Submission Title: [Study of mm wave propagation modeling to realize WPANs]

Date Submitted: [January 2004]

Revised:

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Re: [Millimeter wave propagation characteristics]

Abstract: [60GHz-band Propagation characteristics are presented in this document]

Purpose: [Contribute to mm wave interest group for WPANs]

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Study of mm wave propagation modeling to realize WPANs

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Ami Kanazawa (Communications Research Laboratory)
Study of mm wave propagation modeling to realize WPANs

60GHz-Band is expected to realize a very high rate transmission system. In this document, 60 to 70GHz propagation characteristics are presented for the promotion of new system proposals. Overview of propagation modeling was presented as Doc.: IEEE802.15-03/0365 in Singapore meeting and Doc.: IEEE802.15-03/0458 in Albuquerque. In this document, more detail information are presented.

Content

- Complex permittivity of construction materials
- Correlation bandwidth
- Shadowing durations & attenuation

This measurement results are a summary of the experimental works done in a collaboration research project for Millimeter-wave Ad-Hoc communication in YRP.
Complex permittivity of construction materials

To determine the value of complex permittivity, reflection characteristics was measured. For several materials, measurement of transparency coefficient was done to calculate more accurate complex permittivity. In this contribution, Experimental results and calculation results are presented.
Complex permittivity of construction materials

To calculate the reflection and transmission characteristics from/through the building material, the complex permittivity of construction materials are indispensable.

Reflection coefficient measuring system

Transmitter Antenna

Material under Test

Incident Angle

Styrene Foam Absorber

Radius
Measuring parameter & Characteristic of horn antenna

<table>
<thead>
<tr>
<th>Measuring parameter</th>
<th>Specification/Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>1m</td>
</tr>
<tr>
<td>Polarization</td>
<td>Linear TE/TM</td>
</tr>
<tr>
<td>Incident angle</td>
<td>5° to 80° every 5°</td>
</tr>
<tr>
<td>Frequency</td>
<td>62GHz / 70GHz</td>
</tr>
<tr>
<td>Measuring tool</td>
<td>Network analyzer, etc</td>
</tr>
<tr>
<td>Measuring reference</td>
<td>Al board (1.0m × 1.0m × 3.0mm)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Antenna Frequency</th>
<th>Antenna Gain(dBi)</th>
<th>Beam width</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>E-Polarity</td>
</tr>
<tr>
<td>62GHz</td>
<td>29.8</td>
<td>5.5°</td>
</tr>
<tr>
<td>70GHz</td>
<td>30.7</td>
<td>4.9°</td>
</tr>
</tbody>
</table>

< Toshiyuki Hirose>, <Siemens K.K.>
Construction materials and Size

Those materials and size are common for Reflection measurement and Transparency measurement

<table>
<thead>
<tr>
<th>Construction Material</th>
<th>Seize(length × width × thickness)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Glass (Normal type)</td>
<td>1.0m × 1.0m × 6mm</td>
</tr>
<tr>
<td>B Glass (Infrared absorption type)</td>
<td>1.0m × 1.0m × 6mm</td>
</tr>
<tr>
<td>C Glass (Infrared reflection type)</td>
<td>1.0m × 1.0m × 6mm</td>
</tr>
<tr>
<td>D Glass (with wire netting)</td>
<td>1.0m × 1.0m × 6.8mm</td>
</tr>
<tr>
<td>E Plaster board (Wall)</td>
<td>1.8m × 0.9m × 12.5mm</td>
</tr>
<tr>
<td>F Plaster board (Ceiling)</td>
<td>1.0m × 1.0m × 9.5mm</td>
</tr>
<tr>
<td>G Marble (Bianco carrara)</td>
<td>1.0m × 1.0m × 19.6mm</td>
</tr>
<tr>
<td>H Granite (Caledonia)</td>
<td>1.0m × 1.0m × 25.3mm</td>
</tr>
<tr>
<td>I Granite (Zimbabwe black)</td>
<td>1.0m × 1.0m × 26.2mm</td>
</tr>
<tr>
<td>J Lawn of grass (Dry)</td>
<td>0.5m × 0.5m × 30mm</td>
</tr>
<tr>
<td>K Lawn of grass (Wet)</td>
<td>0.6m × 0.6m × 30mm</td>
</tr>
</tbody>
</table>

Number A to I are Materials for interior decoration
Reflection Coefficient of Glass & Plaster Board

Glass (Normal)  Plaster board (Ceiling material)
Reflection Coefficient of Marble Bianco carrara & Granite Caledonia

Marble Bianco carrara

Granite Caledonia

< Toshiyuki Hirose>, <Siemens K.K.>
Reflection Coefficient of Wet lawn (Effective value)

Measured values and estimated result for wet lawn (70GHz)
Transparency Coefficient

On the condition of antennas aligned in vertical and 2m distance, Transparency was measured as comparison with free space loss. Materials are A to F.

