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| 11bb Evaluation Methodology | | | | |
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# Abstract

This document describes the simulation methodology, evaluation metrics and traffic models for assessing 80.11bb proposals’ performance.

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# Revisions

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# Simulation Methodologies - General Concept

Two types of simulation methodologies are defined to enable the assessment of the performance and gain of proposed 11bb techniques, each having its own advantages:

1. PER simulations – typically used for new PHY features for assessing point to point performance
2. System simulations – provide system-wise (multi-BSS, multi-STA) performance assessment with various degrees of detail as defined in the following three options:
   1. PHY system simulations – provide system-wise (multi-BSS) performance assessment with emphasis on PHY abstraction accuracy and very simplified MAC (e.g. only focus on Channel Access mechanism)
   2. MAC system simulations - provide system-wise (multi-BSS) performance assessment with emphasis on MAC accuracy and very simplified PHY (e.g. AWGN channel)
   3. Integrated system simulations – provide system-wise (multi-BSS) performance assessment with close-to-reality level of details accuracy by integrating both PHY and MAC

All three system simulation options have certain advantages and disadvantages:

1. Integrated system simulation:
   1. Provide comprehensive performance evaluation of PHY and MAC techniques in an environment that is close to a real-world scenario
   2. Provide deeper insight into PHY/MAC interworking:
      1. Proposals around channel access or techniques for improving performance in interference limited scenarios may require both PHY and MAC details.
      2. In some instances performance gain may only be revealed by observing the joint effects of both PHY and MAC models
      3. Enable the understanding of performance tradeoff between layers, e.g. some PHY rate enhancements may sacrifice MAC efficiency
2. PHY and MAC system simulations:
   1. Simplify some of the MAC/PHY details respectively
   2. Provide faster run time thus enabling more extensive research
   3. Speed up the project development by reducing dependency of PHY on MAC and vice versa
   4. Improve insight into the specific reason for performance gains/losses by isolating the MAC and PHY
   5. Enable accurate investigation of techniques that do not require all PHY/MAC details to be simulated

All system simulations options are used over the same simulation scenarios as defined in [SIM-SCENARIO] [REF].

# System Simulation – High Level Description

A system simulation is comprised of multiple drops and multiple transmission events.

A drop is defined as a specific set of AP and STA locations within a topography. Different drops have different STA locations and possibly different AP locations as defined by the simulation scenario document [SIM-SCENARIO] but the topography of the environment remains unchanged.

During a transmission event a set of transmissions occurs across multiple BSS. Multiple transmission events with typical aggregate duration 1-10[sec] beyond a warm-up time are required to assess the performance of a given configuration of APs and STAs. Each BSS may have different start time, duration and end time for its transmission event but time alignment (start, duration, end) of transmission events across different BSSs in the system is a possible outcome of a proposed MAC protocol in particular as it pertains to OBSS.

A ‘warm-up’ period may be used to allow for some parameters to converge. For example:

1. MCS selection - if the MCS adaptation algorithm requires decisions based on past performance then the warm-up period may be used for initializing the algorithm.
2. Offered load - if all flows start exactly at T0, then the offered load goes from 0 to X instantaneously, and a high number of collisions will occur when there is a large number of STAs in the scenario. It will take a warm-up time for the system to recover to a stable operating condition.
   1. The backoff mechanism will effectively reduce the total offered load of the system by increasing the CW at each competing STA and thereby reducing its offered load, until the system total offered load is at Y < X

General simulation structure:

For drop=1:N {

Drop APs and STAs according to the description in [SIM-SCENARIO]

Use the channel impulse response defined in [CHANNEL-MODEL] for the relevant simulation scenario chosen from [SIM-SCENARIO].

