TGn [20] (or TGac [21]) channel modeling block. The latter is an SCM-like [23] geometric model based on stochastic modeling of scatterers, also called cluster model [24]. Fast fading and shadowing phenomena are also taken into account in the TGn and TGac models.

2.3.2. Channel tap handling

Channel taps characterize channel conditions between a pair of conversing STAs. The way they are handled determines the correspondence of the simulated scenario to reality. In addition, the channel modeling block being the most computation resource consuming element of the PHY layer chain, optimization can be done through wise channel management.

2.3.2.1. Temporal

Most PHY-centric simulations look after channel capacity. Therefore different channel conditions have to be considered so that the capacity may be ergodic, if possible. To do so, new channel taps are generated for every transmission. These taps are estimated by the receiver during the training sequence at the beginning of every frame. CSI is available at the receiver through this estimation process. On the other hand, CSI cannot be continually available at the transmitter for beamforming purposes, as assumed in classical simulators.

In the “real world”, as in the proposed simulation platform, the transmitter has to send a sounding frame and wait for an estimate of channel taps (at the given time) to be fed back through a response frame. In addition, channel taps evolve through time (coherently to simulation time) while still remaining correlated. The fed back estimates can thus be used in following transmissions.

2.3.2.2. Multiple station support

Another advantage is facilitated support for multiple STAs. Channel taps between an oriented pair of STAs can be stored away so that the chain can be reused to simulate transmission between another pair of STAs, while having the possibility to recover, later on, the stored channel context. Space division multiple access (or MU-MIMO) is also rendered possible for 802.11ac implementation, by using stored taps to model crosstalk interference.

2.3.3. Gains compared to a MAC-centric approach

We can see from what precedes that compared to a MAC-centric approach [6-12] which oversimplifies the PHY layer, our simulator structure, through realistic channel modeling and complete Tx/Rx chains, allows a more reliable and more flexible PHY section.

2.4. Detailed MAC section presentation

2.4.1. Global structure

The MAC section contains the main MAC functions of the 802.11n (and 802.11ac) in conjunction with an application layer which generates packets. This is where the advantage of using C++ programming language can be most clearly seen: we can generate as many applications per STA as desired, and create also as many STAs as necessary for the simulation thanks to the object concept in C++. In the actual state of things, we have considered the infrastructure mode, i.e. with an access point (AP) assuming the management of the BSS. However, this can be easily extended to an ad hoc mode. In addition, we can also use our MAC section to generate multiple APs (operating on at least one common 20 MHz channel) and see how the system reacts in an overlapping BSS context. Another advantage is that STAs supporting different bandwidths can also be associated to the same AP and one can easily study system behavior in such a scenario. We will note that NS2 and NS3 frameworks were used to develop this MAC section. Hence, this kind of structure offers a lot of possibilities for modeling different scenarios corresponding to every day use cases.

2.4.2. Function presentation

As indicated above, we can define as many applications as desired per node. The latter centralizes topology information (see Figure 1). Applications are managed by an application function which models higher layers and where the traffic category, rate, and duration are defined. Each application generates packets periodically, but with a random jitter for arrival fairness. The obtained traffic is then handed over to a network interface. The latter can either be AP specific or STA specific and handles traffic it relays to the contention and queueing function. In 802.11n, this corresponds to the enhanced distributed contention access (EDCA). The access category (AC) having won access of the channel gives over its packet to the function handling data/acknowledgement transactions. Afterwards the PHY section takes over.

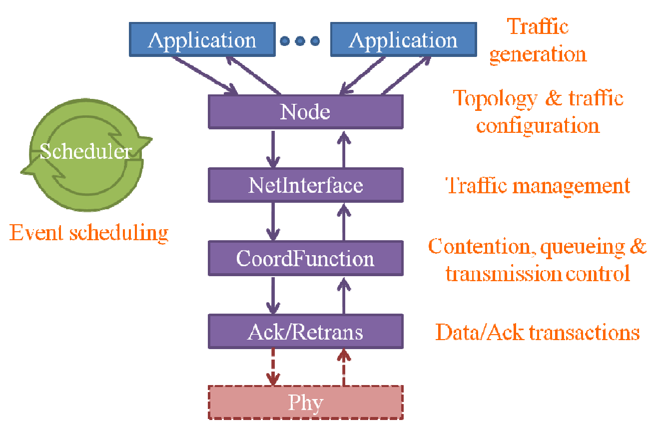


Figure 1. MAC section structure

We note that there is an event scheduler which takes care of the sequencing of channel access requests through callbacks. This way data, control, and management frames, and even collisions, are accounted for meticulously and in a timely manner.