<table>
<thead>
<tr>
<th>Material</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>62GHz</td>
</tr>
<tr>
<td>A Glass (Normal type)</td>
<td>0.674</td>
</tr>
<tr>
<td>B Glass (Infrared absorption type)</td>
<td>0.609</td>
</tr>
<tr>
<td>C Glass (Infrared reflection type)</td>
<td>0.647</td>
</tr>
<tr>
<td>D Glass (with wire netting)</td>
<td>0.647</td>
</tr>
<tr>
<td>E Plaster board (Wall)</td>
<td>0.848</td>
</tr>
<tr>
<td>F Plaster board (Ceiling)</td>
<td>0.861</td>
</tr>
</tbody>
</table>

On the condition of antennas aligned in vertical and 2m distance, Transparency was measured as comparison with free space loss. Materials are A to F.
Complex permittivity

A-F: Actual value calculated by Reflection coefficient and Transparency coefficient
G-K: Effective value calculated by only Reflection coefficient

<table>
<thead>
<tr>
<th>Construction Material</th>
<th>62GHz</th>
<th>70GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Glass (Normal type)</td>
<td>6.24-0.17i</td>
<td>6.16-0.13i</td>
</tr>
<tr>
<td>B Glass (Infrared absorption type)</td>
<td>6.43-0.15i</td>
<td>6.45-0.16i</td>
</tr>
<tr>
<td>C Glass (Infrared reflection type)</td>
<td>6.30-0.15i</td>
<td>6.14-1.67i</td>
</tr>
<tr>
<td>D Glass (with wire netting)</td>
<td>6.08-1.27i</td>
<td>6.25-0.17i</td>
</tr>
<tr>
<td>E Plaster board (Wall)</td>
<td>2.17-0.01i</td>
<td>2.66-0.02i</td>
</tr>
<tr>
<td>F Plaster board (Ceiling)</td>
<td>2.48-0.03i</td>
<td>2.43-0.04i</td>
</tr>
<tr>
<td>G Marble (Bianco carrara)</td>
<td>7.90-0.05i</td>
<td>7.40-0.04i</td>
</tr>
<tr>
<td>H Granite (Caledonia)</td>
<td>4.85-1.42i</td>
<td>4.49-1.29i</td>
</tr>
<tr>
<td>I Granite (Zimbabwe black)</td>
<td>6.75-0.52i</td>
<td>7.00-0.50i</td>
</tr>
<tr>
<td>J Lawn of grass (Dry)</td>
<td>1.00-0.004i</td>
<td>1.00-0.006i</td>
</tr>
<tr>
<td>K Lawn of grass (Wet)</td>
<td>1.00-0.004i</td>
<td>1.00-0.006i</td>
</tr>
</tbody>
</table>
Conclusion of Complex permittivity

There are three types of materials in measurement.

- Large influence by back-surface reflection such as Glass, Plaster board and Marble.
  - Results show the complicated trace

- Small influence by back-surface reflection such as Granite
  - Results show very simple trace

- Small reflection from front surface such as lawn.
  - Results show similar traces for TE and TM mode.
    Variation between wet and dry conditions is negligible.
Correlation bandwidth
Outline of test site for Correlation band width measurement

Diagram showing the layout of the test site with distances marked as follows:
- 1m
- 2m
- 3m
- 4m
- 5m

Key:
- Wall
- Window
- Receiver
- Transmitter
Definition of Correlation bandwidth

Correlation bandwidth is defined by Frequency correlation function

\[ \rho(\Delta f) = \int_{-\infty}^{+\infty} p_h(\tau) \exp(-j2\pi\Delta f \tau) d\tau \]

\[ 0.5 = |\rho(\Delta B)|^2 \]

Table 1. Parameters for experiment.

<table>
<thead>
<tr>
<th>Measurement equipment</th>
<th>HP8510C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>62.5GHz, 70GHz</td>
</tr>
<tr>
<td>Measured bandwidth</td>
<td>3 GHz</td>
</tr>
<tr>
<td>Transmission power</td>
<td>2 dBm</td>
</tr>
<tr>
<td>Antenna</td>
<td>Wave Guide Horn</td>
</tr>
<tr>
<td>Antenna Gain</td>
<td>22 dBi, 16 dBi, 10 dBi</td>
</tr>
<tr>
<td>3 dB beam width</td>
<td>15 deg, 30 deg, 60 deg</td>
</tr>
<tr>
<td>Polarization</td>
<td>V, H</td>
</tr>
<tr>
<td>Antenna Height</td>
<td>1 m</td>
</tr>
</tbody>
</table>
Distance - Correlation bandwidth characteristic

Distance m

60GHz

70GHz

Correlation bandwidth (MHz)

Distance m

Submission Slide17 < Toshiyuki Hirose, Siemens K.K.>
Angle difference from Antenna axis - correlation bandwidth

Incident Angle

Correlation bandwidth

Turn Table
Correlation bandwidth in LOS / NLOS environment

Outline of test site for correlation bandwidth
Correlation bandwidth results in LOS / NLOS environment
- Continue -

70GHz LOS

70GHz Non LOS
Conclusion of Correlation bandwidth

Assuming the transmitter antenna beam width as 60 degrees and communication distance 3m, Correlation bandwidth by Antenna beam width can be obtained up to several 100MHz.