Associate STAs with APs according to the description in [SIM-SCENARIO]

Note – determine users with SINR under that of MCS0 by ‘un-associated user’. Exclude un-associated users in evaluation. For the purpose of information, provide the percentage of un-associated users in evaluation

For transmission event=1:M {

* + Note – one can count time, ensuring that enough time has passed to see M transmission events
  + Note – the transmission event duration may not be the same in each BSS
  + Generate traffic at chosen nodes. Nodes chosen in compliance with
    - Clear Channel Assessment rules and various other EDCA parameters
    - Channel access ordering rules (round robin, proportional fair, distributed access)
  + Generate packets consistent with a link adaptation algorithm
    - SU OL, SU BF, MU
    - MCS selection
  + Perform transmissions
  + Determine packet success or no
  + Collect metrics.

}

}

# PER Simulation Description

PHY PER simulations are used to verify point to point performance or aspects that are suitable for this type of simulation, such as new PHY features and preamble performance.

PHY impairments such as LED non-linearity, synchronization error, channel estimation error and non-linear receivers are more readily incorporated into PER simulations and simulations that vary these parameters may be needed to test proposals if it is postulated that the techniques within those proposals are adversely affected by these impairments.

Other impairments such as the impact of OBSS interference or inter-symbol interference should also be verified by PER simulations by explicitly adding interfering packets to the simulation.

The following table lists PHY impairments:

|  |  |  |  |
| --- | --- | --- | --- |
| **Number** | **Name** | **Definition** | **Comments** |
| IM1 | LED /laser non-linearity | Simulation should be run at an oversampling rate of at least 2x.  To perform convolution of the 2x oversampled transmit waveform with the channel, the channel may be resampled by rounding each channel tap time value to the nearest integer multiple of a sample interval of the oversampled transmit waveform.  Total TX power shall be limited to no more than {17 dBm}.  Note: the intent of this IM is to allow different proposals to choose different light sources. |  |
| IM2 | Carrier frequency offset | Single-user simulations for all comparisons except Offset Compensation shall be run using a fixed carrier frequency offset of {–13.675 ppm} at the receiver, relative to the transmitter. The symbol clock shall have the same relative offset as the carrier frequency offset. Simulations shall include timing acquisition on a per-packet basis.  Downlink multi-user simulations for all comparisons except offset compensation shall be run using a fixed carrier frequency offset selected from the array [*N(1) ,N(2),……,N(16)* ], relative to the transmitter, where *N(j)* corresponds to the frequency offset of the *j*-th client and is randomly chosen from {[-20,20] ppm} with a uniform distribution.  Uplink multi-user simulations for all comparisons except offset compensation shall be run using a fixed carrier frequency offset selected from the array [*N(1) ,N(2),……,N(16)* ], relative to the receiver, where *N(j)* corresponds to the frequency offset of the *j*-th client and is randomly chosen from {[-20,20] ppm} with a uniform distribution. | Unchanged from 802.11ac |
| IM3 | Phase noise | The phase noise will be specified with a pole-zero model.    {PSD(0) = -100 dBc/Hz}  {pole frequency *fp* = 250 kHz}  {zero frequency *fz* = 7905.7 kHz}  Note, this model results in PSD(infinity) = {-130 dBc/Hz}  Note, this impairment is modeled at both transmitter and receiver. | Unchanged from 802.11ac |
| IM4 | Noise figure | Input referred total noise figure from antenna to output of the A/D will be {10dB}. | Unchanged from 802.11ac |
| IM5 | Specification of the optical set-up | Beamwidth at the emitter, optical gain assumed, optical filter and the total effective capture area potentially the detector technology as well. |  |
| IM6 | Ambient light levels | Ambient light also impacts the shot-noise present in the system along with the optical filter description. |  |
|  |  |  |  |

**Comparison criteria**

1. PER vs. SNR curves
2. all MCS’s
3. Simulate all of channel models in [CHANNEL-MODELS]
4. Simulation may include:
5. updated PHY impairments
6. timing acquisition on a per-packet basis
7. preamble detection on a per-packet basis

Proposals shall ensure that at the minimum SNR (worst case performance), the synchronization preamble reaches a detection rate > 0.999, while the header achieves (1 - PER) > 0.99 and the payload (1 - PER) > 0.9. Ensure that these criteria are met when claiming a packet is received successfully based on the payload PER only.

