



The Promise of 5G – The Journey Begins

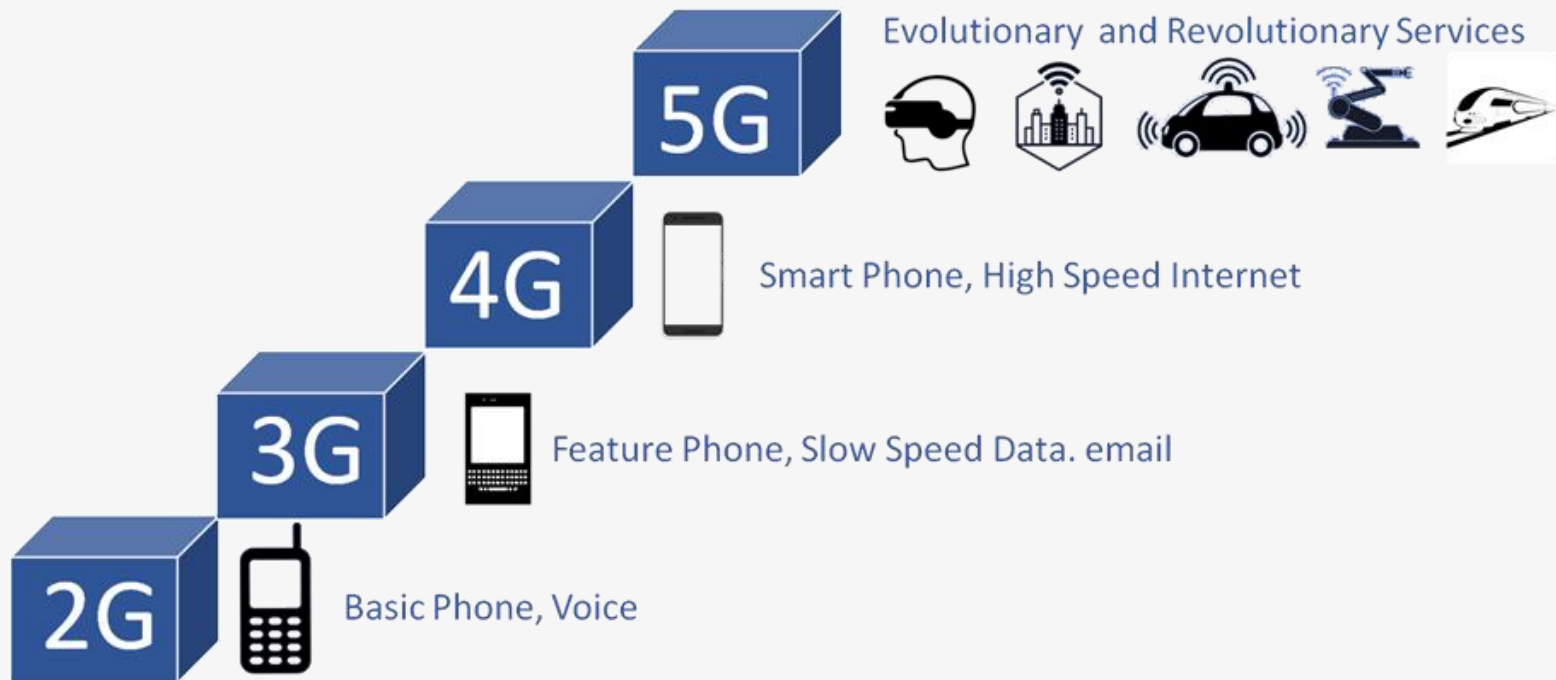
Arogyaswami Paulraj

EE402 A
Stanford University
October 3, 2019

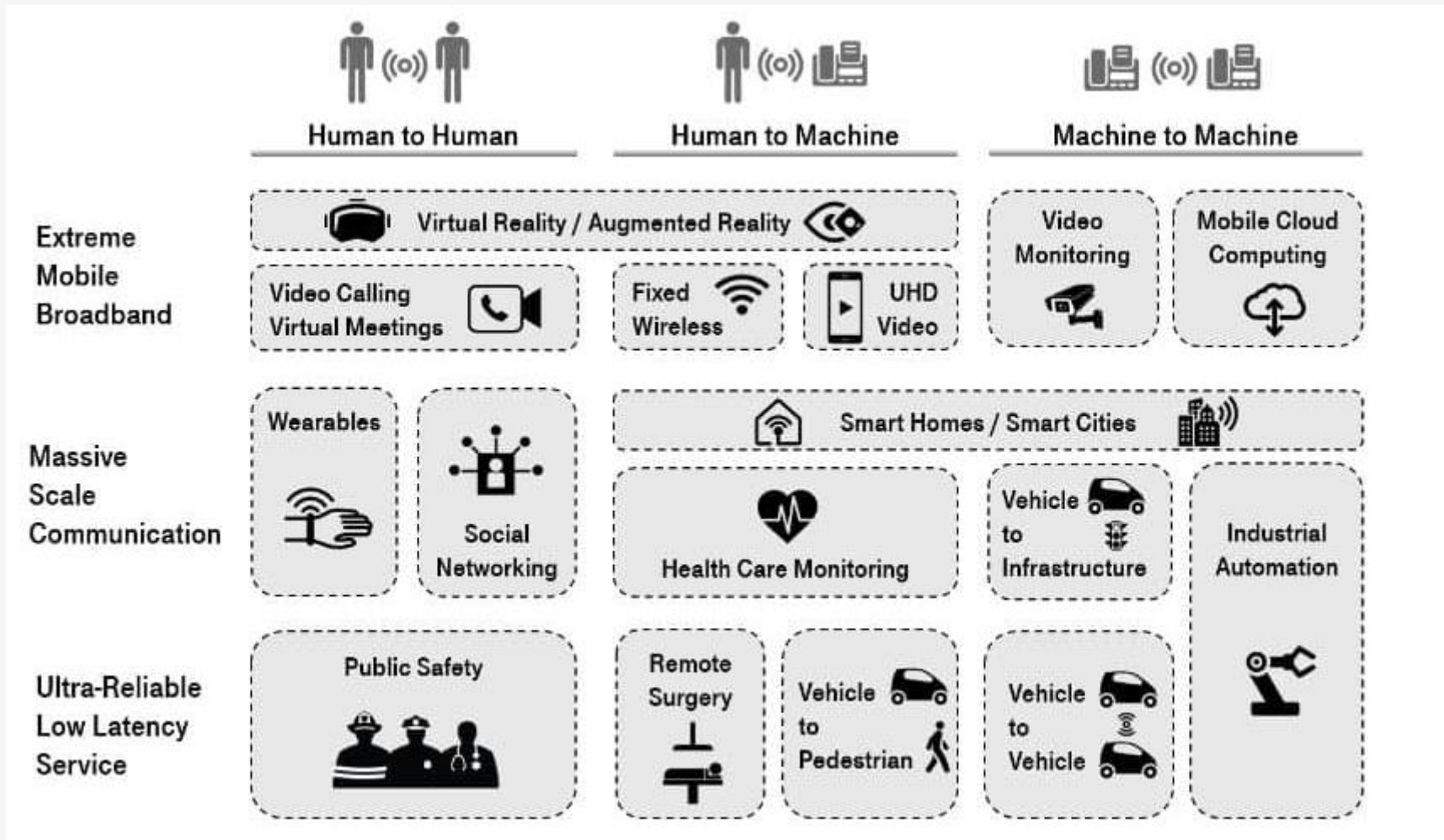
The Killer App - Wireless

- Personal wireless brought huge benefits
 - Mobility, ease of access, reach, scalability, ease of deployment and lower costs
- 5G will bring these and more benefits to sensors, actuators, machines, as well as enabling data analytics and AI, and ultimately Industry 4.0

