5G ENABLING TECHNOLOGY:
MILLIMETER WAVE
CHANNEL CHARACTERIZATION

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Outline

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• Specifications and Critical Performance
• Technology Candidates
• mmWave and its characteristics
• Ongoing Research Activities
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Introduction: 5G

5G Networks likely to address several critical performance areas

Fig.: Challenging Scenarios to be addressed in 5G networks (source: Alcatel-Lucent)
5G Requirements and Specifications

- 1000x capacity/km²

Higher system capacity

- 10-100x bit rates
  (Even for high mobility)

Higher data rate

- 100x connected devices
  (Even in crowded areas)

Massive device connectivity

- Reduced latency : < 1ms

Reduced latency

- Energy saving for NW & terminals
  - Reduced NW cost incl. backhaul

Energy saving & cost reduction
5G Direction of Research ..

- Millimeter Wave (30 to 300 GHz) -
  - Much wide channel bandwidth - possibly 1 - 2 GHz
  - For short-range, point-to-point, line-of-sight connections, providing limitless speeds of wireless connectivity.

However this poses new challenges for handset development where maximum frequencies of around 2-3 GHz and bandwidths of 10 - 20 MHz are currently in use.

The path costs are higher for line-of-sight links, and obstructions block the signals much worse than on lower bands, building penetration becomes more difficult.

Rapid channel fluctuations and intermittent connectivity. Shadowing.

Could be used by indoor small cells (in line with the extreme densification principle)
5G Direction of Research ...

Network Densification

- Small cells essentially move the access point much closer to the end user.
- Densification increases the overall system capacity of a mobile network significantly.

5G networks are likely to consist of the several layers of connectivity that Hetnets are currently suggesting:
  - a macro layer for lower data speed connectivity;
  - a very granular layer for very high data speeds; and
  - many layers in between.

Network deployment and coordination are major challenges to be addressed here, as they increase exponentially with respect to the number of network layers.
5G Direction of Research ..

- **Massive MIMO**
  - MIMO allows multiple streams of data in the same place at the same time on the same frequency.
  - A network with Massive MIMO, the base station employs a much higher number of antennas that create localized beams around each connected device.
  - Base stations with multiple, well-separated antennas can use beamforming to act as a highly directional antenna.
  - The gains in capacity are enormous but so are the technical challenges associated with this concept.
5G Direction of Research ...

- **Device-Centered Architectures**
  - Mobile units to connect to a different base station for upstream and downstream data.
  - 5G may support **multihop**, allowing a user inside a building to connect to a base station through someone else’s mobile.
5G Direction of Research ...

- **Device-to-Device (D2D), Machine-to-Machine (M2M) and Local Caching**
  - Provision for transmitting data directly to other devices.
  - Also, who have *intermittent data coverage* know which of our apps are smart enough to cache data when there is no coverage and sync up once connectivity is restored.

- **Future PHY / MAC:**
  - The use of *new modulation formats including GFDM* (Generalised Frequency Division Multiplexing,) as well as *Filter Bank Multi-Carrier, (FBMC), Universal Filtered MultiCarrier (UFMC)*, and other schemes to the management of the multiple access schemes.
  - All these need to be developed.
5G Direction of Research ...

- **Multi-Network Association**
  - Several networks are currently providing connectivity for end-user devices: *cellular*, Wi-Fi, *mmWave*, and device-to-device etc.
  - 5G systems are likely to tightly coordinate the integration of these domains to provide an uninterrupted user experience.

Whether a 5G device will be able to connect to several connectivity domains?
Also, the ability to successfully switch from one to another?
5G Direction of Research ...

- **Virtualization, Software control and Cloud Architectures**

  - A parallel evolutionary trend to 5G is *software and cloud*, where the network is driven by a distributed set of data centers that provide:
    - service agility,
    - centralized control, and
    - software upgrades.

Software Defined Networks (SDN), Network Functions Virtualization (NFV), cloud, and open ecosystems are likely to be the foundations. They are likely to be deployed for 5G – all of these concepts are necessary to provide the increased capacity and connectivity of billions of devices that 5G specifications promise.
More recently the Nakagawa Laboratory, in Keio University, Japan began work in 2003 using LEDs to transmit data by visible light. Many such numerous research activities focussed on VLC.

Capacity Increase & mmWave

Capacity Increase Technique
- Densification (D)
- Bandwidth & Throughput (B)
- Spectrum Efficiency (S)

mmWave Advantage
- Inherent Shorter Range and Beamsteering Mitigate Interference
- mmWave Bands Support Multi-Gbps Rates
- Beamsteering and MU-MIMO Techniques Support PtP and PtMP in Same Frequency Band
Proposed Frequency: Available Frequency Band

- The 60GHz band offers 5 – 9GHz of unlicensed bandwidth across most Geographies.
- 2.16GHz Bandwidth per channel

Limited number of channels
Attenuation in mmWave Frequency

Source: T.S Rappaport ('11)
Ongoing Research Activities

- Channel Characterization for mmWave system and Model Development for Nano Cell architecture to address Crowded Gathering (Kumbh Mela like situation), Highly dense traffic Junction points.
- Also includes, Massive MIMO and Beamforming Techniques.

- Vertical handover and Heterogenous Networks

- Power efficient mmWave Transceiver Design and implementation in 45nm or 20nm CMOS technology to develop prototyping
Research Activities: Channel Model

Fig.: Two dimensional top-down view of urban canyon propagation geometry

Fig.: 2-ray tracing Channel model

Fig.: Study based on 6-ray tracing Channel model
Some results ...

Fig.: Received Signal Strength for Single Input Single Output (SISO) transmission using Six Ray model for 60GHz carrier
Some results ...

Fig.: Signal Variations introduced with spatial diversity
Some results ...

Fig.: Link Budget analyzed for the mmWave spectrum with different antenna directionality
Some results...

Fig.: Variation in the Received Signal Strength for antenna separation of $\lambda/2$
Some results ...

Due to small wavelength, even small spatial variations lead to significant fluctuations in $P_r$.

Fig.: Received signal for different antenna heights and wall distance.
Some Results ..
Some results...
Some results...
Vertical Handover Mechanism for 5G Wireless and Heterogeneous Networks
Vertical Handover ...

- Characterization of various strategies in order to optimize handover performance (throughput, handover delay, etc.)
Tx/Rx Design at 60GHz

- Low power consumption / High Speed Amplifier Design
- Different Rx architecture such as Direct conversion architecture with single carrier modulation
  - Amplitude variation over wide BW (2.16GHz/CH)
Tx/Rx Design @60GHz: Pulse (ASK) based system

(a) Architecture of a low-power 60GHz pulse receiver and (b) receiver block for pulse receiver.

Around 2Gbits of data received per second.
Tx/Rx CMOS Implementation
Conclusion

- mmWave technology has many things to offer towards 5G (next generation cellular) networks.
- However, it is challenging and we need to address these challenges and become leader in 5G.
Thank You
Thank you for your attention!

Questions?

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