2.4.3. Main MAC functions

MAC particularities are considered mostly in NetInterface, CoordFunction and Ack/Retrans (as defined in Figure 1). Indeed, CSMA/CA (carrier sense multiple access with collision avoidance) with QoS, which is a schematic definition of EDCA, is an essential part of 802.11n. Every AC of every STA can contend for the channel and the outcome is decided in the CoordFunction function, which also builds the frames to transmit. Positive acknowledgment (ACK) is also a particularity of 802.11 systems. Ack/Retrans ensures that simple data MPDUs (MAC protocol data unit) or even aggregate MPDUs (A-MPDU) are correctly acknowledged. Still some MPDUs do not need acknowledgment but are essential in 802.11 systems. Beacons are among such frames. They are generated by the AP's NetInterfaces, which consider them as one of the many control, management or data flows that a NetInterface must manage.

2.4.4. Gains compared to a PHY-centric approach

As can be seen, traffic generation, queueing, and channel access, as well as acknowledgment, are all taken into account in this model. It would not have been the case in a PHY-centric approach [1-5] where all of the previous MAC and upper layer functions are simplified. The system behavior would diverge from reality. This is especially true in a multiple user context.

3. SIMULATION SCENARIOS

3.1. Model validation through aggregation

Before showing any of the improvements that this new simulation platform enables, the first thing to do is to validate the model. We propose to do this through a cut-and-dried concept of 802.11n systems, MPDU aggregation, using NS2 simulator with LUTs as reference.

3.1.1. Reference structure: NS2 system simulator with LUT channel abstraction

In the modified version of NS2 we have used, PHY layer performance is taken into account through LUTs, which are computed off-line through link-level simulations. This way the general particularities of the Tx chain, channel and Rx chain can be accounted for in a statistical manner. The success or failure of reception is established by randomly selecting a PER value and comparing it with the reference LUT PER value, for a given SNR. It will be our reference structure for the validation of the proposed simulation platform.

3.1.2. Simulation parameters

The TGn channel, IEEE 802.11n PHY, and IEEE 802.11n MAC simulation parameters (summarized in Figure 2) are the following:

- 1 AP and 1 STA both having 2 Tx/Rx antennas (and supporting as many spatial streams), being placed 1 m apart;
- User datagram protocol (UDP) best effort traffic at 130 Mbps for 8 s. MAC service data units (MSDU) of 1500 octet (typical MAC payload format) sent using either simple MPDUs, or A-MPDUs of up to 2, 8, and 20 MPDUs depending on the simulation (tagged A-MPDU_2, A-MPDU_8, and A-MPDU_20 resp.);
- Adaptive multi rate retry (AMRR) rate adaptation algorithm [25] starting at minimum rate (i.e. $r_0=r_1=r_2=r_3=6.5$ Mbps, r_0 being the highest rate) and used with rate counts (which are the numbers of retries per rate) set to $c_0=3$, $c_1=3$, $c_2=1$,and $c_3=3$;

- Maximum transmit opportunity (TxOP) set to 3008 µs (equivalent to standard maximum of video access category) to limit transmission duration to an end-usage-wise realistic TxOP;

- TGn channel model B (residential environment), with 20 MHz bandwidth and central carrier frequency of 5.2 GHz (channel n°40). MCSs up to 15 are activated (because the use of two spatial streams is enabled);

- Tx power of 17 dBm (half power), no antenna gains at Tx and Rx, Rx noise level of 7 dB, and system loss of 8.5 dB;

- 802.11n [14] standard compliant Tx and Rx chains using mandatory binary convolutional coding (BCC) and long guard interval (GI);

- Use same seed (50) to generate TGn channel taps for all simulations in this scenario. The rate adaptation algorithm can thus keep up with channel tap evolutions. These evolutions are coherent because the channel is initialized once.

The AP and STA are placed close to one another so that the rate adaptation algorithm can use the maximum PSDU (PHY service data unit) transmission rate (i.e. 130 Mbps). The CoordFunction can aggregate as many MPDUs as allowed by the maximum TxOP, using the current maximum rate (r0) to compute the frame's possible duration. We can thus send A-MPDUs with a high number of aggregates (as much as 30). The proof of concept, where A-MPDU_20s are to be used, is applicable. In addition, the chosen application rate corresponds to the maximum PSDU data rate. We thus insure that saturation could only be at MAC layer and/or PHY layer.

