A Flexible Wideband Millimeter-Wave Channel Sounder with Local Area and NLOS to LOS Transition Measurements

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Agenda

- Background, Motivation, and Challenges
- CmWave and MmWave Channel Sounders in the Literature
- New Dual-Mode NYU Channel Sounder
- Measurement System Hardware and Calibration
- LOS to NLOS Transition and Local Area Measurements and Results
- Conclusions and Noteworthy Observations
How do traditional channel sounders work at sub-6 GHz?

- TX antenna(s) with a **sectored** or is **quasi-omnidirectional** pattern
- User Equipment (UE) or RX employs **multiple omnidirectional antennas** (typically dipoles or patches)
- Multiple **RF chains** at TX and/or RX or **electronic switching** between elements
- Sophisticated post-processing algorithms to **de-embed** antenna patterns and to temporally and spatially resolve multipath components (**MPCs**): RiMAX; ESPRIT; SAGE; MUSIC
- Less than one second to record multiple channel snapshots (long-term synchronization not a requirement for excess delay)
Motivation

Why a new channel sounder methodology at mmWave?

- Free space path loss (FSPL) much greater in first meter of propagation:
  - ~30 dB / 36 dB more attenuation at 30 GHz / 60 GHz compared to 1 GHz
- Directional horn antennas provide gain at TX/RX
- Benefits:
  1. Increased link margin
  2. Spatial filtering / resolution
  3. Extraction of environment features and characteristics for ray-tracing and site-planning

- Downsides:
  1. 0.5-4 hours for full TX/RX antenna sweeps
  2. Lack of synchronization and channel dynamics between measurements captured at different angles
  3. RF front-ends and components are expensive, fragile, and costly

NYU Channel Sounder

Horn antennas
Requirements for mmWave channel modeling given new measurement methodology

- Measure path loss at long-range distances (100’s of meters)
- Ultra-Wideband signal (≥ 1 GHz bandwidth) with nanosecond MPC resolution
- Angular/spatial resolution for AOD and AOA modeling
- Real-time measurements to capture small-scale temporal dynamics greater than the Doppler rate of the channel and rapidly fading blockage scenarios
- Synchronized measurements between TX and RX for accurate time of flight / true propagation delay and for synthesizing omnidirectional PDPs
Types of Channel Sounders

- Direct RF pulse systems: repetitive short probing pulse w/ envelope detection
- VNA: measures S21 parameter via IDFT
- Sliding correlator: exploits a constant envelope signal for max power efficiency; low bandwidth ADC.
- OFDM/FFT/Other types: direct-correlation / real-time with wideband ADC acquisition; thousands of PDPs/CIRs per second
- New NYU channel sounder with two modes: sliding correlator and real-time correlation (32 microsecond sampling interval). See [29] for more info.

Two Architectures for Channel Sounder RX

- **Sliding Correlator**
  - Analog correlation with RX chip rate slightly offset from TX rate: 499.9375 Mcps (slide factor of 8,000: **39 dB processing gain**)
  - Period of **time-dilated PDP** allows much **lower ADC sampling rate**:
    - \(2047 \times \frac{1}{500 \text{ MHz} - 499.9375 \text{ MHz}} = \frac{2047}{62.5 \text{ kHz}} = 32.752 \text{ ms}\)
  - Default averaging of 20 PDPs to improve SNR: 655 ms

- **Real-time spread spectrum** (**direct-correlation**)
  - Sample raw I and Q baseband channels with high-speed ADC (**1.5 GS/s** on each channel): \(y(t) = h(t) \ast x(t) \Leftrightarrow Y(f) = H(f) \cdot X(f)\)
  - FFT, matched filter, and IFFT performed on periodic complex received waveform:
    \[ h(t) = \text{IFFT} \left[ \frac{\text{FFT}[y(t)]}{\text{FFT}[x(t)]} \right] \]
  - Minimum periodic PDP snapshot of 32.753 \(\mu s\) (30,500 PDPs per second). Memory for up to **41,000 consecutive PDPs**

FPGA Digital Logic and Triggers

- Variable length and repetitive PN codes
  - Default length: $2^{11}-1=2047$ chips
  - Up to 500 Mcps (1 GHz RF bandwidth)
- Extremely long codes when memory is limited
- Integration with LabVIEW-FPGA and FlexRIO Adapter Modules (FAM)
- DAC clocked at 125 MHz (8 ns SCTL) with 16 time-interleaved channels (SerDes) for 2 GS/s rates
- Flexible digital triggers along chassis backplane assist synchronization

NYU Channel Sounder RX – Sliding Correlator

- TX/RX antenna control via FLIR Pan-Tilt D100 gimbal with game controller
- **Automatic azimuth sweeps** for AOD/AOA
- **Automatic linear track translations** for small-scale measurements
- **Real-time feedback** of channel with PDP and azimuth power spectra display
- Rubidium (Rb) references at TX/RX for time/frequency synchronization
- Ad hoc WiFi control of TX antenna from RX system (50 to 75m)
Indoor and Outdoor (Tetherless) Methods for Drift Calibration

