Visions of the Wireless Future: Insights into Emerging Technologies

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Directory of Wireless@MIT
Over 20 PIs and 50 Graduate Students
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- Amazon
- Cisco
- Google
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- Telefónica
Fundamental Architectural Change

**Traditional Approach**
Optimize within isolated layers

- Network & Apps
- Comms. and Coding
- HW and Radios

Disruptive gains are unlikely

**New Approach**
Optimize across the layers

- Network and Apps
- Comms. and Coding
- HW and Radios

Major opportunities!
MegaMIMO

10x Higher Data Rates
The FCC projects that the US will face a spectrum shortfall in 2013.

The iPhone 4 demo failed due to wireless congestion.

Jobs’s reaction: “If you want to see the demos, shut off your laptops, turn off all these MiFi base stations, and put them on the floor, please.”
MegaMIMO

Alleviates the capacity crunch by transmitting more bits per unit of spectrum
Today’s Wireless Networks

Today, Access Points Can’t Transmit Together in the Same Channel
Today’s Wireless Networks

Access Point 1  Access Point 2  Access Point 3

Interference!

User 1  User 2  User 3

Today, Access Points Can’t Transmit Together in the Same Channel
Access Points Can Transmit Simultaneously in the Same Channel

Interference:
- $d_2 + d_3 \approx 0$

Data: $d_1$ survives

Interference:
- $d_1 + d_3 \approx 0$

Data: $d_2$ survives

Interference:
- $d_1 + d_2 \approx 0$

Data: $d_3$ survives
MegaMIMO = Distributed MIMO

Access Points act as a huge distributed MIMO transmitter with sum of antennas

10 Access Points ➞ 10x Higher Throughput
Testbed of Software Radios

Dense Conference Room Like Deployment
Results from Prototype

10x throughput gain over existing Wi-Fi

<table>
<thead>
<tr>
<th>Number of Access Points on Same Channel</th>
<th>Total Throughput [Mb/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
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<tr>
<td>3</td>
<td>120</td>
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<tr>
<td>4</td>
<td>160</td>
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<td>5</td>
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<td>7</td>
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<td>8</td>
<td>320</td>
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<tr>
<td>9</td>
<td>360</td>
</tr>
<tr>
<td>10</td>
<td>400</td>
</tr>
</tbody>
</table>

MegaMIMO

802.11
Centimeter-Scale Localization

Today, RF-based localization has about one meter accuracy.

**Challenge:** Multipath effects confuse the localization system.

**Solution:** Use the multipath reflection pattern as a signature of the location.
Use Multipath Reflections

Power of Reflection vs. Spatial Angle (degree)
Use Multipath Reflections

Power of Reflection vs. Spatial Angle (degree)
Use Multipath Reflections

Can localize to within a few centimeters
Works even with RFIDs

Battery-free stickers to tag any and every object
No more customer checkout lines
No more customer checkout lines

RFIDs on Basket
RFID-tagged Laptop
Charger

RFID-tagged Laptop

RFID-tagged Handbag

Smart Homes
Smart Homes

Reference RFIDs
Smart Homes

RFIDs on the Door Frame

Charger left behind!
Can your cellphone give you X-ray vision?
WiVi: See through-walls with WiFi

- WiFi signals traverse walls and reflect off objects

- **Challenge:** reflections off the separating wall are 10,000x higher than off a human behind the wall

- **Solution:** use two transmit antennas and one receive antenna; the two transmitted waves cancel each other for static objects but not animated objects

- See video on YouTube
  
  https://www.youtube.com/watch?v=uJkQzLjYBFI
Low-power Realtime GHz-Wide Spectrum Sensing
Imagine

A low-power cheap sensor that captures GHz-wide spectrum in realtime

→ Thousands of sensors to map spectrum usage
→ Very efficient dynamic spectrum sharing
→ Can detect fleeting signals like radar
Realtime GHz Spectrum Sensing is Difficult

- Today, sequential scanning of tens of MHz can easily miss radar signals
- Key Challenge: high-speed ADCs

Tens of MHz ADC
- < a dollar
- Low-power
- High resolution

A Few GHz ADC
- Hundreds of dollars
- 10x more power
- Poor resolution
Idea: Leverage Sparsity

Sparse recovery show that one can acquire sparse signals using sub-Nyquist sampling

Sparse FFT

No random sampling → can use low-speed ADCs
Benefits of Sparse FFT

• Sub-sample the data → Can use low-speed ADCs
• Very fast algorithm → Lower-power consumption

• Used sparse FFT to build a GHz receiver from three 50 MHz ADCs
• Both senses and decodes sparse spectrum
Sense GHz using 3 tens of MHz ADCs
Decoding Senders Randomly Hopping in a GHz

Both Senses and Decodes
3D Photography Using Sparse FFT

- Generate depth and perspective using a camera array
- Images are correlated → 4D frequencies are sparse
- **Goal:** reduce the number of camera elements to enable implementation in a hand-held device
- **Solution:** Camera images are correlated → Use sparse FFT
Results show that we can accurately reconstruct unsampled camera outputs.
Conclusion

The future will be full of amazing wireless technologies that will change our life.