# Network Infrastructures

A.A. 2017-18
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# Next Generation 5G Wireless Networks

Slides based on:

M. Agiwal, A. Roy and N. Saxena, "Next Generation 5G Wireless Networks: A Comprehensive Survey," in *IEEE Communications Surveys & Tutorials*, vol. 18, no. 3, pp. 1617-1655, third quarter 2016. doi: 10.1109/COMST.2016.2532458

## Introduction to Next Generation 5G Wireless NEtworks

- Global mobile traffic experienced around 70% growth
- Only 26% smartphones (of the total global mobile devices) are responsible for 88% oftotal mobile data traffic
- Exponential growth in mobile video (multimedia) traffic. Since 2012 video traffic is more than half of the global mobile traffic
- An average mobile user is expected to download around 1 terabyte of data annually by 2020

## Up-coming new applications

- Internet of Things (IoT),
- Internet of vehicles (IoV),
- Device to Device (D2D) communications,
- ehealthcare,
- Machine to Machine (M2M) communications
- Financial Technology (FinTech).

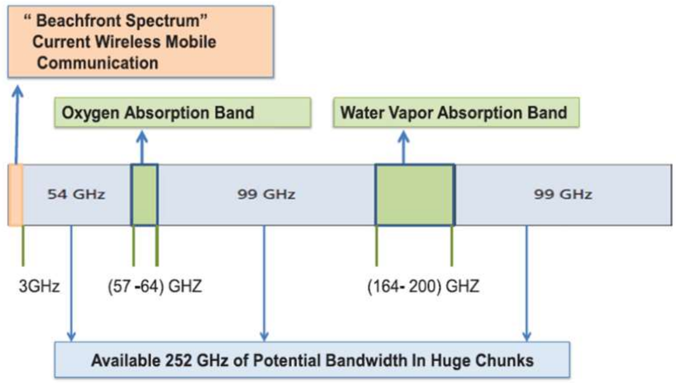
# Motivations

- With a theoretical 150 Mbps maximum downlink data rate, traditional LTE systems, with 2 × 2 MIMO can support only up to *(150/4)* simultaneous full HD (@ 4 Mbps rate) video streaming
- M2M communications and IoT requires supporting of tens of thousands of connected devices in a single cell (not possible in the current LTE)
- It is needed to satisfy the exponential rise in user and traffic capacity in mobile broadband communications

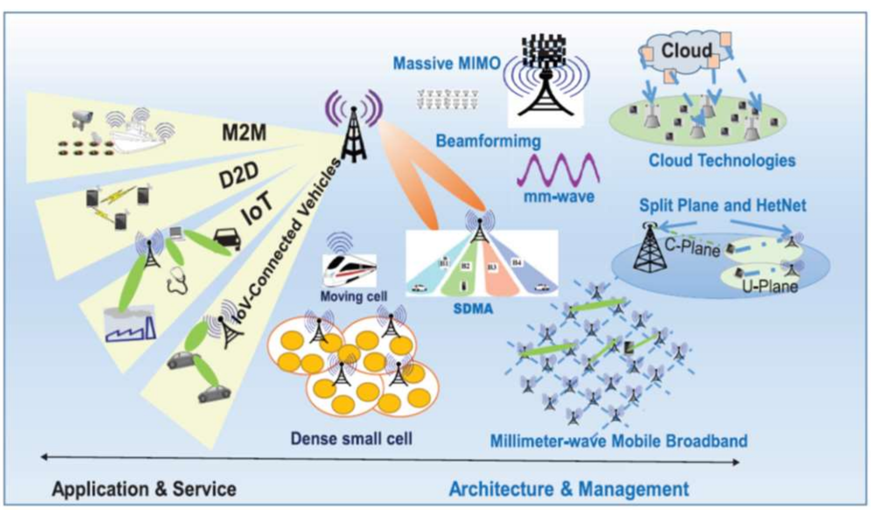
# New Horizons in Radio Spectrum

- Capacity for wireless communication depends on spectral efficiency and bandwidth
- Almost all wireless communications use spectrum in 300 MHz to 3 GHz band
- 5G wireless networks lies in exploring this unused, high mm-wave band, ranging from 3
- Even a small fraction of available mm-wave spectrum can support hundreds of times of more data rate and capacity over the current cellular spectrum~ 300 GHz