# PHY System Simulation Detailed Description

The emphasis here is on accurate modeling of the PHY using PHY abstraction (see description in Appendix I) with focus on DATA packets.

Only the very basic MAC is simulated. This is captured in the following description of a PHY system simulation using the approach taken in [17]:

1. Drop AP’s and STA’s according to scenario (random and/or deterministic placement chosen from set of possible locations as defined in the Channel Model document [CHANNEL-MODEL])
   1. Ensure that every STA <-> associated AP link can sustain MCS0 (or another predetermined MCS) in both directions. The uplink and downlink MCS do not need to be the same.
   2. Channel for every link in network determined in the Channel Model document [CHANNEL-MODEL])
2. Once drop has been made, for link between every pair of devices in the building have:
   1. Channel Impulse Response (CIR)
   2. Multipath channel
3. TX event: determine set of active TX nodes and RX SINR based on that set
   1. Initialize visited BSS set as empty.
   2. Randomly select an un-visited BSS
      1. Identify potential TX/RX pair in selected BSS: Randomly determine downlink/uplink according to downlink probability, and randomly select one of STA’s in selected BSS
      2. If no TX/RX pair is found
   3. Continue above until every BSS has been initiate/tried once.
   4. Once complete, the set of active TX nodes in the current TX event has been determined.
4. For each TX event, visit BSS’s in a random order -> thereby leading to possibly different active TX set for each TX event
5. For a single drop, run many TX events and compute a per-flow throughput
6. Flow is either uplink from a STA or downlink to a STA. Total # of flows = 2 \* # STA’s
7. Perform above across many drops to get averaging across spatial distribution

An implicit assumption is made that transmissions in OBSS are not time synchronized since STAs may not be able to hear the preamble of other STAs.

# Integrated System Simulation Detailed Description

Integrated system simulation is a discrete-event simulation, which accurately models the behaviors of both PHY and MAC as a discrete sequence of events in time. Each event occurs at a particular instant in time and marks a change of state in the system. Between consecutive events, no change in the system is assumed to occur; thus the simulation can directly jump in time from one event to the next, as shown in Figure 1.



Figure 1: Clock advancement in an event-driven simulator

The feature set of integrated system simulation includes a minimal feature list and a nice-to-have feature list, as shown Table 1.

Table 1: Feature list of integrated system simulation

|  |  |  |
| --- | --- | --- |
|  | *Full feature list* | |
| *Minimum features* | *Nice-to-have Features* |
| MAC | Channel Access | Multiple channels |
| Control frame (RTS/CTS/ACK/Block ACK) | Control frame (CTS2self) |
| EDCA | Management frame |
| Aggregation | … |
| Link Adaption |  |
| Transmission mode (SU-OL, Beamforming,…) selection |  |
| Power save mechanism (PS mode, PS polling, U-APSD |  |
| PHY | Effective SINR Mapping and PER prediction | … |
| MMSE |  |
|  |  |
|  |  |

MAC process should model the features of EDCA, Channel Access, aggregation, control frame (RTS/CTS/ACK) transmission and reception, link adaptation and sending the received result to statistics collection block, as illustrated in the Figure 2.



Figure 2: Detailed modelling of MAC

Notes: The feedback delay of channel state information in link adaptation should be considered.

PHY process includes abstraction of sending packets from MAC to channel, receive packets from channel and notify MAC. The following features should be detailed modeled, including SINR calculation based on receiver algorithm, effective SINR mapping, PER prediction, etc, as illustrated in Figure 3.



Figure 3: Detailed modelling of PHY

Integrated system simulation should follow the packet reception and preamble detection procedure as described in Appendix 4.

The simulation procedure follows the following steps:

## Step 1: initialization

* Drop APs and STAs according to description in [SIM-SCENARIO], and initialise the internal state of each node device.
* Determine channel model for each AP and STA according to the description in [SIM-SCENARIO].
* Associate STAs with APs according to description in [SIM-SCENARIO].
* Create an event list as the main event scheduler of the simulator.

Notes: The location of each STA remains unchanged during a drop. Additionally, the STA is assumed to remain attached to the same AP for the duration of the drop.

