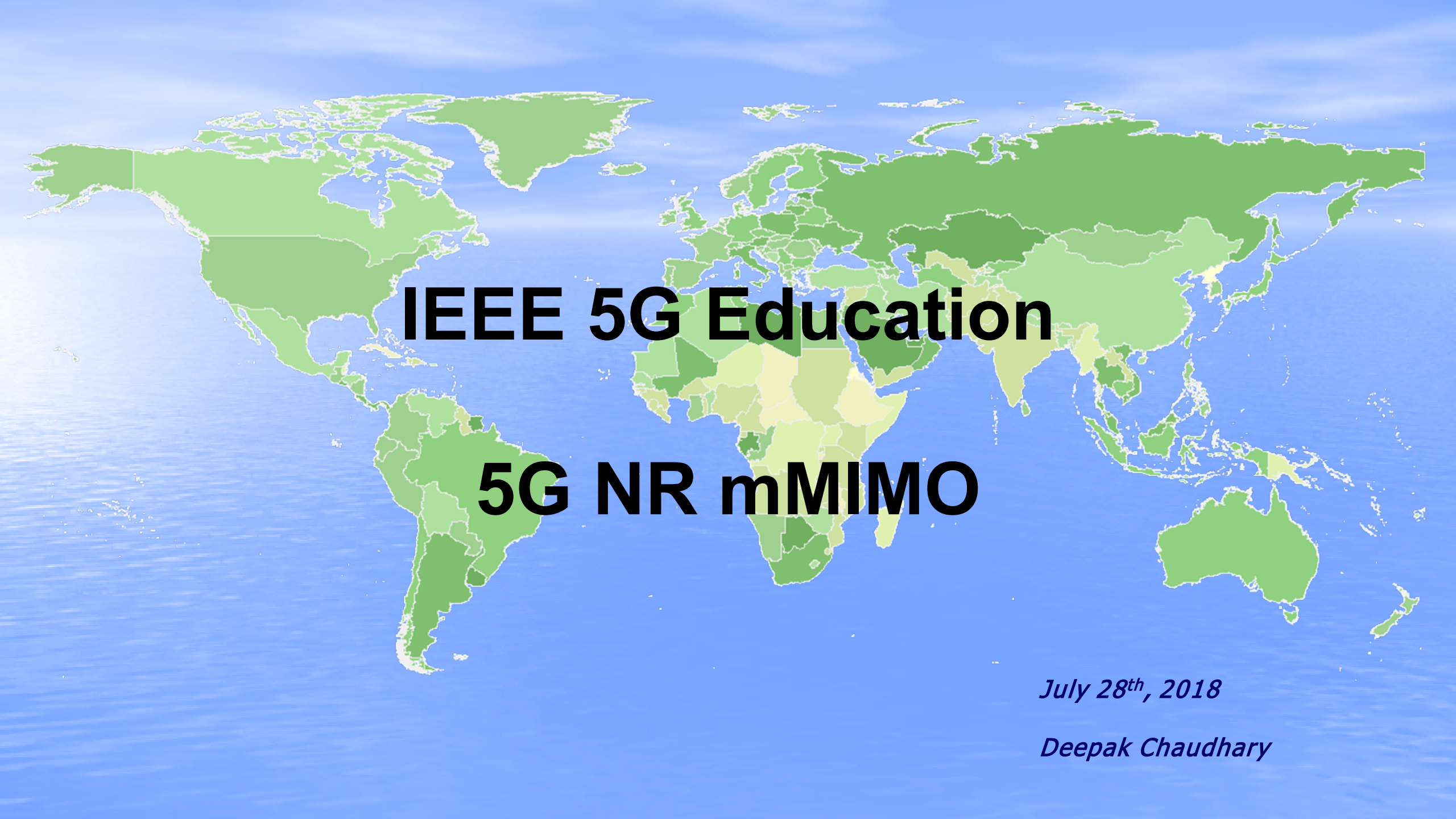

IEEE 5G Education

5G NR mMIMO

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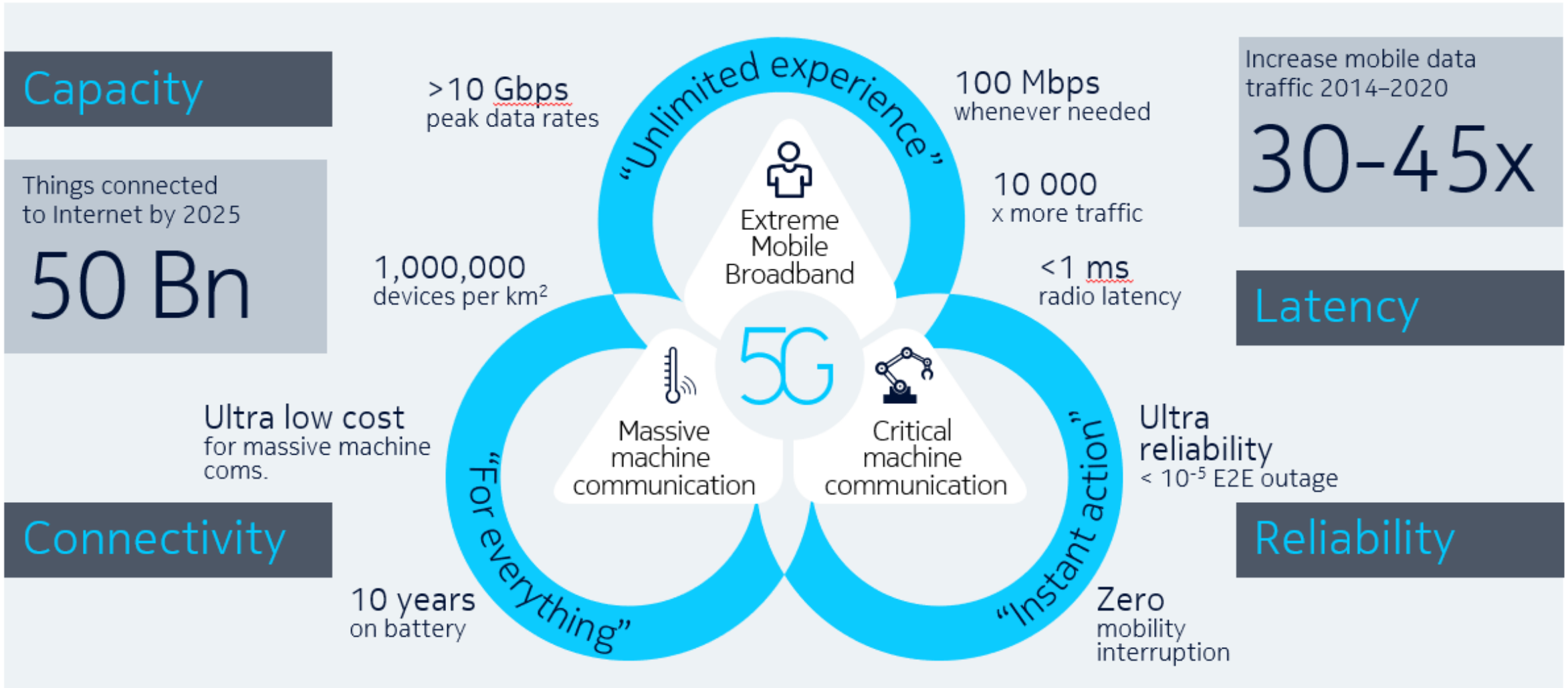
What is 5G?

1. In very simple words – 5th generation mobile network beyond 4G. It will have internet speeds faster than 4G.
2. It is more than just a network, connection or format. It will include the connection to internet, the connections to each device, and the broad spectrum of devices used in the network.
3. Combination of the networks.