# mm-wave band




# Applications and architectures



# Major requirements

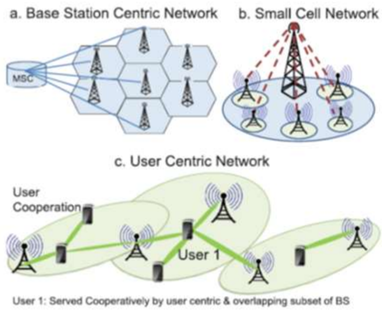
1. 1 ~ 10 *Gbps data rates in real networks*: This is almost 10 times increase from traditional LTE network's theoretical peak data rate of 150 Mbps
2. 1 *ms round trip latency*: Almost 10 times reduction from 4G's 10 ms round trip time
3. *High bandwidth in unit area*: It is needed to enable large number of connected devices with higher bandwidths for longer durations in a specific area
4. *Enormous number of connected devices*: In order to realize the vision of IoT, emerging 5G networks need to provide connectivity to thousands of devices
5. *Perceived availability of* 99.999%: 5G envisions that network should practically be always available.
6. *Almost* 100% *coverage for 'anytime anywhere' connectivity*: 5G wireless networks need to ensure complete coverage irrespective of users' locations
7. *Reduction in energy usage by almost* 90%: Development of green technology is already being considered by standard bodies.
8. *High battery life*: Reduction in power consumption by devices is fundamentally important in emerging 5G networks

# Comparison of generations

COMPARISON OF 1G TO 5G TECHNOLOGIES

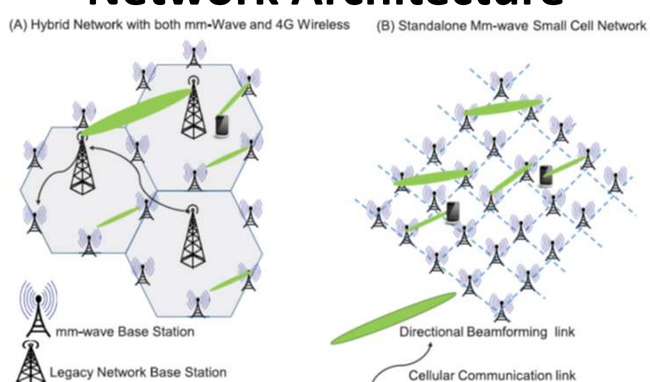
| Technology | 1G | 2G/2.5G | 3G | 4G | 5G |
|---|---|---|---|---|---|
| Deployment | 1970/1984 | 1980/1999 | 1990/2002 | 2000/2010 | 2014/2015 |
| Bandwidth | 2kbps | 14-64kbps | 2mbps | 200mbps | >1gbps |
| Technology | Analog cellular | Digital cellular | Broadbandwidth/ cdma/ip technology | Unified ip & seamless combo of LAN/WAN/WLAN/PAN | 4G+WWWW |
| Service | Mobile telephony | Digital voice,short messaging | Integrated high quality audio, video & data | Dynamic information access, variable devices | Dynamic information access, variable devices with AI capabilities |
| Multiplexing | FDMA | TDMA/CDMA | CDMA | CDMA | CDMA |
| Switching | Circuit | Circuit/circuit for access network&air interface | Packet except for air interface | All packet | All packet |
| Core network | PSTN | PSTN | Packet network | Internet | Internet |
| Handoff | Horizontal | Horizontal | Horizontal | Horizontal&Vertical | Horizontal&Vertical |

# 5G architecture




- **User centric networking**: user is no longer the final resolution of the wireless network but is expected to participate in storage,relaying, content delivery and computation within the network