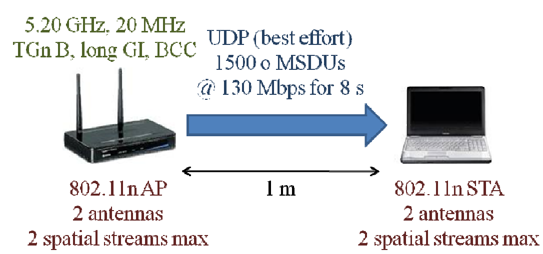


Figure 2. Simulation scenario and parameters for model validation

We will also note that all listed simulation parameters except those in the last two bullets, which are specific to the PHY section, are also used by the NS2 simulator. The two simulators are initialized with identical conditions.

3.2. Contribution of the simulator in a hidden node scenario

A STA establishes whether there is a signal through its carrier sense function. However if two or more STAs are out of range of each other but in range of another STA, carrier sense is eluded and collisions often occur. This is the hidden nodes problem [19]. The proposed simulator can be used to better characterize the consequences of this phenomenon.

3.2.1. Classical structures

3.2.1.1. Reference structure: NS2 system simulator with LUT channel abstraction

The NS2 (MAC-centric) simulator presented above can finely model contention access. However, if there is a collision detected by the event scheduler, colliding frames are automatically considered as corrupt, not acknowledged and must be retransmitted. This is done whatever the collision power, duration and location within the received frame. Clearly this way of doing things seems harsh. But considering that NS2 uses an abstracted PHY layer, it has no way of determining whether the collision leads to decoding errors or not. This simulator serves as our reference structure.

3.2.1.2. Contribution of real-time channel modeling

A PHY-centric simulator cannot, as such, model the complex channel access procedure of CSMA/CA. It cannot be used as a reference structure. However this approach can be interesting in that the interference caused by collisions can be simulated [26]. We can thus see whether the PHY layer Rx chain can recover from the induced signal distortions. The interference caused by the collision is considered as white Gaussian noise having the same power as the collision causing frame. It is added to the received signal on the concerned OFDM (orthogonal frequency division multiplexing) symbols. This can however be done only if the collision occurs in the PHY payload. If the PHY header is affected, we consider that the frame is lost. Indeed the PHY header contains synchronization, scaling, estimation, and payload MCS information. These fields enable the decoding of the PHY payload, and are thus crucial.

That is why in our simulation platform, in addition to collision-free data frames, the MAC section hands over data frames having undergone collision during PHY payload transmission to the fine grained PHY simulation chain. Information on the power of the collision inducing signal and on the relative position of collision affected OFDM symbols is also handed over.

3.2.2. Simulation parameters

Simulation parameters, depicted in Figure 3, are the same as in the previous scenario except concerning the following points:

- Two STAs placed diametrically with regards to the AP and transmitting UDP traffic to the latter;
- One of the STAs, STA1, moves further away from the AP (starting at 10 m) in a periodic manner (5 m every 2 s). The static STA, STA2, is placed far enough (20 m) so as to rapidly be in a hidden node situation with STA1;
- STA1 generates MSDUs of 100 octets and does not allow the use of MPDU aggregation. STA2 enables A-MPDU_2s;
- Seeds 50 and 52 are used for the TGn channels between STA1 and the AP, and STA2 and the AP (resp.).

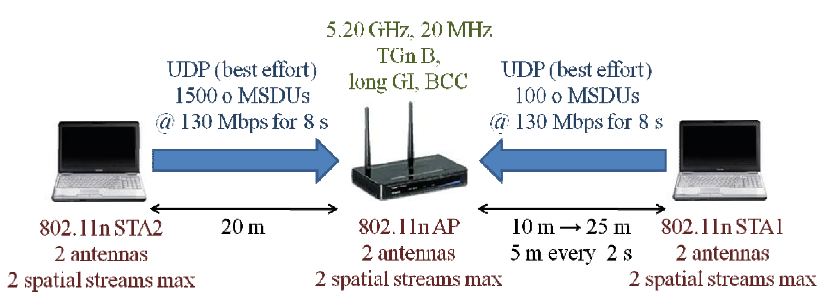


Figure 3. Simulation scenario and parameters exposing model contributions

Here also, the new simulation parameters, except the ones in the last bullet, are also used in the NS2 reference simulator.