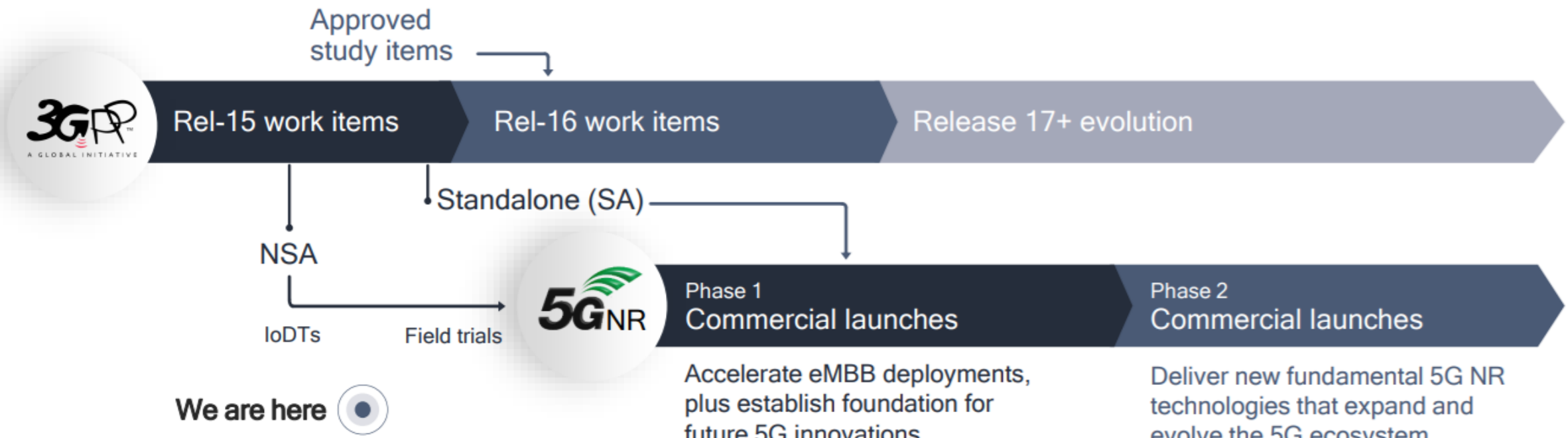
4. Heterogenous network (HeNet) – a wireless network which provides a service through a wireless LAN and is able to maintain the service when switching to a cellular network is called a wireless heterogeneous network.

5. A network could have macro, Small Cells, LTE and Wi-Fi all working as big happy network. It could be any spectrum 600 MHz, 700 MHz, 1.9GHz, 2.5GHz, 24GHz, 28GHZ and 60GHz. It could includes unlicensed spectrum Wi-fi or LTE-U or lightly licensed band like 3.65GHz.

