5G Technologies for the next generation Networks

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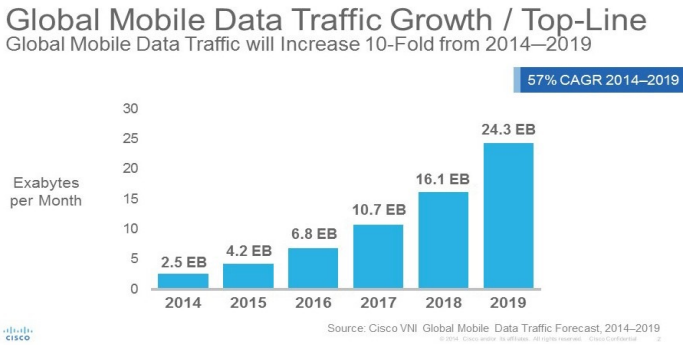
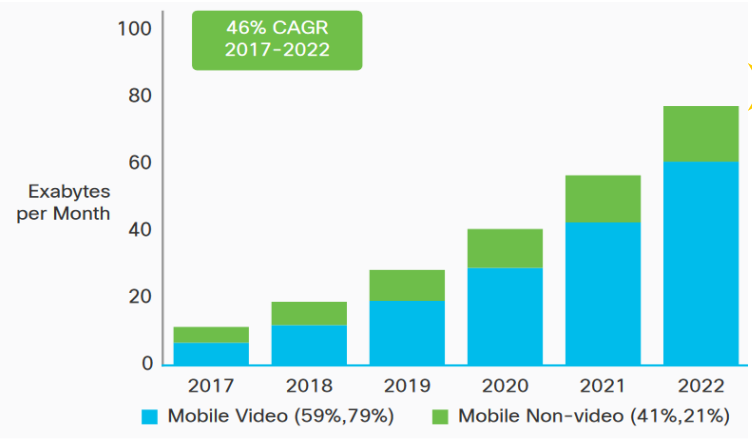
Introduction – 1/20



- Global mobile traffic experienced around 70% growth.



- Increasing smartphone usage is resulting in an exponential growth in mobile video (multimedia) traffic.

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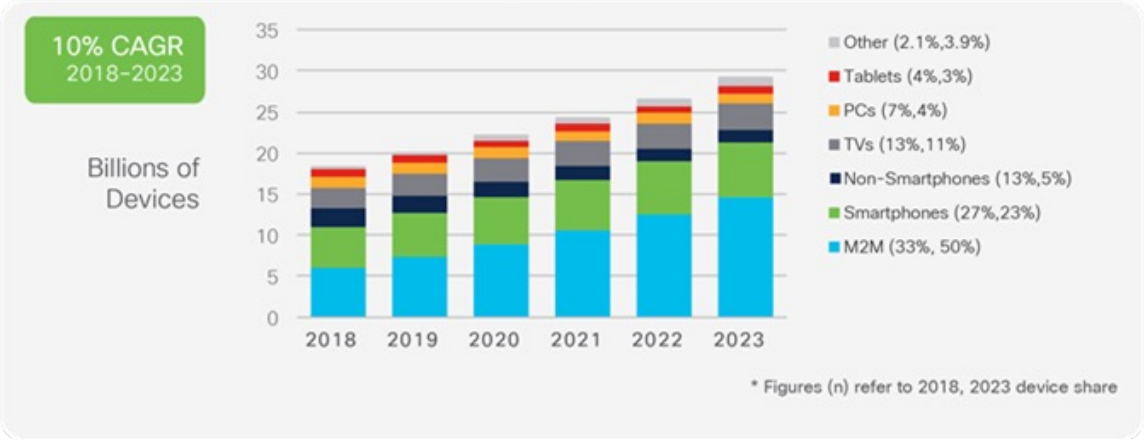


- Novel ICT solutions such as the Internet of Things, the Internet of Vehicles, Device to Device (D2D) and Machine to Machine (M2M) communications, or the eHealthcare are causing a dramatic increase of the device connectivity and traffic rate in the network.

Introduction – 3/20

- Supporting this enormous and rapid increase in data usage and connectivity is an extremely daunting task in present 4G LTE cellular systems.
- LTE cellular network is exploring avenues of different research and development. However, it is unlikely to sustain this ongoing traffic explosion.
- Capacity depends on spectral efficiency and bandwidth, and this is also related to cell size.
- Information rate depends on the bandwidth of the transmission medium and the quality of the transmitted signal, i.e., signal-to-noise power ratio.

Introduction – 4/20

- The Shannon-Hartley theorem sets an upper bound for the channel capacity, C as:

$$C = B \cdot log_2(1 + \frac{S}{N})$$

- where B is channel bandwidth and S/N is the signal-to-noise ratio. By using the analogy of wireless channels with highways, the bandwidth would correspond to the width of the road.
- Increasing channel capacity by increasing bandwidth is equivalent to making the road wider by increasing number of lanes.

Introduction – 5/20

- It is not that simple to build wider roads with more lanes, just as it is not that simple to increase the bandwidth since the wireless spectrum is a scarce and often expensive resource.

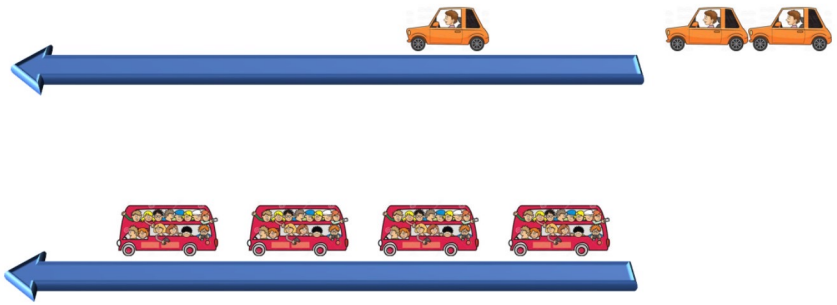
- Since the mobile network operators do not have unlimited frequency spectrum they are concerned about how well the spectrum assets are utilized. This is often measured as spectral efficiency, the channels ability to carry information given fixed bandwidth.

Introduction – 6/20

"the information rate that can be transmitted over a given bandwidth in a specific communication system. It is a measure of how efficiently a limited frequency spectrum is utilized by the physical layer protocol."
From the Shannon formula for channel capacity, spectral efficiency can be numerically stated as C/B. The value is expressed in bits per second per hertz (bps/Hz).

about how well the spectrum is utilized.
This is often measured as spectral efficiency, the channels ability to carry information given fixed bandwidth.

Introduction – 7/20



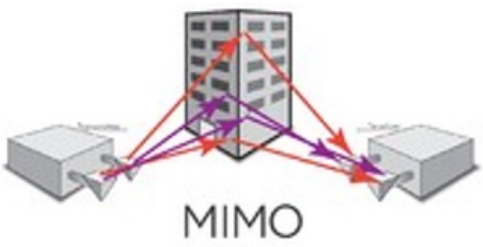
- If we want to enhance the capacity of the high-way without more lanes, we can let the commuters use buses instead of private cars.
- The highway carries more traffic in terms of the number of commuters, and the efficiency is higher.
- Similarly, spectral efficiency of a communication system can be enhanced by packing more information, bits, in a single transmission.

Introduction – 8/20

- This, however cannot be done unless the quality of the channel is sufficient, just as a bus cannot access a road that is not well paved.
- The last term of the Shannon-Hartley theorem is the signal-to-noise ratio or simply signal quality. Improving signal-to-noise ratio will improve the channel capacity and spectral efficiency.
- In an ideal world, the cell towers could be placed uniformly giving high quality signals throughout the surrounding coverage area.

