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Submission Title: [A Modified Performance Evaluation Scheme for Computer Simulation]

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Re: [ ]

Abstract: [Proposing a modified simulation scheme and summarizing items to evaluate PHY performance]

Purpose: [To be considered in 15.3c technical requirement by computer simulation]

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A Modified Performance Evaluation Scheme for Computer Simulation

Hiroshi Harada, Ryuhei Funada, Yoshinori Nishiguchi, Ming Lei, Chang-Soon Choi, Shuzo Kato (NICT), Hiroyoshi Konishi (MASPRO), Kazuaki Takahashi (Panasonic), Ichihiko Toyoda (NTT), Kenichi Kawasaki (Sony), and Hiroyuki Nakase (Tohoku University)
Summary of this document

- Propose a scheme to evaluate PHY performance by computer simulation in TG3c
  - Link budget
  - Frame design
  - BER (and/or) PER performance

- Propose parameters to evaluate PHY performance
  - Impact of power amplifier (PA)
  - Impact of channel model (CM)
  - Impact of phase noise (PN)

- Summarize items described in contributed document that shows PHY performance

- Show simulated results of transmission performance by considering the impact of PA, CM, and PN by single carrier system (BPSK, QPSK, OQPSK, MSK)
Propose a scheme to evaluate PHY performance by computer simulation in TG3c

- Two evaluations for system design
  - Calculation of link budget
    - Clarify received CNR when considered usage model discussed in TG3c
  - Frame design
    - Confirm that transmission rate at PHY-SAP satisfies the requirement specified in usage model
- BER and/or PER performance
  - Show CNR v.s. BER/PB
    - Clarify transmission performance at several CNR
    - Clarify transmission impact of power amplifier, phase noise, channel model, coding, and so on
    - How many dB must be gained/reduced to/from link budget when the above impact is considered (feed back to calculation of link budget)
An example of link budget calculation

<table>
<thead>
<tr>
<th>Distance</th>
<th>1</th>
<th>3</th>
<th>5</th>
<th>m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier bit rate</td>
<td>2</td>
<td></td>
<td></td>
<td>Gbps</td>
</tr>
<tr>
<td>TX power</td>
<td>10</td>
<td>dBm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tx antenna gain</td>
<td>10</td>
<td>dBi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency band</td>
<td>59-66</td>
<td>GHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Center frequency</td>
<td>62.5</td>
<td>GHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>wavelength</td>
<td>4.8</td>
<td>mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Path loss</td>
<td>68.35939</td>
<td>77.90182</td>
<td>82.33879</td>
<td>dB</td>
</tr>
<tr>
<td>RX Antenna gain</td>
<td>10</td>
<td>dB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boltzmann constant</td>
<td>1.38065E-23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>300</td>
<td>K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rx Noise figure</td>
<td>10</td>
<td>dB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eb/N0</td>
<td>32.45826</td>
<td>22.91583</td>
<td>18.47886</td>
<td>dB</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>BPSK</th>
<th>QPSK</th>
<th>DQPSK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required Eb/N0 for BER=10^-5</td>
<td>9.5</td>
<td>9.5</td>
<td>12 dB</td>
</tr>
<tr>
<td>Required Eb/N0 for BER=10^-12</td>
<td>14</td>
<td>14</td>
<td>16.2 dB</td>
</tr>
</tbody>
</table>

This is an example and the data shown in this sheet is NOT equal to the proposal for PHY model from contributors.
### An example of frame design

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Bandwidth (Bt)</td>
<td>7 GHz</td>
</tr>
<tr>
<td>Number of channels (Nch)</td>
<td>3</td>
</tr>
<tr>
<td>Maximum band width/channel</td>
<td>2.333333 GHz</td>
</tr>
<tr>
<td>M-ary modulation level</td>
<td>2</td>
</tr>
<tr>
<td>Symbol rate</td>
<td>1.6 GHz</td>
</tr>
<tr>
<td>Roll off rate (a)</td>
<td>0.35</td>
</tr>
<tr>
<td>Band width</td>
<td>2.16 GHz</td>
</tr>
<tr>
<td>PSDU in one packet</td>
<td>2048 byte</td>
</tr>
<tr>
<td>PSDU Coding rate</td>
<td>3/4</td>
</tr>
<tr>
<td>PSDU transmission time</td>
<td>6826.667 ns</td>
</tr>
<tr>
<td>PSDU data transmission rate</td>
<td>3.2 Gbps</td>
</tr>
<tr>
<td>PLCP Header</td>
<td>25 byte</td>
</tr>
<tr>
<td>PLCP Coding rate</td>
<td>1/2</td>
</tr>
<tr>
<td>PLCP Header duration</td>
<td>125 ns</td>
</tr>
<tr>
<td>PLCP Data transmission rate</td>
<td>3.2 Gbps</td>
</tr>
<tr>
<td>PLCP Preamble duration</td>
<td>100 ns</td>
</tr>
<tr>
<td>Shared ratio</td>
<td>0.968093</td>
</tr>
<tr>
<td>PSDU transmission rate (PHY-SAP)</td>
<td><strong>2.323422</strong> Gbps</td>
</tr>
</tbody>
</table>

