Cellular Mobile Communication-3

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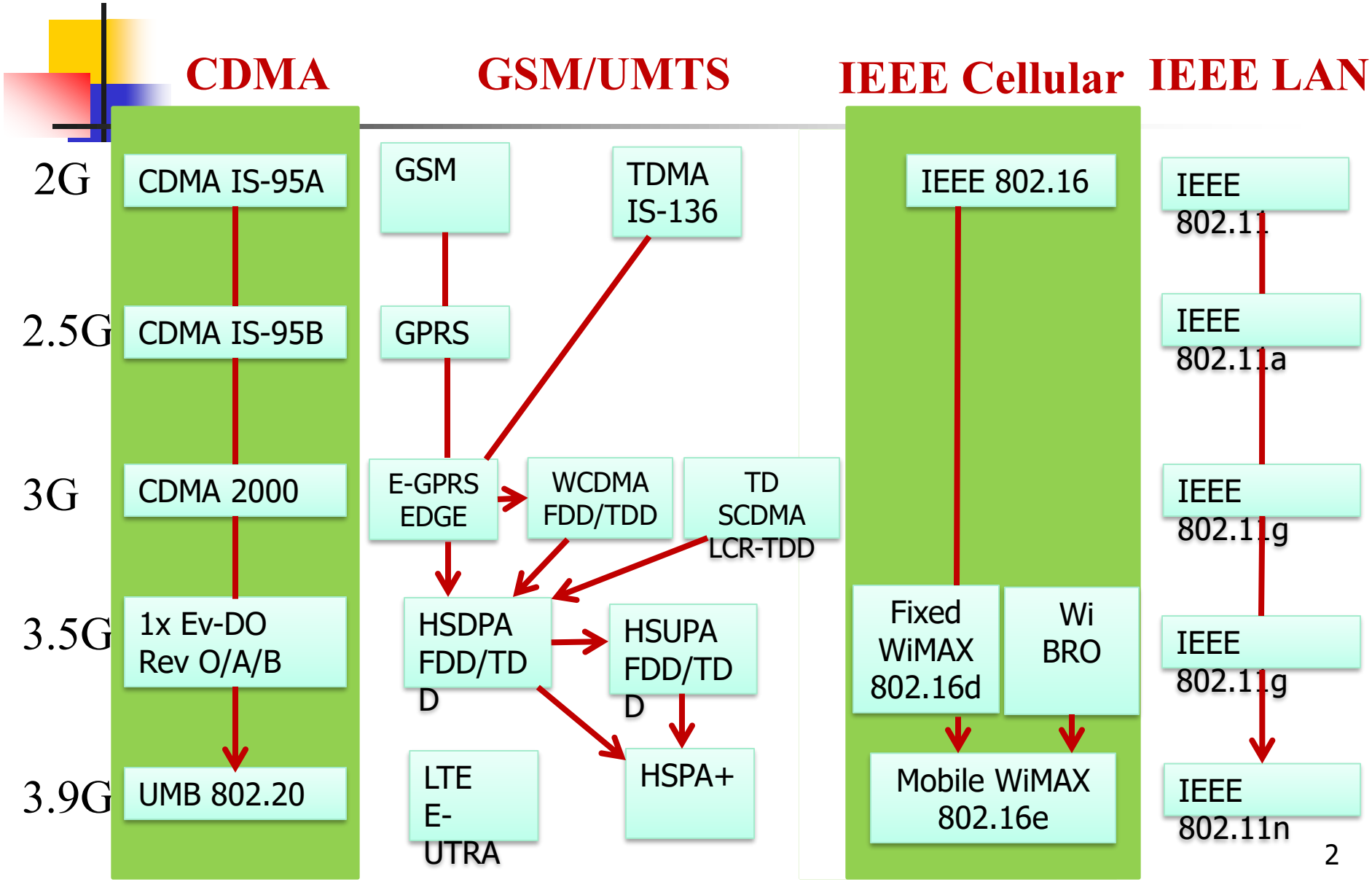
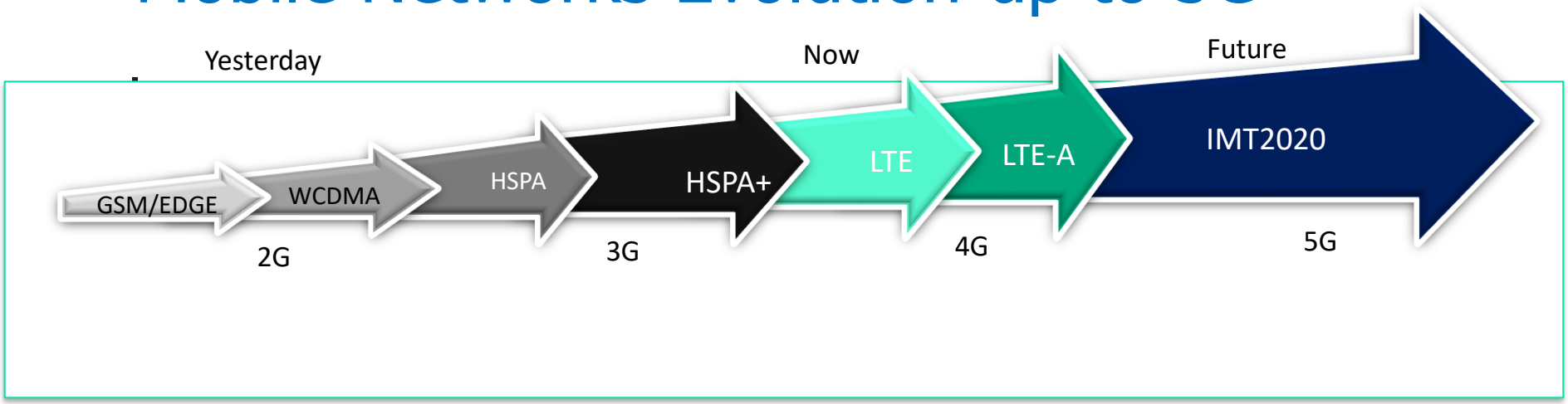
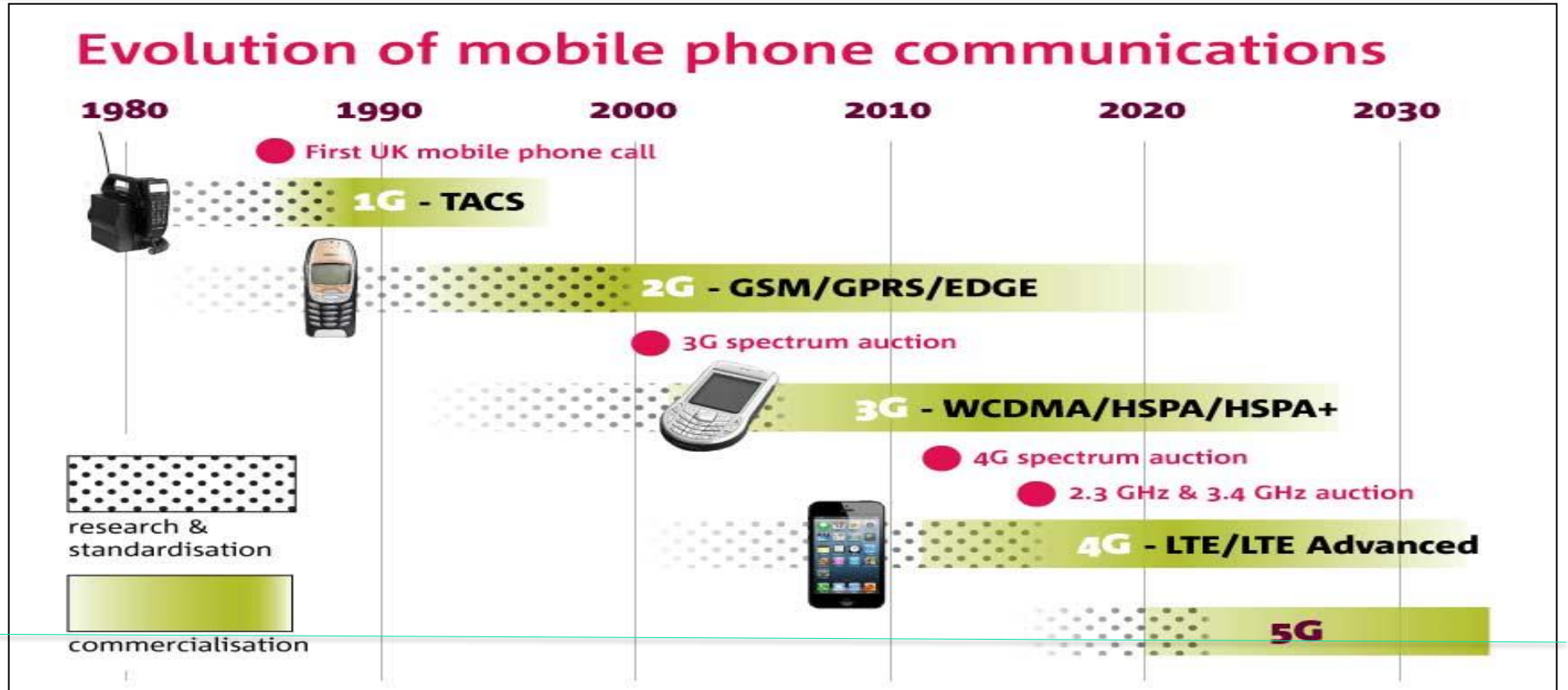
Evolution to 4G

