Submission Title: [UWB Channel Measurement Results in Indoor Residential Environment – High-Rise Apartments]

Date Submitted: [19 May, 2004]

Source: [Chia-Chin Chong, Youngeil Kim, SeongSoo Lee]
Company [Samsung Advanced Institute of Technology (SAIT)]
Address [RF Technology Group, i-Networking Lab, P. O. Box 111, Suwon 440-600, Korea.]
Voice:[+82-31-280-6865], FAX: [+82-31-280-9555], E-Mail: [chiachin.chong@samsung.com]

Re: [Response to Call for Contributions on IEEE 802.15.4a Channel Models]

Abstract: [This contribution describes the UWB channel measurement results in indoor residential environment. Measurements were conducted in several types of high-rise apartments based in several cities in Korea. It consists of detailed characterization of the path loss and temporal-domain parameters of the UWB channel with bandwidth from 3 to 10 GHz.]

Purpose: [Contribution towards the IEEE 802.15.4a Channel Modeling Subgroup.]

Notice: This document has been prepared to assist the IEEE P802.15. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.

Release: The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15.
UWB Channel Measurement Results in Indoor Residential Environment – High-Rise Apartments

Chia-Chin Chong, Youngeil Kim, SeongSoo Lee
Samsung Advanced Institute of Technology (SAIT), Korea
Outline

- Motivation
- Measurement Setup & Environment
- Data Analysis & Post-Processing
- Channel Measurement Description
- Measurement Results
- Conclusion
- Future Work
Motivation

- Study the UWB wave propagation characteristics in indoor residential environment
- Develop a channel model suitable for UWB applications in high-rise apartments
- Submit contributions to the IEEE802.15.4a channel modeling subgroup standardization activities
Measurement Setup (1)

• Frequency domain technique using VNA
  – Center frequency, $f_c$: 6.5GHz
  – Bandwidth, $B$: 7GHz (i.e. 3-10GHz)
  – Delay resolution, $\Delta \tau$: 142.9ps (i.e. $\Delta \tau=1/B$)
  – No. frequency points, $N$: 1601
  – Frequency step, $\Delta f$: 4.375MHz (i.e. $\Delta f=B/(N-1)$)
  – Max. excess delay, $\tau_{\text{max}}$: 229.6ns (i.e. $\tau_{\text{max}}=1/\Delta f$)
  – Sweeping time, $t_{\text{sw}}$: 800ms
  – Max. Doppler shift, $f_{d,\text{max}}$: 1.25Hz (i.e. $f_{d,\text{max}}=1/t_{\text{sw}}$)
Measurement Setup (2)

- UWB wideband planar dipole antennas
- Measurement controlled by laptop with LabVIEW via GPIB interface
- Calibration performed in an anechoic chamber with 1m reference separation
- Static environment during recording
- Both large-scale & small-scale measurements
  - Large-scale: different RX positions → “local point”
  - Small-scale: 25 (5x5) grid-measurements around each local point → “spatial point”
  - At each spatial point, 30 time-snapshots of the channel complex frequency responses are recorded
Measurement Setup (3)

TX antenna

Propagation Channel

RX antenna

Vector network analyzer (Agilent 8722ES)

Power Amplifier (Agilent 83020A)

Laptop with LabVIEW

Low Noise Amplifier (Miteq AFS5)

Attenuator (Agilent 8496B)

GPIB Interface

Coaxial Cables
Measurement Environment

• Measurements in various types of high-rise apartments based on several cities in Korea → typical types in Asia countries like Korea, Japan, Singapore, Hong Kong, etc.
  – 3-bedrooms
  – 4-bedrooms
  – 5-bedrooms (to be done!)
• Both LOS and NLOS configurations
• TX-RX antennas:
  – Separations: up to 20m
  – Height: 1.25m (with ceiling height of 2.5m)
  – TX antenna: always fixed in the center of the living room
  – RX antenna: moved around the apartment (i.e. 8-10 locations)
• To date, in total of 12,000 channel complex frequency responses are collected (i.e. 2 apartments x 8 RX local points x 25 spatial points x 30 time snapshots → 2x8x25x30=12,000)
3-Bedroom Apartment

- Main Entrance
- Balcony
- Grid-Measurement
- Bathroom 1
- RX4
- RX8
- Glass window
- Kitchen & Dining Room
- RX3
- RX6
- Bedroom 2
- Bathroom 2
- RX2
- RX1
- RX5
- Bedroom 1
- Living Room
- TX
- RX7
- Bedroom 3
- RX1
- RX5
- Balcony
- Glass window
- Glider glass door

Submission
4-Bedroom Apartment (1)
4-Bedroom Apartment (2)

Living Room

Bedroom 3

Bedroom 4

Kitchen
Measurement Results (1)
Measurement Results (2)

3-D Channel Complex Frequency Response

-30 -25 -20 -15 -10 -5 0
Normalized Power, P [dB]

Frequency, f [GHz]

Time, t [s]
Data Analysis & Post-Processing

• All measurement data are calibrated with the calibration data measured in anechoic chamber to remove effect of measurement system
• Perform frequency domain windowing to reduce the leakage problem
• Complex passband IFFT is deployed to transform the complex frequency response to complex impulse response
• Perform temporal domain binning before extract channel parameters
Complex Passband IFFT
Channel Model Description

- **Path loss**
- **Temporal-domain parameters:**
  - RMS delay spread, $\tau_{\text{rms}}$
  - Mean excess delay, $\tau_m$
  - No. of paths within 10dB of peak, NP10dB
  - No. of paths within 20dB of peak, NP20dB
  - No. of paths within 30dB of peak, NP30dB
Path Loss