## Step 2: event creation and processes

There are three types of events defined, including traffic generation event, MAC event, and PHY event. These events are inserted into the event list, and trigger subsequent MAC/PHY processes based on their particular time instant.

* Traffic generation event: is created by upper layer at the time instant of packet generation according to the traffic model. It triggers the packet generation process to generate a packet.

Note: the packet can include only the information of time instant and size, instead of actual bit stream.

* MAC event: is created by either upper layer at a transmitter or PHY layer at receiver. MAC events created by upper layer trigger the MAC process at the transmitter for the packet in MAC layer. MAC events created by PHY layer determine whether the packet is correctly received or not based on the PER predicted in PHY and trigger MAC process at the receiver when the packet is correctly received.
* PHY event: is created by MAC layer at a transmitter when the packet in MAC layer is ready for transmission. It triggers a PHY process at a receiver to predict PER for the packet.

Step 2 includes the following processes:

* packet generation process
  + For each traffic generation event, generate a packet including packet time instant and packet size
  + Create a MAC event when the packet is passed from upper layer to MAC layer
  + Create (next) traffic generation event according to each AP/STA’s traffic models

Notes: Start times for each traffic type for each STA should be randomized as specified in the traffic model being simulated.

MAC process at transmitter, if the MAC event is from upper layer:

* + Check Clear Channel Assessment from energy detection in PHY and NAV in MAC
  + Carry out EDCA with CSMA/CA procedure
    - Count down backoff timer
    - Send RTS/CTS configurable by scenario/technique
  + Select transmission mode, e.g. SU OL, MU, choose MCS, and perform packet aggregation, then create a PHY event and insert it into the event list based on the generation time of PHY event, and wait for PHY process
    - Packet aggregation rules specified in each simulation scenario are to be applied before transmission.

MAC process at receiver, if the MAC event is from PHY layer:

* + Determine the event success/failure based on PER as the abstract packet delivered by PHY
  + Send ACK/BA if packet transmission is successful
    - Notify the packet receive results to upper layer (Optional)

PHY process

* + Each AP/STA in the network performs energy detection and updates its Clear Channel Assessment indication
  + Each AP/STA with channel busy in the network updates its NAV
  + TX: obtain precoding matrix, then notify RX
  + Channel: generate instantaneous fading channel (or load from offline files)
  + RX: calculate SINR of each tone based on receiver algorithms, e.g. MMSE, and perform PHY abstraction to obtain post SINR, and then PER
  + Create a MAC event to trigger MAC process at receiver

Repeat step 2 with sufficient simulation time to collect statistics.

## Step 3: Statistics collection

Collection the statistics according to the performance metrics defined in **[TBD]**

Note: in order to obtain reliable results, sufficient numbers of drops are simulated to ensure convergence.

Following is a more detailed description:

For drop=1:N

{

Step1:

{

Drop APs and STAs according to description in [SIM-SCENARIO];

Associate STAs with APs according to description in [SIM-SCENARIO];

Create event list for the scheduler of simulator;

Initialize the traffic generation event for each AP/STA;

}

Step2:

While simulation time is less than the end time

{

While traffic generation event occurs

{

Generate a packet of the size according to traffic model;

Create MAC event when the packet is passed to MAC;

Create the next traffic generation event at the time instant according to traffic model;

}

While MAC event occurs

{

If MAC event is from upper layer

{

If the Clear Channel Assessment indicates idle and NAV is not set

{

EDCA with CSMA/CA procedure

{

Count down backoff timer;

}

Select transmission mode, e.g. SU OL, MU;

Choose MCS;

Packet aggregation;

Create PHY events, and wait for PHY process;

}

}

If MAC event is from PHY layer

{

Determine the packet transmission success/failure based on PER;

If packet transmission is successful

{

Notify the packet receive status to upper layer (optional);

Send ACK;

}

}

}

While PHY event occurs

{

Each AP/STA in the network performs energy detection and updates its Clear Channel Assessment indication;

Each AP/STA with channel busy in the network updates its NAV;

TX: obtain precoding matrix, then notify RX;

Channel: generate instantaneous fading channel (or load from offline files);

RX: calculate SINR of each tone based on receiver algorithms, perform PHY abstraction to obtain post SINR and get PER;

Create a MAC event to notify PER to MAC, and wait for MAC process;

}

}

Step3:

Collect statistics.