Introduction – 9/20

- In practice mobile operators are limited to certain tower locations and they try to improve the signal quality by extensive tuning and optimization work.
- The lack of freedom in choosing site locations and building new cell sites also limits the operators' ability to increase capacity in dense areas.
  - Multiple-input and multiple-output, is a method for multiplying the capacity of a radio link using multiple transmission and receiving antennas to exploit multipath propagation.



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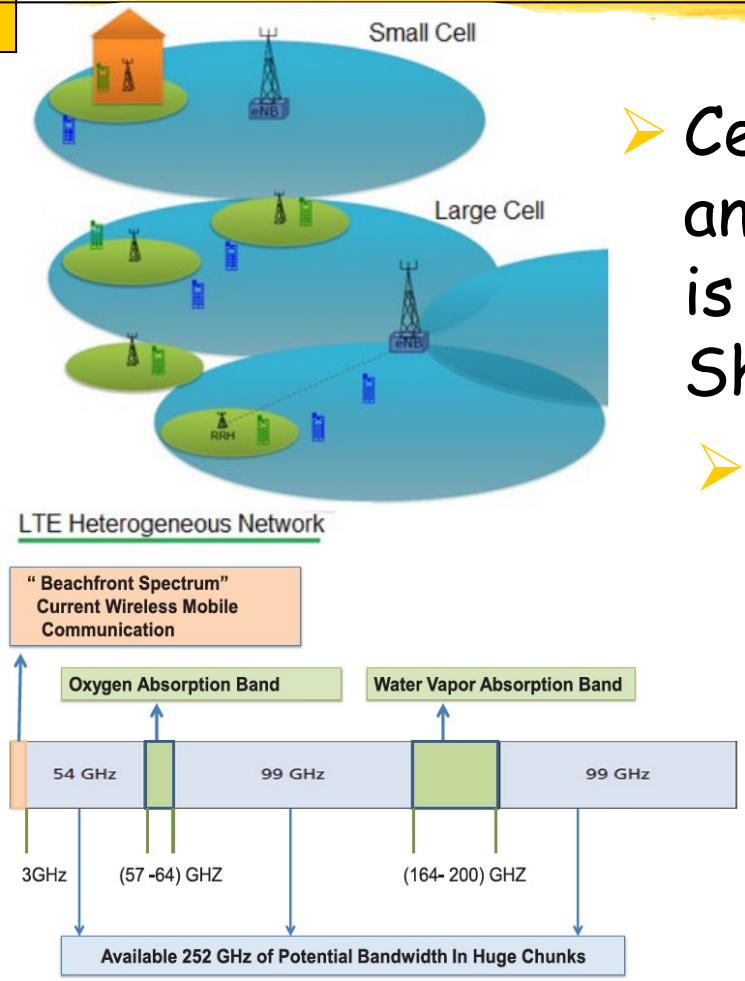


- Cell sizes are becoming small and physical layer technology is already at the boundary of Shannon capacity.
  - Almost all wireless communications use spectrum in 300 MHz to 3 GHz band.

  This band has benefits from its reliable propagation characteristics over several kilometers in different radio environments.

Introduction – 11/20

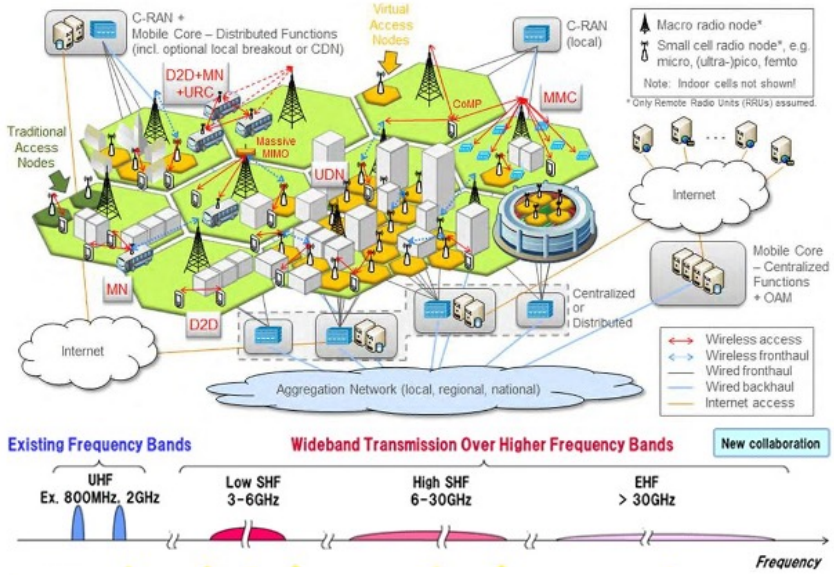
- With 5G still in its early stages of implementation and not yet available in every country, you might be hearing about the 5G bandwidth spectrum, 5G spectrum auctions, mmW 5G, etc.

Higher Frequency	Lower Frequency
• Faster speeds	• Slower speeds
• Shorter distances	• Longer distances

- The millimeter waves, which are in the high-band spectrum, have the advantage of being able to carry lots of data.

Introduction – 12/20

- Mm-wave are absorbed more easily and are useful in densely packed networks, but not so helpful for carrying data long distances (due to the attenuation).



- In 5G spectrum, different parts of the spectrum can be used to maximize distance, minimize problems, and get as much throughput as possible.

Introduction – 13/20

- A frequency of 600 MHz, for example, has lower bandwidth, but because it's not affected as easily by things like moisture in the air, it doesn't lose power as quickly and is able to reach 5G phones and other 5G devices further away, as well as better penetrate walls to provide indoor reception.
- A service provider might use higher 5G frequencies in areas that demand more data. However, low-band frequencies are useful for providing 5G access to more devices from a single tower and in areas without direct line-of-sight to a 5G cell.

Introduction – 14/20

- The 5G paradigm implies also a shift from static network design and management, to a dynamic model: adaptive strategies which tune the network configuration to local transmissive conditions, and to spatio-temporal patterns of traffic demand.
- A central role is played by SDN, NFV, Network Slicing, and Cloud RAN.
- Network softwarization is made possible by SDN making the network programmable, and NFV replacing equipment with software running on commodity hardware.

