Network Infrastructures

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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).

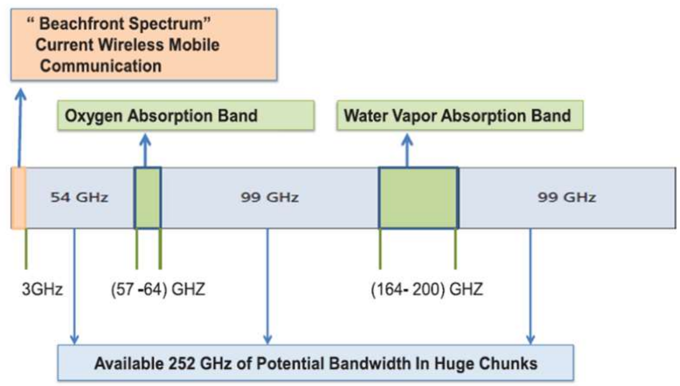
Motivations

- 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

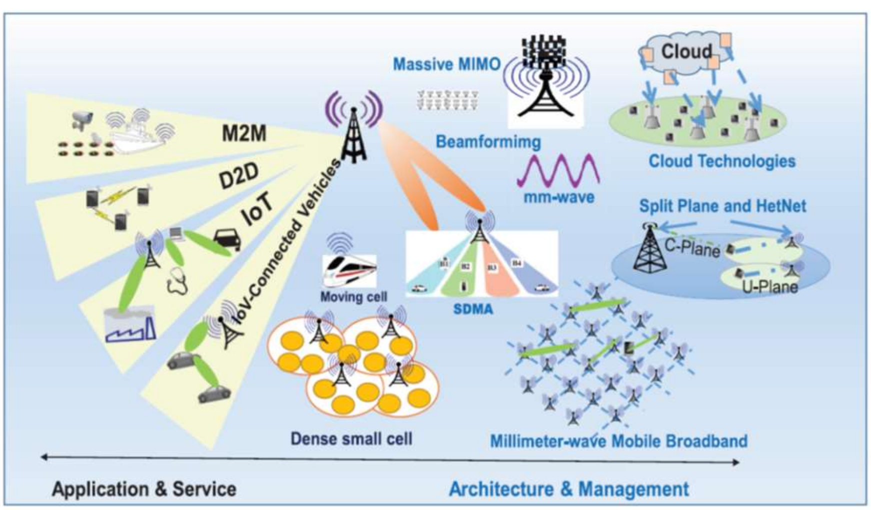
New Horizons in Radio Spectrum

- 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

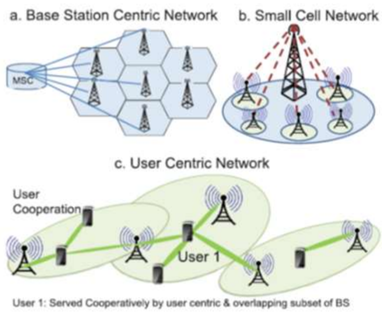
1. 1 ~ 10 *Gbps data rates in real networks*: This is almost 10 times increase from traditional LTE network's theoretical peak data rate of 150 Mbps
2. 1 *ms round trip latency*: Almost 10 times reduction from 4G's 10 ms round trip time
3. *High bandwidth in unit area*: It is needed to enable large number 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