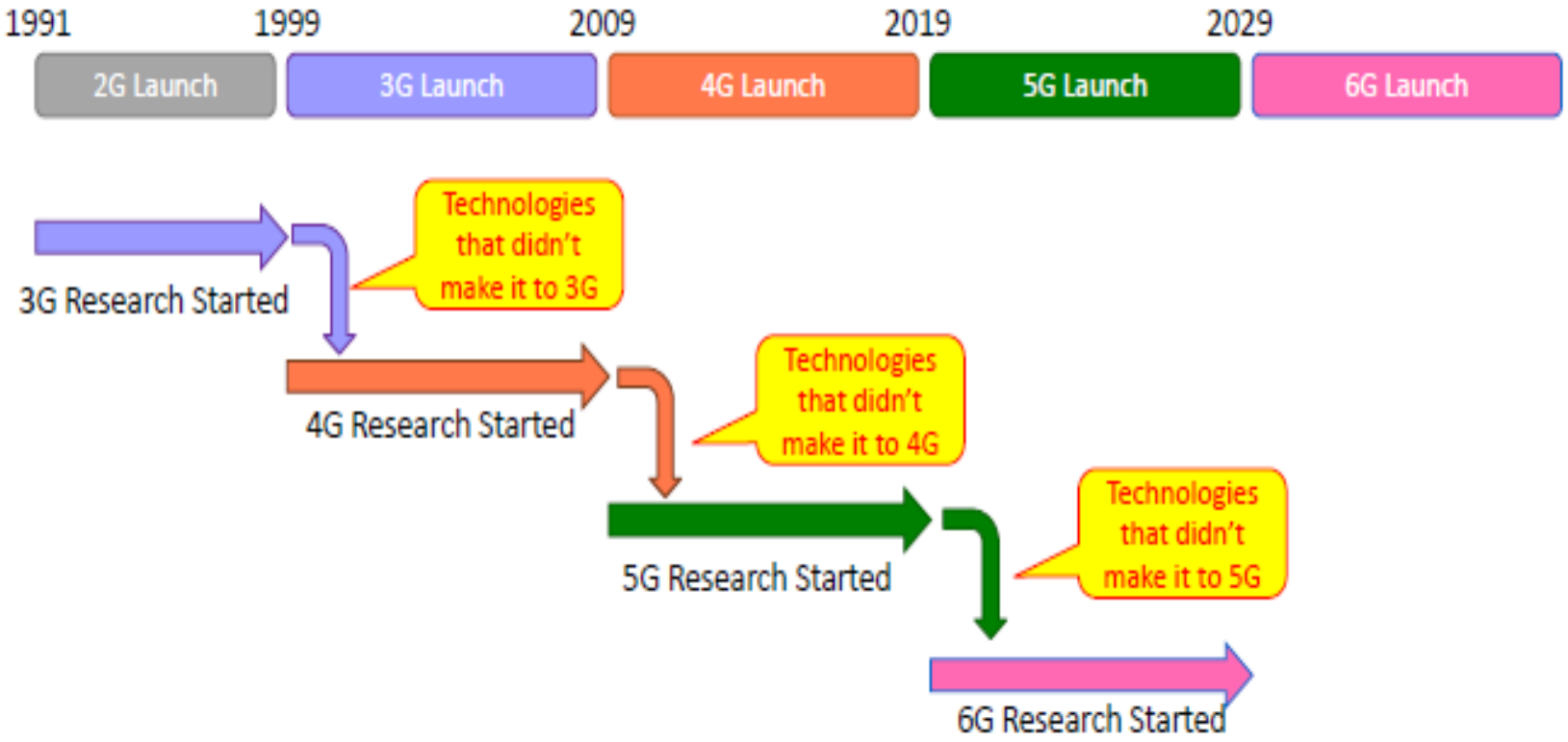


Mobile Networks Evolution-up to 5G

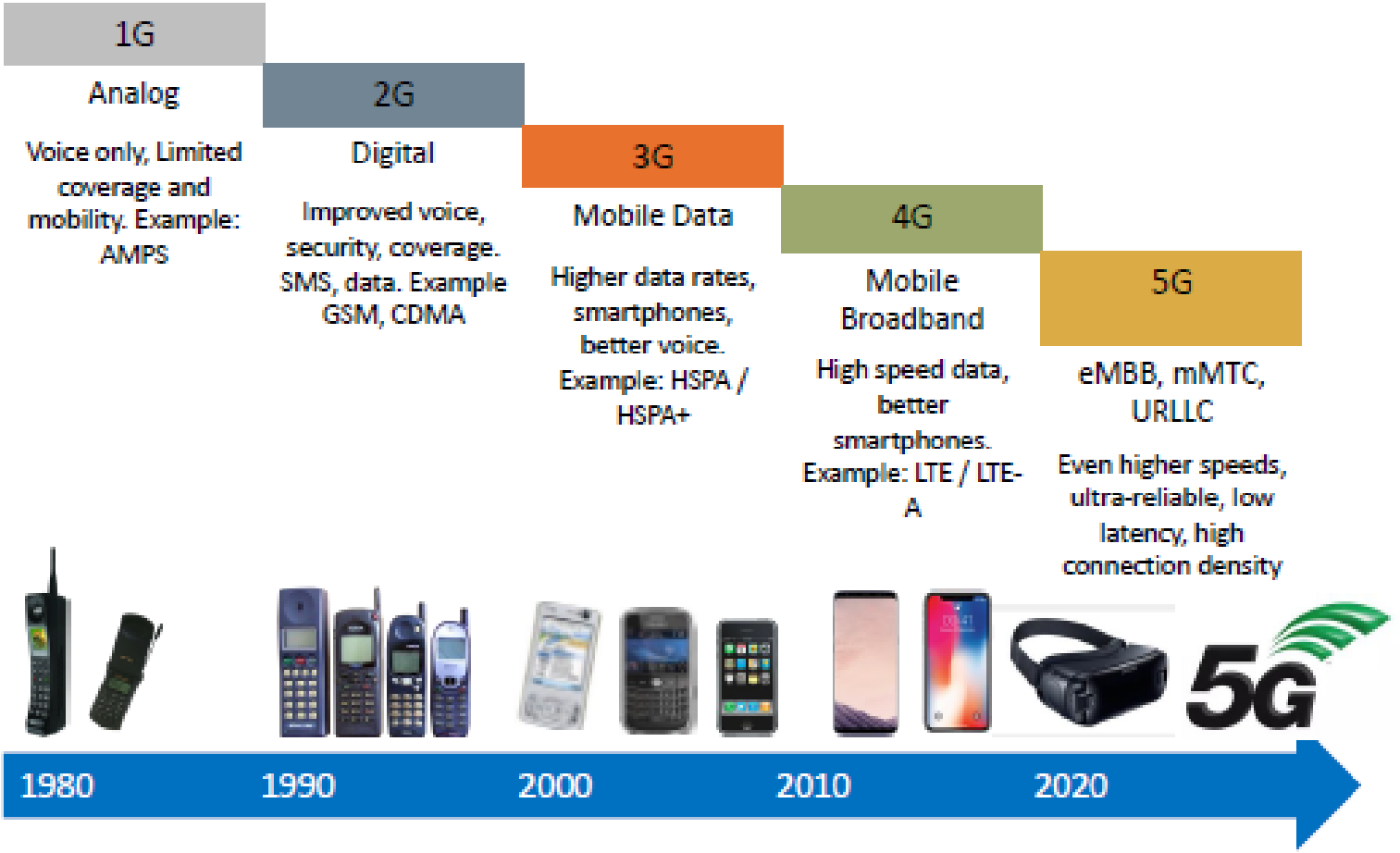




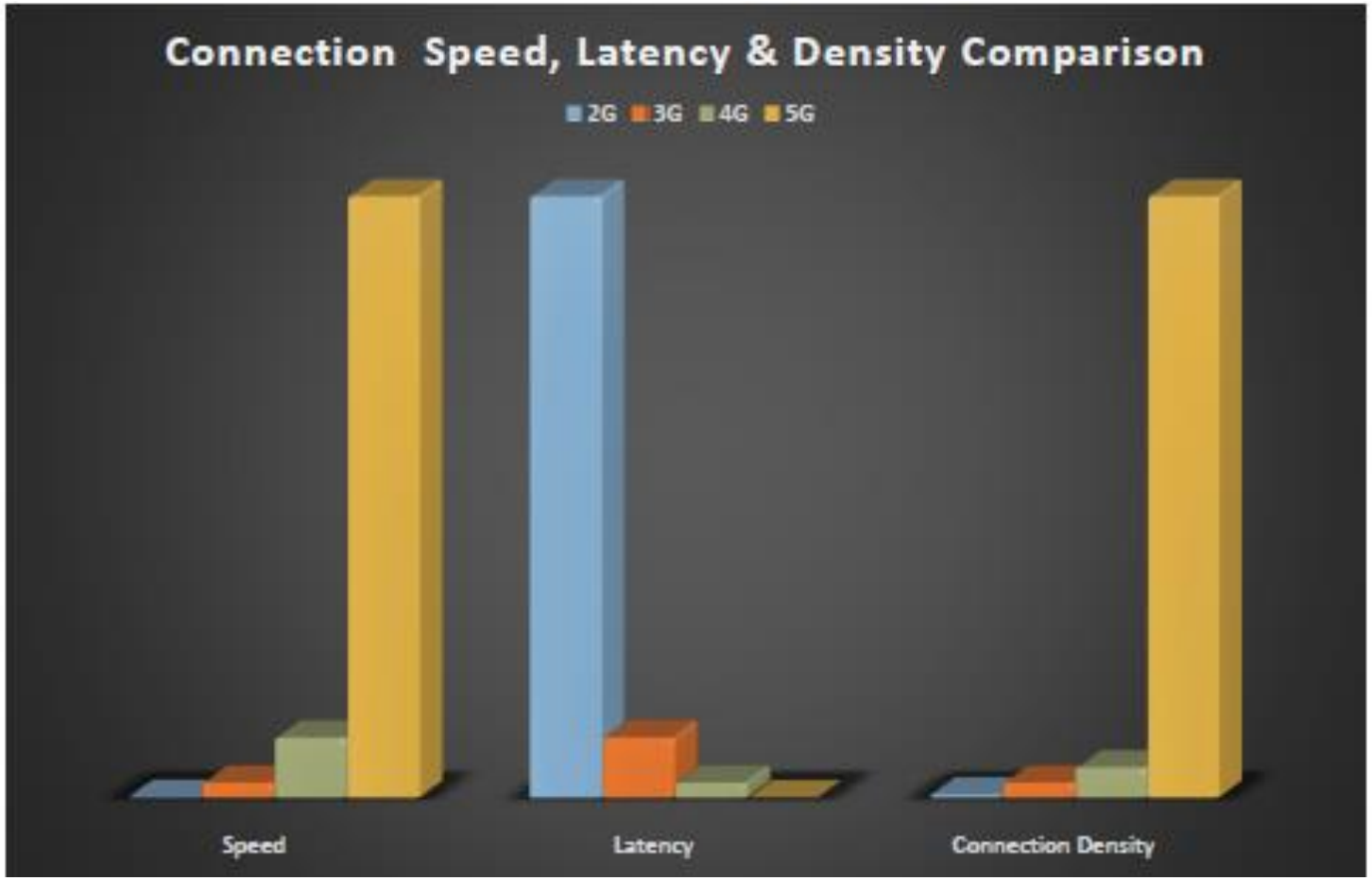
Technology Research Timeline



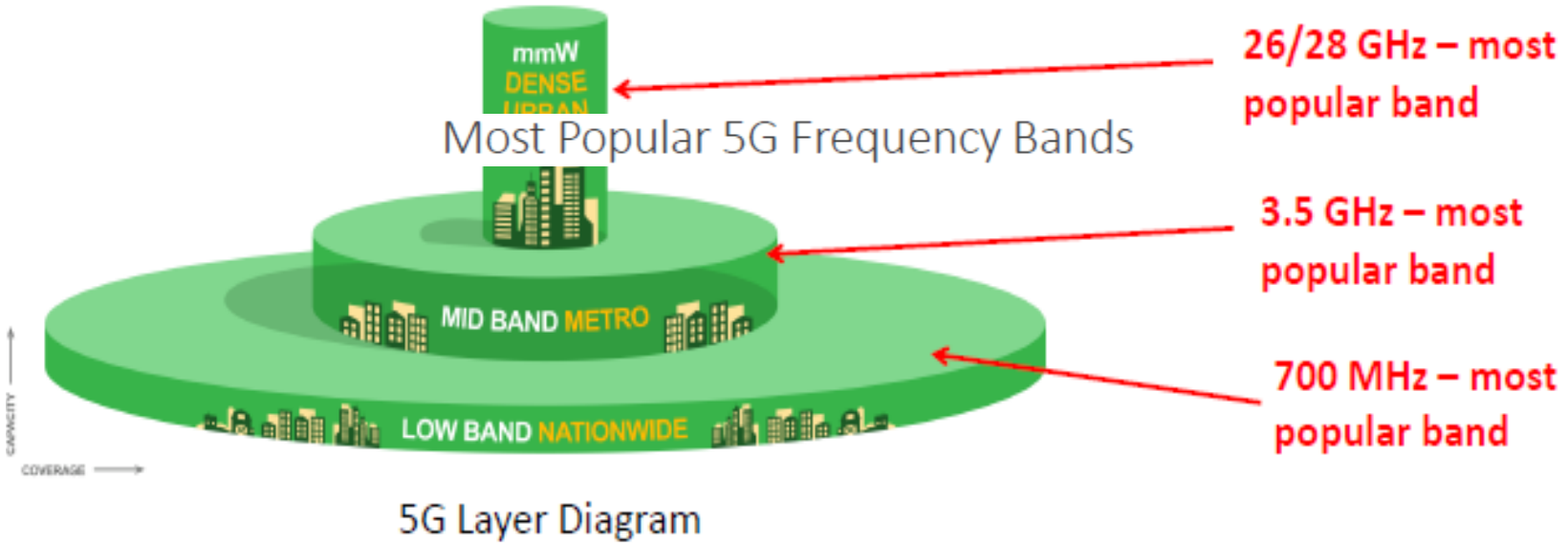
Mobile Technology Evolution



Comparison of 2G,3G,4G & 5G

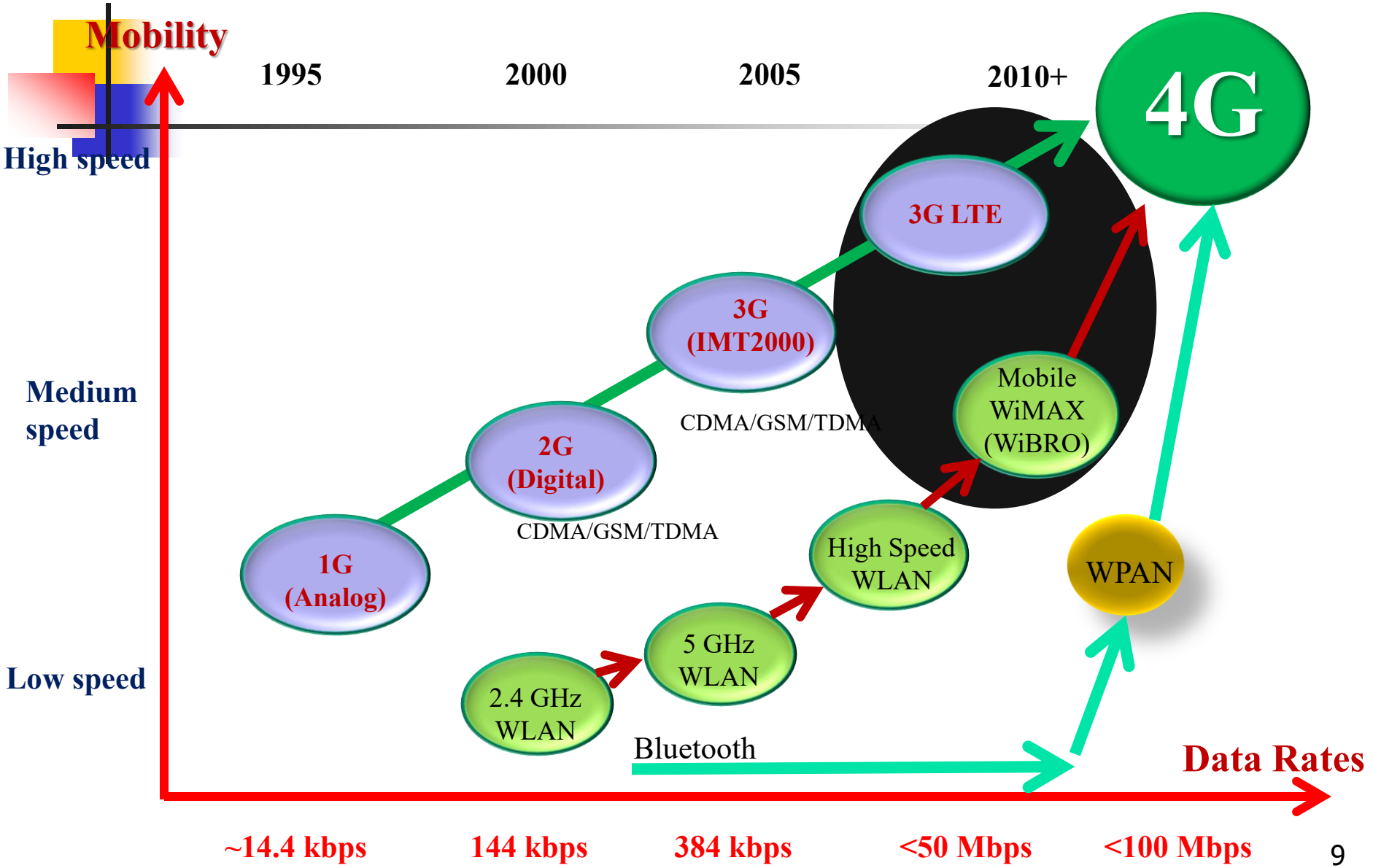


5G Frequency Bands



5G Layer Diagram

Technology towards 4G



4th GENERATION

- high-speed data access
- high quality streaming video
- combination of wi-fi and wi-max
- SDR,OFDM,OFDMA and MIMO

4G's Goals

- **Seamless Roaming**
- "Seamless" and "wireless," when put together, represent a technology of wireless Internet that hands you off to another network without interruption so you may continue your activities online without even noticing that you connected into another network. Another name for it is "**seamless roaming**."