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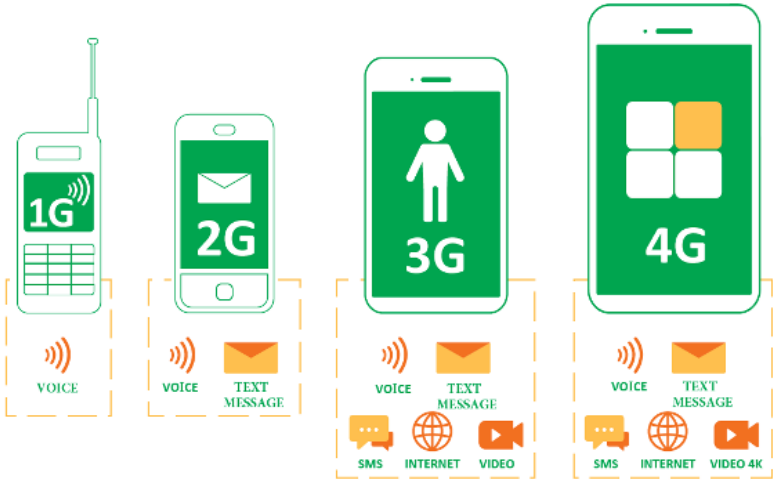
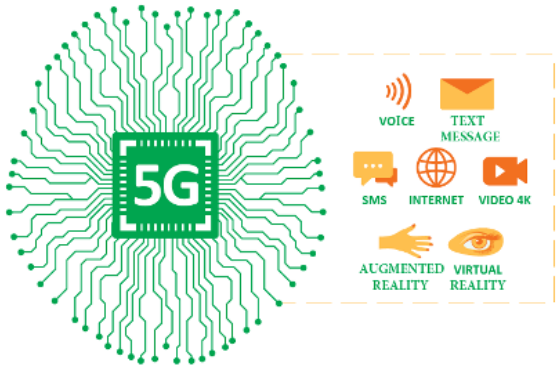
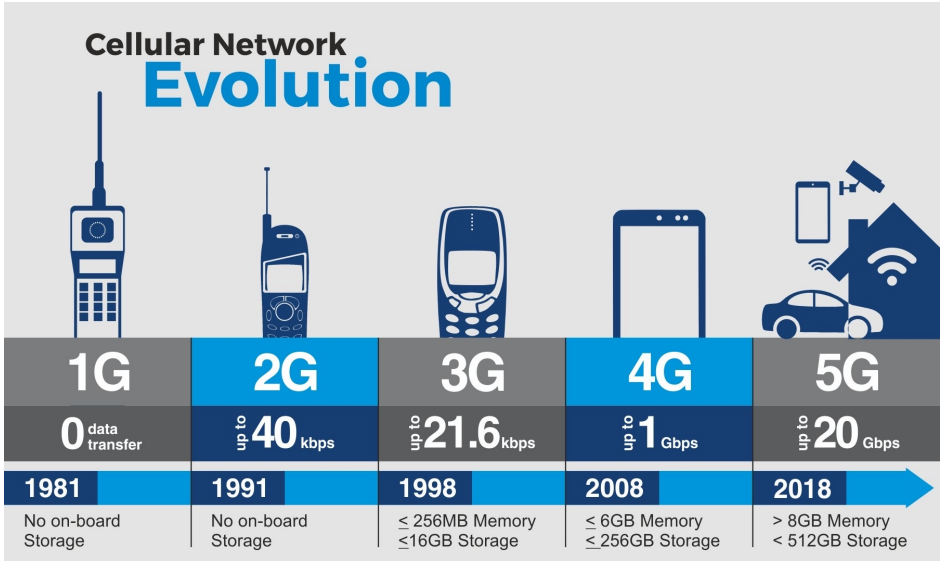




- The 5G is the evolution of cellular systems to cope with increasing traffic and QoS demands.



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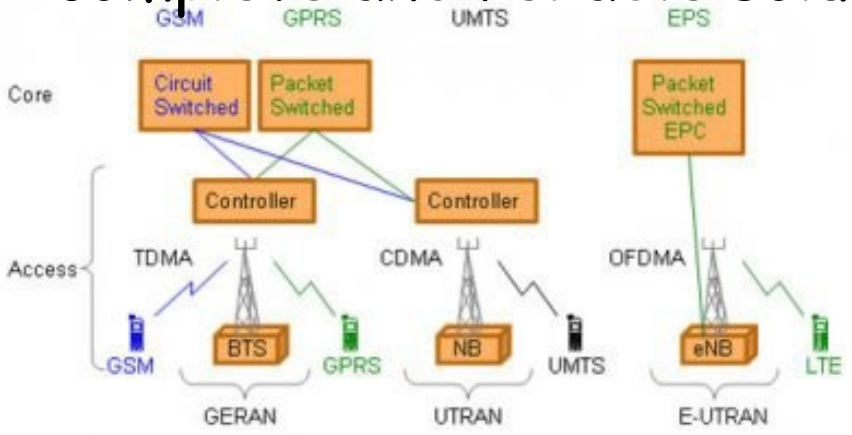
- The 1G was announced in initial 1980's, using analog signals and a data rate up to 2.4kbps. It has a lot of disadvantages like below par capacity, reckless handoff, inferior voice associations, and with no security, since voice calls were stored and played in radio towers due to which vulnerability of these calls from unwanted eavesdropping by third party increases.
- The 2G was introduced in late 1990's, with digital signals and Global Systems for Mobile communications (GSM) offering a data rate up to 64kbps.

Introduction – 17/20

- 2.5G generally subscribes a 2nd generation cellular system merged with General Packet Radio Services (GPRS), a packet oriented mobile data standard, and can assist data rate up to 144kbps.
- The 3G was established in late 2000, with a transmission rate up to 2Mbps, merging high speed mobile access to services based on Internet Protocol (IP). 3G handsets require more power than most 2G models, and 3G network plans are more expensive than 2G.

Introduction – 18/20

- 4G is generally referred as the descendant of the 3G and 2G standards. 3rd Generation Partnership Project (3GPP) is presently standardizing Long Term Evolution (LTE). A 4G system improves the prevailing communication networks by imparting a complete and reliable solution based on IP.



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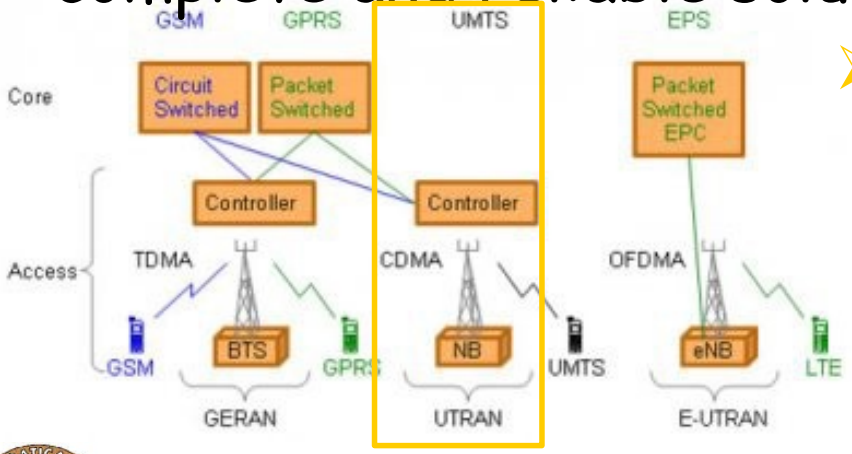

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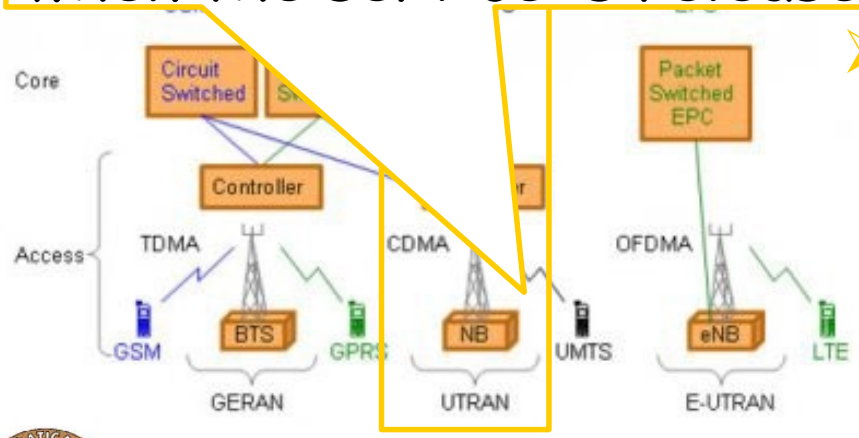
In UMTS the IP address is allocated to the UE when a datacom service is established and released when the service is released.