}

# MAC System Simulation Description

MAC system simulation is an integrated system simulation stripped out of the details of PHY modelling, e.g. a SISO configuration with AWGN - path loss and penetration loss should be modeled according to the scenario-specific definition.

MAC system simulation should follow the packet reception and preamble detection procedure as described in Appendix 4.

# Simulation Methodology Choice

Proponents of different techniques should provide justification for their proposed simulation methodology used to justify the technique’s gains.

Examples:

* PHY PER simulation:
  1. New PHY – a PER simulation is typically sufficient in order to decide the number of pilots, interleaver parameters and other parameters.
  2. Preamble performance
  3. Implementation losses of current and new PHY modes.
  4. Interference, especially if varying across the packet, impact on PER.
* PHY System simulation:
  1. Impact of number of detectors/emitters on multi-BSS performance
  2. Impact of PHY techniques in the context of multi-BSS
  3. Impact of frequency re-use in multi-BSS
  4. Impact of Clear Channel Assessment levels on system throughput
* MAC System simulation:
  1. Impact of MAC scheduler – for example EDCA vs. RAW (as in 11ah) vs. HCCA vs. other techniques
  2. Impact of frequency re-use in multi-BSS
  3. Impact of Clear Channel Assessment levels
* Integrated System simulation:
  1. Performance evaluation of 11BB solution in the environment close to real-world
  2. Impact of crosslayer techniques affecting both PHY and MAC layers in the context of multi-BSS

Note that some techniques can be simulated using multiple simulation tools to provide better insight

# Metrics

11BB evaluation methodology defines evaluation of spectrum efficiency improvement in both link level and system level.

## Link Level Simulation

For PER simulations the typical metric is dB gain/loss in waterfall curves. The operating range to be observed is 1% to 10% PER.

## System Level Simulation

For system simulations it is suggested to use the following metrics to evaluate the system performance [2]-[9], [19]-[21]:

### Per-STA Throughout

Per-STA throughput metrics are used to measure the user experience in the area covered by one or multiple BSSs in different simulation scenario [SIM-SCENARIO].

Definition – Per-STA throughput is measured at MAC SAP by the number bits (or bytes) of MAC payload successfully transmitted over the given measurement period in the full buffer simulation.

• Per-STA throughput at 5 percentile of throughput CDF curve measures the minimum throughput performance of stations at the cell edge.

• Per-STA throughput at 50 percentile of CDF curve measures the average throughput of stations in all participating BSS in the simulation.

• Per-STA throughput at 95 percentile of CDF curve measures the top performance of stations at the cell center of BSS.

Although the main target of 11AX is to improve the performance at 5 and 50 percentile of throughput CDF curve, it is suggested to measure Per-STA throughput at the 5, 50, and 95 percentile points. The entire throughput CDF curve and other information such as MCS histogram may help to evaluate the overall system performance improvement [3].

Per-STA throughout for DL and UL are measured separately.

### Per-BSS Throughput

Per-BSS throughput is used to evaluate BSS capacity in the various simulation scenarios described in [SIM-SCENARIO]. This metric directly relates to the aggregated Per-STA throughputs in BSS and can be used to compare different deployment densities and heterogeneous deployments.

Definition – Per-BSS throughput is the aggregated Per-STA throughput among all the associated stations in a BSS.

Per-BSS throughout could be measured by aggregating Per-STA throughputs of all the stations in a BSS, or derived from Per-STA throughput times the number of associated stations in a BSS.

Per-BSS throughout for DL and UL are measured or calculated separately.

### Packet Loss

The packet loss metric is used to evaluate the system robustness especially in the high density deployment scenario. This metric reflects an aspect of system performance different from throughput and transmission latency.