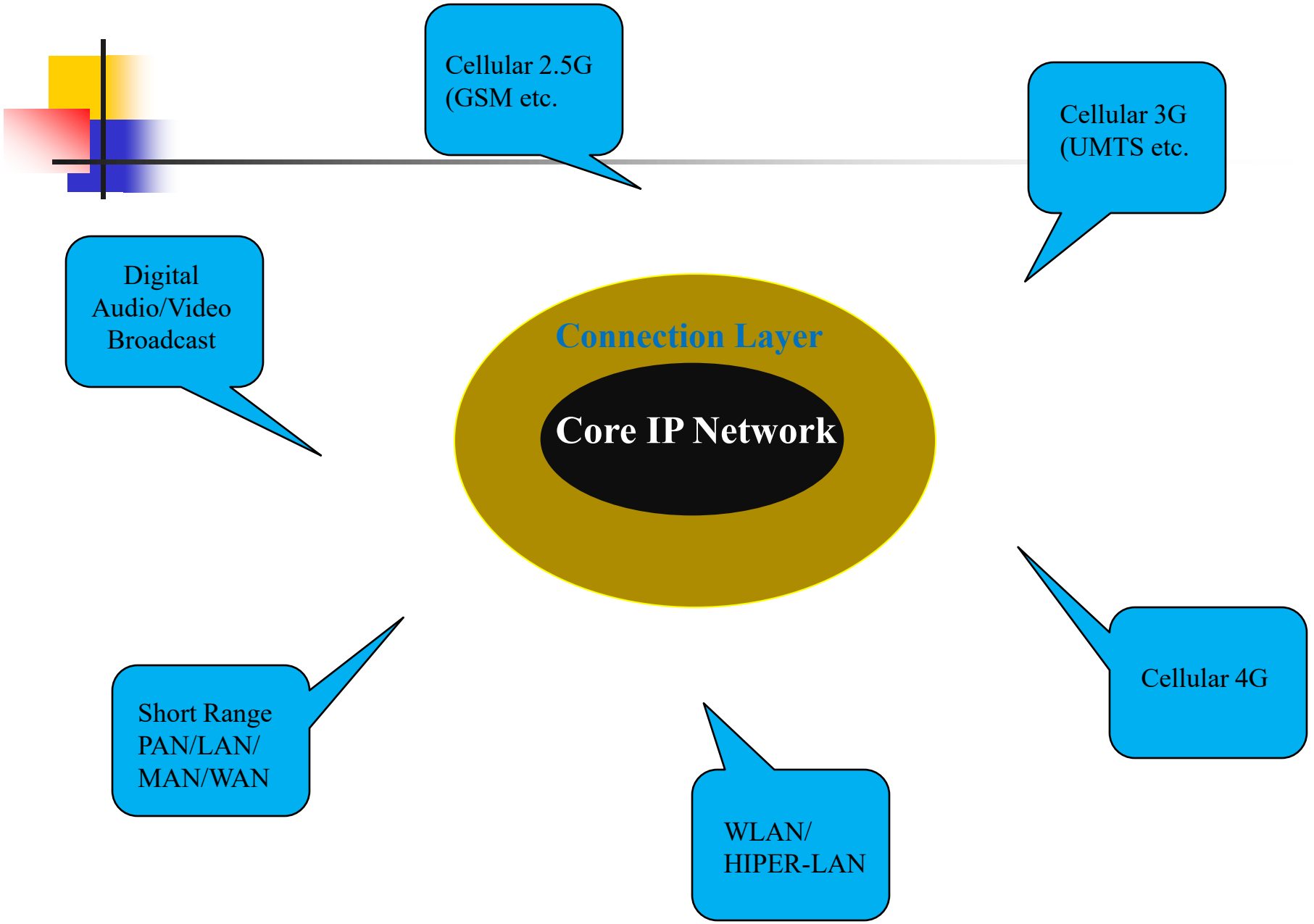
Features of 4G

- Faster and more reliable.
  - 100 Mb/s (802.11g wireless = 54Mb/s, 3G = 2Mb/s)
- Lower cost than previous generations
- Multi-standard wireless system.
  - –Bluetooth, Wired, Wireless (802.11x)
- Ad Hoc Networking.
- IPv6 Core.
- OFDM used instead of CDMA.
- Potentially IEEE standard 802.11n
  - –Most information is proprietary.

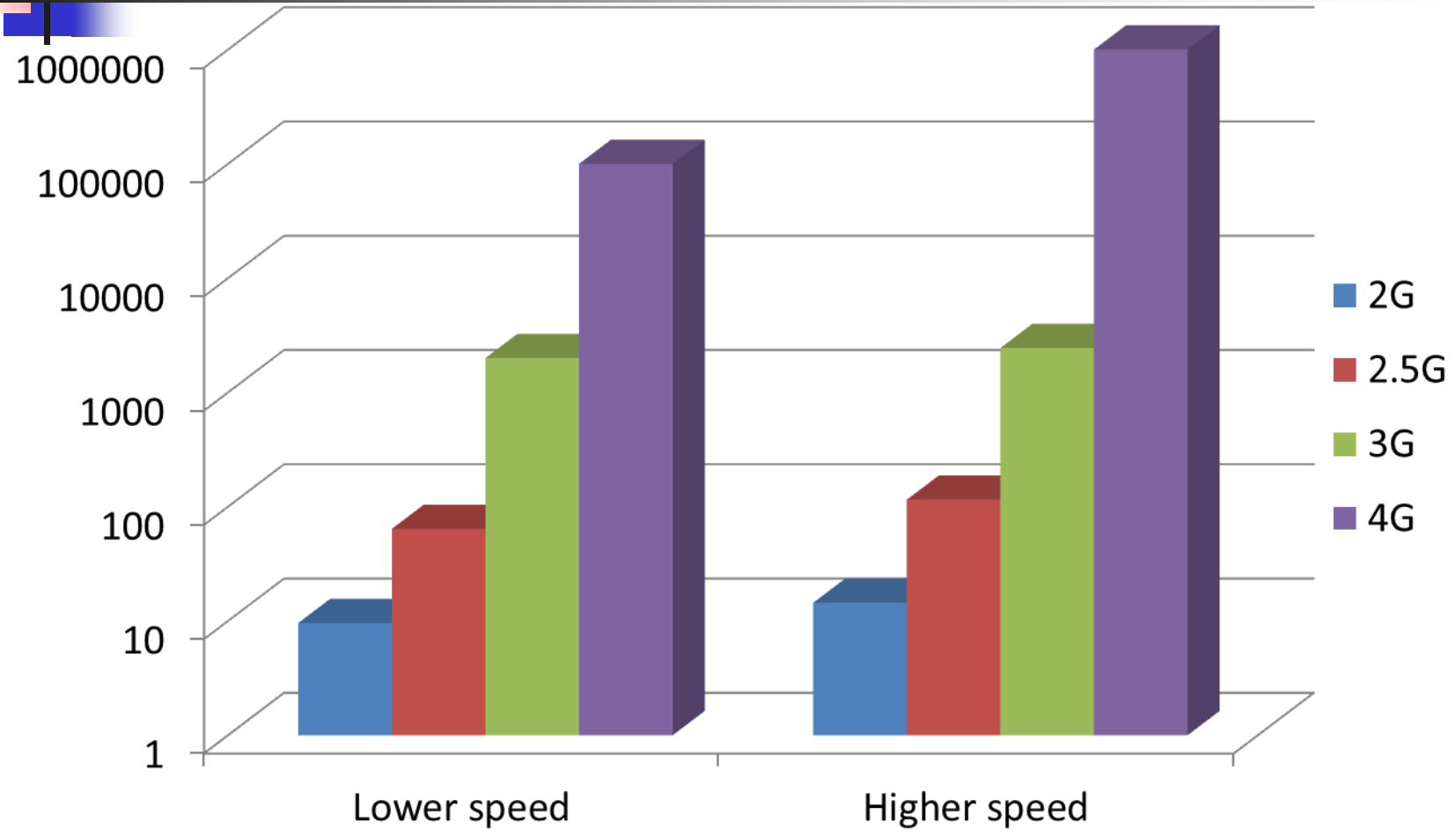
VS.

Technology	3G	4G
Frequency Band	1.8 - 2.5GHz	2 - 8GHz
Bandwidth	5-20MHz	5-20MHz
Data Rates	Up to 2Mbps	100Mbps moving - 1Gbps stationary
Access	W-CDMA	VSF-OFCDM and VSF-CDMA
FEC	Turbo-codes	Concatenated codes
Switching	Circuit/Packet	Packet

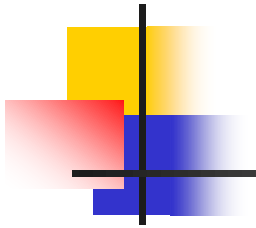
Networks in 4G



Data Rate Comparison (Kbps)



4G (LTE)

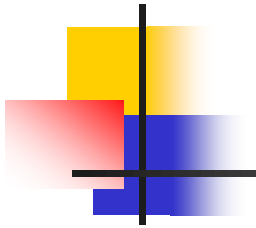


- LTE stands for Long Term Evolution
- Next Generation mobile broadband technology
- Promises data transfer rates of 100 Mbps
- Based on UMTS 3G technology
- Optimized for All-IP traffic