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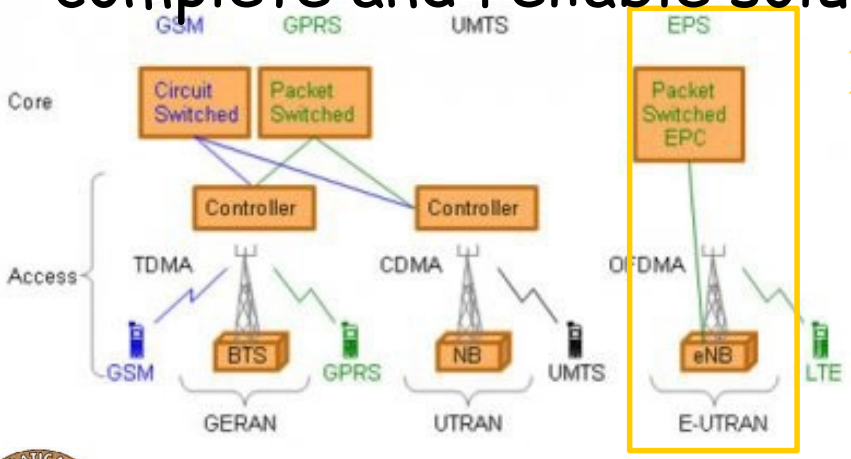
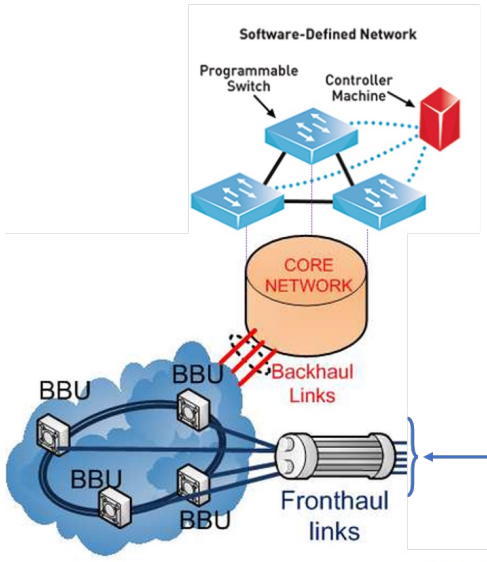
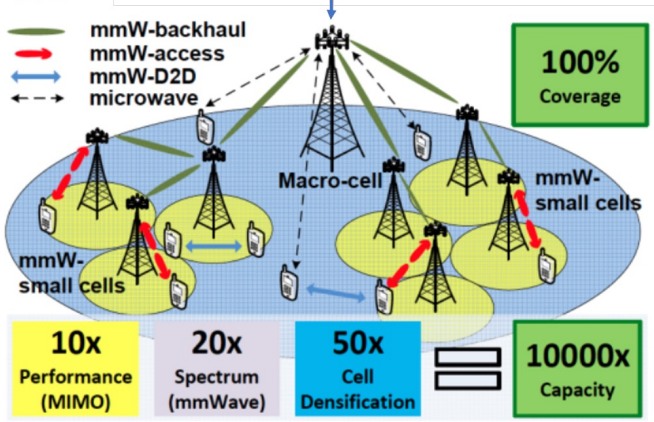


- The Evolved Packet System (EPS) is purely IP. The IP address is allocated when the mobile is switched on and released when switched off.

Introduction – 19/20



- The 5G vision encompasses novel solutions based on the network softwarization and mm-wave communications aiming at providing ultra-fast, efficient, secure and reliable communications means.



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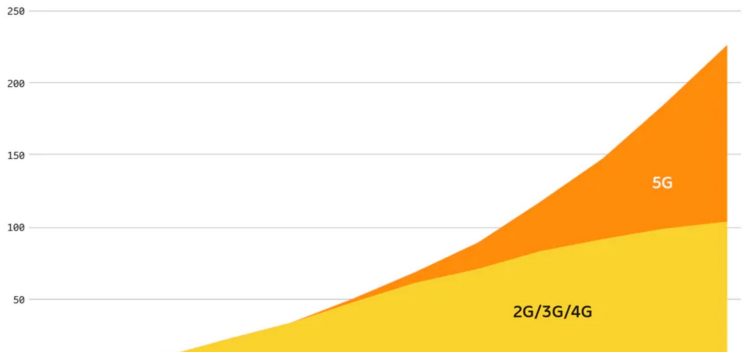

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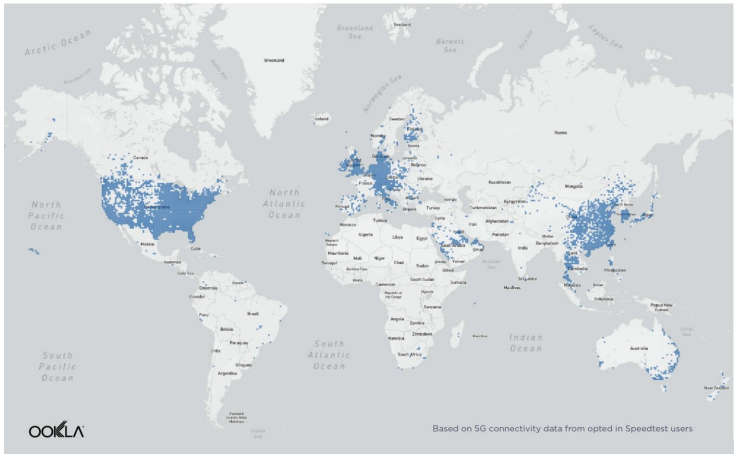
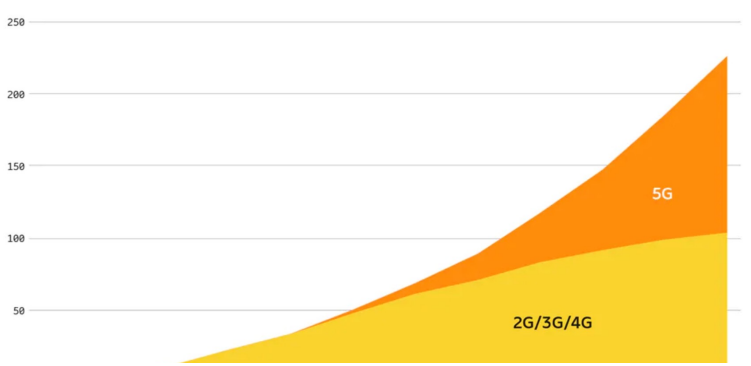
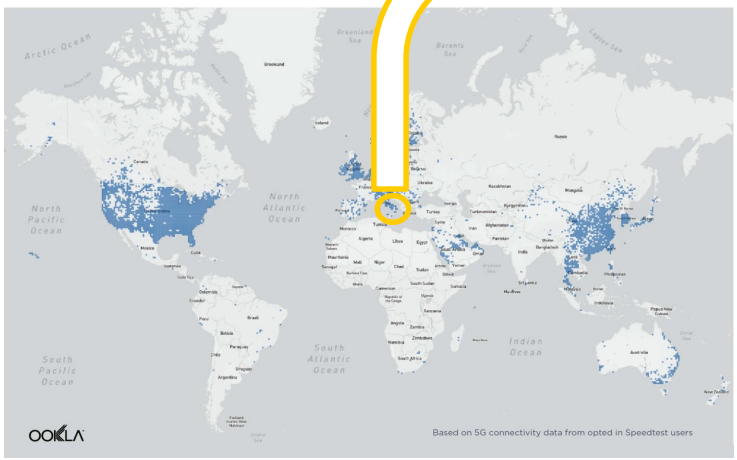
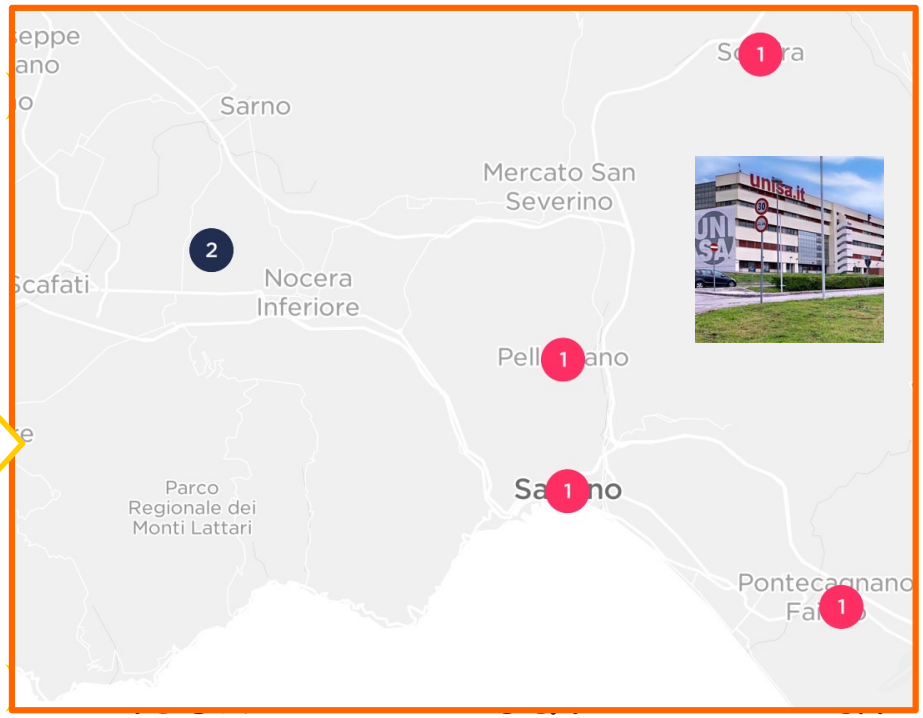