5G will create new possibilities



First 5G NR standard complete – the global 5G standard



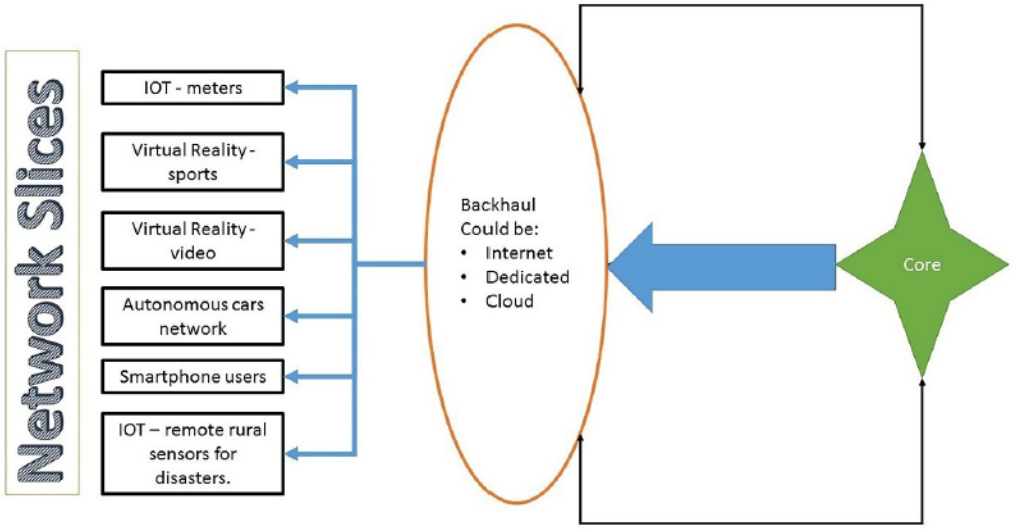
Application and 5G requirements

	Use cases	Application description	5G requirements
Immersive and interactive experience	5G to home	Fixed Wireless Access to homes (FWA) with low fiber penetration via 5G	**Fiber-like speeds** to multiple 10s of households from one site
	In Vehide Infotainment	Video-driven mass infotainment inside fast moving public and private vehicles	Increased **capacity** (10/3 Gbps DL/UL) Lower **latency for AR/VR** (< 5-10ms)
	5G hot spots (overlay)	Virtual Reality streaming from event onto user devices on site at large scale	**Ultra-High throughput** 1-2Gbps; lower latency (<10 ms) required for AR/VR; very high capacity (>500 Users/cell)
Machine (Truck/Robot/Drone) as a Serve	Wireless Robotic Platforms	Robots for Logistic, Cleaning, Monitoring, Manufacturing (Industry 4.0) and Surgery	**Ultra-reliable** (failure rate $<10^{-7}$) **low E2E latency** communication (5-25 ms)
	UAV Traffic Management	E2E fleet management for delivery drones: Traffic Management for UAV (TMUAV)	**Ultra-low-latency** and **high reliability** for safety/security. Increased uplink **capacity** (10 Gbps UL)
	Connected Vehides	Truck platooning as an entry point into autonomous driving solutions	**Ultra-low-latency and high reliability** for extreme safety / security

5G Network Slicing

Network slicing is 5G's way to get you everything. One network will not provide all services for everyone, so they have 5G which will encompass many networks, wireless networks, into one big network. You can't do everything with one wireless network.
Most IOT devices don't need broadband. Most smartphones need mobile coverage.
Most laptops need broadband. Most gamers need massive broadband to get the VR to work. Each specific group has a different need.

5G network to include them all, they came up with a term like network slicing. The reality is that they will all be different networks that could be sharing the same core or even backhaul. We are creating a way to share resources and build in efficiencies



What makes 5G network faster?

- ✓ Carrier Aggregation
- ✓ Carrier Aggregation with unlicensed Band
- ✓ Massive MIMO
- ✓ Improvement in LTE
- ✓ New Spectrum

Backhaul and Core in 5G Network

SDN – Software Defined Networking ->It makes Routing architecture smarter and efficient

NFV – Network Function Virtualization -> it uses SDN to make network virtual. It makes network function work closer to user.

Cloud Computing -> Bring Application closer to the user, provides lower latency, improved customer experience where network see lower congestion.

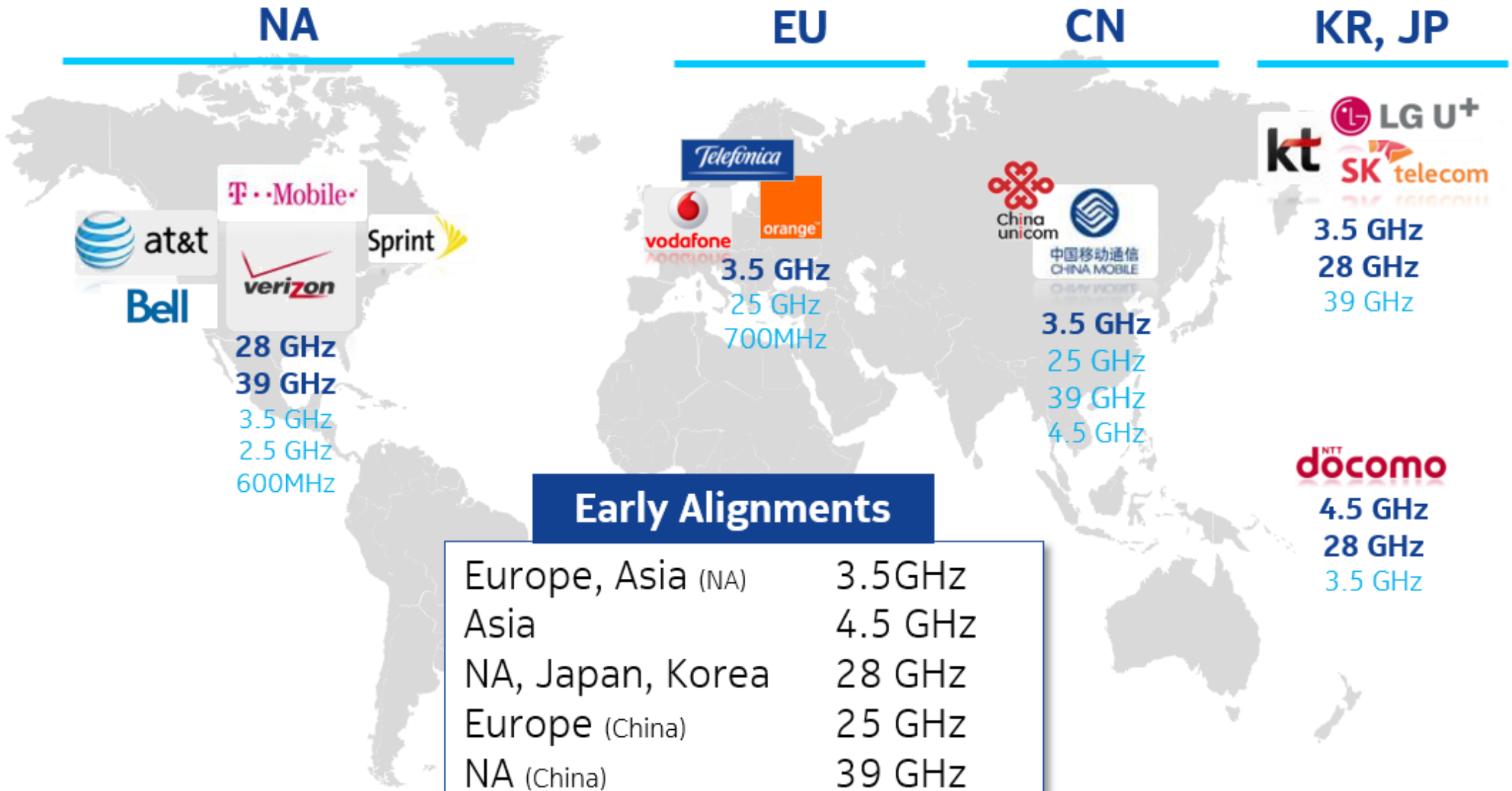
Edge Computing -> taking application beyond cloud, making them running on server very close to the users.