- Path loss (PL) vs. Distance (d):

\[ PL_{dB}(d) = PL_0 + 10n \log_{10} \left( \frac{d}{d_0} \right) \]

- \( d_0 = 1 \text{m} \)
- \( PL_0 \): intercept
- \( n \): path loss exponent

- Perform linear regression to the above equation with measured data to extract the required parameters
Path Loss vs. Distance – LOS

Path Loss under LOS Scenario in 3-Bedroom Apartment

Path Loss under LOS Scenario in 4-Bedroom Apartment
Path Loss vs. Distance – NLOS

Path Loss under NLOS Scenario in 3-Bedroom Apartment

Path Loss under NLOS Scenario in 4-Bedroom Apartment
Path Loss Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>3-Bedroom Apartment</th>
<th>4-Bedroom Apartment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( n )</td>
<td>( PL_0 )</td>
</tr>
<tr>
<td>LOS</td>
<td>1.18</td>
<td>50.1</td>
</tr>
<tr>
<td>NLOS</td>
<td>2.18</td>
<td>52.2</td>
</tr>
</tbody>
</table>
Temporal-domain Parameters

- These parameters were obtained after taking frequency domain Hamming windowing, passband IFFT & temporal domain binning with bin size 100ps

<table>
<thead>
<tr>
<th>Location</th>
<th>( \tau_{\text{true}} ) [ns]</th>
<th>( \tau_{\text{est}} ) [ns]</th>
<th>NP10dB</th>
<th>NP20dB</th>
<th>NP30dB</th>
<th>( \tau_{\text{med}} ) [ns]</th>
<th>( \tau_{\text{m}} ) [ns]</th>
<th>NP10dB</th>
<th>NP20dB</th>
<th>NP30dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOS</td>
<td>( \mu ) &amp; 14.00</td>
<td>( \sigma ) &amp; 1.53</td>
<td>5.88</td>
<td>1.25</td>
<td>4.04</td>
<td>( \mu ) &amp; 29.91</td>
<td>( \sigma ) &amp; 11.15</td>
<td>145.38</td>
<td>38.89</td>
<td>12.48</td>
</tr>
<tr>
<td>NLOS</td>
<td>( \mu ) &amp; 38.61</td>
<td>( \sigma ) &amp; 8.03</td>
<td>36.09</td>
<td>15.48</td>
<td>19.58</td>
<td>7.64</td>
<td>141.63</td>
<td>42.23</td>
<td>512.57</td>
<td>78.28</td>
</tr>
</tbody>
</table>
Mean Excess Delay vs. Distance – LOS

Local Mean Excess Delay vs. Distance - LOS (3-Bedroom Apartment)

Average mean excess delay = 5.88ns
Standard deviation mean excess delay = 2.60ns

Local Mean Excess Delay vs. Distance - LOS (4-Bedroom Apartment)

Average mean excess delay = 5.01ns
Standard deviation mean excess delay = 3.08ns
Mean Excess Delay vs. Distance – NLOS

Local Mean Excess Delay vs. Distance - NLOS (3-Bedroom Apartment)

- Local mean excess delay
- Local mean excess delay + Std
- Local mean excess delay - Std

Average mean excess delay = 36.49ns
Standard deviation mean excess delay = 14.60ns

Local Mean Excess Delay vs. Distance - NLOS (4-Bedroom Apartment)

- Local mean excess delay
- Local mean excess delay + Std
- Local mean excess delay - Std

Average mean excess delay = 14.97ns
Standard deviation mean excess delay = 6.15ns
RMS Delay Spread vs. Distance – LOS

Local RMS Delay Spread vs. Distance - LOS (3-Bedroom Apartment)

Average RMS delay spread = 14.01ns
Standard deviation RMS delay spread = 2.42ns

Local RMS Delay Spread vs. Distance - LOS (4-Bedroom Apartment)

Average RMS delay spread = 12.48ns
Standard deviation RMS delay spread = 1.95ns
RMS Delay Spread vs. Distance – NLOS

May 2004

doc.: IEEE 15-04-0282-00-004a

Local Local RMS delay spread vs. Distance - NLOS (3-Bedroom Apartment)

Local RMS delay spread, $\tau_{rms,local}$ [ns]

Distance, $d$ [m]

Average RMS delay spread $= 38.61$ ns
Standard deviation RMS delay spread $= 4.16$ ns

Local Local RMS delay spread vs. Distance - NLOS (4-Bedroom Apartment)

Local RMS delay spread, $\tau_{rms,local}$ [ns]

Distance, $d$ [m]

Average RMS delay spread $= 21.91$ ns
Standard deviation RMS delay spread $= 8.85$ ns
May 2004

Distribution of No. of Paths – LOS

Distribution of the number of paths - LOS (3-bedroom apartment)

Distribution of the number of paths - LOS (4-bedroom apartment)
Distribution of No. of Paths – NLOS

NP10dB

NP20dB

NP30dB

NP10dB

NP20dB

NP30dB

Probability
Conclusion

- Frequency domain technique UWB measurement campaign has been carried out in various types of high-rise apartments covering frequencies from 3 to 10 GHz.
- Measurement covered both LOS & NLOS scenarios.
- Channel measurement results for path loss and temporal-domain parameters (e.g. mean excess delay, RMS delay spread, number of paths) are presented.
Future Work

• Extract S-V channel parameters
• Extract small-scale amplitude statistics
• Propose a suitable statistical channel model