Massive MIMO at 60 GHz vs. 2 GHz: How Many More Antennas?

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joint work with

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Cellular Massive MIMO in PCS bands offers uniformly high QoS

- 1 ms × 200 kHz channel coherence, 100 antennas
- Max-min fairness power control
We compared PCS (1.9 GHz) with mmWave (60 GHz) in line-of-sight.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell radius</td>
<td>500 m</td>
</tr>
<tr>
<td>Mobility</td>
<td>negligible</td>
</tr>
<tr>
<td>No. of multiplexed terminals</td>
<td>18</td>
</tr>
<tr>
<td>Base station height</td>
<td>30 m</td>
</tr>
<tr>
<td>Terminal height</td>
<td>1.5 m</td>
</tr>
<tr>
<td>Propagation</td>
<td>free-space/line-of-sight</td>
</tr>
<tr>
<td>Antenna type</td>
<td>omni (0 dBi)</td>
</tr>
<tr>
<td>Power control</td>
<td>max-min fairness (uniform QoS)</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>20 MHz</td>
</tr>
<tr>
<td>Downlink power</td>
<td>10 W</td>
</tr>
<tr>
<td>Uplink power</td>
<td>200 mW</td>
</tr>
<tr>
<td>Base station noise figure</td>
<td>9 dB</td>
</tr>
<tr>
<td>Terminal noise figure</td>
<td>9 dB</td>
</tr>
</tbody>
</table>
Simple, exact performance formulas are available in closed form...

- Zero-forcing in the downlink:
  \[
  y_k = \sqrt{\sum_{k'=1}^{K} \left[ (H^H H)^{-1} \right]_{k',k'} \eta_{k'}} \cdot q_k + w_k
  \]

- SINR for \( k \)th terminal:
  \[
  \text{SINR} = \frac{\rho \beta_k \eta_k}{\sum_{k'=1}^{K} \left[ (H^H H)^{-1} \right]_{k',k'} \cdot \eta_{k'}}
  \]

- Max-min fairness choice of \( \eta_k \):
  \[
  \eta_k = \frac{\sum_{k'=1}^{K} 1/\beta_{k'}}{\beta_k}
  \]

- Resulting max-min optimal SINR:
  \[
  \overline{\text{SINR}} = \frac{\rho}{\sum_{k'=1}^{K} \left[ (H^H H)^{-1} \right]_{k',k'}/\beta_{k'}}
  \]

(uptlink similarly)
Link budget calculation: 128-antenna PCS $\rightarrow$ 128,000-antenna mmWave

\[
\begin{align*}
A_e &\approx 0.12\lambda^2 \\
(\frac{60}{1.9})^2 &\approx 1000\times!
\end{align*}
\]
But more antennas $\rightarrow$ better orthogonality $\rightarrow$ less power to invert channel

\[
\text{SINR} = \frac{\rho}{\sum_{k'=1}^{K} [(H^H H)^{-1}]_{k', k'} / \beta_{k'}}
\]

...so much fewer antennas might be needed
128-antenna PCS compares to 10,000-antenna mmWave

PCS
128 antennas
uniform QoS

mmWave
10,000 antennas
uniform QoS

arXiv:1702.06111
All arrays are physically rather compact

<table>
<thead>
<tr>
<th>95%-likely SINR</th>
<th>Number of antennas</th>
<th>Array diameter (meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PCS</td>
<td>mmWave</td>
</tr>
<tr>
<td>10 dB</td>
<td>58</td>
<td>370</td>
</tr>
<tr>
<td>20 dB</td>
<td>100</td>
<td>853</td>
</tr>
<tr>
<td>30 dB</td>
<td>177</td>
<td>5100</td>
</tr>
</tbody>
</table>
The array geometry does not really matter
Conclusion

10,000-antenna mmWave might compare to 128-antenna PCS,

in static line-of-sight
Question: will blocking at mmWave require a sparse frequency reuse?

- wood (3 cm): 5-10 dB
- human body: 20-35 dB
- window (single): 2-3 dB
- window (double): 10-15 dB
- window (coated): >40 dB
- brick wall: “∞”
Question: in mmWave bands, can hybrid beamforming help?

Less electronics?
Even 16-fold reduction yields $10,000 \div 16 = 625$!
From measurements: in PCS bands, hybrid beamforming is not effective

2.6 GHZ
128 ant.
linear array
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