Fog Computing -> (a term made up by Cisco) this is taking the cloud and shoving it as close to the end user as possible, to the edge where the IOT will be able to make smart decisions in very little time, low latency.

Cloud RAN -> C-RAN is where the RAN will not have a local BBU, but a virtual BBU. Like CRAN which is Centralized RAN which is where the BBU hotel is remote, and fiber connected the BBU to each radio Head. Cloud RAN is where the BBU function is more virtual whereas Centralized RAN has a direct physical connection to the BBU.

Global Spectrum

Legend
Firm
Next in Line



Early Alignments

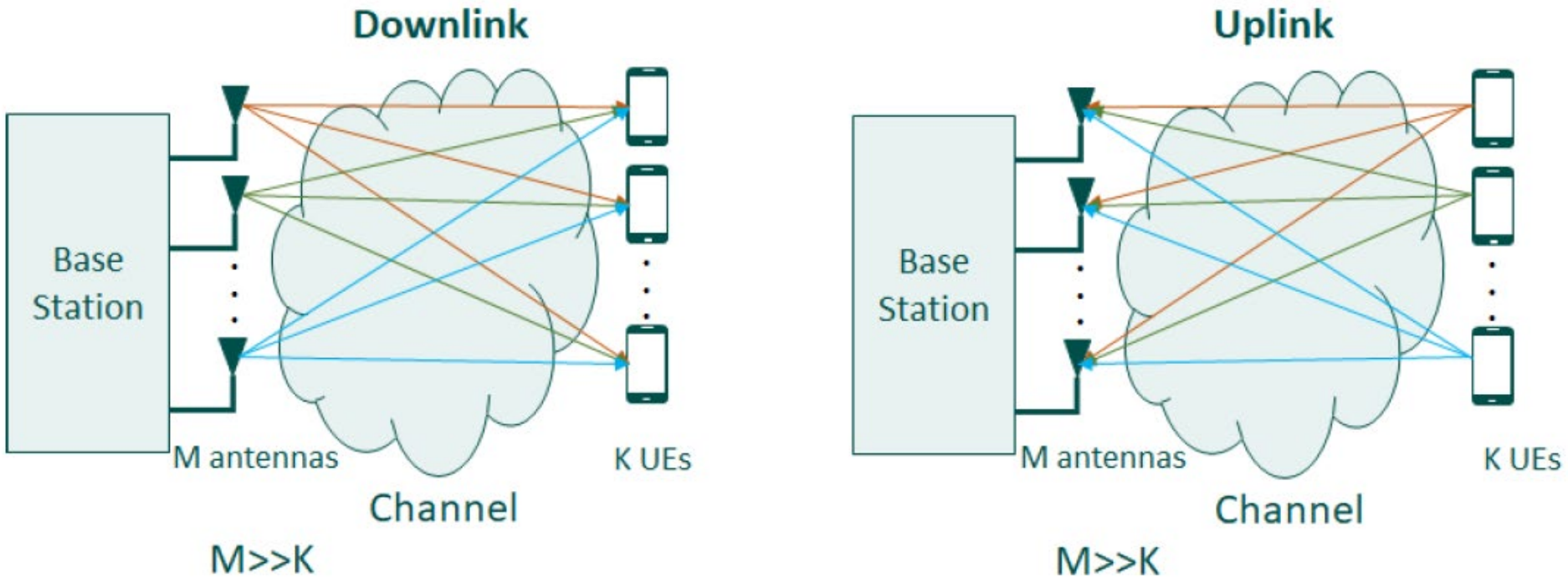
Europe, Asia (NA)	3.5GHz
Asia	4.5 GHz
NA, Japan, Korea	28 GHz
Europe (China)	25 GHz
NA (China)	39 GHz

***Plans continue to evolve**

Massive MIMO and What it does?

Lots of antennas = Better signal propagation both ways, with better nose reduction and more throughput
Massive MIMO has become one of the foundational technologies for the 5G evolution

mMIMO will provide increase sector capacity, improved radiated energy efficiency and low latency.