4. PERFORMANCE EVALUATION

4.1. Model validation through aggregation

The UDP downlink (DL) rates obtained through the reference NS2 simulator and the new cross-layer simulator (denoted as XLS) for simple MPDU and A-MPDU_2 transmissions are illustrated in Figure 4. The reference NS2 simulator uses LUTs to decide whether a frame is correctly received or not. These correspondence tables are obtained by averaging PERs over at least 500 different channels for each SNR value. Particular evolutions of channel taps are thus smoothed out and a consistent PER-SNR curve is obtained for each MCS. XLS UDP DL curves are plotted for a specific channel (TGn with seed 50). They are thus much affected by the evolutions of this channel (fast fading, as well as slow fading). Still the obtained average UDP rates are the same for the two simulators, for simple MPDUs and A-MPDU_2s. In addition, by performing a sufficient number of simulations using different channels (thus different TGn seeds) and averaging, the results obtained by XLS should roughly match those of NS2 in this scenario.

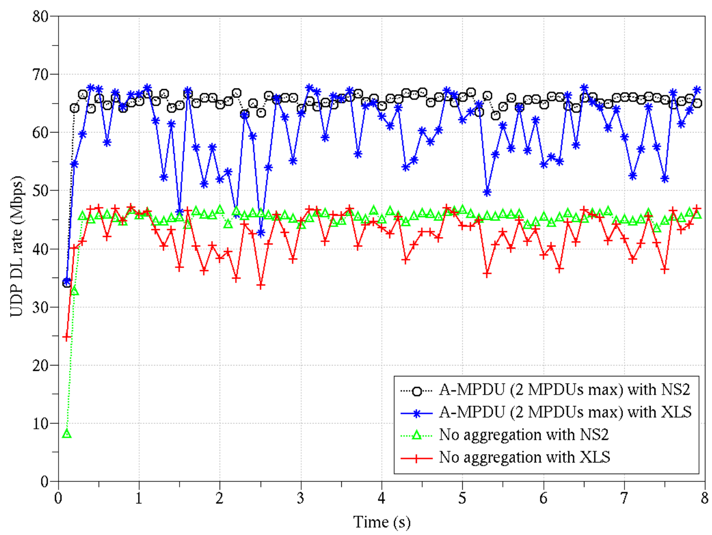
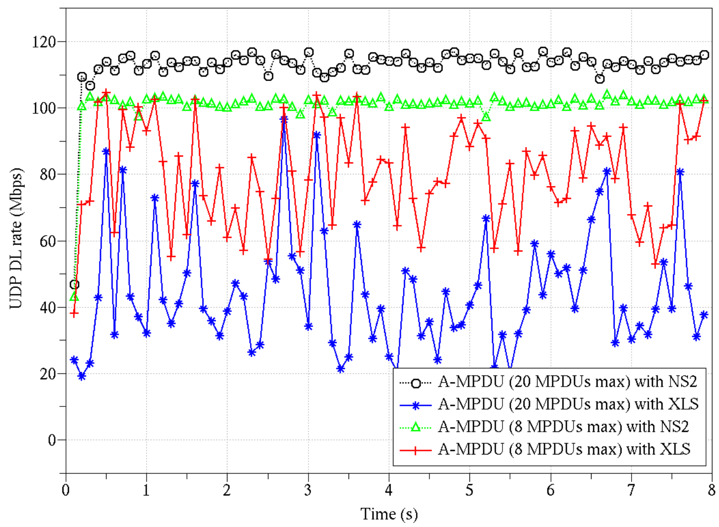


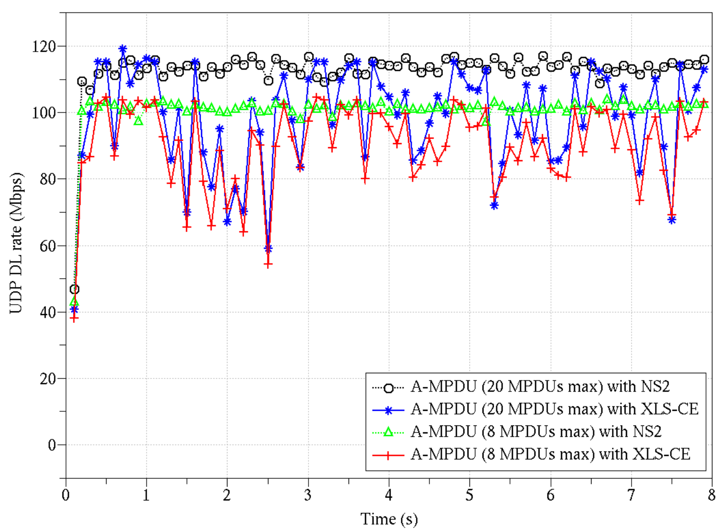
Figure 4. UDP downlink rates as a function of simulation time for transmissions without MPDU aggregation and with A-MPDUs (of at most 2 MPDUs) using the reference NS2 simulator and the proposed cross-layer simulator

An easy way to reach higher UDP rates, and see the interest of the new XLS platform, without modifying PHY parameters would be to use A-MPDUs with more MPDUs. The results of such simulations are given in Figure 5 (a), where A-MPDU_8s and A-MPDU_20s are used. When using the XLS, performance of A-MPDU_20 transmissions is even worse than that of simple MPDU transmissions (compare Figure 5 (a) and Figure 4). The latter have an average rate of 45 Mbps whereas the former have 40 Mbps.