- The 5G is nowadays more than a vision as many concrete deployments are available and 5G services are started to be commercialised.
- Check out at https://www.speedtest.net/ookla-5g-map.

Introduction – 20/20







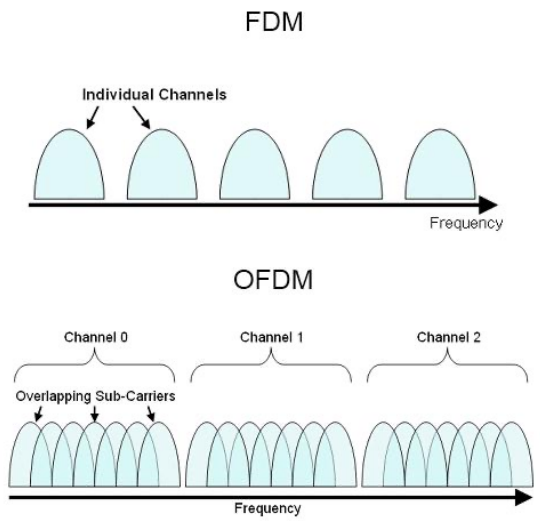
https://www.speedtest.net/ookla-5g-map.

Key Improvements – 1/15

- The main improvements envisioned by the 5G technologies are the following ones:
  - New Radio Multiplexing Technologies;
  - New Efficient Spectrum Usage Techniques;
  - New Energy Saving Mechanisms;
  - CapEx/OpEx Reduction Techniques;
  - New Spectrum;
  - Application Specific Improvements.

Key Improvements – 2/15

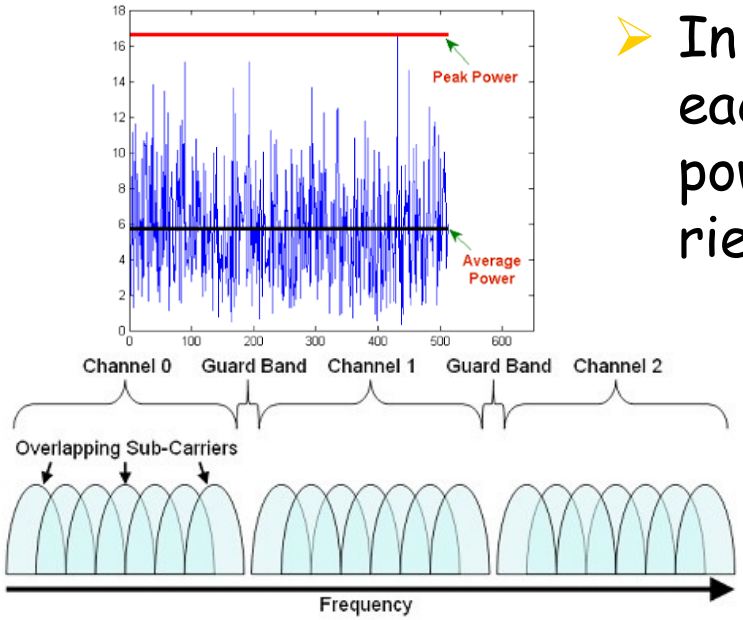
- The Orthogonal Frequency Division Multiplexing (OFDM) divides a serial stream of data in parallel and then modulates it by orthogonal sub-carriers with partial overlapping frequency bands.



- The main advantage of using OFDM system is to increase the robustness against frequency selective fading or narrowband interference. Other advantages are high data transmission rate, high bandwidth efficiency, robustness against multi-path fading and less complex equalizer.

Key Improvements – 3/15

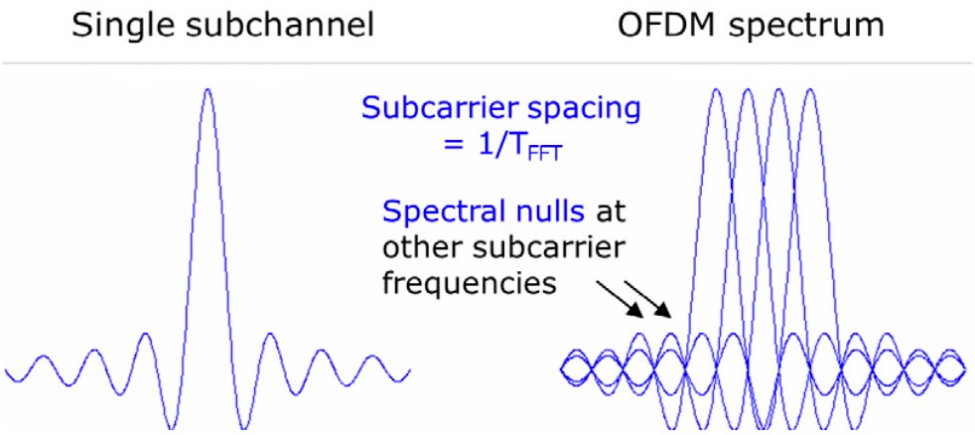
- The OFDM systems have two major concerns i.e. high Peak-to-Average-Power Ratio (PAPR) of transmitted signal (i.e., the ratio of peak power to the average power of a signal) and synchronization (timing and frequency) at the receiver.