LTE-Advance: Real 4G

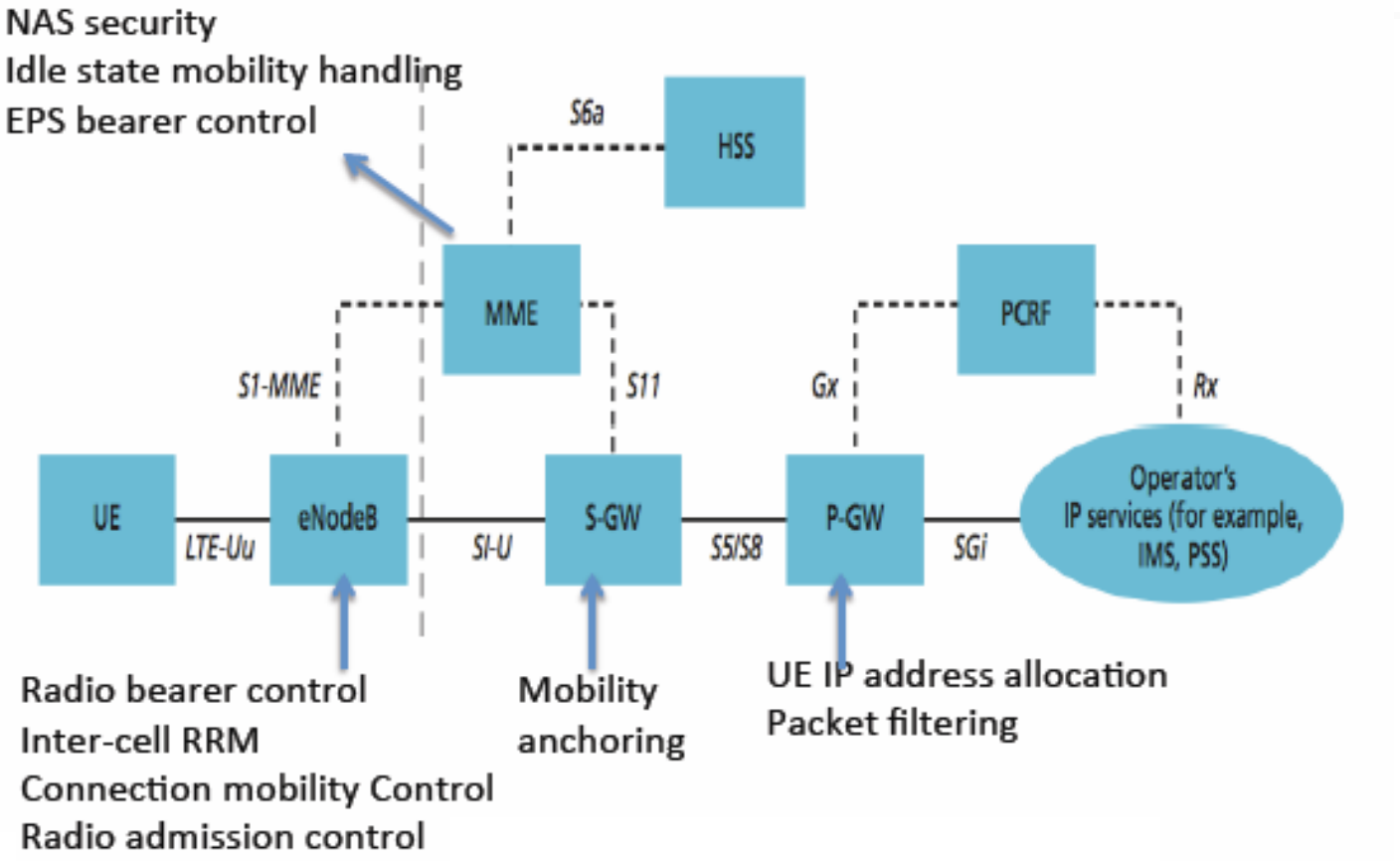
		IMT-A	LTE (Rel.8)	LTE-A (Rel.10)	LTE-A THEORETICAL
Bandwidth		Scalable At least 40 MHz	Scalable 1.4 MHz – 20 MHz	Max 2x20 (40 MHz)	Scalable Up to 5x20 (100 MHz)
Peak Data Rates		DL = 1 Gbps UL = 1 Gbps	DL = 150 Mbps (2x2) UL = 50 Mbps	DL = 300 Mbps (2x2) UL = 100 Mbps (2x2)	DL = 3 Gbps (8x8) UL = 1.5 Gbps (4x4)
Latency	User Plane (UP)	10 ms max	4.9 ms	4.9 ms	4.9 ms
	Control Plane (CP)	100 ms max	50 ms	50 ms	50 ms
Max peak spectral efficiency	Downlink (DL)	15 bps / Hz	16.3 bps / Hz	16.8 bps / Hz	30 bps / Hz
	Uplink (UL)	6.75 bps / Hz	4.32 bps / Hz	8.4 bps / Hz	15 bps / Hz

Major LTE Radio Technologies

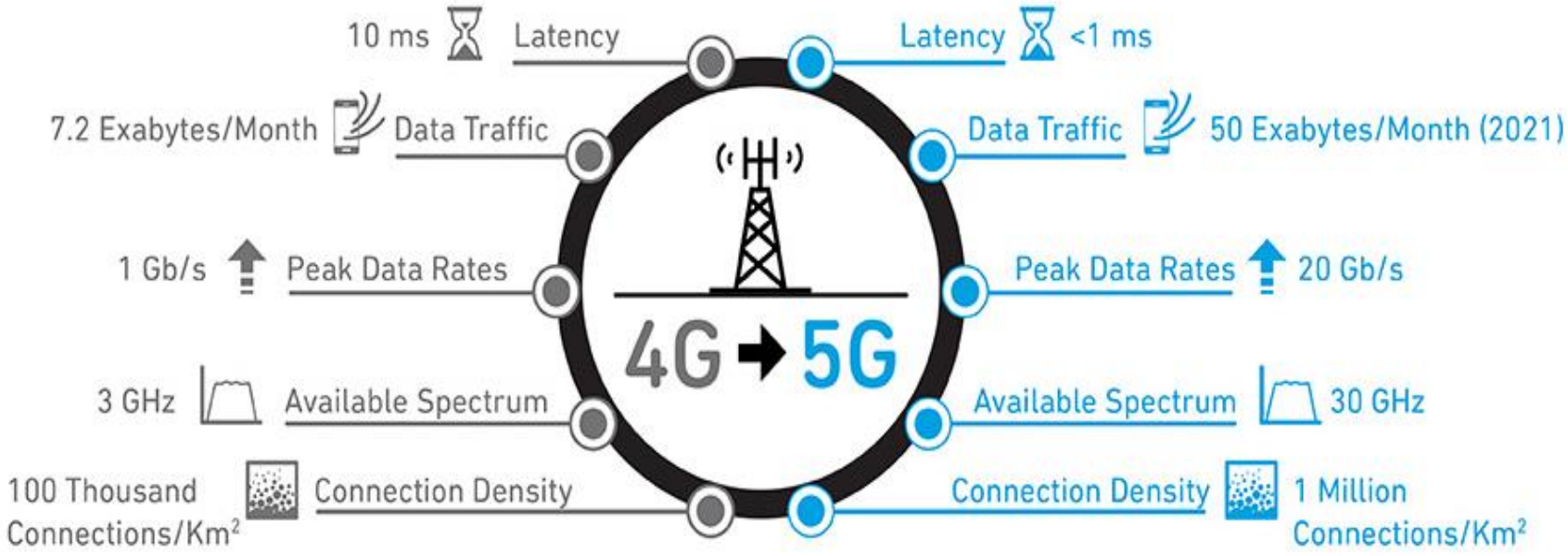


- Uses Orthogonal Frequency Division Multiplexing (OFDM) for downlink
- Uses Single Carrier Frequency Division Multiple Access (SC-FDMA) for uplink
- Uses Multi-input Multi-output(MIMO) for enhanced throughput
- Reduced power consumption
- Higher RF power amplifier efficiency (less battery power used by handsets)

LTE Architecture



4G towards 5G



Generations Comparison

Comparison chart of Generation in Telecommunication

GENERATION	1G	2G	3G	4G	5G
DEPLOYMENT	1970/1984	1980/1989	1990/2002	2000/2010	2017/2020
DATA BANDWIDTH	2Kbps	14-64 Kbps	2Mbps	200Mbps	1Gbps
STANDARDS	AMPS	TDMA, CDMA, GPS, GPRS	WCDMA	Single unified standard	Single unified standard

Generations Comparison…

GENERATION	1G	2G	3G	4G	5G
TECHNOLOGY	Analog cellular	Digital cellular	Broadband with CDMA, IP technology	Unified IP and seamless combination of broadband of LAN, WAN and WLAN	Unified IP and seamless combination of broadband, LAN, WAN, WLAN and WWWW
SERVICES	Mobile technology (voice)	Digital Voice, SMS, Higher capacity packetized	Integrated high quality audio and video	Dynamic information Access, Wearable devices	Dynamic information Access, Wearable devices with AI capabilities
MULTIPLEXING	FDMA	TDMA, CDMA	CDMA	CDMA	CDMA
SWITCHING	Circuit	Circuit and packet	packet	All packet	All packet
CORE NETWORK	PSTN	PSTN	Packet network	Internet	Internet
HANDOFF	Horizontal	Horizontal	Horizontal	Horizontal and Vertical	Horizontal and Vertical

COMPARISON OF 1G-5G

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	Broadband width/ 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

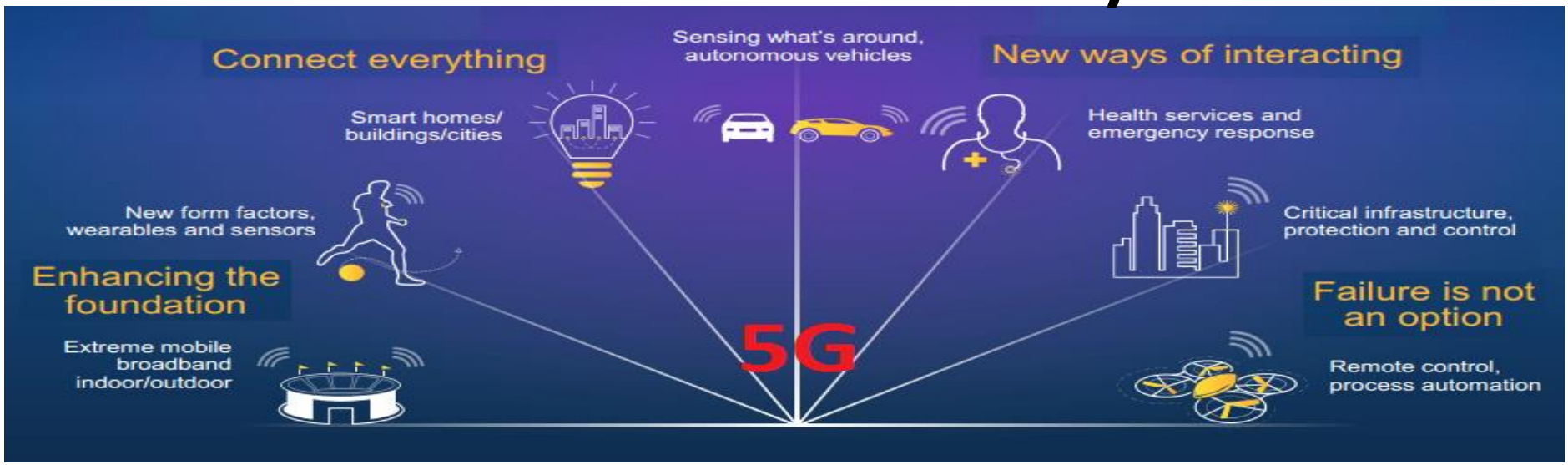
What Is 5G???

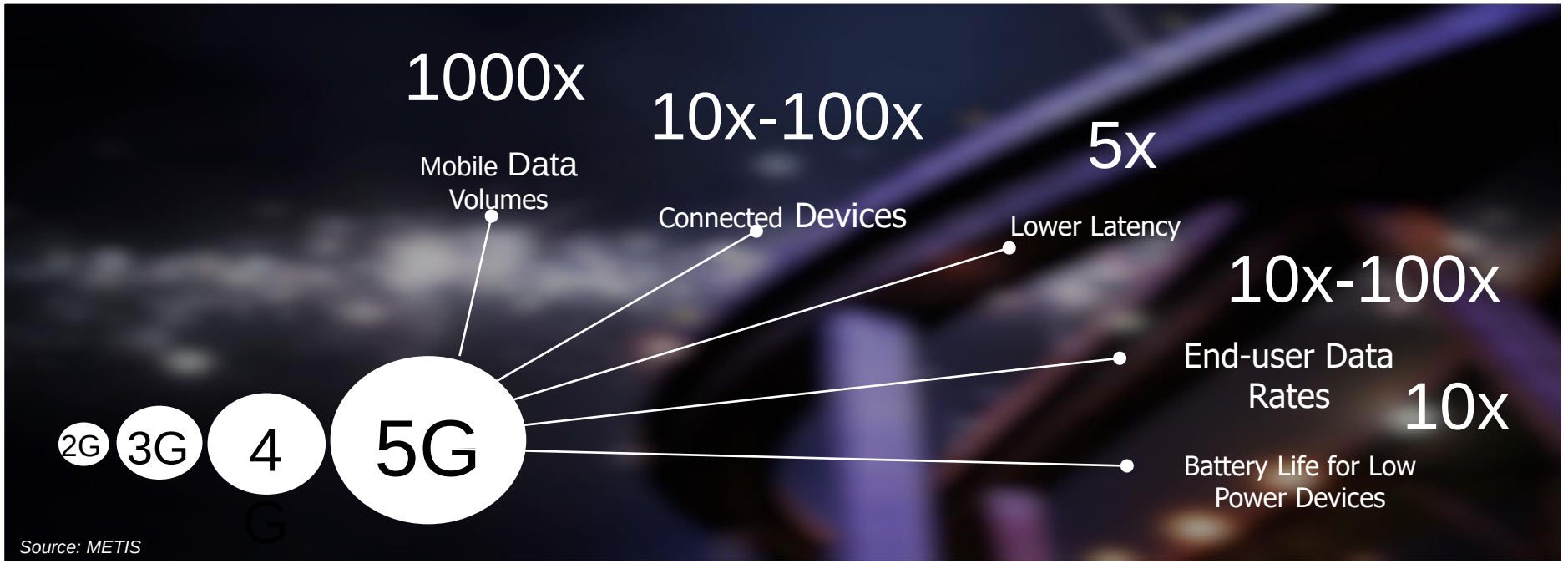
- 5G is a packet switched wireless system with wide area coverage and high throughput.
- 5G wireless uses OFDM and millimeter wireless that enables data rate of 20 mbps and frequency band of 2-8 GHz.
- 5G is going to be a packed based network.