Definition – The packet loss is defined as the number of MAC packet not delivered at all or not delivered in time to the receiver over the total number of offered MAC payloads.

The packet loss means that the MAC packet could not be decoded by the receiver due to the interference or low RSSI, or the MAC packet could not be delivered at the receiver in time for QoS flow due to traffic congestion.

### Transmission Latency

The metric of transmission latency is used to measure the time delay of medium acquisition in channel access mechanism. The transmission latency is used to evaluate an aspect of MAC performance in various QoS transmissions.

Definition – The transmission latency is measured from the time that MAC receives a packet till the time that PHY starts transmitting.

The transmission latency may include the time delay of

• AIFS

• Backoff time

• Other system parameters

**Per STA Energy per Transmit Bit**

The metric of per STA energy per transmitted bit, measured in units of joules per bit, is defined as the total energy consumed by a STA divided by the total number of successful data bits transmitted by the STA.

**Per STA Energy per Receive Bit**

The metric of per STA energy per received bit, measured in units of joules per bit, is defined as the total energy consumed by a STA divided by the total number of successful data bits received by the STA.

**Energy Efficiency Ratio (EER)**

Energy efficiency ratio is defined as the ratio of average energy consumed during one successfully exchanged data bit between STAs using any new proposed power save mechanism over the baseline power save mechanism.



**Network Energy Efficiency Ratio (N-EER)**

N-EER defined as the ratio of average energy consumed for M stations of interests during an event (Tevent) for series of successfully exchanged data bits between STAs using any new proposed power save mechanism over the baseline power save mechanism. The mathematical calculation of N-EER is described as follow.



The values for voltage and current may be chosen from Power Model Parameter table in Simulation Scenario document [26]

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# Appendix 1 - PHY Abstraction

The objective of PHY abstraction is to accurately predict PER simulation results in a computationally efficient way to enable running system simulations in a timely manner.

# Appendix 3 – RBIR and AWGN PER Tables

The embedded spreadsheet contains the RBIR and AWGN PER tables. The results under the Mean column shall be used for all simulations and calibration.



# Appendix 4 – Packet Reception and Preamble Detection Procedure

The original discussion of the following text can be found in [25].

1. PPDU capture: if more than one PPDU arrives at a receiver within a PPDU capture window of A nsec, then the strongest of the arriving PPDUs shall be the one captured (A is TBD but with one option of 800ns).
   1. The PPDU capture window of A nsec starts at the first arrival PPDU with rx power higher than rx sensitivity;
   2. A PPDU with rx power lower than rx sensitivity is dropped, which does not impact current receiver status;
2. At the end of the PPDU capture window, the receiver locks to the strongest PPDU whose preamble is to be decoded and other PPDUs coming within the duration of the preamble of the strongest PPDU are considered as interference and shall be not detected.
   * Take the whole preamble of each PHY PPDU as a standalone sub-frame.
     + The packet length in bytes used in preamble PER computation is calculated based on the assumption of 3-byte/4us (MCS0)
   * Model the preamble decoding the same as a sub-frame decoding
   1. If preamble passes (i.e., successfully decoded), the receiver continues to receive the rest part of the PPDU, i.e., to decode each MPDU;
      * If successfully decoding of a MAC frame, defer for NAV;

* Control frame is dealt with as a standalone sub-frame
* Apply NAV cancellation for RTS according to current std spec
  + - Otherwise, set Clear Channel Assessment to busy for the entire PPDU duration if rx power higher than TBD [rx sensitivity or Clear Channel Assessment-SD].
    - At the same time just after the end of the preamble, a preemption window (the window size is TBD in [0, PPDU duration]) begins during which time if a new PPDU arrives with rx power at least PdB above the current reception, then the current reception is terminated and the PPDU capture phase is re-entered with this new PPDU (P is expected to be have a value of about 9 dB)
  1. If preamble fails, the receiver terminates current reception
     + The entire PPDU fails
     + The receiver is unlocked again and then Clear Channel Assessment-ED threshold is used to determine if the medium is busy.