Implications of Millimeter Wave for 5G System Design

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Also with PHAZR (see http://phazr.net for more information)

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www.profheath.org
Current cellular spectrum in US

Total available bandwidth = ~600MHz

- 700MHz auctioned in 2008
  - $18,957,582,150
  - 1090 licenses
- AWS-3 auctioned in 2015
  - $41,329,673,325
  - 1611 licenses

Spectra below 3 GHz is packed and $$/Hz of bandwidth is huge

To get more bandwidth, need to go to higher carrier frequencies

See e.g. http://wireless.fcc.gov/auctions/default.htm?job=auction_summary&id=73
The future is in the mmWave bands (30GHz to 300GHz)

- Lots of potential spectrum currently used for backhaul or legacy systems
- Different licensing options available for many bands

Spectrum for 5G is (almost) ready!!!

- 4 GHz
  - LMDS
    - 0.85 GHz
    - 1.6 GHz
    - 1.4 GHz

- Unlicensed
  - 7 GHz
  - 7 GHz
  - 7 GHz

- 10 GHz E-band
  - Auctioned in 2000
    - $410,649,085 / 2,173 licenses
  - Expected to be unlicensed

- More is available above 90GHz

Implications on 5G systems

mmWave spectrum and higher data rates
Implications of using millimeter wave spectrum

Shared licensed access possible to reduce cost, give carriers access to more spectrum*  
Cognitive radio for shared spectrum with satellite or radar  

Higher data rates  
New applications possible**

** Osseiran et al.,"Scenarios for 5G mobile and wireless communications: the vision of the METIS project," IEEE Commun. Mag., May 2014
What are the potential rate gains with mmWave?

MmWave gains are more than a spectrum multiplier

Baseline 2 GHz w/ 50 MHz BW
Upper cmWave 28 GHz: 500 MHz (expect 10x)
mmWave 72 GHz: 2 GHz (expect 40x)

* Note the fine print about dense networks, more to come

New 5G killer apps enabled by mmWave

- Virtual Reality
- High data rate
- Autonomous Robots
- Small size equipment
- V2X Communications
- Low latency
- Automated Driving
- High data rates

MmWave high data rates are required in different 5G scenarios

Osseiran et al., "Scenarios for 5G mobile and wireless communications: the vision of the METIS project," IEEE Commun. Mag., May 2014
Implications on 5G systems

mmWave differentiating features
Differentiating features of mmWave

Blockage

- Upper array blocked with fingers
- Lower array blocked by person

Directional and adaptive antenna arrays

Advanced MIMO architectures

Which are the impacts on a 5G system?
Implications of adaptive arrays

Initial access and handoff become more difficult

Interference is bursty, less severe, SINR higher

Large arrays at BS and UE

Stronger interference

Weaker interference

Cell boundaries blur

New antennas, cables, infrastructure, baseband

Implications of more advanced MIMO solutions

- Hardware power consumption plays a bigger role in PHY design
- Process more signals with few-bit ADCs
- Hybrid architecture at the BS and the UE with many fewer RF chains than antennas
- Compressive channel estimation, new pilot designs

Implications on 5G systems

Blockage
Blockage is a major channel impairment

- **blockage due to buildings**
  - line-of-sight
  - non-line-of-sight

- **blockage due to people**
  - hand blocking
  - self-body blocking

Need models for blockage & system analysis including blockage


**Implications of blockage**

- More BS/km² and multibase connectivity provide diversity
- Indoor users not covered by outdoor infrastructure
- Blockages reduce the impact of interference
- Multiple arrays on handset

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Solutions to building blockage

Add more infrastructure

Fallback to lower frequency and lower rate

User...go around the building if you want coverage

Add enough antenna gain to work effectively when blocked

Need to cover the non-line-of-sight user
Solution to body and self-body blocking for 5G

Network supports fast switching

System detects blockage and reroutes signals

Unblocked BS

Body blocked BS

Similar solutions as building blockage, but different timescale

Solution to hand blockage for 5G

- Multiple arrays on handset if space is available (hard with multi-band)
- Train users not to block the arrays with their fingers (warning labels or shock)

Hand blockages and variable orientation require careful device engineering

A vision for 5G mmWave infrastructure

New concepts for the infrastructure
Sensing at the infrastructure

Radar operating in another band

BS supporting V2X

Radar at the infrastructure can help predict blockages

Could leverage communication at other bands

Improves communication link efficiency and reduces overheads


** N. Gonzalez-Prelcic, Roi Mendez-Rial, and R. W. Heath Jr., "Radar aided beamforming in mmWave V2I communications support antenna diversity," ITA 2016
Backhaul at mmWave

Out-of-band wireless backhaul possible in other mmWave spectra

Wired backhaul will require very high capacity Tens of Gbps

Backhaul is a 5G killer

Inband wireless backhaul will work due to pointy beams with low overlap

Many new components of 5G infrastructure

- Self-backhauled network
- Combination of sensing, learning and communication
- mmWave sensing-BS
- mmWave backhaul
- Multiband-connectivity
- Relays
In Summary

Millimeter wave is coming to 5G

Check out research videos at goo.gl/yYx250
References from Heath research group

- **MmWave book**

- **Overview papers**
References from Heath research group

◆ 5G cellular performance analysis with millimeter wave
References from Heath research group

◆ Millimeter wave ad hoc networks


References from Heath research group

- Millimeter wave wearables
References from Heath research group

- Single user narrowband hybrid precoding (part 1/2)
References from Heath research group

- Single user narrowband hybrid precoding (part 2/2)
References from Heath research group

- Single user frequency selective hybrid precoding
References from Heath research group

◆ Multiple user hybrid precoding


References from Heath research group

Channel estimation for mmWave systems


References from Heath research group

* Low resolution ADCs including one-bit ADCs 1 / 2
References from Heath research group

- Low resolution ADCs including one-bit ADCs 2 / 2
References from Heath research group

Applications in V2X systems


Other references