LOS to NLOS Transition with Corner Loss in ITU-R P.1411-8

FIGURE 4

Typical trend of propagation along street canyons with low station height
for frequency range from 2 to 16 GHz

Relative signal level

LoS region
Corner region
NLoS region

Relative signal level

$L_{\text{LoS}}$
$L_{\text{corner}}$
$L_{\text{air}}$

$\frac{w_1}{2} + 1$
$\delta_{\text{corner}}$

Distance of travel from station 1

STN1 $x_1$

STN2 $x_2$

LOS to NLOS Transition Measurements with Sliding Correlator Mode

- LOS to NLOS Transition Measurements
- 5 LOS: 29.6 m to 49.1 m (Euclidean)
- 11 NLOS: 50.8 m to 81.6 m (Euclidean)
- Bridge street width: 18 m
- 10 story buildings
- RX locations in 5 m adjacent increments to form an “L”-shaped route
- TX antenna HPBW: 7°/7° Az/El
- RX antenna HPBW: 15°/15° Az/El
- TX Az/El antenna pointing angles remained fixed at 100°/0°
- RX EI fixed at 0° for all locations
- RX azimuth sweeps in HPBW increments with starting position at strongest angle of arrival
- TX/RX antenna heights at 4 m / 1.5 m
- 5 repeated sweeps at each location for temporal variations
LOE to NLOS Transition Results

- Omnidirectional path loss synthesized from azimuth sweeps at each location [32]
- RX92 to RX87 half-way down urban canyon results in \(~25\,\text{dB}\) attenuation (path distance of 25 meters)
- When moving around corner:
  - Vehicle speed of 35 m/s will experience 35 dB/s fading rate
  - Mobile at a walking speed of 1 m/s will experience 1 dB/s fading rate
- LOS PLE higher than free space due to coarse antenna boresight alignment

LOS to NLOS Transition Results

**LOS**

73 GHz Polar Plot at RX 92 for TX: L8

- Environment: LOS
- TR Separation: 49.1 m
- TX Height: 4 m
- RX Height: 1.5 m
- Measurement: 2
- $\text{TX}_{AZ/EL} = 100^\circ / 0^\circ$
- $\text{RX}_{EL} = 0^\circ$
- $\text{TX HPBW}_{AZ/EL} = 7^\circ / 7^\circ$
- $\text{RX HPBW}_{AZ/EL} = 15^\circ / 15^\circ$

**NLOS**

73 GHz Polar Plot at RX 87 for TX: L8

- Environment: NLOS
- TR Separation: 60.6 m
- TX Height: 4 m
- RX Height: 1.5 m
- Measurement: 3
- $\text{TX}_{AZ/EL} = 100^\circ / 0^\circ$
- $\text{RX}_{EL} = 0^\circ$
- $\text{TX HPBW}_{AZ/EL} = 7^\circ / 7^\circ$
- $\text{RX HPBW}_{AZ/EL} = 15^\circ / 15^\circ$
Local Area Cluster Measurements / with Sliding Correlator Mode

- Omnidirectional path loss synthesized from azimuth sweeps at each location [32]
- 5 LOS: 57.8 m to 70.6 m (Euclidean)
- 5 NLOS: 61.7 m to 73.7 m (Euclidean)
- RX locations for LOS and NLOS are placed in 5 m adjacent increments that form a semi-circle
- Local area grid approximately 5 m x 10 m

LOS and NLOS Local Area

<table>
<thead>
<tr>
<th>Measurement Set</th>
<th>LOS: RX61 to RX65</th>
<th>NLOS: RX51 to RX55</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omnidirectional Received Power STD</td>
<td>4.3 dB</td>
<td>2.2 dB</td>
</tr>
<tr>
<td>Min/Max Omni Path Loss [dB]</td>
<td>105.1 dB / 114.7 dB</td>
<td>134.04 dB / 139.3 dB</td>
</tr>
<tr>
<td>Avg. Omni Path Loss [dB]</td>
<td>111 dB</td>
<td>137 dB</td>
</tr>
</tbody>
</table>

Conclusions and Observations

- New NYU dual-mode mmWave channel sounder with **sliding correlator** and **real-time spread spectrum** capabilities:
  - Long-distance (**100’s of meters**) and large-scale path loss measurements
  - Accurate **AOD and AOA angular spreads** in azimuth and elevation
  - Capture **dynamic channel fades** over short intervals in **large crowds**
- LOS to NLOS transition measurements along a route using sliding correlator
  - Results show significant **corner loss of 25 dB over a 25 m path from LOS to NLOS**
  - Two **main spatial lobes at RX in LOS** for a single TX pointing direction
- LOS and NLOS local area cluster measurements using sliding correlator
  - **Relatively low standard deviation** in received power for **LOS** RX locations in a 5 m x 10 m grid: 4.3 dB
  - **Low standard deviation** in received power for **NLOS** RX locations in a 5 x 10 m grid: 2.2 dB
Acknowledgement to our NYU WIRELESS Industrial Affiliates and NSF:
References


References


Questions