Having designed the XLS platform to be as close as possible to real systems, channel taps are estimated at the beginning of the incoming frame. Rx channel estimation is simulated through the PHY header's long training frame sequences [22]. These estimates are then used for channel equalization of the rest of the frame. However if channel taps have changed notably in between, correct equalization cannot be done. The aging of these estimates can induce errors. There is nonetheless an amplifying factor: as indicated above, the number of MPDUs to be aggregated is determined using the highest rate r0 of the AMRR algorithm. For this rate and a maximum duration of 3008 µs, the TGn channel does not globally change much. But if consecutive errors induce rate decrease (through AMRR rate fallback), the frame will last longer. The odds of having important channel tap changes increase, eventually leading to errors. This chain reaction causes the UDP rate to drop notably. To verify this assertion, we have slightly modified the XLS PHY section so as to have OFDM symbol by OFDM symbol continuous estimation (XLS-CE). Estimates are updated throughout the whole frame reception process. The results obtained with this alteration are illustrated in Figure 5 (b). These results are on average similar to those obtained by NS2.



(a)



(b)

Figure 5. UDP downlink rates as a function of simulation time for transmissions with A-MPDUs of at most 8 MPDUs and 20 MPDUs using NS2 and XLS. Channel estimation is done either once at the beginning of each frame (a), or for every OFDM symbol of each frame (b)

Therefore the difference in UDL UL rates for A-MPDU_8 and A-MPDU_20 transmissions between NS2 and XLS is due to the aging of channel estimates. Taking into account this phenomenon can be a strong advantage in some studies. It is only with this kind of simulator that channel evolution (PHY) and MCS adaptation (MAC) can be simultaneously accounted for.

As stated above the effects of the rate adaptation algorithm on throughput are quite important. On all previous UDP DL graphs obtained using XLS, there is a rate decrease between 1 s and 1.5 s. The evolution of PHY payload data rates is given in Figure 6 for this period. It can be seen that after 1.17 s the rate adaptation algorithm falls back to more robust modulations. The fallbacks could be due to ACK loss. As a control frame, the success or failure in receiving an ACK frame in XLS is determined through the use of LUTs. However, a uniformly distributed random variable is used for this purpose. Thus the odds of having bursts of error on ACKs only is very rare (if it were so PHY payload data rates of NS2 simulations, based also on LUTs, would have been less stable). The fallbacks could also be due to a deep fade of the TGn channel at that moment. These evolutions induce bursts of error. Knowing that the same channel (seed 50) is used for all the simulations of this scenario, the second assumption explains the rate decrease.

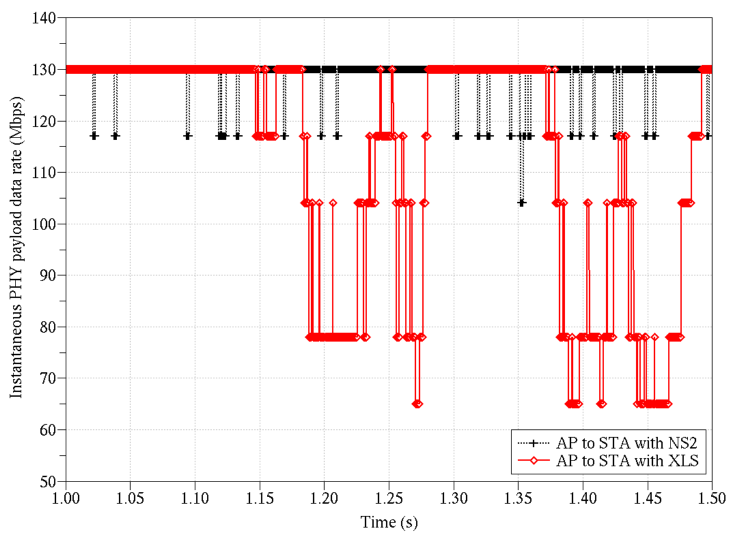
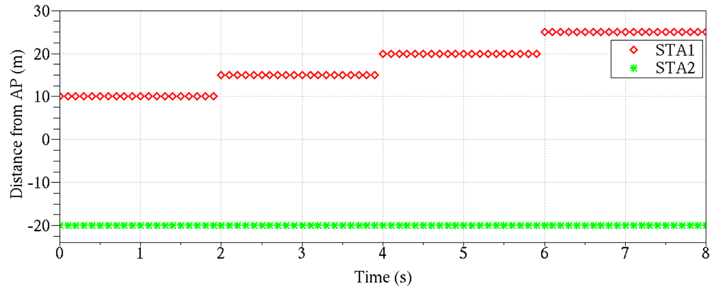