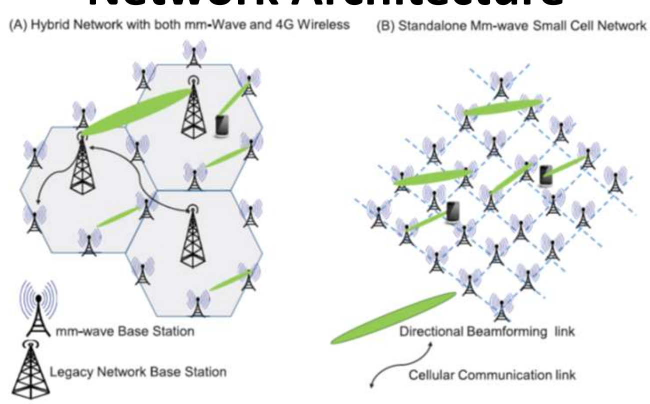
Technology	1G	2G/2.5G	3G	4G	5G
Deployment	1970/1984	1980/1999	1990/2002	2000/2010	2014/2015
Bandwidth	2kbps	14-64kbps	2mbps	200mbps	>1gbps
Technology	Analog cellular	Digital cellular	Broadbandwidth/ cdma/ip technology	Unified ip & seamless combo of LAN/WAN/WLAN/PAN	4G+WWWW
Service	Mobile telephony	Digital 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

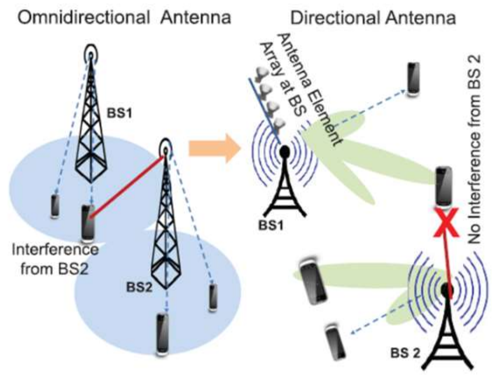
Standalone and Hybrid mm-wave Network Architecture



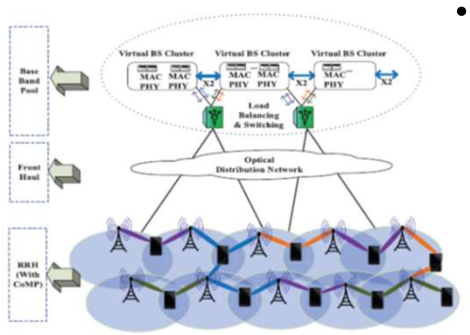
- The propagation and penetration of mm-wave signal in outdoor environment is quite limited→ ultra dense deployment is necessary in areas requiring high data rates
- Small cell sizes (at the order of 100-200 m)

Conventional antennas vs Smart Beamforming

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

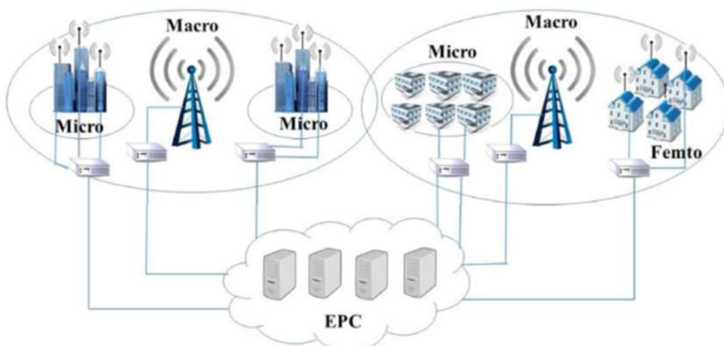


Cloud Radio Access Network (C-RAN) Architecture



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

Heterogeneous Approach—HetNets

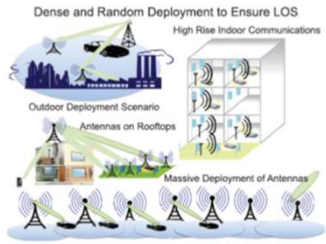


- HetNets are typically composed of small cells, having low transmission power, besides the legacy macrocells
- By deploying low power small BSs, network capacity is improved and the coverage is extended to coverage holes