OBJETIVES OF 5G

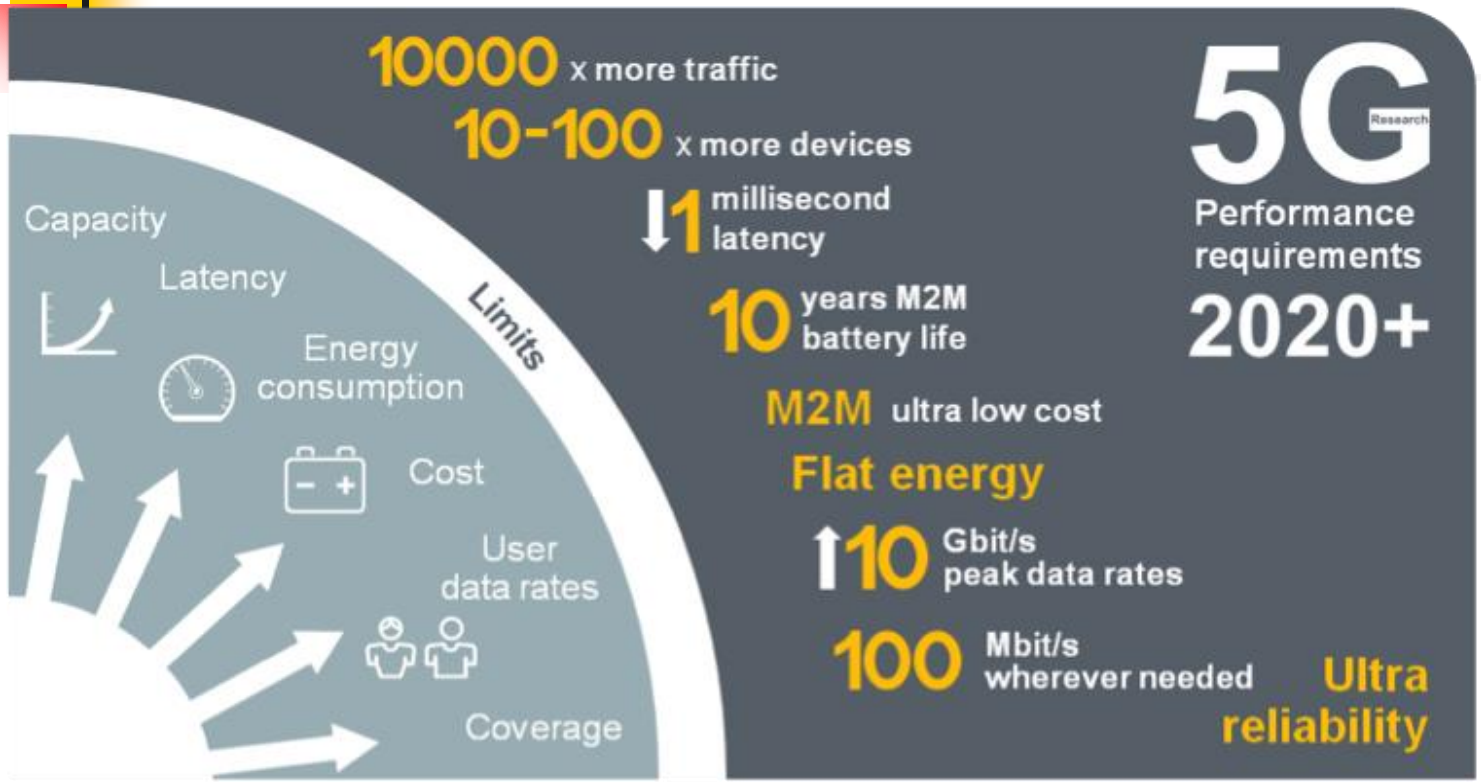
- 5G being developed to accommodate QoS rate requirements set by further development of existing 4G applications.
- Flexible channel bandwidth between 5 and 20MHz, optionally up to 40MHz.
- Data rate of at list 1Gb/s between any two points in the world.
- Increase system spectral efficiency of up to 3bit/s/Hz/cell in the downlink and 2.25bit/s/Hz/cell for indoor usage.

5G is an end-to-end ecosystem to enable a fully mobile and connected society





5G Mobile Network Expected Performance



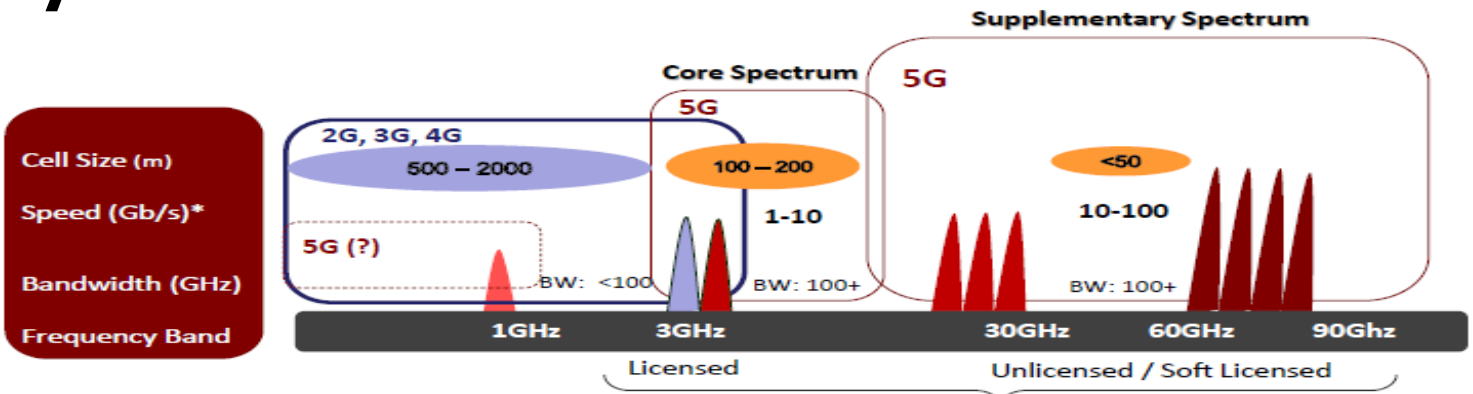
Multi domain performance

Energy Performanc

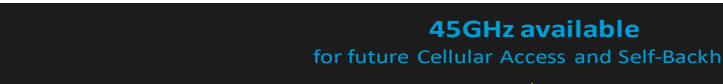
Critical machine type

Global standard

Spectrum remains a Challenge for 5G and for Wireless Industry



- ✓Best use of low (below 6Ghz) & high frequencies (mmWave) - Sub 6GHz as core spectrum, mmWave (10-100 GHz) for ultra dense access & backhaul, Supplementary Services
- ✓Ideally 100+ MHz channel bandwidth
- ✓Dynamic Spectrum Allocation
- ✓Coordinated Shared Access
- ✓ Use of temporal & local availability of spectrum
- ✓Carrier Aggregation



Three key frequency ranges are currently worthy of consideration for different 5G deployment scenarios

Sub-1 GHz

- Ideal coverage band could provide a very useful means of extending a superior 5G user experience into rural areas and deep inside buildings.
- Could not support extremely wide bandwidths and therefore enable the fastest possible data rates
- But Help prevent a new digital divide by ensuring the improved experience.
- Reaches more people in both developed, and especially developing, markets.

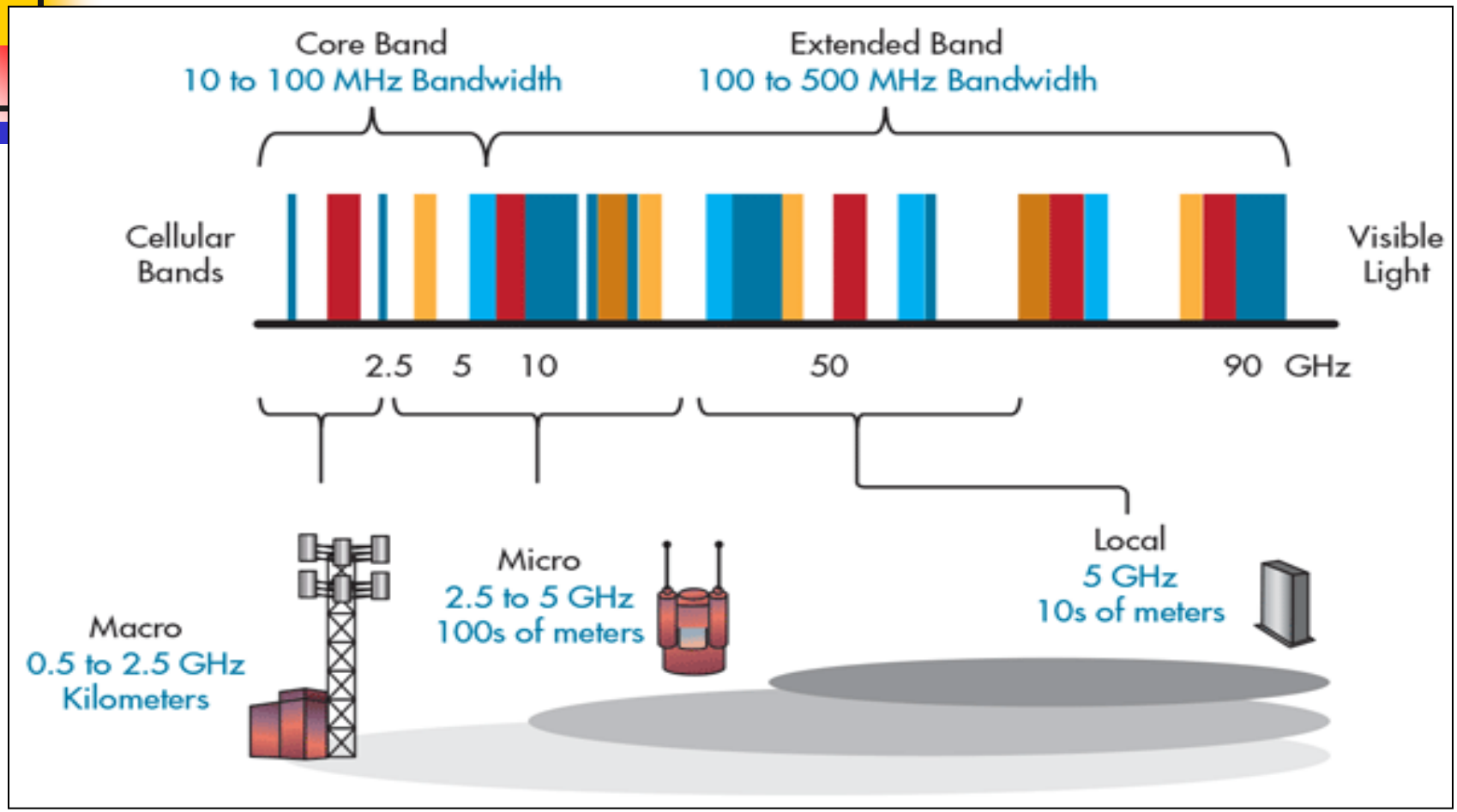
1-6 GHz

- There are numerous existing mobile bands between 1 GHz-2.6 GHz, and when 5G technology is ready to deploy there may be others between 2.6 GHz and 4 GHz.
- Although these bands offer a reasonable mixture of coverage and capacity they are unlikely to be able to support the highest potential 5G data rates without carrier aggregation.