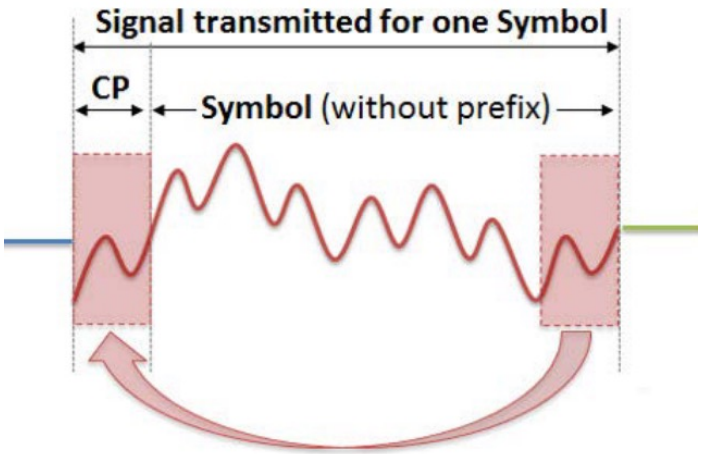


- In order to guarantee orthogonality, each subcarrier should have a zero power at the neighbouring subcarriers.
  - This results in a power ripple and there is a significant spectrum overflow beyond the spectrum used by the subcarriers.

Key Improvements – 4/15

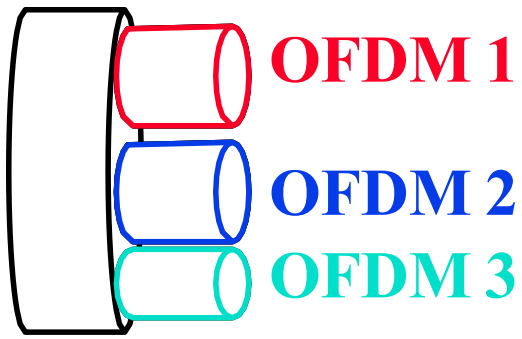
- The other problems are that the entire band should use the same subcarrier spacing, and the entire time should use the same symbol size and cyclic prefix (the last μ samples of a block are inserted as guard samples at the beginning of the block and used to estimated the channel quality).

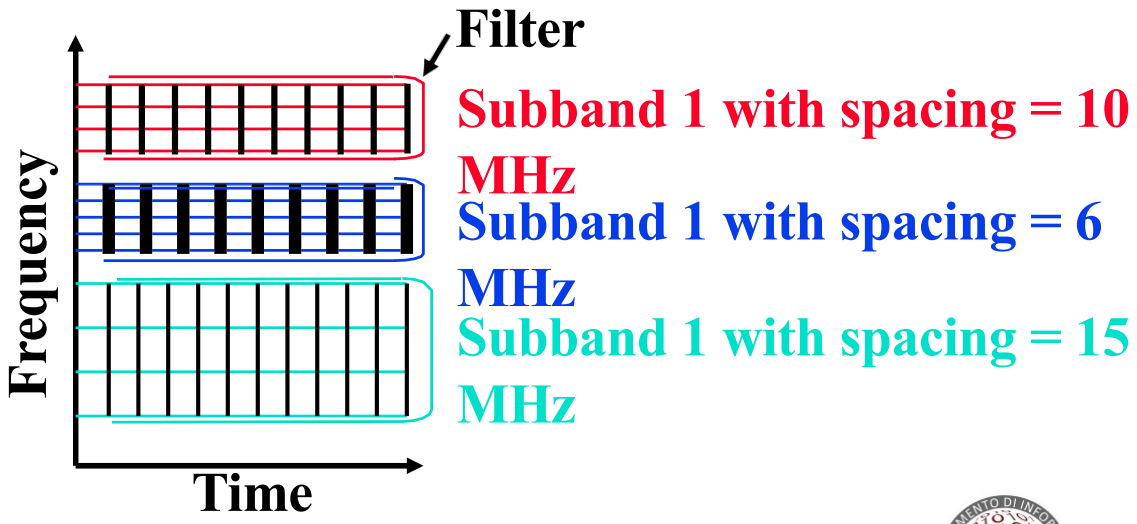




Key Improvements – 5/15

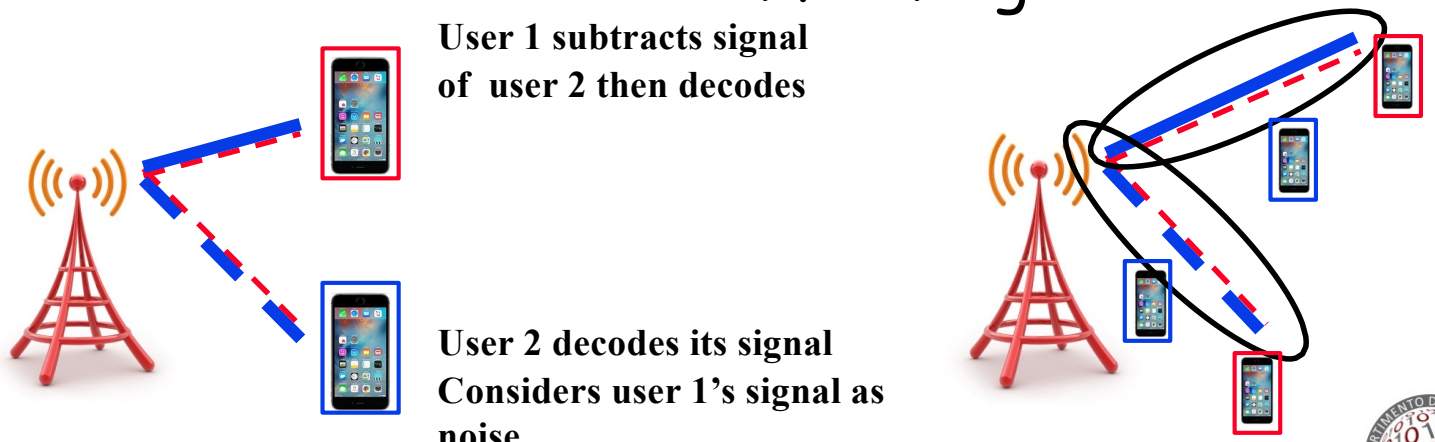
- Spectrum Filtered OFDM (f-OFDM): Band divided into multiple subbands, each using different OFDM parameters optimized for the application and being filtered to avoid inter-subband interference.
- Different users (subbands) do not need to be time synchronized.





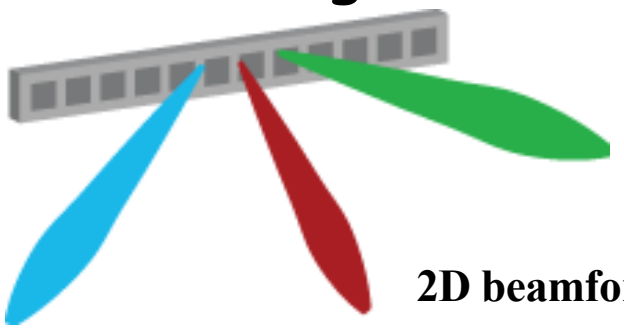
Key Improvements – 6/15

- Non-Orthogonal Multiple Access (NOMA): Users are distinguished by power levels: users with poor channel condition get higher power and decode their signal treating others as noise, and users with lower power subtract the higher powered signals before decoding.
- It can also be used with beamforming and MIMO.