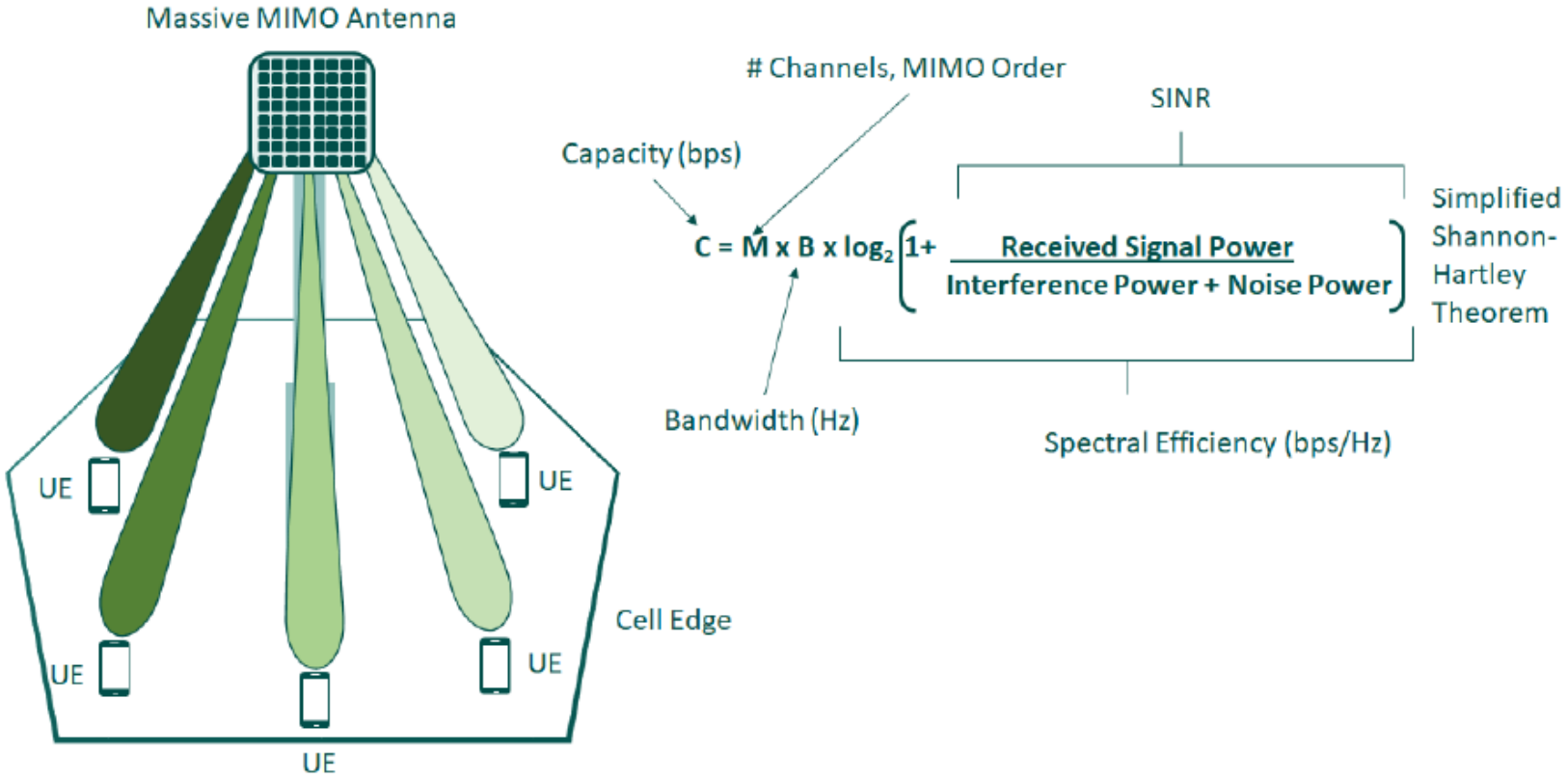
mMIMO Why?

Scarce and expensive spectrum – it is the highly attractive solution for MNO (mobile Network Operators). This can dramatically increase the capacity and coverage
In Urban and dense urban environment requires optimized RAN and base station spacing – mMIMO is the perfect solution to increase the spectral efficiency and low coast alternative to increase the capacity without adding more base station in the network

How we can improve user experience by increasing the Throughput of a data request.
By adding more cells in the network – Costly proposition and time consuming to deploy.
By using bigger spectrum – Again costly proposition, licensed spectrum.
mMIMO is the perfect suitable technique

Spectrum efficiency is function of Signal to Noise plus interference ration (SINR). To increase the Spectrum efficiency to double, SINR by 17X required based on Shannon Hartley Theorem. Adding several hundred channels in-use in a massive MIMO environment can help increase the spectral efficiency. This help to improve network capacity as a cost effective solution.