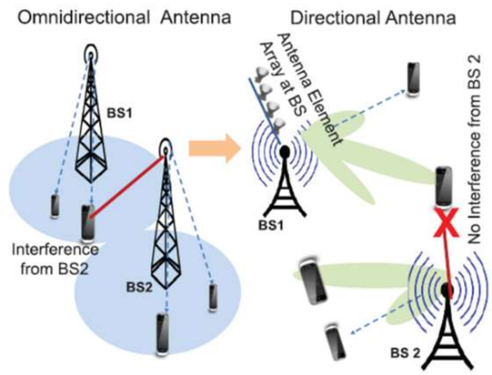
# Standalone and Hybrid mm-wave Network Architecture



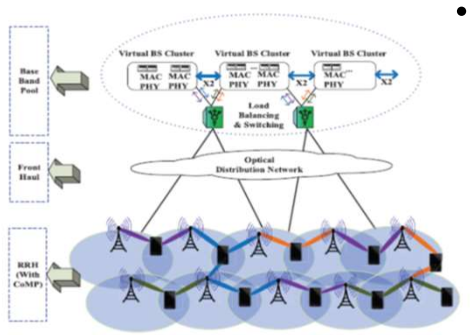

- The propagation and penetration of mm-wave signal in outdoor environment is quite limited→ ultra dense deployment is necessary in areas requiring high data rates
- Small cell sizes (at the order of 100-200 m)

## Conventional antennas vs Smart Beamforming

- Adaptive beamforming techniques, resulting in the introduction of Spatial Division Multiple Access (SDMA) guarantee enhanced performance

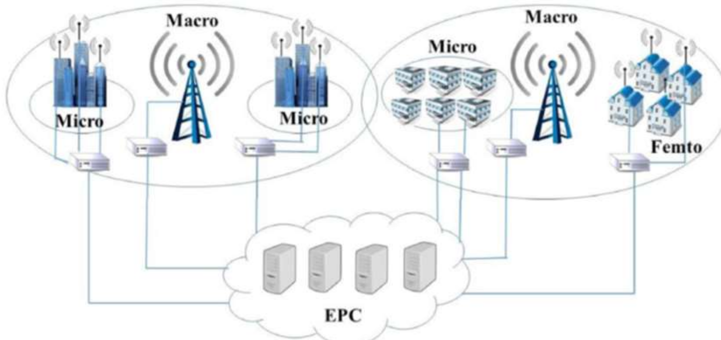



## Cloud Radio Access Network (C-RAN) Architecture




- Cloud computing based radio access shared pool of configurable resources enabling minimal deployment, management and operational efforts

# Heterogeneous Approach—HetNets

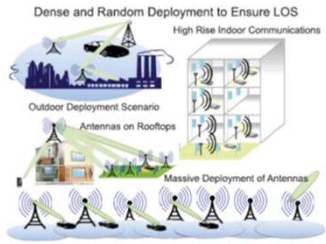



- HetNets are typically composed of small cells, having low transmission power, besides the legacy macrocells
- By deploying low power small BSs, network capacity is improved and the coverage is extended to coverage holes

# Key points 5G Architecture

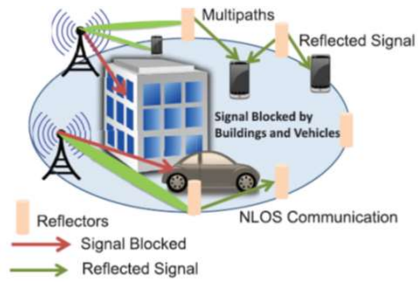
| Work Area | Key Points |
|---|---|
| Radio Network Evolution | • Dense deployment of multiple BS.<br>• Limited mm-wave penetration.<br>• LOS/ NLOS communication.<br>• Standalone mm-wave/hybrid with legacy network. |
| Advanced Air Interface | • Electromagnetic waves controlled by antenna array.<br>• Directional Radiation.<br>• Beamforming hardware challenges.<br>• Beamforming in analog and digital domain. |
| Next Generation Smart Antenna | • Narrow beam and SDMA capabilities.<br>• Circular/planner/segmented subarray.<br>• Application specific antenna type. |
| Splitting of Plane - SDN | • Different data and control plane.<br>• Software design networks and open flow.<br>• SON for RAN optimization.<br>• CoMP |
| Centralized Architecture with C-RAN | • Centralized platform<br>• Baseband unit / Radio receiver head<br>• RAN as a service.<br>• Backhaul and fronthaul. |
| Heterogeneous Approach - HetNets | • Small cells with varying transmission power.<br>• Coordinated operation.<br>• Interference of diverse cells. |