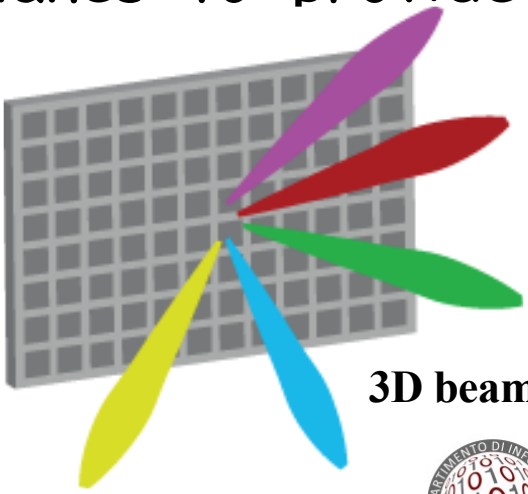


Key Improvements – 7/15

- Several efficient spectrum usage techniques are applied in 5G. Most beamforming schemes control the beam pattern radiation in the horizontal plane.
- In contrast to such two-dimensional beamforming (2DBF), 3DBF adapts the radiation beam pattern in both elevation and azimuth planes to provide more degrees of freedom.



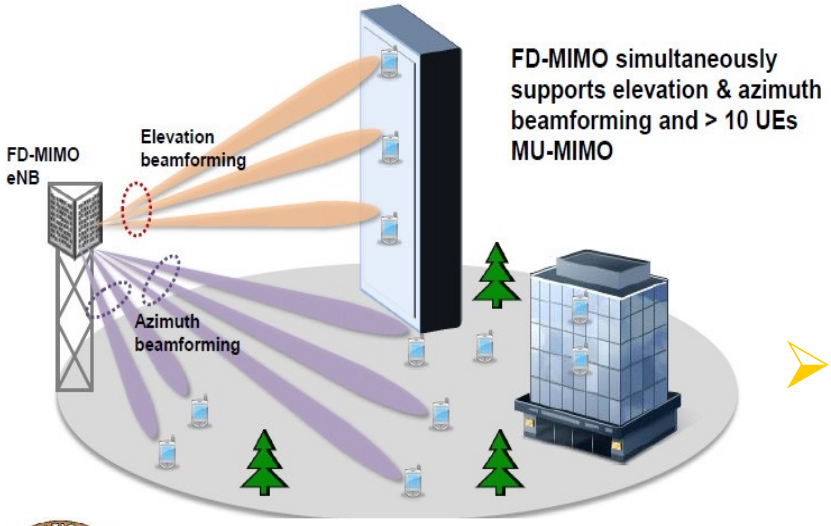
2D beamforming



3D beamforming

Key Improvements – 8/15

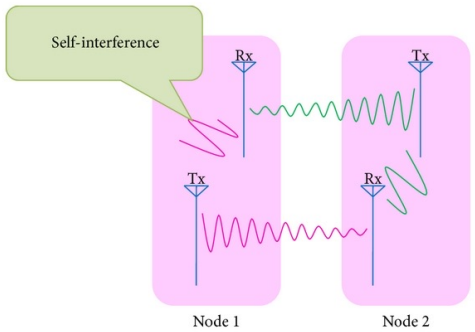
- By utilizing information on angle of arrival (AoA) of users and estimating direction of arrival (DoA) of each users' signal, base station is capable of distinguishing different users using proper beamforming and also steering the array's beam to a desired direction which optimizes some preferred performance metric of the network.



- 3D beamforming can be performed with few antennas.

Key Improvements – 9/15

- Simultaneous transmission and reception doubles the throughput, reduces end-to-end latency, allows transmitters to monitor the channel.
  - It is difficult to realize because transmitted signals may be too strong and interfere with reception.



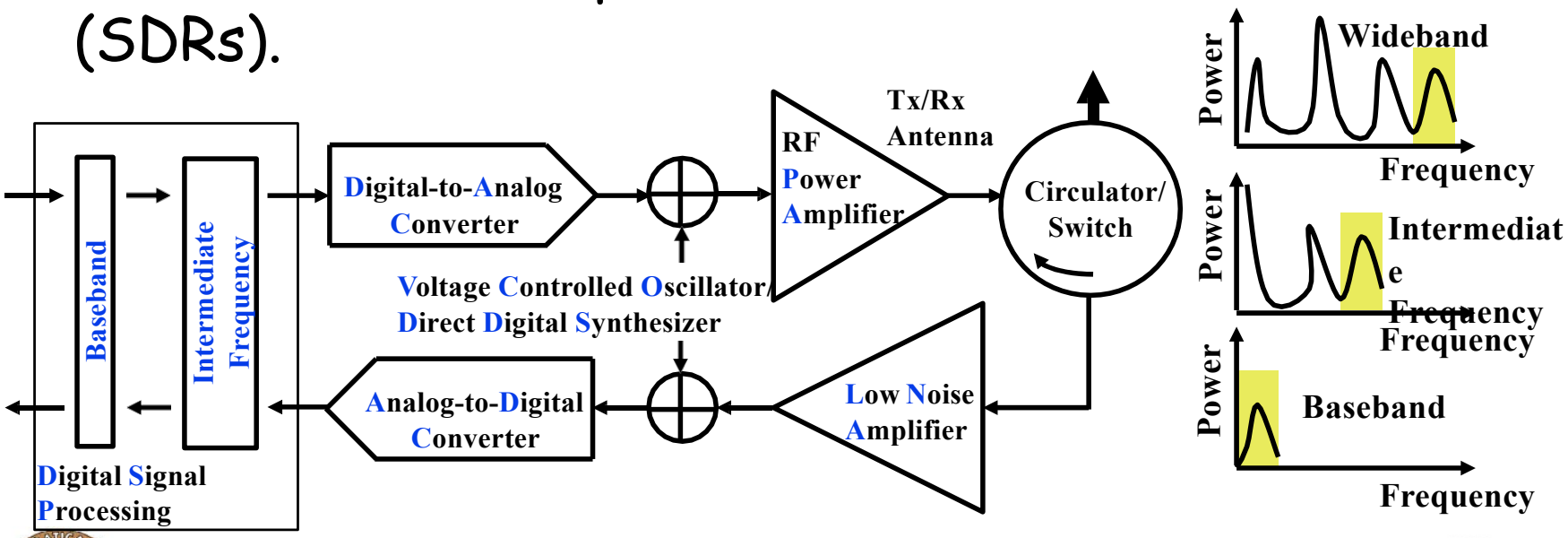
- A frequency division duplexing (FDD) transmits and receives at the same time by using two channels in the same frequency.

Key Improvements – 10/15

- A time division duplexing (TDD) operates half-duplex on a single channel, creating the illusion of full-duplex by rapidly switching back-and-forth between transmit and receive.
- In-band full-duplex is done by the Self-Interference cancellation (SIC) to double the spectrum efficiency. The transmit signal can be cancelled out at the receiver by creating an accurate model of the signal and using it to generate a new signal that when combined with the signal arriving at the receiver leaves only the desired receive signal.

Key Improvements – 11/15

- Multimode Base Stations: supporting 2G/3G/4G/WiFi/WiMAX, multi-band, multi-frequency, multiple modulation formats, multiple air interfaces requires Software Define Radios (SDRs).