<table>
<thead>
<tr>
<th></th>
<th>15°</th>
<th>30°</th>
<th>60°</th>
</tr>
</thead>
<tbody>
<tr>
<td>60G</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3m</td>
<td>700MHz</td>
<td>700MHz</td>
<td>200MHz</td>
</tr>
<tr>
<td>70G</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3m</td>
<td>700MHz</td>
<td>680MHz</td>
<td>200MHz</td>
</tr>
</tbody>
</table>

The value varied by Angle difference of antenna axis.
A Study on Shadowing Characteristics
Agenda of Shadowing Characteristics

1. Characteristics of shadowing effect
   - Measurement procedure and scenery
   - Measurement results
2. Characteristics of human movement
   - Measurement outline
   - Investigation results
3. Proposal for estimation of shadowing duration
4. Conclusions
Measurement Procedure

The width of hall:
22m x 13m
(Wooden inner walls)

Measurement layout in the exhibition hall

Rx Antenna

Tx Antenna
Measurement Scenery

The exhibition hall scenery

Transmitting Antenna
### Measurement Parameter

**Parameter for experiment**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td>70GHz</td>
</tr>
<tr>
<td><strong>Antenna Height</strong></td>
<td></td>
</tr>
<tr>
<td>Tx</td>
<td>1.05m, 2.05m</td>
</tr>
<tr>
<td>Rx</td>
<td>1.05m</td>
</tr>
<tr>
<td><strong>Distance</strong></td>
<td>3.3m, 7.3m, 10.8m</td>
</tr>
<tr>
<td><strong>Antenna</strong></td>
<td>Wave Guide Horn</td>
</tr>
<tr>
<td><strong>Antenna Gain</strong></td>
<td>22dBi</td>
</tr>
<tr>
<td><strong>3dB beam width</strong></td>
<td>15degrees</td>
</tr>
<tr>
<td><strong>Polarization</strong></td>
<td>Vertical</td>
</tr>
</tbody>
</table>
Cumulative Probability Distributions of Relative Signal

The averaged data of each propagation distance was described in this figure.

The result of cumulative probability distributions shows a strong consistency between the data of 1.05m and 2.05m.
The Variation of Averaged Shadowing Durations

Shadowing duration becomes longer in 3.3m path in comparison with other paths.

Frequency: 70.0GHz
ht: 2.05m, hr: 1.05m
Ant.: Horn (15 degrees)
Polarization: Vertical

- d=3.3m
- d=7.3m
- d=10.8m
The Variation of Averaged Shadowing Durations

All data was included when transmitting antenna height was set at 1m and 2m, respectively.

The averaged shadowing duration decreased gradually with an increase in attenuation level.
Characteristics of Human Movement
Outline of Investigation

- It is necessary to make clear not only the averaged shadowing duration but also the characteristics of human movement in the actual environment.
  - estimate the total amount of shadowing duration per hour

- We investigated characteristics of human movement in the two offices of different sizes.
Measurement Procedure

- The width of office: 12m x 13m
- Observed time: 08:30 ~ 17:00 (2days, 2 offices)

A sample layout of the number of shadowing events
Characteristics of the Number of Shadowing Events Per Hour

Regression curve

\[ N = 260Dp \]

\[ 0.05 \leq Dp \leq 0.08 \]

The N increased gradually in proportion with Dp.
Relation Between Level Attenuation and the Number of Persons

All measured data at each distance and height are included.

An attenuation level increase with the number of persons.

Received level hardly attenuated even if persons exist on propagation path. (ht = 2.0m)
Regression Curve

\[
\text{Loss}_{\text{shadowing}} = 0.43 + 39.1 \log(x+1)
\]

\[0 \leq x \leq 5\]

\text{Loss}_{\text{shadowing}} \quad \text{shadowing loss relative to the free space level}

\[
x \quad \text{: the number of persons in the LoS path}
\]
Proposal for Estimation of Total Amount of Shadowing Durations

-Tsd is expressed as follow

\[ Tsd = Ts_{ave} \times N \]

\( Tsd \): total amount of shadowing duration per hour
\( Ts_{ave} \): averaged shadowing duration
\( N \): the number of shadowing event per hour

- Tsd can be estimated using relation of N and Dp, function of attenuation level.

\[ Tsd = f(L_{ATT}) \times 260 \times Dp \]

\( Ts_{ave} \): function of attenuation level (Slide30)
\( Dp \): density of population (Slide34)
Conclusion

- Relation between attenuation level and averaged shadowing duration were investigated.
  - Attenuation = $10\text{dB}$:
    Shadowing duration is $0.52 \text{ s}$.
  - Attenuation = $20\text{dB}$:
    Shadowing duration is $0.25 \text{ s}$.

- Total amount of shadowing duration per hour
  - We proposed that it was estimated by using attenuation level and density of population.
  - Experimental formula was proposed.
Reference