**Packet configuration**

- PLCP Preamble
- PLCP Header
- PSDU

This is an example and the data shown in this sheet is NOT equal to the proposal for PHY model from contributors.
BER and PER performance by MATLAB

Functions in the simulation program
- Data generation
- Frame (Packet) configuration
- Modulation
- **Power amplifier**
- Channel
- Phase noise
- Demodulation
- Evaluation

Evaluation issue
- Packet synchronization performance
- BER (dependent on UM)
- PER (dependent on UM)
- Interference to adjacent channel
- Tolerance to interference from adjacent channel

Submission Hiroshi Harada, NICT
Proposed parameters to evaluate PHY performance

(1) Impact of power amplifier (PA)

- **PA model**
  - System performance of 60GHz WPAN is degraded by PA non linearity
  - Spectrum of 60GHz WPAN is also expanded by non-linearity of PA
  - Not only AM-AM model but also AM-PM must be needed because the degradation by AM-PM characteristics is larger than that by AM-AM.

- **To prepare PA model**
  - Correct or call for data-sheet of AM-PM performance of PA
  - Based on such sheet, a MATLAB code for the simulation needs to be prepared.
  - One proposal was shown in the doc. IEEE15-06-0396-01-003c based on modified Ghorbani model

![Modified Rapp model](image-url)
Impulse response of TSV model

\[ \gamma: \text{Amplitude of each ray exponentially decays by the order of } e^{-t/\gamma}. \]

\[ \Gamma: \text{Amplitude of each cluster exponentially decays by the order of } e^{-t/\Gamma}. \]

Each ray arrives according to the exponential distribution with average value of \(1/\lambda\).

Each cluster arrives according to the exponential distribution with average value of \(1/\Lambda\).

Statistical two-path response (LOS desktop model)

Fixed impulse response (Other models)
Proposed parameters to evaluate PHY performance

(3) Impact of phase noise (PN)

- Phase noise model
  - System performance of 60GHz WPAN is degraded by PN
  - Phase noise affects signal generators of TX and RX
  - For the simulation, relative phase noise must be considered at receiver side

- To prepare PN model
  - Call for data-sheet of phase noise performance
  - Based on such sheet, a MATLAB code for the simulation needs to be prepared.
  - One proposal will be shown in the doc. IEEE15-06-0477-00-003c

Proposed phase-noise model for TG3c

\[
PSD(f) = PSD(0) \frac{[1+(f/f_p)^2]}{[1+(f/f_z)^2]}
\]

PSD(0) = -87 dBc/Hz
pole frequency \(f_p = 1\)MHz
zero frequency \(f_z = 100\)MHz
Items described in contributed document that shows PHY performance

- Show basic PHY parameter
  - Modulation scheme
  - Demodulation scheme
  - Coding
  - Filter configuration (TX and RX)
  - Total bandwidth
  - Transmission speed
  - Interleave (if use)
  - Frame configuration
  - Used Channel model
- Show proposed link budget
- Show proposed frame structure
- Show the performance
  - CNR v.s. BER and PER
  - Packet synchronization performance
  - Interference to adjacent channel
  - Tolerance to interference from adjacent channel
Example of PHY simulation

- Modulation scheme
  - BPSK/QPSK/OQPSK/MSK

- Demodulation scheme
  - Coherent detection

- Coding
  - Convolutional coding $R=7/8$, $K=7$ (BPSK)/ $R=3/4$, $K=7$ (others)

- Channelization
  - 2 (BPSK), 4 (QPSK/OQPSK/MSK)

- PA model
  - Shown in slide 8: OBO=1 or 3dB

- Phase noise model
  - Shown in slide 10: Pole frequency =1 MHz, Zero frequency = 100 MHz, PSD(0)=-90dBc/Hz