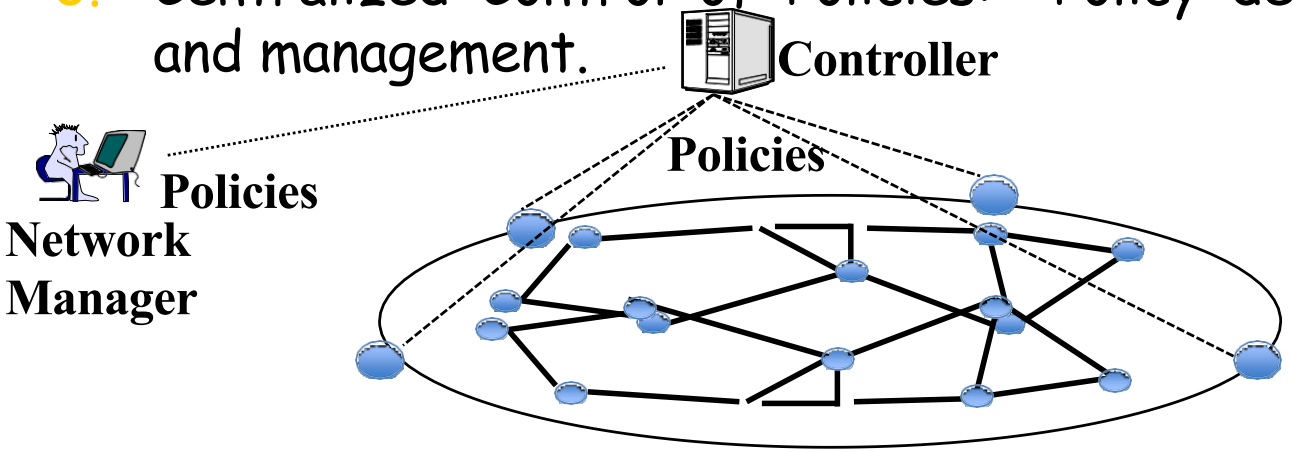


Key Improvements – 12/15

- New Energy Saving Mechanisms:
  - Discontinuous Transmission (DTX): do not transmit during silence so that resources can be reused by others. It was difficult to do in static allocation like GSM, but it is already part of LTE.
  - Antenna Muting: turn off some antenna at low load so as to have energy savings.
  - Cell on/off switching: under low load a cell or small cell can be turned off. Off cells broadcast Discovery reference signals (DRS) periodically so that they can be turned on if necessary.
  - Power Save Mode for IoT.

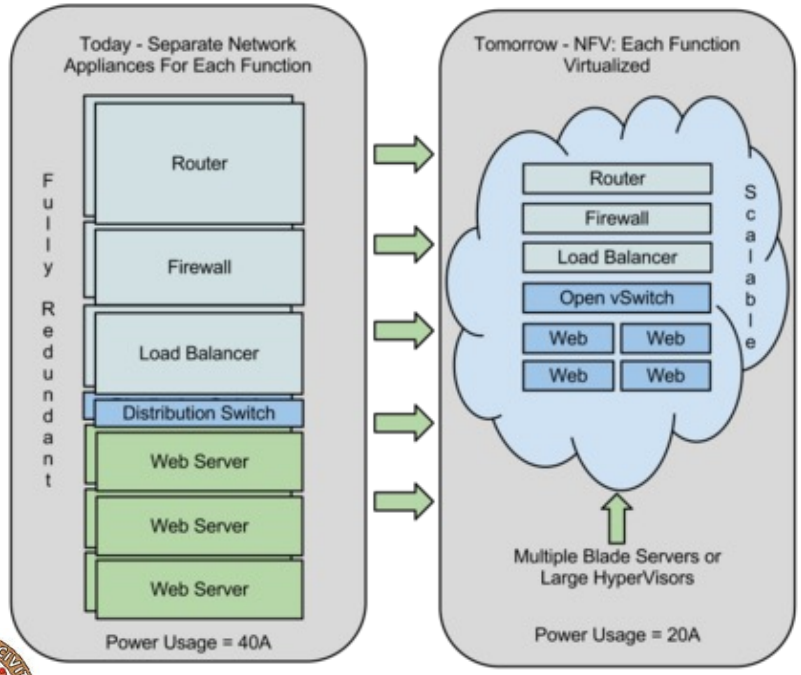
Key Improvements – 13/15

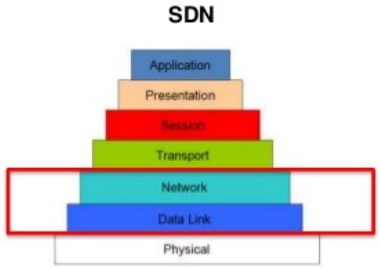
- CapEx/OpEx Reduction Techniques:
  - Software Defined Networking (SDN)
    1. Abstract the Hardware: No dependence on physical infrastructure. Software API.
    2. Programmable: Shift away from static manual operation to fully configurable and dynamic.
    3. Centralized Control of Policies: Policy delegation and management.



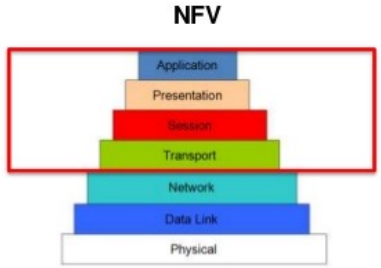
Key Improvements – 14/15

- Network Function Virtualization (NFV): Standard hardware is fast and cheap, so no specialized hardware should be used. NFV suggest to implement all functions in software and virtualize all network functions.

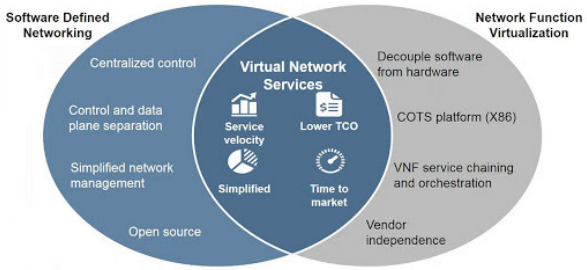




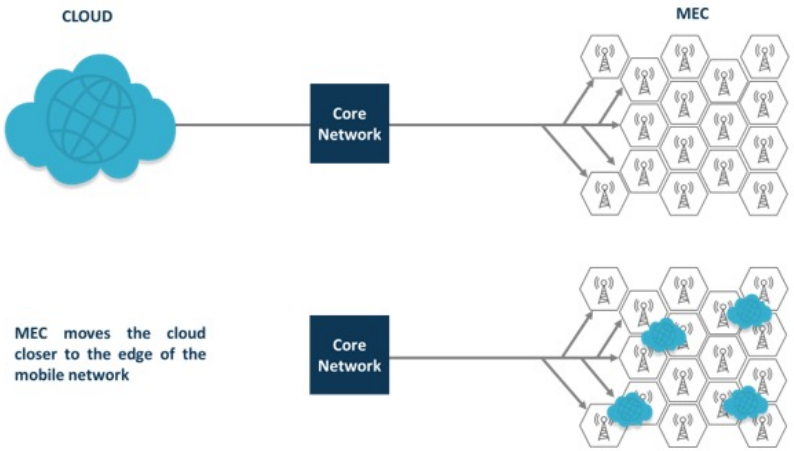
- Optimize network infrastructure such as Ethernet switches, routers and wireless access points
- OSI Layer 2-3



- Optimize deployment of network functions such as: load balancer, firewall, WAN optimization controller, deep packet inspection etc.
- OSI Layer 4-7



Key Improvements – 15/15



- Mobile Edge Computing (MEC): To service mobile users/IoT, the computation needs to come to edge so as to be closer to the user.

- Cloud Radio Access Network (C-RAN): Centralize baseband processing in a cloud.