Millimeter Wave Wireless Networks: Potentials and Challenges

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Joint work with Ted Rappaport, Elza Erkip

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5G Requirements

- From Nokia whitepaper, “Looking ahead to 5G. Building a virtual zero latency gigabit experience”
MmWave: The New Frontier for Cellular

- Massive increase in bandwidth
  - Up to 200x total over long-time
- Spatial degrees of freedom from large antenna arrays

From Khan, Pi “Millimeter Wave Mobile Broadband: Unleashing 3-300 GHz spectrum,” 2011

Commercial 64 antenna element array
Key Challenges for Mobile Cellular

- All transmissions are directional:
  - Friis’ Law: \( \frac{P_r}{P_t} = G_t G_r \left( \frac{\lambda}{4\pi r} \right)^2 \Rightarrow \text{Path loss } \propto \lambda^{-2} \)
  - Can be overcome with beamforming: \( G_t, G_r \propto \lambda^{-2} \)
  - But requires directional search, tracking to support mobility

- Shadowing
  - Mortar, brick, concrete > 150 dB
  - Human body: Up to 35 dB
  - NLOS propagation relies on reflections and scattering
Millimeter Wave Cellular Vision

- Small cells
- Directional transmissions
- Relaying / mesh topology

Uday Mudoi, Electronic Design, 2012

http://www.miwaves.eu/
NYC 28 and 73 GHz Measurements

- Focus on urban canyon environment
  - Likely initial use case
  - Mostly NLOS
  - “Worst-case” setting
- Measurements mimic microcell type deployment:
  - Rooftops 2-5 stories to street-level
- Distances up to 200m

All images here from Rappaport’s measurements:

Isotropic Path Loss Comparison

- Isotropic NLOS path loss measured in NYC
  - ~ 20 - 25 dB worse than 3GPP urban micro model for fc=2.5 GHz
- But beamforming will offset this loss.
- Bottom line: mmW has no effective increase in path loss
## Comparison to Current LTE

- Initial results show significant gain over LTE
- Further gains with spatial mux, subband scheduling and wider bandwidths

<table>
<thead>
<tr>
<th>System antenna</th>
<th>Duplex BW</th>
<th>fc (GHz)</th>
<th>Antenna</th>
<th>Cell throughput (Mbps/cell)</th>
<th>Cell edge rate (Mbps/user, 5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DL</td>
<td>UL</td>
</tr>
<tr>
<td>mmW TDD</td>
<td>1 GHz</td>
<td>28</td>
<td>4x4 UE</td>
<td>1514</td>
<td>1468</td>
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<td></td>
<td></td>
<td></td>
<td>8x8 eNB</td>
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<tr>
<td></td>
<td>73</td>
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<td>8x8 UE</td>
<td>1435</td>
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<tr>
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<td></td>
<td>8x8 eNB</td>
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<tr>
<td>Current LTE</td>
<td>20+20 MHz</td>
<td>2.5</td>
<td>(2x2 DL, 2x4 UL)</td>
<td>53.8</td>
<td>47.2</td>
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<tr>
<td></td>
<td>FDD</td>
<td></td>
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</tbody>
</table>

10 UEs per cell, ISD=200m, hex cell layout
LTE capacity estimates from 36.814

~ 25x gain
~ 10x gain
A Big Question
What is the killer app for mmWave?

- What applications can drive huge amounts of data?
  - Video?
  - Machine to machine?
  - Many users bursty vs. few users continuous?

- What will drive very low latency (e.g. ~1ms)?
  - Network delays?
  - Mobile vs. cloud partition?
  - Where will data be located?

- Power, form factor, cost?