Defining mMIMO

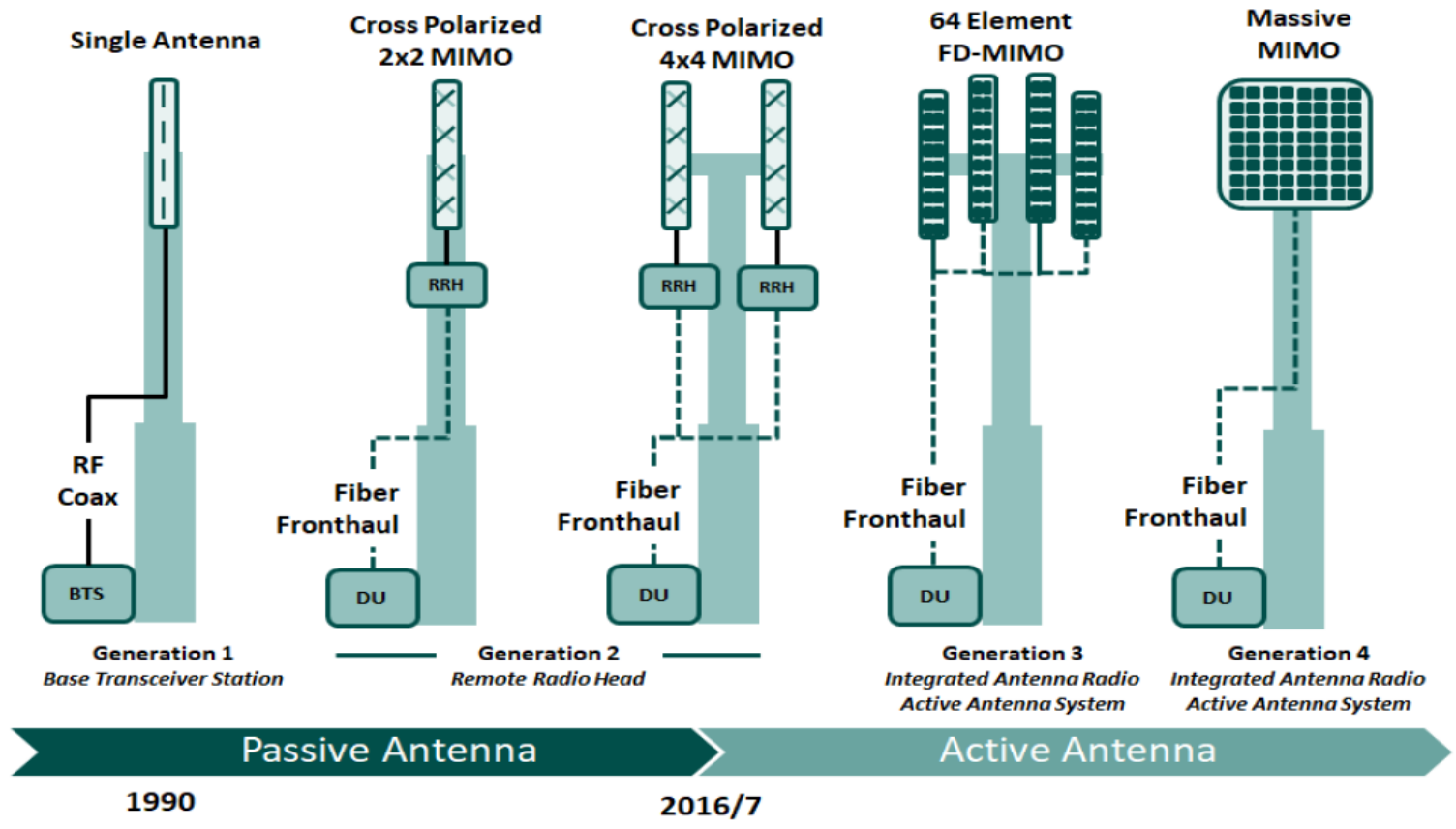


Network Throughput (bps/km²)=Cell Density (cell/km²) x Bandwidth (Hz) x Spectral Efficiency (bps/Hz/Cell)

Massive MIMO

- In mMIMO we are able to use inexpensive low power component as total power is shared among several antennas. mMIMO enables reduction in total power among antenna arrays.
- mMIMO also help to large reduction in latency of the interface as the transmitted signal take less fading dips from one place to another
- mMIMO is best used in TDD where both Uplink and Downlink are identical or reciprocal. As reciprocity used to calculate Channel State Information. (CSI)
- mMIMI is easy to deploy for high band freq with shorter wavelength of the spectrum which don’t require bigger antenna hence less weight antenna compared to low band freq network.

Antenna Evolution



BTS: Base Transceiver Station/Base Station
DU: Digital Unit/Baseband
RRH: Remote Radio Head/Radio Unit

Massive MIMO - Advantages

- It promises to improve capacity of the sector by 10X
- Radiated Energy Efficiency by About 100X – Large number of Antennas and beamforming, energy can be focused to particular UEs constructively hence not transmitting the energy where not desired.
- Channel Hardening – mMIMO transmitting signal in several multipath reduces fading of the signal to zero impact.
- Massive MIMO antenna low cost – as per power transmitted in sector divided among all the antenna components hence doesn't require high cost antenna components
- Latency – Delay is reduced with large number of antennas transmitting the same signal to the UEs

Massive MIMO - Disadvantages

- mMIMO hardware must be calibrated to ensure Accurate Channel Reciprocity in TDD
- Pilot Contamination
- Non-Orthogonal Channel response
- mMIMO Introduces New Fronthaul Architecture
- mMIMO less flexiable than Prior-Generation RRU
- Not Effective for high Mobility UEs
- Testing of large Antenna Count Arrays can be expensive

mmWave – Millimeter Wave

- Range of Electromagnetic spectrum which includes wavelength from 1 -10 mm corresponding to frequency range of 30G – 300 GHz waged between microwave and infrared waves
- In context to 5G, it may includes slight lower frequency rage from 24GHz (wavelength of 12.5mm)
- 5G network are not expected to deploy waves in the range of 100GHz
- Wifi and Bluetooth both deploy in the range of 2.4GHz (Wavelength 125mm)

mmWave is Fiber Like Wireless

- All electronic devices used in daily life use specific radio frequency spectrum which are restricted up to 30GHz.
- This range is currently highly congested hence modern wireless communication standards are focusing more on standards over 30GHz (Millimeter Waves)
- Due to rapid growth in Mobile data and high speed communication needs has driven the exploration of the millimeter wave frequency spectrum (30GHz-300GHz)
- Number of manufacturer are producing components that can handle millimeter waves and Semiconductor technologies are capable of operating at frequencies up to 90GHz specially V-band (57 to 66GHz) and E-Band (71 to 86 GHz).
- The 60GHz (V-band) unlicensed industrial-scientific-medical (ISM) band is getting lots of attention specially short-range wireless technologies.
- The WiGi (Wireless Gigabit) technology based on 60GHz spectrum, enables devices to communicate for a short range (distance about 10 meters) at high data rates of up to 8Gbit/S.
- Some application includes transmitting videos from a tablet, laptop, set-top box, to an HDTV, from a game or DVD player to a TV set, Wireless video camera and wireless HD projectors.

