Wideband Channel Characteristics for Indoor Reception of Satellite Transmissions at 2.4 GHz

ISART
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Outline

- Requirement for data
- Previous studies
- The wideband channel
- Design
- Measurement campaign
- Data reduction
- Results
- Conclusions
Requirement for wideband data

- Satellite systems are proposed that will offer (some degree) of indoor coverage
  - IMT-2000 systems at ~2 GHz
  - Galileo at 1.2 / 1.5 GHz
  - S-DAB at 1.5 GHz
- System designers therefore need to understand the nature of the wideband satellite-indoor channel
  - Inform choice of modulation characteristics
  - Impact of polarisation
  - Elevation dependence
Previous studies

- Aegis study on building penetration loss at 1-5 GHz
  - Used helium balloon to explore variety of elevation angles
  - Results presented at ICAP ’03
- Wideband outdoor-indoor measurements at cellular frequencies & 2.4 GHz
  - Generally near-horizontal paths
The wideband channel (1)

- Input delay spread: $h(t, \tau)$
- Delay Doppler spread: $S(\tau, v)$
- Time-variant transfer: $T(f, t)$
- Output Doppler spread: $H(f, v)$
The wideband channel (2)

\[ T_d = \frac{\sum_{i=1}^{n} P_i \tau_i}{\sum_{i=1}^{n} P_i} \]

Mean delay:

\[ S = \sqrt{\frac{1}{P_t} \sum_{i=1}^{n} p_i \tau_i^2 - T_d^2} \]

Delay Spread:

(P.1407)
Experimental approach (2)

Autocorrelation of PN sequence
Experimental approach (1)

Channel sounder used the ‘sliding correlator’ approach
### Sounder parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier frequency</td>
<td>2400 MHz</td>
</tr>
<tr>
<td>Chip rate</td>
<td>100 Mb/s</td>
</tr>
<tr>
<td>Sequence length</td>
<td>511 bits</td>
</tr>
<tr>
<td>dynamic range (max)</td>
<td>54 dB</td>
</tr>
<tr>
<td>Slip rate</td>
<td>12 kHz</td>
</tr>
<tr>
<td>IF Filter BW</td>
<td>24 KHz</td>
</tr>
<tr>
<td>Scaling factor</td>
<td>8,167</td>
</tr>
<tr>
<td>IF frequency</td>
<td>45 MHz</td>
</tr>
</tbody>
</table>
Transmitter design (1)

2.400 GHz synthesiser → PN Generator → PA → 1 W eirp

100.000 MHz synthesiser → PN Generator
Transmitter design (2)

Transmitted spectrum (without filter)
Transmitter design (3)

*Balloon payload*
Receiver design (1)

Simplified, low-cost, architecture
Receiver design (2)

Performance of integrating filter

Correlator Output

-50 -40 -30 -20 -10 0 10 20 30

0 10 20 30 40 50

Relative delay (ms)

dB

30 kHz filter
180 kHz filter

AEGIS
Correlating receiver
Measurement campaign (1)

- Need to approximate planar wavefront as closely as possible
- $D^2$ loss of direct & multipath components
Measurement campaign (2)

*CP antenna design*
Measurement locations (1)

- 'Front'
- 'Back'

Metres

0 0.75 1.25 2.5
Measurement locations (2)

30 Anyards Road
Data reduction (1)

Time-series of channel temporal response
Data reduction (2)

new acf db
Data reduction (3)

- **Antenna pointing**
  - Need to discard results where overall received power $<-3$dB w.r.t. boresight

- **Clipping level**
  - Manual inspection & setting of appropriate level
Data reduction (4)

Clipping levels
Overall results
Delay spread vs. loss
Polarisation dependence

- **Strongest multipath components from 1st order reflections**
- **Rejected by mutually CP antennas**

![Graph showing polarisation dependence](image-url)
Spread of measurements

Guildford (Back, CP-VP)
Overall cumulative statistics

![Graph showing overall cumulative statistics](image)

- **RMS delay spread (ns)**
- **% time delay spread not exceeded**
- **CP-VP**
- **CP-CP**

The graph illustrates the cumulative statistics for RMS delay spread over time, with two distinct lines representing CP-VP and CP-CP.
CP-VP statistics

![Graph showing CP-VP statistics with RMS delay spread (ns) on the y-axis and % time delay spread not exceeded on the x-axis. The graph includes lines for G_U.CV, G_B.CV, and G_F.CV.]
Leeds University measurements

- A related S@TCOM project
  - ‘Galileo discriminators for urban and indoor environment and exploitation of the mass market’
  - Astrium / Roke Manor / Leeds University
- Sounder operated at 1.6 GHz
  - ‘Spectrum-friendly’ modulation
  - Results comparable to Aegis findings
Leeds University measurements

- median delay spread
  - Leeds: 30-65 ns
  - Aegis: 10-80 ns
- benign location – range of delay spread
  - Leeds: 11-60 ns
  - Aegis: 9-62 ns
- worst location – range of delay spread
  - Leeds: 9 - 193 ns
  - Aegis: 5 -105 ns
Building loss measurements

-40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15

Loss

1.3 GHz

2.4 GHz

5.7 GHz

Elevation Angle
Building loss measurements

Dependence on floor (2.4 GHz)

-35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35

Elevation

Loss

Gnd floor
first floor
2nd / top

ÆGIS
Building loss measurements

![Graph showing building loss measurements across different frequencies.](image)
Conclusions

- Indoor satellite channel exhibits great variability

- Median delay spread typically 10-80ns
  - Possible ISI for systems with 10-100 MHz bandwidth
  - Worst case delay extends to 105ns in current study

- CP antennas minimise delay spread

- Building median penetration typically 12dB
  - Some bandwidth & elevation dependence
Thank you!

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