- Channel model
  - TSV-model (doc.: IEEE 15-06-0468) / LOS office

- Evaluation
  - BER performance / PER (2kbyte) performance
Channel model used in the simulation

- Channel model used for evaluation
  - LOS office model (analyzed by NICT)
    - Assuming distance between Tx and Rx: 1 m
    - Directional antenna pattern:
      - Pattern: Gaussian distribution
      - Half-power angle of antenna: Tx 60 deg, Rx 30 deg

<table>
<thead>
<tr>
<th>Channel model</th>
<th>Decay factor of NLOS clusters</th>
<th>Small Rician Effect</th>
<th>S-V model oriented parameter</th>
<th>Number of clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LOS office</strong></td>
<td>Ω₀(D) [dB]</td>
<td>k (Δk)</td>
<td>Γ [ns]</td>
<td>N</td>
</tr>
<tr>
<td><strong>Tx:60 Rx:30°</strong></td>
<td>-90.2</td>
<td>2.63 (11.4 dB)</td>
<td>38.8</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>37.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>64.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.41</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8.04</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7.95</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>66.4</td>
<td></td>
</tr>
</tbody>
</table>

(* Rx antenna beam-width were changed from 60 deg, which were used in the experimental analysis to 30 deg for simulation evaluation)
# A frame design

<table>
<thead>
<tr>
<th></th>
<th>QPSK/OQPSK/MSK</th>
<th>BPSK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total system bandwidth (Bt)</td>
<td>7 GHz</td>
<td>7 GHz</td>
</tr>
<tr>
<td>Assuming channelization</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Maximum bandwidth per channel</td>
<td>2.3333333333 GHz</td>
<td>3.5 GHz</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Detection</th>
<th>QPSK/OQPSK/MSK</th>
<th>BPSK</th>
</tr>
</thead>
<tbody>
<tr>
<td>M-array modulation level</td>
<td>coherent</td>
<td>coherent</td>
</tr>
<tr>
<td>Symbol rate</td>
<td>1.6</td>
<td>2.8 Gsps</td>
</tr>
<tr>
<td>Roll off rate (a)</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>2.16</td>
<td>3.78 GHz</td>
</tr>
<tr>
<td>Number of channels</td>
<td>1 ch</td>
<td>1 ch</td>
</tr>
<tr>
<td>PSDU in one packet</td>
<td>2048 byte</td>
<td>2048 byte</td>
</tr>
<tr>
<td>PSDU Coding rate</td>
<td>3/4</td>
<td>7/8</td>
</tr>
<tr>
<td>PSDU transmission time</td>
<td>6826.666667 ns</td>
<td>6687.346939 ns</td>
</tr>
<tr>
<td>Transmission rate w/o coding</td>
<td>3.2 Gbps</td>
<td>2.8 Gbps</td>
</tr>
<tr>
<td>PSDU transmission rate</td>
<td>2.4 Gbps</td>
<td>2.45 Gbps</td>
</tr>
</tbody>
</table>
BER and PER performance (AWGN) (w/o, w coding)

By using coding R=3/4 K=7, Eb/No=5dB is required to got less than 8% of PER.
BER and PER performance (AWGN)
(Impact of PA, w coding)

The impact of PA model is less than 0.5 dB degradation.
BER and PER performance (AWGN) (Impact of Phase noise, w/o PA, w coding)

The impact of PN model (PLL) is less than 0.3 dB degradation.
BER and PER performance (LOS office-TSV)
(Impact of Phase noise and PA, w coding)

Back Off = 3dB

By using coding R=3/4 K=7, Eb/No=5dB is required to get less than 8% of PER when MSK is used under LOS office environment.
Conclusions

- Proposed a scheme to evaluate PHY performance by computer simulation in TG3c
  - Link budget
  - Frame design
  - BER (and/or) PER performance

- Proposed parameters to evaluate PHY performance
  - Impact of power amplifier (PA)
  - Impact of channel model (CM)
  - Impact of phase noise (PN)

- Summarized items described in contributed document that shows PHY performance

- Showed simulation results of transmission performance by considering the impact of PA, CM, and PN by single carrier system (BPSK, QPSK, OQPSK, MSK)
  - Impact of PA to BER or PER is less than 0.5 dB
  - Impact of PN to BER or PER is less than 0.3 dB
  - In the case of MSK, required Eb/N0 is 5dB to get 8% of PER in the LOS office environment.

- Clarified that coding is very important item to get PER performance required in TG3c and the impact of PA and PN is minimized by the coding