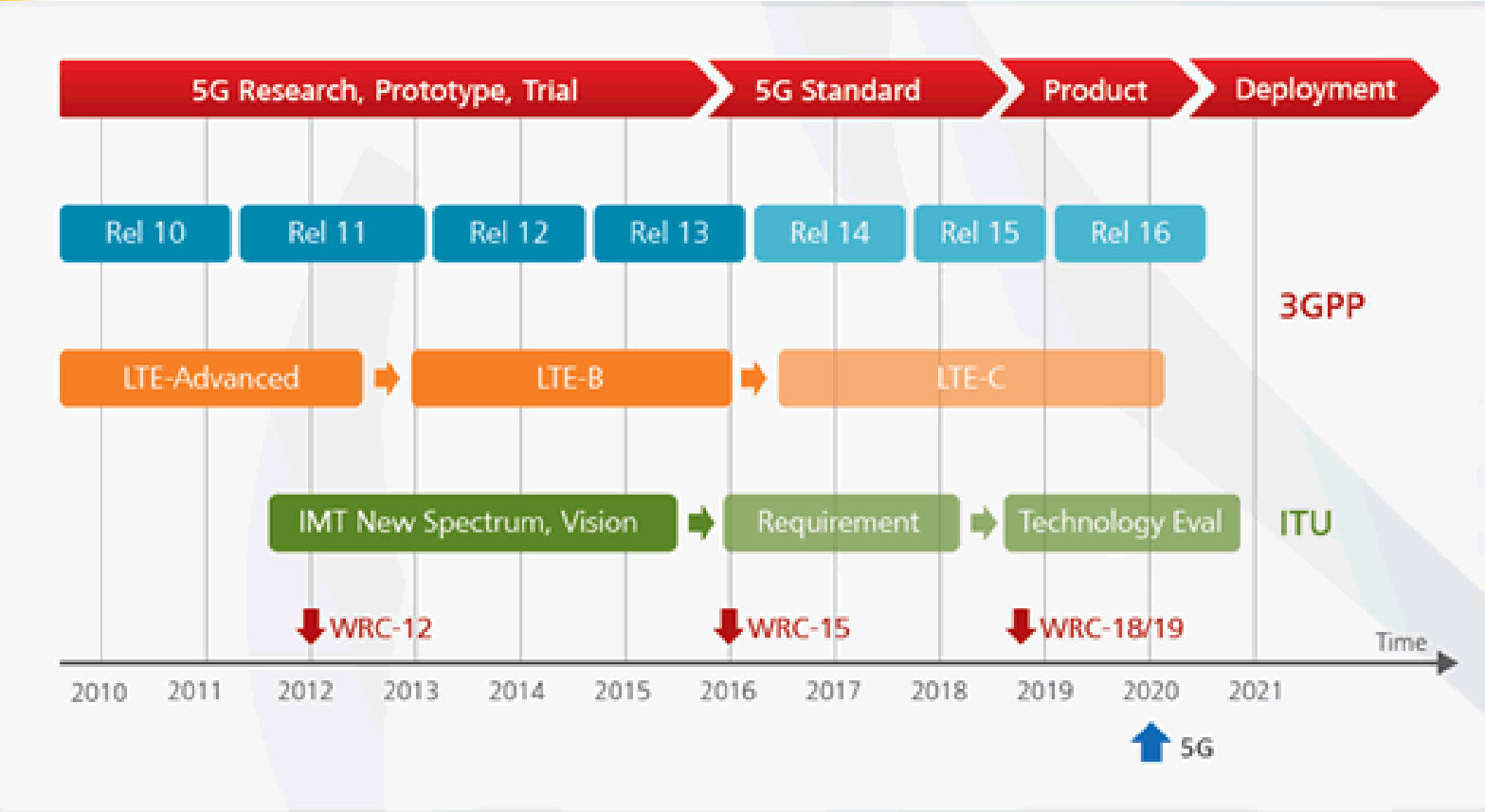
Above 6 GHz

- This spectrum could support very wide channel sizes and therefore extremely fast data rates, and massive additional mobile network capacity, making it fertile territory for 5G research.
- However, heavy reliance on these bands without complimentary lower frequency spectrum may mean 5G services are limited to small urban areas and inside buildings as its radio propagation qualities would favor small cell sizes.

5G Bands and its impact on Cell size



Standardization of 5G Time line (ITU & 3GPP)

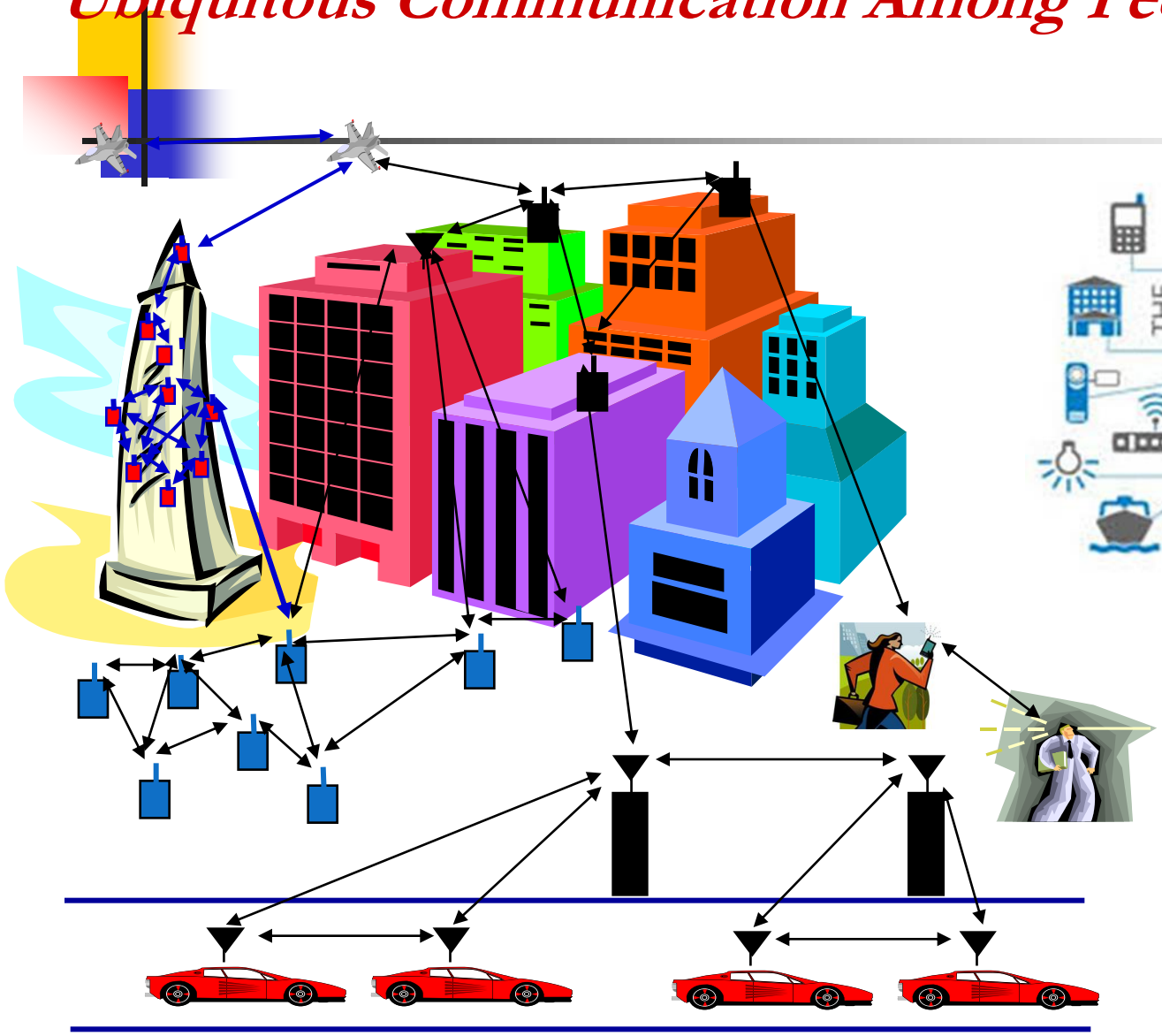


5G is still going on

- 5G race is still going on, Commercial deployment of 5G systems is expected in years 2020+, Field trials planned from year 2018 onwards, not yet based on commercial products.
- 5G will provide at least a ten-fold improvement in user experience compared to 4G in terms of peak data rates and minimal latency
- 5G will deliver an ecosystem for sustainable technical and business innovation
- 5G will support multi tenancy and network resource slicing models, New architectures will be used (using Likely many of the generalized concepts – SDR, CR, SDN, NFV, …)
- 5G will be designed to be a sustainable and scalable technology
- 5G spectrum and Bands not yet finalized

Future Wireless Networks

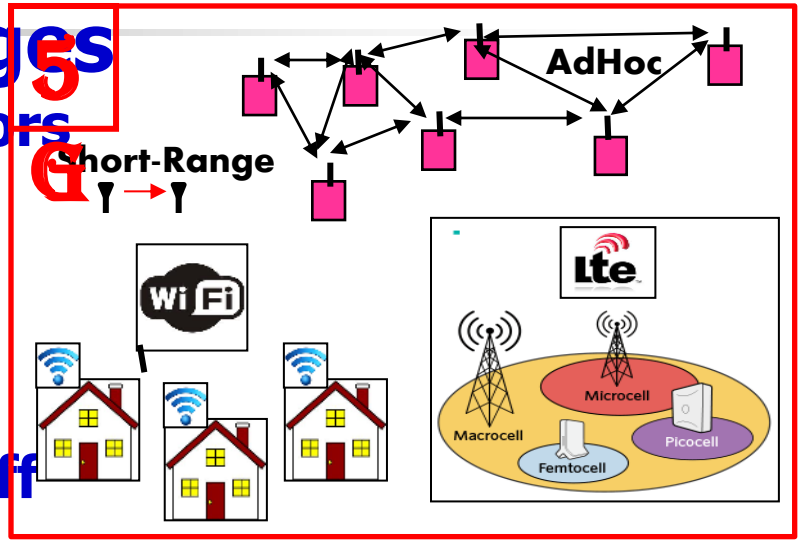
Ubiquitous Communication Among People and Devices



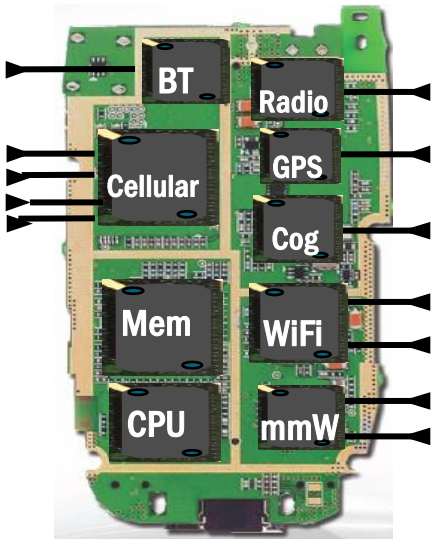
- Next-Gen Cellular/WiFi
- Smart Homes/Spaces
- Autonomous Cars
- Smart Cities
- Body-Area Networks
- Internet of Things
- All this and more …

Challenges

- **Network/Radio Challenges**
  - Gbps data rates with "no" errors
  - Energy efficiency
  - Scarce/bifurcated spectrum
  - Reliability and coverage
  - Heterogeneous networks
  - Seamless internetwork handoff

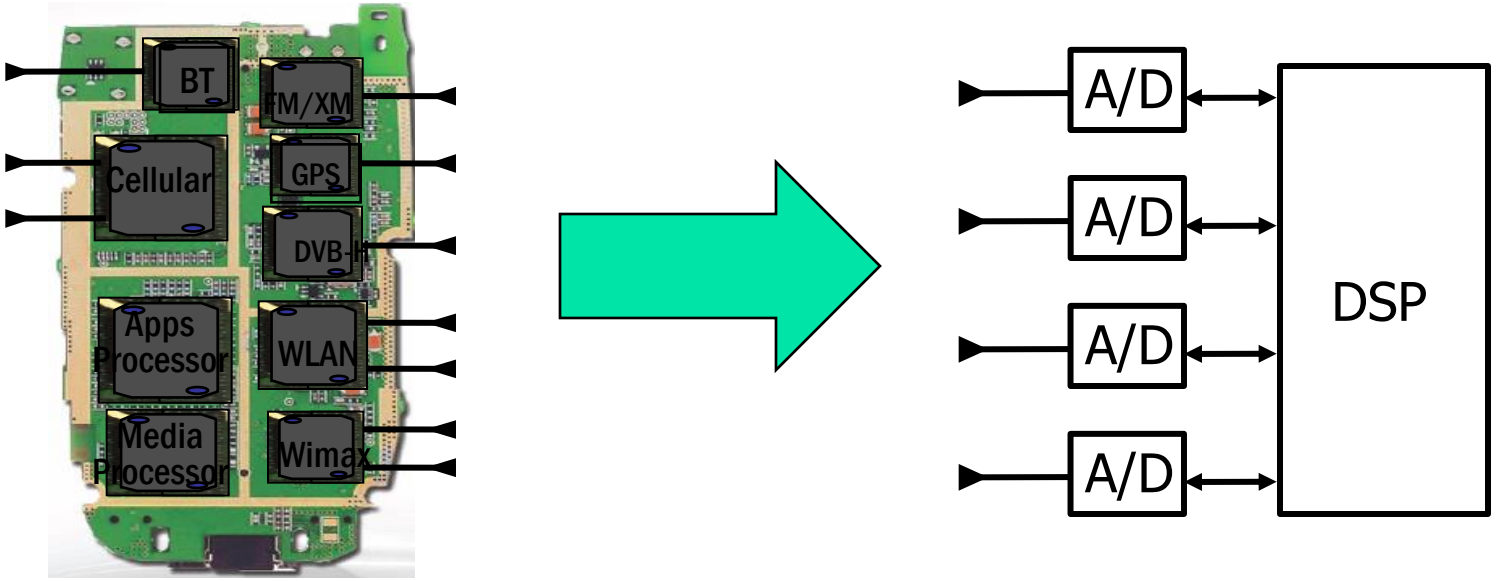


- **Device/SoC Challenges**
  - Performance
  - Complexity
  - Size, Power, Cost
  - High frequencies/mmWave
  - Multiple Antennas
  - Multiradio Integration
  - Coexistance



Software-Defined (SD) Radio:

Is this the solution to the device challenges?