# Physical layer




LOS would require massive antenna deployment without any predefined pattern

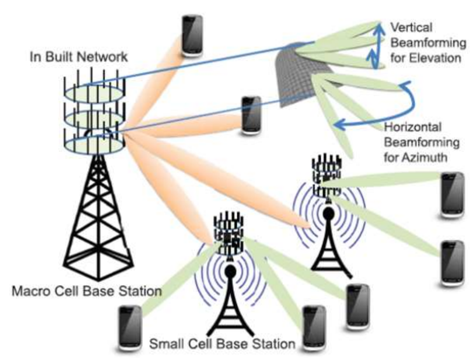
Outdoor mm-wave signals are mostly confined to outdoor. Very little signal penetrate indoor through glass doors, open doors and windows




# Massive MIMO and beanforming

Design of smart antenna is vital for effective mm-wave communications.

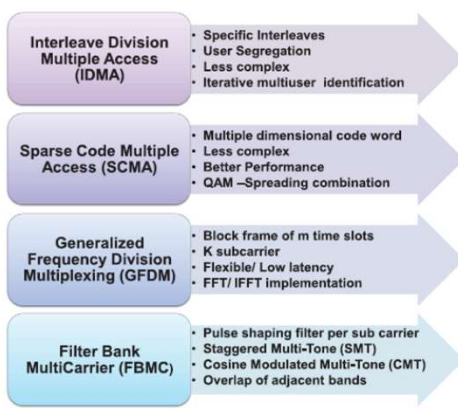
- Directional beams are integral to emerging 5G networks
- Massive MIMO provides BS with a huge number of antennas.
- A massive MIMO enabled BS.
- The grid of antennas is capable of directing horizontal and vertical beams.



# Key points PHY

| Work Area | Key Points |
|---|---|
| Understanding mm-wave Channels | • Propagation loss and penetration<br>• LoS, NLOS<br>• Doppler<br>• Multipath/Power Delay Profile |
| Adaptive Beamforming | • Adaptive beamforming<br>• Angle of arrival<br>• Antenna training |
| Switched Beam | • Sectorized antenna model<br>• Overlapping sectors<br>• Cost effective |
| Massive MIMO Systems | • High number of antennas per BS<br>• Coherent superposition of waveforms<br>• Inexpensive low power components<br>• MIMO / small cell combination |
| Full Duplex Radio Technology | • Offers to double the spectral efficiency<br>• Limited by crosstalk b/w Tx & Rx, pathloss<br>• Limited by Self Interference (SI)<br>• Active & passive SI cancellation<br>• Improves feedback and latency |

# MAC layer



## 5G Applications

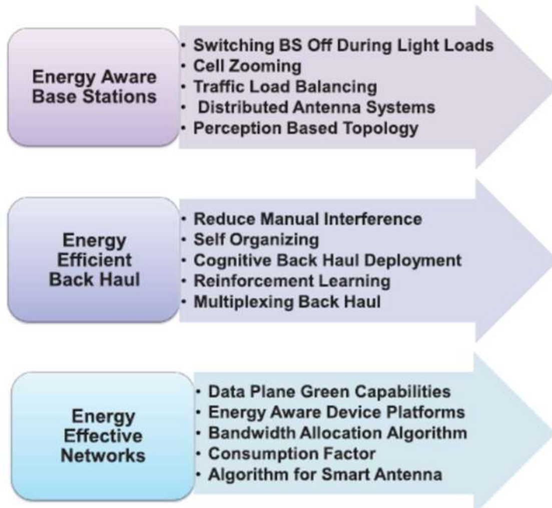
| | |
|---|---|
| D2D COMMUNICATION | • Peer to Peer Data Communication/ Proximity Service/ mobile devices as relays. |
| M2M COMMUNICATION | • Automated Data Generation, Processing, Transfer, Exchange and Actuation between Intelligent Machines. |
| INTERNET OF THINGS | • Internet Connected Smart Objects and Data Interoperability for Numerous Applications / Large Scale Development of IoT Services. |
| INTERNET OF VEHICLES | • Huge Spatio Temporal Data (Big Data)/ Vehicular Cloud/ Low Latency, Safety, Traffic Management and Reduced Collision Probabilities. |
| HIGH DATA RATE on HST | • Reliable High Data Rate on High Speed Trains/ Distributed Antenna Systems (DAS). |
| HEALTH CARE | • Health Monitoring of Individuals/ Remote Patient Real Time Health Monitoring/ Huge Data Processing, Storage And Real Time Communication. |
| FINANCIAL TECH | • Mobile Computing in Banking, Payments, Personal Finance Management, Social Payments, Peer To Peer Transaction and Local Commerce. |
| SMART HOME and SMART CITY | • Smart Homes - Automation, Embedded Systems, Entertainment, Appliances, Efficiency and Security / Sustainability. |
| SMART GRID | • Sensing, Communication and Control, Strengthens Efficiency and Reliability of Power Grids/ Large-scale Cyber-physical Systems. |