Key points 5G Architecture

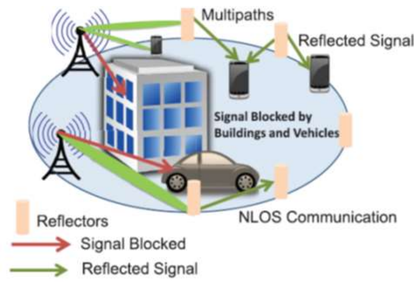
Work Area	Key Points
Radio Network Evolution	• Dense deployment of multiple BS. • Limited mm-wave penetration. • LOS/ NLOS communication. • Standalone mm-wave/hybrid with legacy network.
Advanced Air Interface	• Electromagnetic waves controlled by antenna array. • Directional Radiation. • Beamforming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

Physical layer



LOS would require massive antenna deployment without any predefined pattern

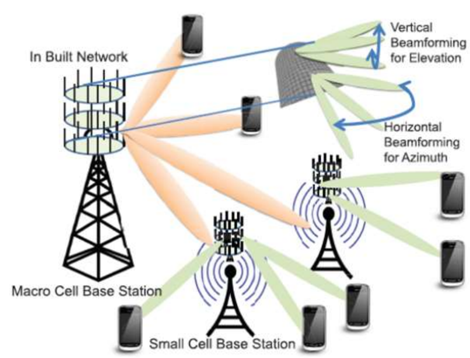
Outdoor mm-wave signals are mostly confined to outdoor. Very little signal penetrate indoor through glass doors, open doors and windows



Massive MIMO and beanforming

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

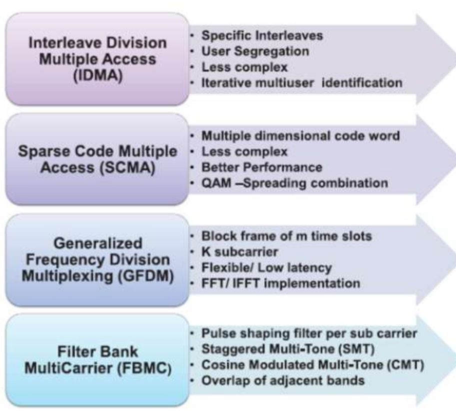
- Directional beams are integral to emerging 5G networks
- Massive MIMO provides BS with a huge number of antennas.
- A massive MIMO enabled BS.
- The grid of antennas is capable of directing horizontal and vertical beams.



Key points PHY

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

MAC layer



5G Applications

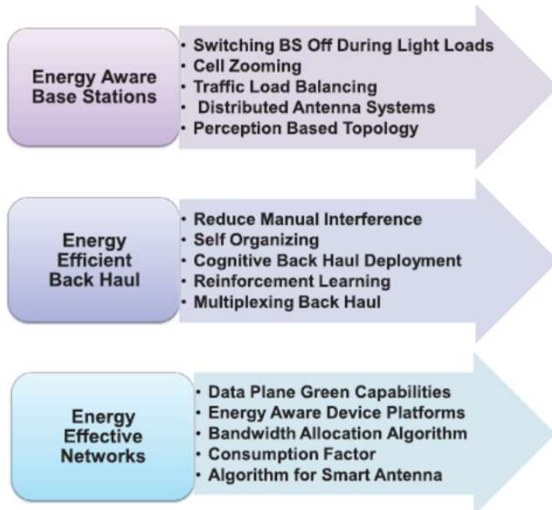
D2D COMMUNICATION	Peer to Peer Data Communication/ Proximity Service/ mobile devices as relays.
M2M COMMUNICATION	Automated Data Generation, Processing, Transfer, Exchange and Actuation between Intelligent Machines.
INTERNET OF THINGS	Internet Connected Smart Objects and Data Interoperability for Numerous 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 •Colored conflict graphs •Spare resources for QoS improvement •Dynamic bandwidth allocation
Refining Quality of Experience (QoE)	•UHD/3D video content •User satisfaction •Interactiveness, product feel, ability to serve purposes •Predictive model of user QoE •SDN/cloud •Topology management
Self Organizing Networks	•Self configuration •Self optimization •Self healing •Big Data empowered SON (BSON) •Centralized SON •SON function performance model •Online/offline SON •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.