Figure 6. Instantaneous PHY payload data rates as a function of simulation time for A-MPDU transmissions of at most 2 MPDUs using NS2 and XLS

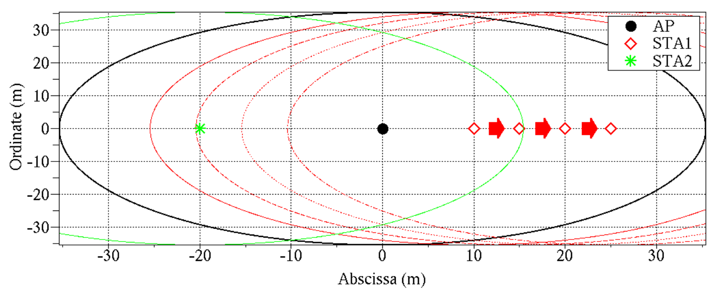
All the same, results show that the proposed model is valid. It can thus be used to fully model an 802.11n/ac environment. Some additional options like support for channel estimate aging can come in handy for finer analysis. Studies on the aging of CSI fed back to the transmitter, for beamforming purposes, can benefit from this XLS.

4.2. Contribution of the simulator in a hidden node scenario

In this scenario STA1 and STA2 are placed diametrically with regards to the AP. With STA1 moving away from the AP by 5 m every 2 s (see Figure 7 (a)), the consequent gap growing between STA1 and STA2 favors hidden node scenario. Indeed by using the minimum receiver sensitivity (-82 dBm for BPSK ½ modulations [14]) we can compute the range of each STA's transmission. Figure 7 (b) shows the maximum range covered by the AP, STA1 (with one ellipsoid per location), and STA2.



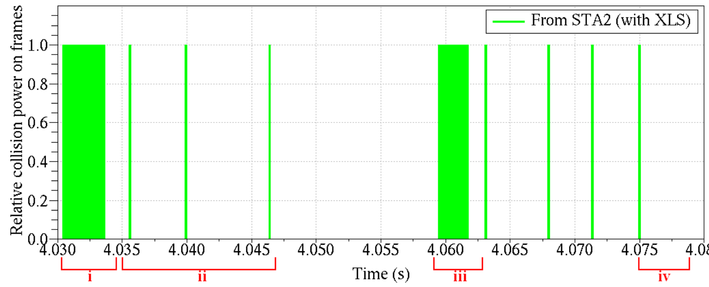
(a)



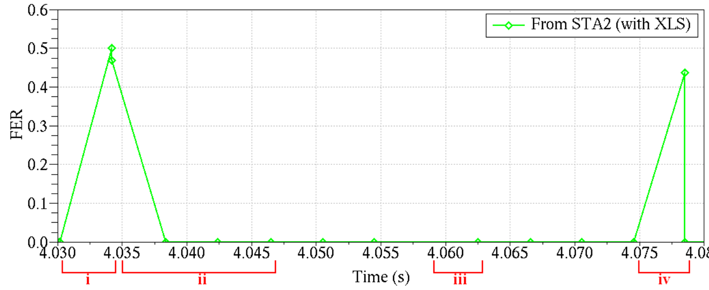
(b)

Figure 7. Positions of STA1 and STA2 through time (a) and on an AP centered grid displaying maximum range (b)