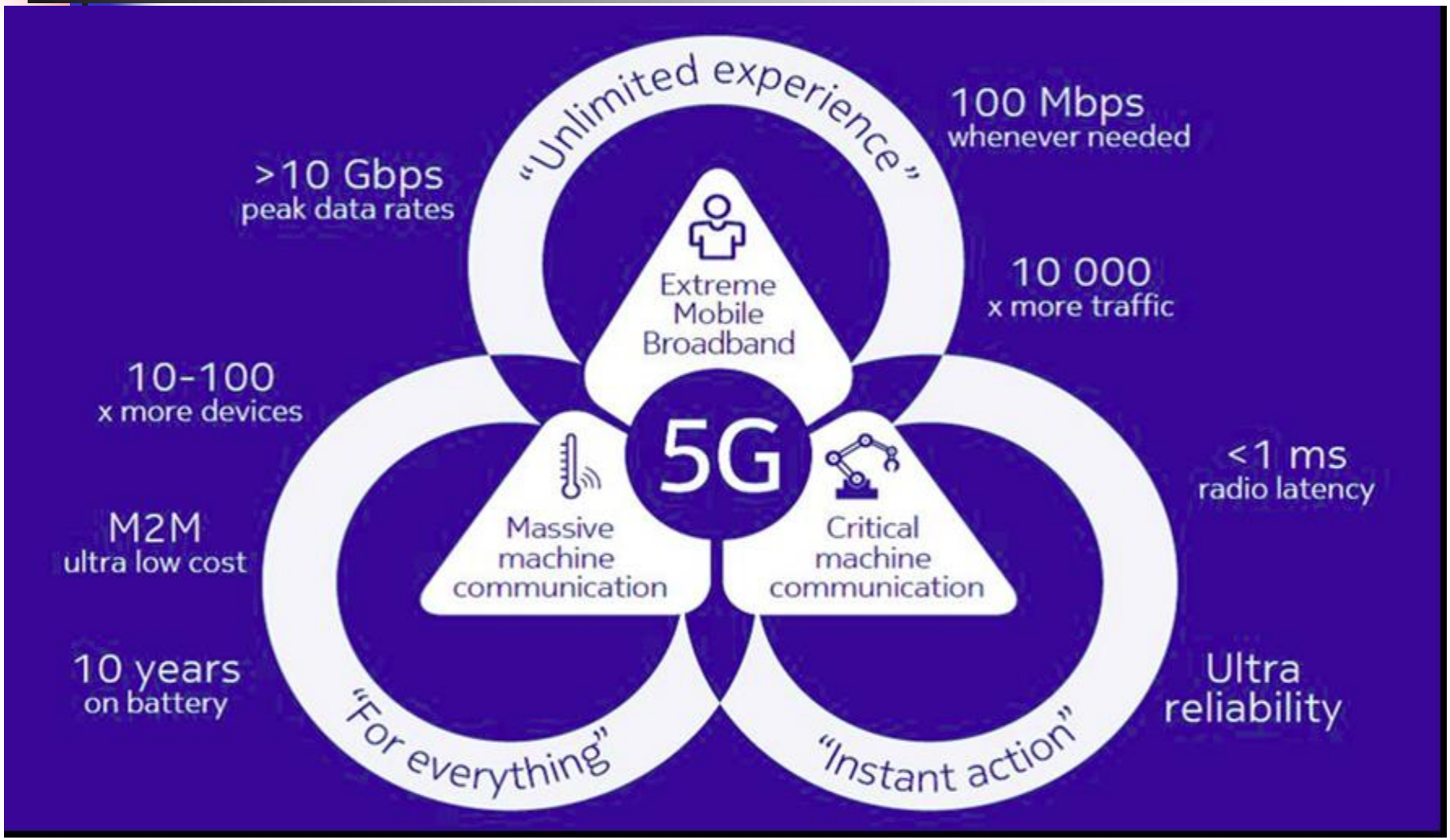
Wideband antennas and A/Ds span BW of desired signals

DSP programmed to process desired signal: no specialized HW

Today, this is not cost, size, or power efficient

SubNyquist sampling may help with the A/D and DSP requirements

5G Upgrades from 4G



Spectrum Regulation

- Spectrum a scarce public resource, hence allocated
- Spectral allocation in US controlled by FCC (commercial) or OSM (defense)
- FCC auctions spectral blocks for set applications.
- Some spectrum set aside for universal use
- Worldwide spectrum controlled by ITU-R
- Regulation is a necessary evil.

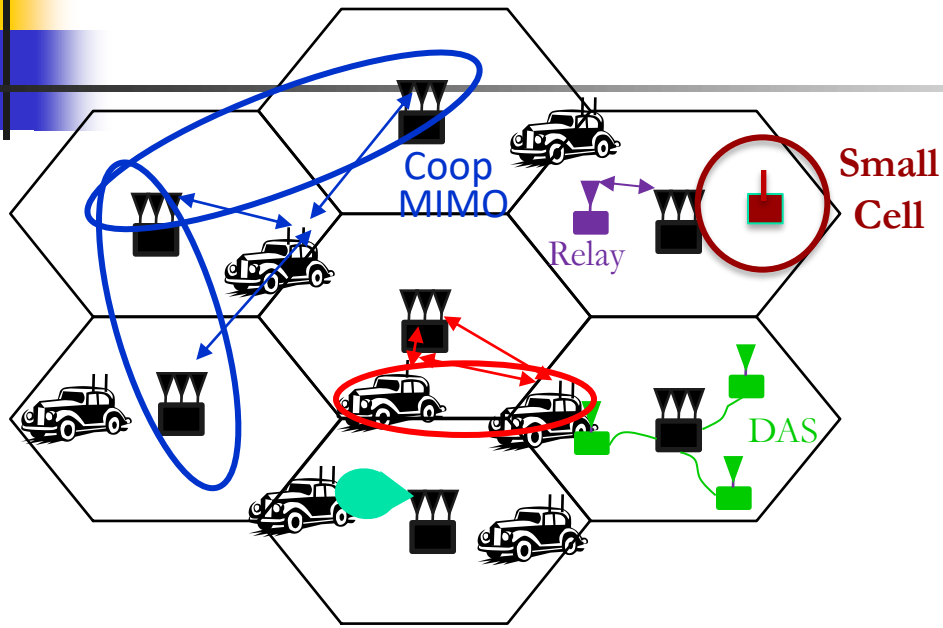
Innovations in regulation being considered worldwide in multiple cognitive radio paradigms

Standards

- Interacting systems require standardization
- Companies want their systems adopted as standard
  - Alternatively try for de-facto standards
- Standards determined by TIA/CTIA in US
  - IEEE standards often adopted
  - Process fraught with inefficiencies and conflicts
- Worldwide standards determined by ITU-T
  - In Europe, ETSI is equivalent of IEEE

Standards for current systems are summarized in Appendix D.

Rethinking "Cells" in Cellular

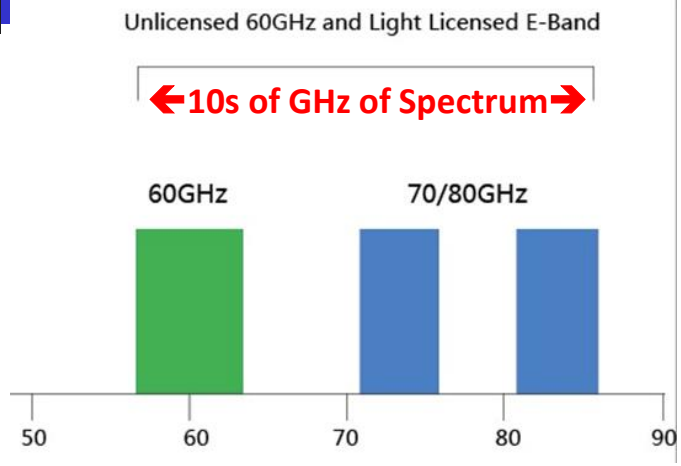


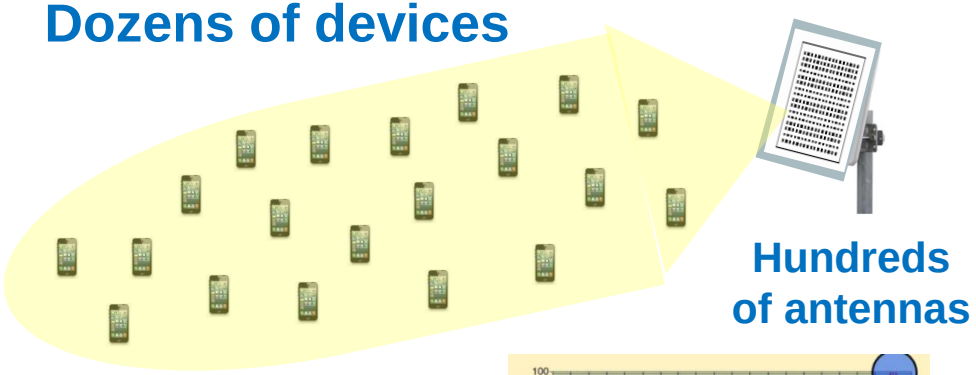
How should cellular systems be designed for

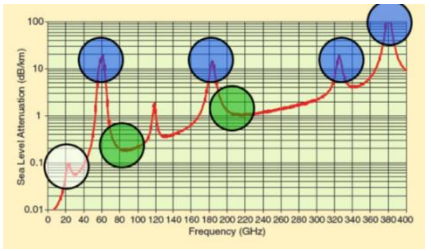
- *Capacity*
- *Coverage*
- *Energy efficiency*
- *Low latency*

- Traditional cellular design "interference-limited"
  - MIMO/multiuser detection can remove interference
  - Cooperating BSs form a MIMO array: what is a cell?
  - Relays change cell shape and boundaries
  - Distributed antennas move BS towards cell boundary
  - Small cells create a cell within a cell
  - Mobile cooperation via relays, virtual MIMO, network coding.

mmWave Massive MIMO

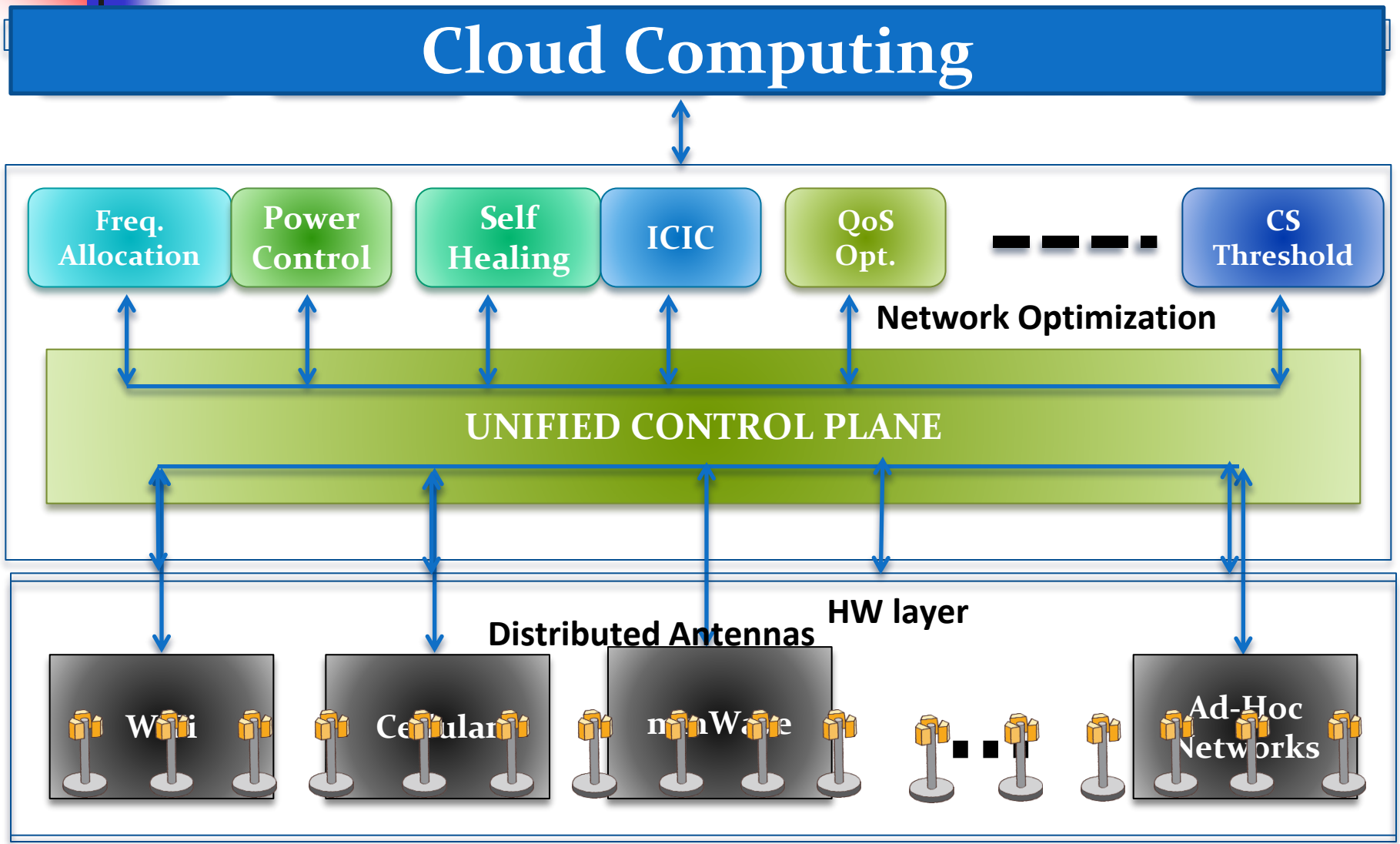




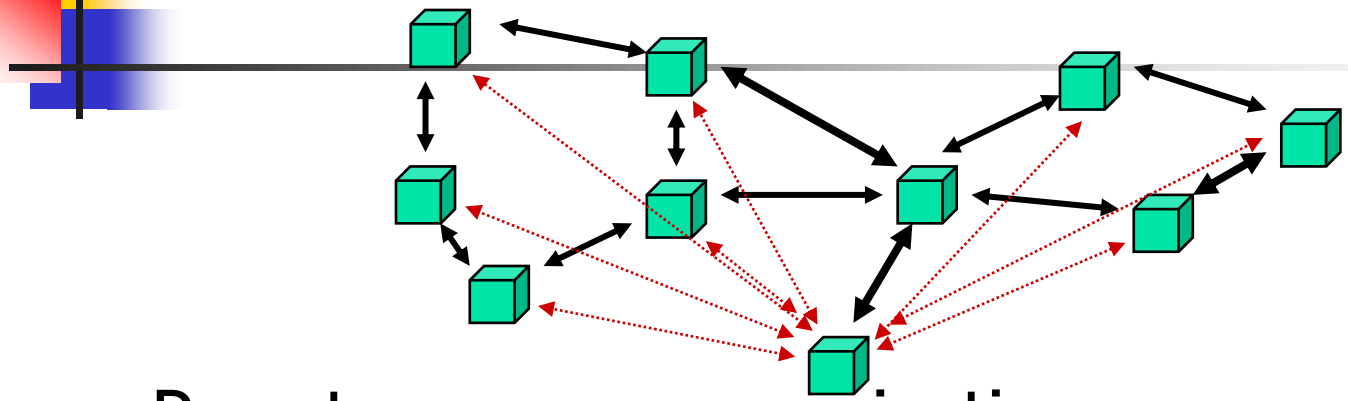


- Mm-Waves have large non-monotonic path loss
  - Channel model poorly understood
- For asymptotically large arrays with channel state information, no attenuation, fading, interference or noise
- mmWave antennas are small: perfect for massive MIMO
- Bottlenecks: channel estimation and system complexity
- Non-coherent design holds significant promise