mmWave – with 5G

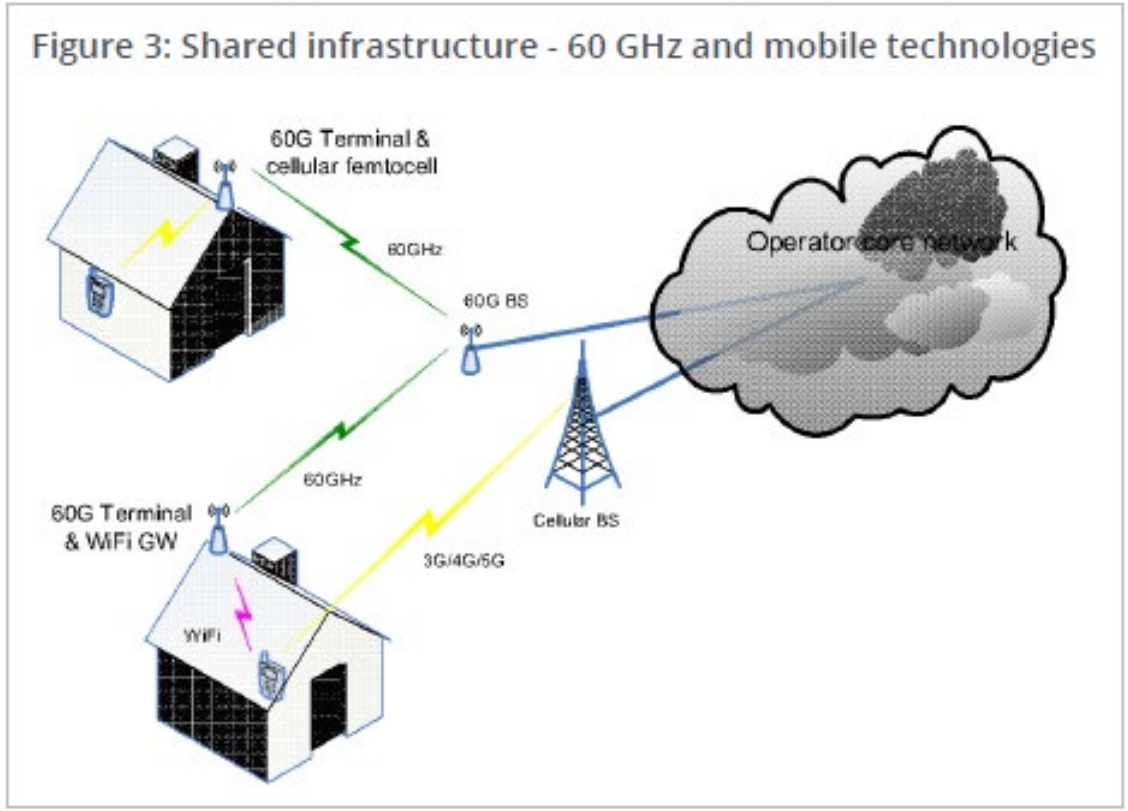
- Current mobiles users require high-speed data transfer rates and more reliable services and 5G next generation wireless has the potential.
- 5G Networks are expected to be driven by the increased wireless capacity and speeds offered by high-frequency millimeter waves.
- mmWave Larger bandwidth, Higher resolution, low interference, small component, increased security and cost efficacy finding use in several commercial applications
- The applications include automotive radars, headsets, telecommunication, military & defense, industrial satellite communication, imaging.

<u>Disadvantages</u>

- Atmospheric absorption, Free space loss, scattering of signal due to rain, mechanical resonance as these signal coincide with gaseous molecules
- Non-line of sight issues and costly components.