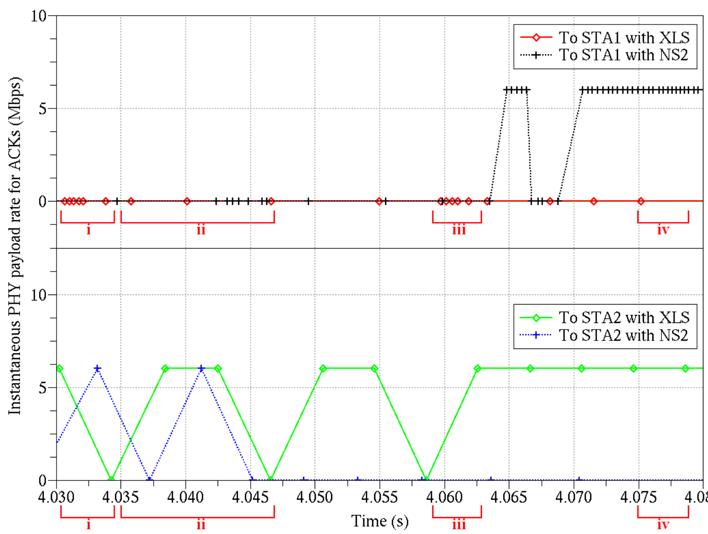
We can see from Figure 7 (b) that when STA1 is 10 m and 15 m away from the AP, the two STAs can sense each other. Collisions should thus be very rare. Because of CSMA/CA, there is collision only if both STAs have backoffs ending at the same time. In this case both STA's frames start at the same time and collision occurs during the PHY header. Both frames are regarded as lost, because of the importance of the PHY header. When STA1 is 20 m and 25 m away from the AP though, STA1 and STA2 become hidden nodes. Both STAs will transmit without taking the other into account, not being able to sense its transmissions. However ACKs coming from the AP are received by both. The occurrence and amplitude of collisions as perceived by the AP on frames from STA2 is given in Figure 8 (a). Figure 8 (b) illustrates the per-MPDU FCS error rate (FER) of frames received from STA2. The reader shall note that errors are detected by comparing the transmitted FCS and receiver computed FCS. The PSDU rates of ACK frames sent towards each STA are given, Figure 8 (c). By combining the three graphs we can see whether there was a collision (green rectangle in Figure 8 (a)) or not, if the received MDPU was correct (null FER, Figure 8 (b)) or not, and if the data frame has been acknowledged (strictly positive rate, Figure 8 (c)) or not. In addition all expected ACKs and block ACKs (BA) being registered, a "0 Mbps ACK rate" is equivalent to a missed ACK or a missed BA.



(a)



(b)



(c)

Figure 8. Forwarded collision amplitudes for STA2's transmissions (a), FER for frames received from STA2 (b), and ACK data rates used by the AP towards STA1 and STA2 (c)

During the first four illustrated milliseconds (interval i), STA1 has missed six ACKs, meaning that it has transmitted that many short (i.e. containing 100 octet data) frames to the AP. The latter has been receiving, in the same interval, a long (i.e. 2 MPDUs containing 1500 octet data each) frame from STA2. The PHY header of this frame being collision-free, its PHY payload is forwarded to the fine grained PHY section of the XLS. STA1's frames, received during STA2's PHY payload reception, have corrupted preambles and are thus not forwarded. Once all OFDM symbols of STA2's frame are received, the decoded bits are transferred to the MAC section which verifies whether the FCS is correct or not for each MPDU. It is based on the outcome of this test that the AP decides whether or not to acknowledge the concerned MPDU. FER is thus a concise indication of the impact of errors on each MPDU. FERs of MPDUs contained in an A-MPDU are grouped on the graph. Using this information we can see that STA2's A-MPDU was lost due to collisions (FER of 0.5 and 0.47 for MPDU n°1 and n°2 resp.). The following three A-MPDU_2s sent by STA2 (interval ii) are correctly decoded (null FERs) despite collisions of important power. STA1 and STA2 are indeed at the same distance from the AP (i.e. 20 m). However, only the first two frames are acknowledged, the BA for the last one having collided with a frame from STA1. Using the XLS platform thus enables to encompass the Rx chain's error correction capacity.

Another phenomenon concerning collisions in a hidden node scenario can be seen through the analysis of frames sent by STA2 at 4.059 s (interval iii) and 4.075 s (interval iv). Indeed the duration of the collision is not the only determining parameter, its localization within the frame is also very important. The first frame of the interval has a relatively long collision period. This is caused by the transmission of five frames by STA1, as implied by the corresponding missed ACKs. Still both its MPDUs are correctly acknowledged and the BA is correctly received. The second studied frame (interval iv) has a relatively short collision period. However the induced interference corrupted the first MPDU of this frame. Therefore the capacity of the Rx chain to recover from collisions complicates efforts to establish a simple collision threshold strategy. A simulator finely modeling both PHY (to compass the Rx chain) and MAC (to simulate the CSMA/CA driven access) layers is needed to study the effect of collisions.