Software-Defined Network Architectures

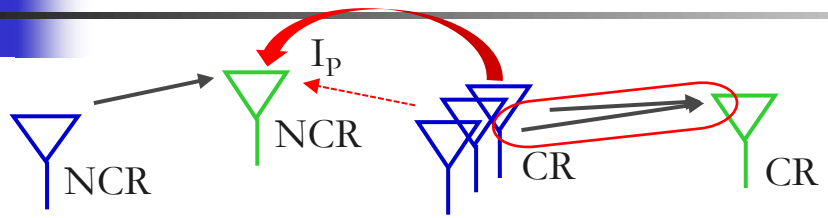


Ad-Hoc Networks

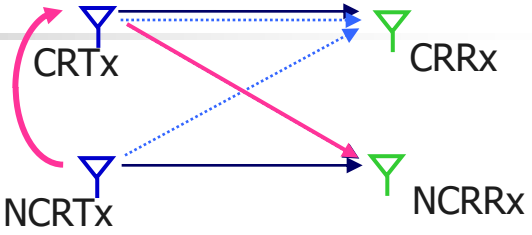


- Peer-to-peer communications
  - No backbone infrastructure or centralized control
- Routing can be multihop.
- Topology is dynamic.
- Fully connected with different link SINRs
- Open questions
  - Fundamental capacity region
  - Resource allocation (power, rate, spectrum, etc.)
  - Routing

Cognitive Radios



MIMO Cognitive Underlay

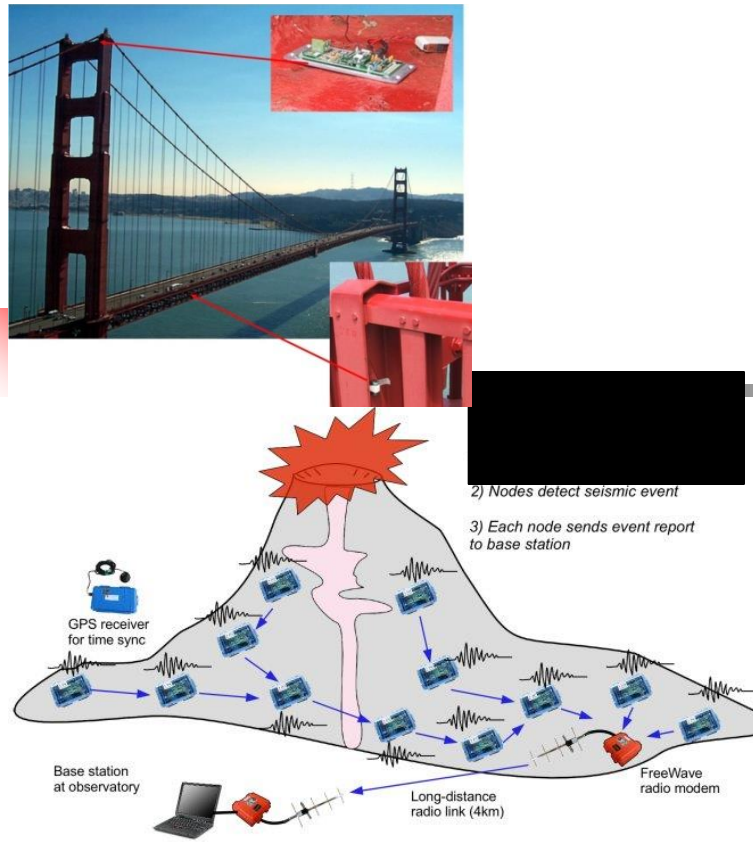


Cognitive Overlay

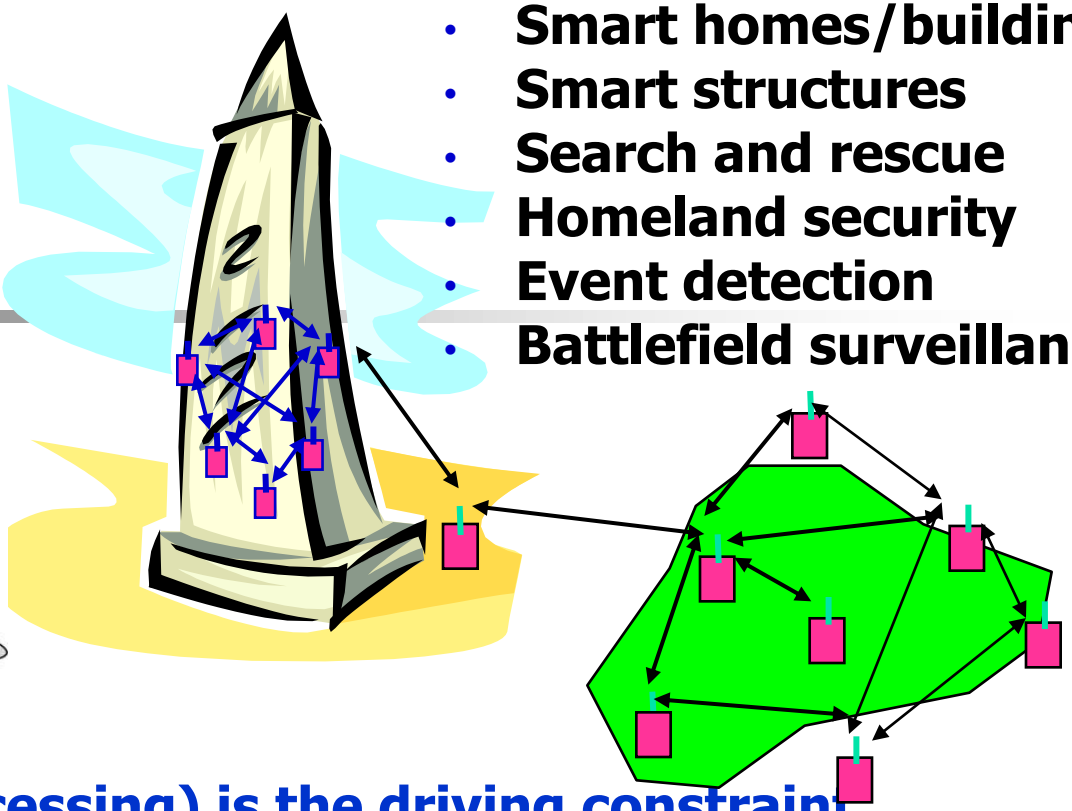
- Cognitive radios support new users in existing crowded spectrum without degrading licensed users
  - Utilize advanced communication and DSP techniques
  - Coupled with novel spectrum allocation policies
- Multiple paradigms
  - (MIMO) Underlay (interference below a threshold)
  - Interweave finds/uses unused time/freq/space slots
  - Overlay (overhears/relays primary message while cancelling interference it causes to cognitive receiver)

Wireless Sensor Networks

Data Collection and Distributed Control

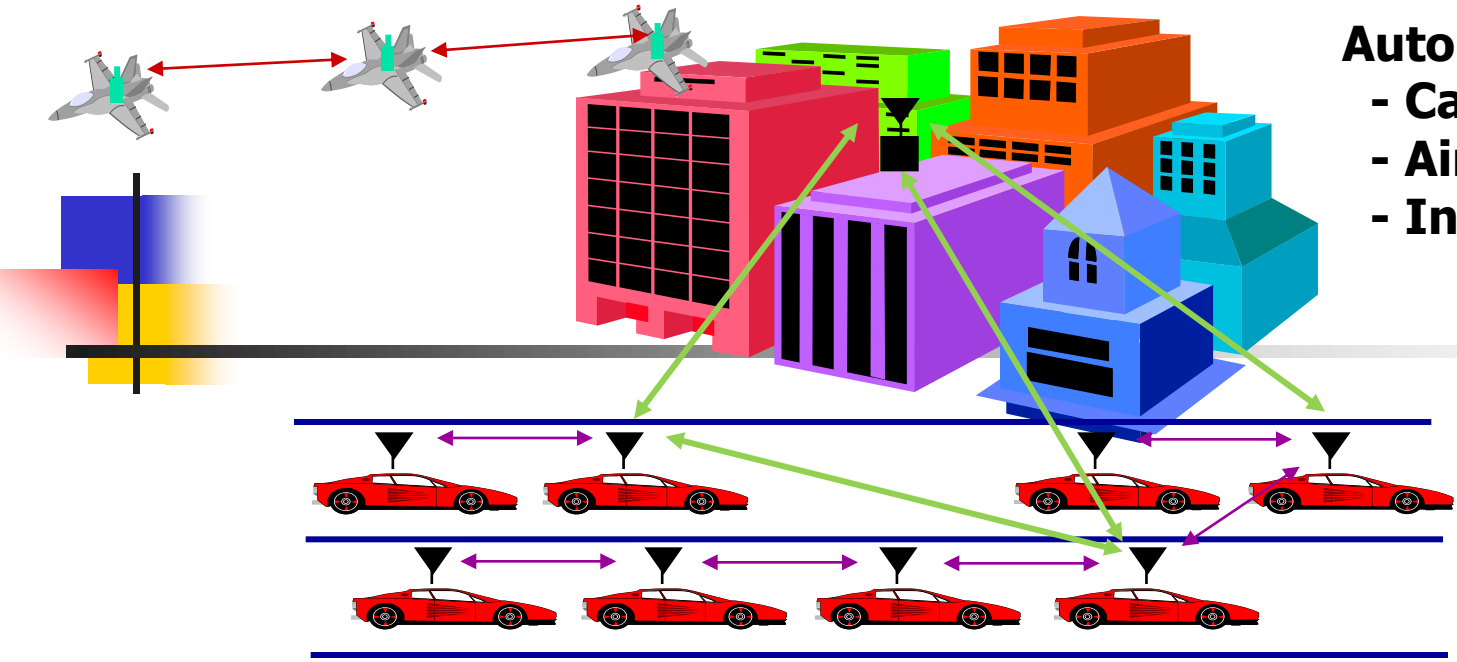


- Smart homes/building
- Smart structures
- Search and rescue
- Homeland security
- Event detection
- Battlefield surveillance



- Energy (transmit and processing) is the driving constraint
- Data flows to centralized location (joint compression)
- Low per-node rates but tens to thousands of nodes
- Intelligence is in the network rather than in the devices

Distributed Control over Wireless



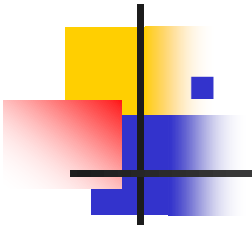
Automated Vehicles
- **Cars**
- **Airplanes/UAVs**
- **Insect flyers**

Interdisciplinary design approach

- **Control requires fast, accurate, and reliable feedback.**
- **Wireless networks introduce delay and loss**
- **Need reliable networks and robust controllers**
- **Mostly open problems**

: Many design challenges

Main Points



- The wireless vision encompasses many exciting applications
- Technical challenges transcend all system design layers
- 5G networks must support higher performance for some users, extreme energy efficiency and/or low latency for others
- Cloud-based software to dynamically control and optimize wireless networks needed (SDWN)
- Innovative wireless design needed for 5G cellular/WiFi, mmWave systems, massive MIMO, and IoT connectivity
- Standards and spectral allocation heavily impact the evolution of wireless technology