mmWave for Ultra-Dense Networks (UDNs)

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Panel: 5G/mmWave Capacity Improvements: A Systems Perspective
Moderator: Chris Anderson, USNA/ITS
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"What are UDNs, anyway?"*

Three features of UDNs:
1. Large number of network access points (APs) (obviously...)
   a) More APs than devices (?)
   b) Offload macro traffic
   c) Extensive frequency reuse
2. Dense and heavily interconnected cross-tier network structure
3. Fast network access & flexible inter- and intra-tier switching (i.e., rapid, seamless handovers)

Two Equations, Two Metrics

• Hwang et al.¹

  ▪ Capacity density: \( \delta_R \left[ \frac{\text{bits/s}}{\text{km}^2} \right] = \delta_{\text{cell}} \left[ \frac{\text{cells}}{\text{km}^2} \right] \times C \left[ \frac{\text{bits/s/Hz}}{\text{cell}} \right] \times B \left[ \text{Hz} \right] \)

  ▪ Increase cell density (UDN), bandwidth (spectrum migration), or spectral efficiency per cell (diminishing returns)

• Lopez-Perez et al.²

  ▪ Total network capacity: \( C \left[ \text{bits/s} \right] = \sum_{m=1}^{M} \sum_{u=1}^{U_m} B_{m,u} \left[ \text{Hz} \right] \log_2 \left( 1 + \gamma_{m,u} \right) \)

  ▪ Densification makes \( C \) increase linearly w.r.t. \( M \)

  ▪ Densification reduces \( U_m \) but increases \( B_{m,u} \) (fewer devices per cell)

  ▪ Densification increases \( \gamma_{m,u} \) (results in slower growth in \( C \))

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### Some Interference Management Techniques for sub-GHz UDNs

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<th>Technique</th>
<th>Network</th>
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<td>Random Time Slot Selection</td>
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<td>Distributed control</td>
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<td>Adaptive power/attenuation control, carrier selection, beamforming</td>
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<td>Beamforming codebook restriction (Sungsoo)</td>
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<td>Tiered spectrum assignment</td>
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<td>Adaptive frequency hopping by Small Cells</td>
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<td>Cognitive-assisted spectrum aware usage by small cells</td>
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<td>Nonlinear interference cancellation</td>
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<td>Carrier Aggregation, CoMP</td>
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UDNs Are a Natural Fit for mmWave

Benefits for UDNs:
• Short propagation distances decrease the interference “horizon”
• Short wavelengths allow massive MIMO or phased arrays to support high gain along LoS/dominant path, collection of signal energy from reflective paths, and adaptive nulling of nearby interferers
• No multi-tier interference

Some challenges:
• Tracking beams/devices/paths
• Energy conservation requirements
• Management requirements
• Effect of mmWave backhaul