Knowing that the PHY layer can correct a part of the collisions, the rather steady performance obtained for the total UDP UL rate (see Figure 9 (a)) with the XLS platform can be understood. NS2 considers that all collisions corrupt the frames they affect. Most STAs' frames are considered lost in the hidden node situation. Consequently the rate adaptation algorithm falls back and the CSMA/CA mechanism increases contention windows. The odds of having collisions decrease but the number of sent frames also decreases. This explains the important rate variations that we see for UDP UL rates for STA1 (see Figure 9 (b)) and STA2 (see Figure 9 (c)). When one of the STAs is penalized by the CSMA/CA mechanism for having had consecutive erroneous transmissions, the other STA makes use of this "collision-free" period to send its frames. The end result of NS2 simulations, in this particular scenario, diverges from the stable rate that would normally be expected. On the other hand, in XLS the AP manages to correct some of the collision induced errors, and the total UL rate remains stable. One will also notice that, with NS2, the UDP UL rate of STA2 falls after 2 s. This is due to the fact that when STA1 is 15 m away from the AP, it is very close to the range limit of STA2 (see Figure 7 (b)). A small shadowing factor can topple things to a hidden node scenario, which is the case for NS2 simulation results.

Therefore there is clearly an advantage in having fine and real-time models of PHY and MAC layers when considering some phenomena.

5. CONCLUSION

In this paper, we presented a novel 802.11n/ac simulation platform composed of a MAC simulation module which interfaces with a PHY simulation module in a symbiotic manner. This way, channel variations, Tx/Rx chain specificities, and channel access mechanisms are faithfully taken into account, while minimizing computational resource consumption.

Through MPDU aggregation performance evaluation, we have validated our real-time channel modeling simulator in that similar performances are obtained as with a NS2 simulator using LUT channel abstraction. We have also shown in this paper that the proposed PHY/MAC simulation platform provides a more realistic modeling of some phenomena. The impact of channel estimate aging and the impact of deep fades can be accounted for while finely modeling contention access. In addition, the collision correction ability of the PHY chain was shown in a hidden nodes context.

The proposed 802.11n/ac simulator structure is thus a very interesting platform for modeling phenomena and testing optimizations simultaneously involving PHY and MAC layers. MU-MIMO performance evaluation studies can fully benefit from this platform.

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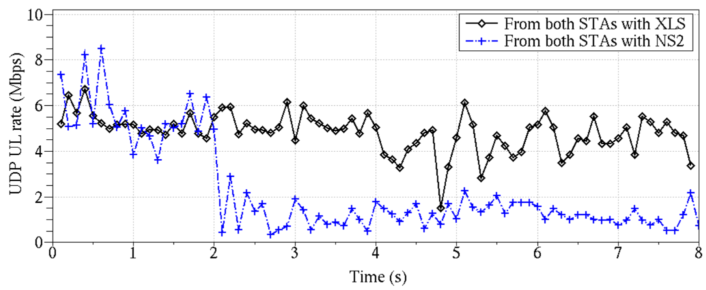
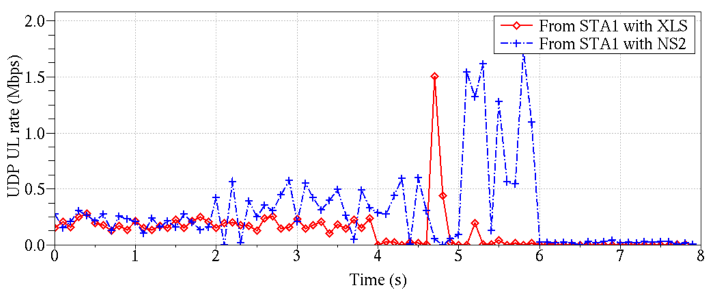
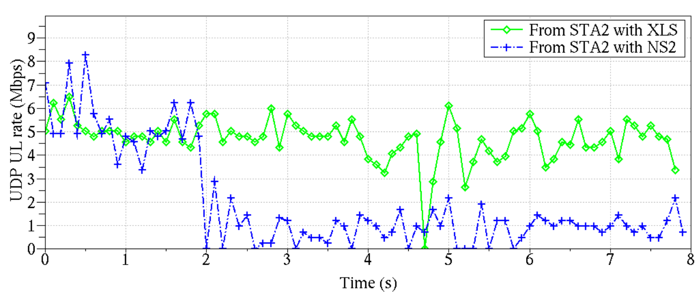


(a)



(b)



(c)

Figure 9. UDP UL as a function of simulation time for A-MPDU (of at most 2 MPDUs) transmissions using NS2 and the proposed cross-layer simulator for both STAs (a), for STA1 only (b), and for STA2 only (c)

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