mmWave – with 5G

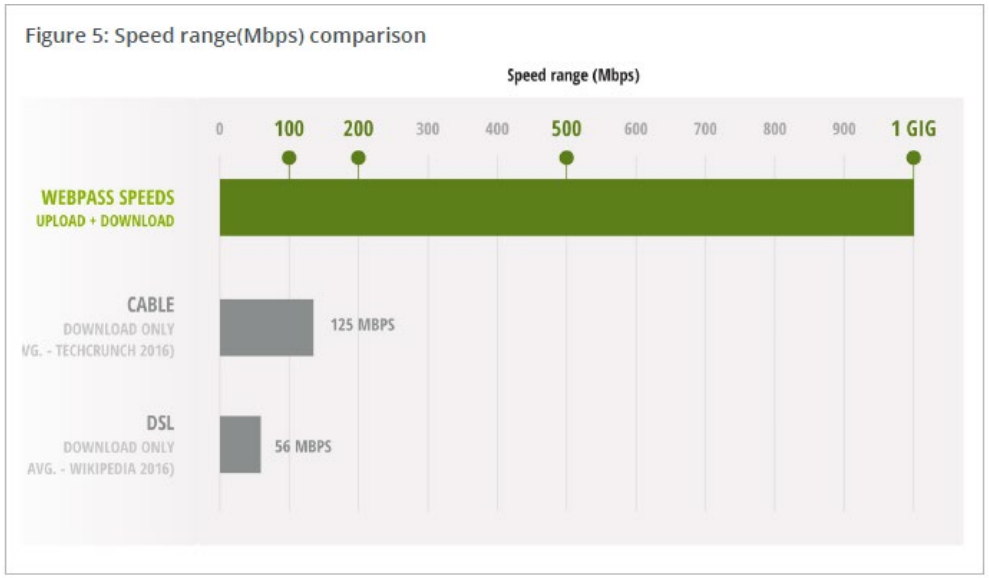
- Downside of mmWaves promise for future 5G networks is that licensed mmWave spectrum has begun to be dominated by large ISPs like Verizon and AT&T in the US. 55% and 66% of the popular 28 and 39GHz bands, respectively. Total 58% of the licensed mmWave spectrum
- Good news is that unlicensed and lightly-licensed mmWave such as the 60Ghz V-Band and 70//80 Hz E-Band. Can provide the benefits of mmWaves without the prohibitive costs of licensed spectrum.



mmWave – with 5G

Example of mmWave deployment:

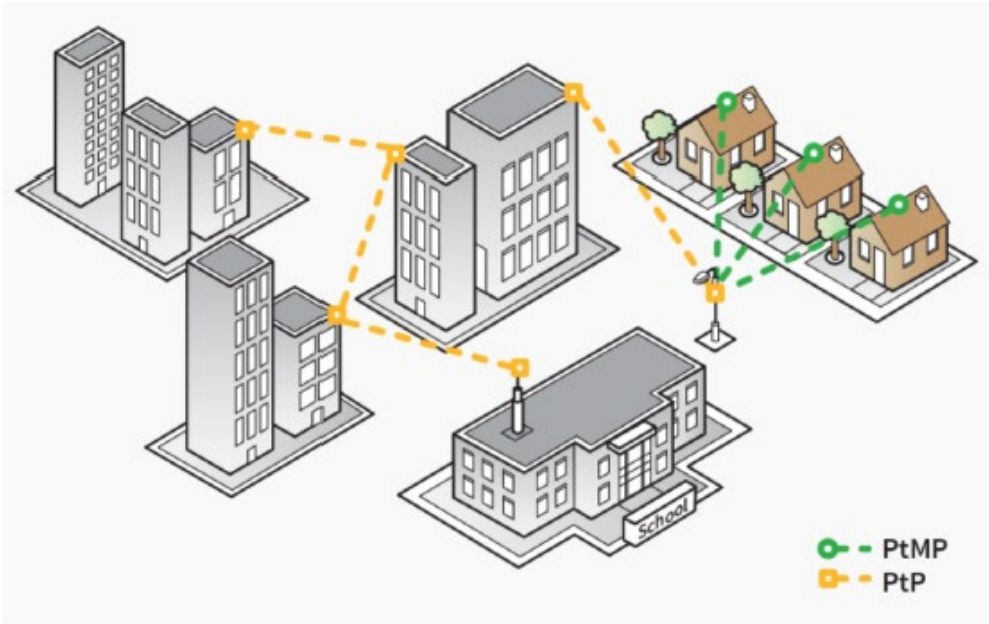
- Google acquired gigabit ISP Webpass is using commercially available mmWave technology to provide broadband service. It uses a combination of fiber networks and PtP mmWave radios to deliver gigabit broadband to residential and business customers.
- Another advantage of the 60GHz band is that it readily complements 3G/4G/5G mobile technology and can share the infrastructure with other technologies.
- Webpass strategy is to use wireless in complement to fiber deployments where it makes more sense to deploy wireless mmWave.



mmWave – Business Case of FWA

5G FWA is well-suited to serve as an alternative to expensive and slow FTTH (Fiber to the home) deployments, specifically in the so-called last mile (i.e., the final infrastructure connection to homes, MDUs, or businesses). Instead of deploying fiber directly to the premises (FTTP), the last mile can instead be replaced with fiber-like wireless networks. By using high capacity mmWave technologies for these networks, the gigabit throughput of fiber can be maintained despite the lack of a physical fiber connection

Figure 6: Illustration of PtMP and PtP wireless topologies

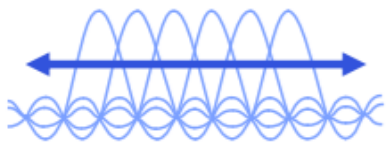


Back Up Slides

3GPP Rel-15 establishes a solid foundation for 5G NR

For enhanced mobile broadband and beyond

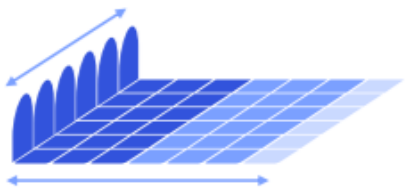
Scalable OFDM-based air interface



Scalable OFDM numerology

Efficiently address diverse spectrum, deployments/services

Flexible slot-based framework



Self-contained slot structure

Key enabler to low latency, URLLC and forward compatibility

Advanced channel coding

Multi-Edge LDPC and CRC-Aided Polar

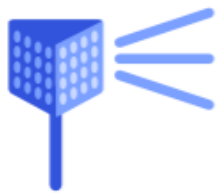
Efficiently support large data blocks and a reliable control channel

Massive MIMO

Reciprocity-based MU-MIMO

Efficiently utilize a large number of antennas to increase coverage/capacity

Mobile mmWave



Beamforming and beam-tracking

Enables wide mmWave bandwidths for extreme capacity and throughput