COSMOS Millimeter Wave
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Millimeter Wave Communications

- Vast untapped spectrum above 6 GHz
  - Up to 100x more bandwidth
  - High-dim antenna arrays

- But, many challenges for mobile cellular
  - Path loss, blocking, ...

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

- **Millimeter wave: It can work!**
  - First measurements in urban canyon environment
  - Distances up to 200m
  - Propagation via reflections

- **Proved feasibility of cellular systems**
  - Measurements made urban macro-cell type deployment
  - Rooftops 2-5 stories to street-level

**Significant Gains Over LTE**

<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 8x8 eNB</td>
<td>1514</td>
<td>1468</td>
</tr>
<tr>
<td></td>
<td></td>
<td>73</td>
<td>8x8 UE 8x8 eNB</td>
<td>1435</td>
<td>1465</td>
</tr>
<tr>
<td>Current LTE FDD</td>
<td>20+20 MHz</td>
<td>2.5</td>
<td>(2x2 DL, 2x4 UL)</td>
<td>53.8</td>
<td>47.2</td>
</tr>
</tbody>
</table>

- MmWave delivers IMT Vision

-- 10 UEs / cell; 100 m ISD

Source: ITU-R IMT-2020 Vision
Rapid Progress in 3GPP

- Advanced demos
- Several trials underway
  - VZ, Sprint, AT&T
- FCC allocation of 28 and 37 GHz bands
- Commercial chip sets

Qualcomm, “Making 5G NR a Reality”
Key Challenges for mmWave

• **Directionality**
  – High isotropic path loss
  – Compensated by directional beams
  – Impacts all aspects of cellular design

• **Blockage**
  – MmWave signals blocked by many common materials
  – Brick > 80 dB, human body > 25 dB
  – Leads to highly intermittent channels

• **What COSMOS can answer:**
  – Can mmWave work on a large scale?
  – How?
COSMOS MmWave Research

- Wide Area Channel Measurements
  - Multi-sites, macro-diversity, blocking, dynamics
- Beam forming, adaptive arrays
- Beam search, initial access
- Scheduling, MAC, idle mode
- Networking
  - Congestion control, multi-path routing, edge networking
- Integrated Access / Backhaul
- Low latency, high-throughput applications
  - VR/AR, connected car
COSMOS MmWave Nodes

- Build powerful SDR platform
  - Massive baseband processing
  - Multi-Gbps throughput (large nodes)
- 28 GHz phased arrays
  - Vendor to be decided
- Programmable, open interface
  - Experimentation for beamforming, directional MAC layer, ...
- Built on 5G OFDM New Radio
  - Can connect to 5G devices when available

SiBeam 60 GHz phased array
- 12 steerable elements
- 23 dBi gain

NI 5G SDR based on PixE platform
**COSMOS MmWave Backhaul**

- **Cellular backhaul for small cells**
  - Currently extremely costly (up to 50% OPEX)
  - Bottleneck for deployments
- **MmWave provides low-cost alternative**
  - Potential use in same frequency as access
- **COSMOS could integrate mmWave backhaul nodes**

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MiWeba, “MmWave Evolution for backhaul and access”

Interdigital 60 GHz EdgeLink antenna
- 38 dBi gain
- 802.11ad based
mmWave/MIMO at Columbia

The first mmWave CMOS Phased-Array Transceivers

mmWave CMOS Power Amplifiers with Record Output Power and Efficiency

First mmWave Full-Duplex Transceiver

First CMOS (massive) MIMO Transceivers
Full-Duplex at Columbia

- The Columbia FlexICoN project addresses FD wireless challenges holistically – from the PHY layer to the MAC layer.
- We demonstrated the first self-interference cancelling FD RFICs from RF to mmWave.
- We demonstrated the first FD antenna interfaces, including CMOS non-magnetic circulators.
- We have developed algorithms for resource allocation and evaluated rate gains.
FD Testbed Development

Gen 1 FlexICoN FD Node
- Frequency-flat RF canceller.
- 90dB SIC imparted to 5MHz 0dBm TX signal.

Gen 2 FlexICoN Wideband FD Node
- Wideband FDE-based RF canceller.
- 95dB SIC imparted to 5MHz 5dBm TX signal.

Gen 1 node installed in ORBIT
14+ Year History of mmWave Subsystem Research at IBM

Leading-edge highly-integrated technology solutions to enable wireless communication and sensor systems with less volume, weight and cost

- **60-GHz SiGe Single-Element and Phased Array Radios**
- **94-GHz Scalable Phased Array**
- **E-band Fixed-Beam Radio for Backhaul**
- **5G**

- **2003**: World’s First Monolithic mmWave (60 GHz) Radio
- **2005**: 60GHz 16-Element Phased Array TX+RX Chip-Set
- **2007**: 94-GHz 64-element Scalable Phased Array TX+RX
- **2009**: 60-GHz Low-Power Radio in 32nm SOI
- **2011**: Low-power, Switched Beam 60GHz CMOS TX+RX
- **2013**: 28-GHz 64-element Phased Array TX+RX

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**COSMOS**

Rutgers, Columbia University, in the City of New York, NYU <sh>

**World’s First Monolithic mmWave (60 GHz) Radio**

**60GHz 16-Element Phased Array TX+RX Chip-Set**

**94-GHz 64-element Scalable Phased Array TX+RX**

**Low-power, Switched Beam 60GHz CMOS TX+RX**

**28-GHz 64-element Phased Array TX+RX**
28GHz Phased Array Transceiver Module with 4 ICs and 64 Dual-polarized Antennas (Co-developed by IBM and Ericsson)

Module features:
- 64-dual polarized antennas and 4 ICs each with 32 TRX elements
- 128 TRX elements in total
- 8 independent 16-element beamformers, each supporting 1 polarization of 16 ant.
- RF true time delay based architecture
- 28GHz RF, 5GHz ext. LO, 3GHz input/output IF
- 54dBm saturated EIRP on each polarization

Measured 8 simultaneous 16-element beams
Measured 2 simultaneous 64-element beams
Measured Precise 1.4°/step beam steering

28GHz phased array eval. board
Example outdoor link experiment at IBM