## Two key issues

SUSTAINABLE NETWORKS

QUALITY OF EXPERIENCE

# Sustainable networks




# Quality of Experience

| Work Area | Key Points |
|---|---|
| Reinforcing Quality of Service (QoS) | •Guarantee for high QoS/QoE<br>•Colored conflict graphs<br>•Spare resources for QoS improvement<br>•Dynamic bandwidth allocation |
| Refining Quality of Experience (QoE) | •UHD/3D video content<br>•User satisfaction<br>•Interactiveness, product feel, ability to serve purposes<br>•Predictive model of user QoE<br>•SDN/cloud<br>•Topology management |
| Self Organizing Networks | •Self configuration<br>•Self optimization<br>•Self healing<br>•Big Data empowered SON (BSON)<br>•Centralized SON<br>•SON function performance model<br>•Online/offline SON<br>•eDNA/eCells |

# Comparison with Legacy Cellular Networks

| Feature | Legacy Cellular Network | Proposed 5G Network |
|---|---|---|
| Carrier Frequency | Range (700MHz $\sim$ 3 GHz) | Mm-wave spectrum ranging from 3-300GHz |
| Radio Network | BS centric | User centric and site specific |
| Density/Diversity | Limited | Enormous |
| BS Density | High density deployment | Ultra high deployment micro/pico/femto cells |
| Site Specific | Not necessarily | Key enabling feature |
| Air Interface | Omnidirectional | Highly directional |
| Antenna Size | Large | Small antennas |
| Antenna Array | Not applicable | Array of small antennas - planner/circular/segmented |
| Beamforming | Not essential | Key enabling technology |
| Antenna Training | Not applicable | TX-RX beams should point towards each other |
| Channel Model | Available | Under study |
| Penetration | No complications | mm-wave don't penetrate common materials/ humans |
| LOS Communication | Not essential | Key enabling technology |
| Multipath | No complications | Assist in NLOS communication |
| MIMO | Limited MIMO capabilities | Massive MIMO |
| Control and user plane | Single entity | Split plane (SDN) |
| Cloud RAN | Improves performance | Simplifies BS for ultra dense deployment |
| Multiple Access | TDMA/FDMA/CDMA/OFDM | SDMA/SCMA/IDMA/GFDM/FBMC/UFMC |
| MAC Directivity | Not applicable | DMAC/ Multihop MAC/ DNAV/ Directive RTS/CTS |
| Random Access | Synchronized | synchronous and asynchronous signalling |
| STR | Not feasible | Proposed |
| Data Rate | Mbps | Gbps |

# Conclusions

- 5G technological revolution is expected to have a profound impact on the future wireless communications.
- Comparing to the existing 3G/4G cellular systems, next generation 5G wireless have significant different features There are a wide variety of opportunities for future research works in wireless cellular systems.
- A plethora of new applications, like IoT, smart grids and IoV are expected to be
supported under the umbrella of 5G systems.