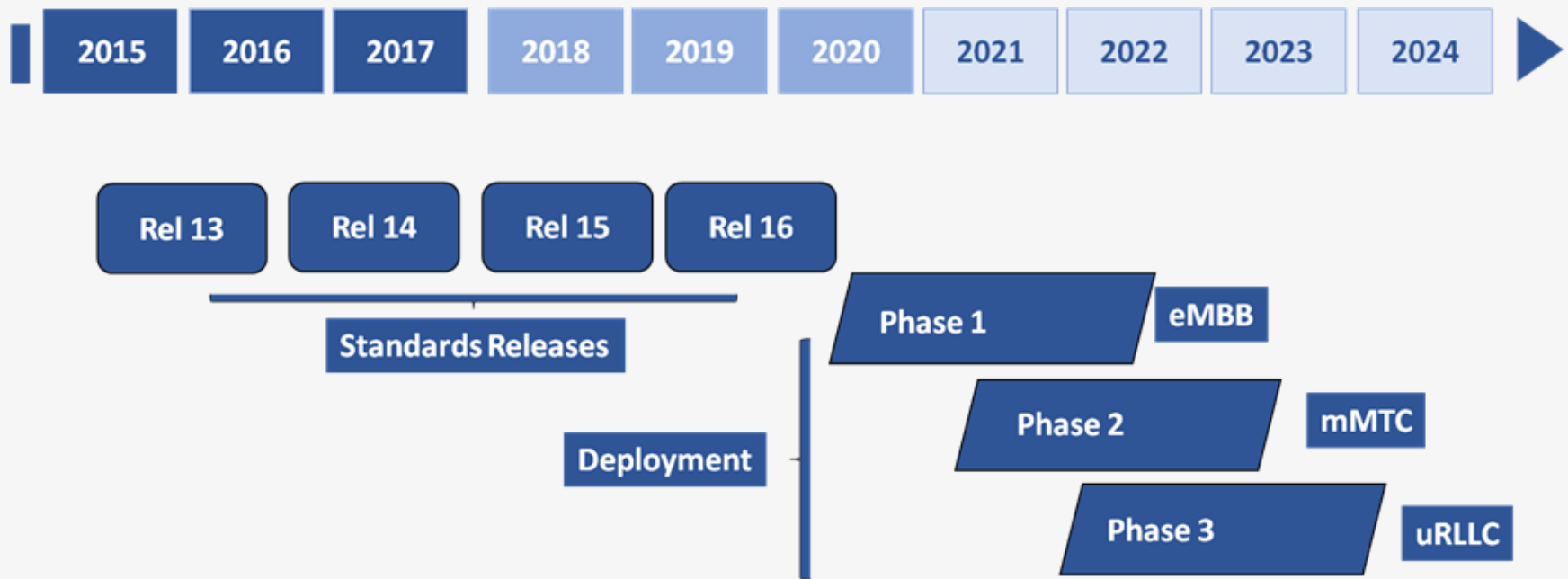
More than a Another G



5G - Transformational Fabric



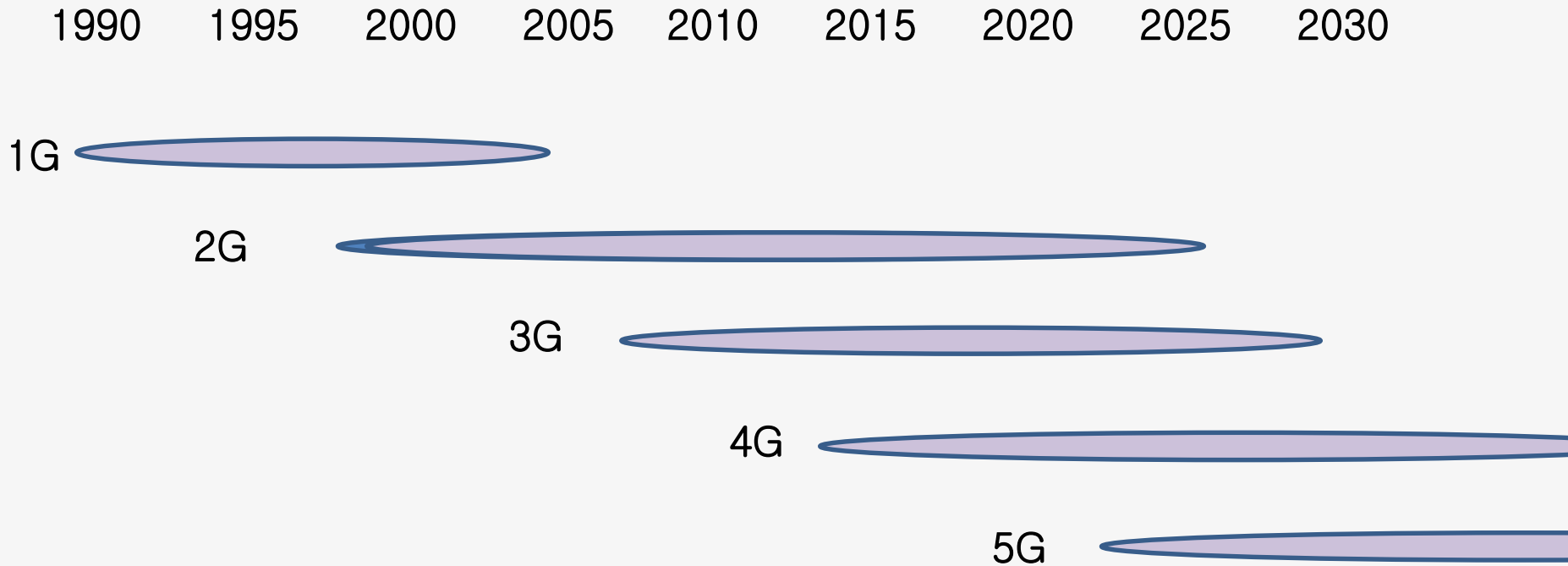
Standards and Deployments



Technology Evolution

1G	Analog,		Phones	
2G	Digital	Ckt Switch	TDMA	Phones
3G			CDMA,	Phones
4G		Pkt Switch	MIMO - OFDMA	Smart Phones
5G			MIMO – OFDMA	Smart Phones IoT, LL-UR

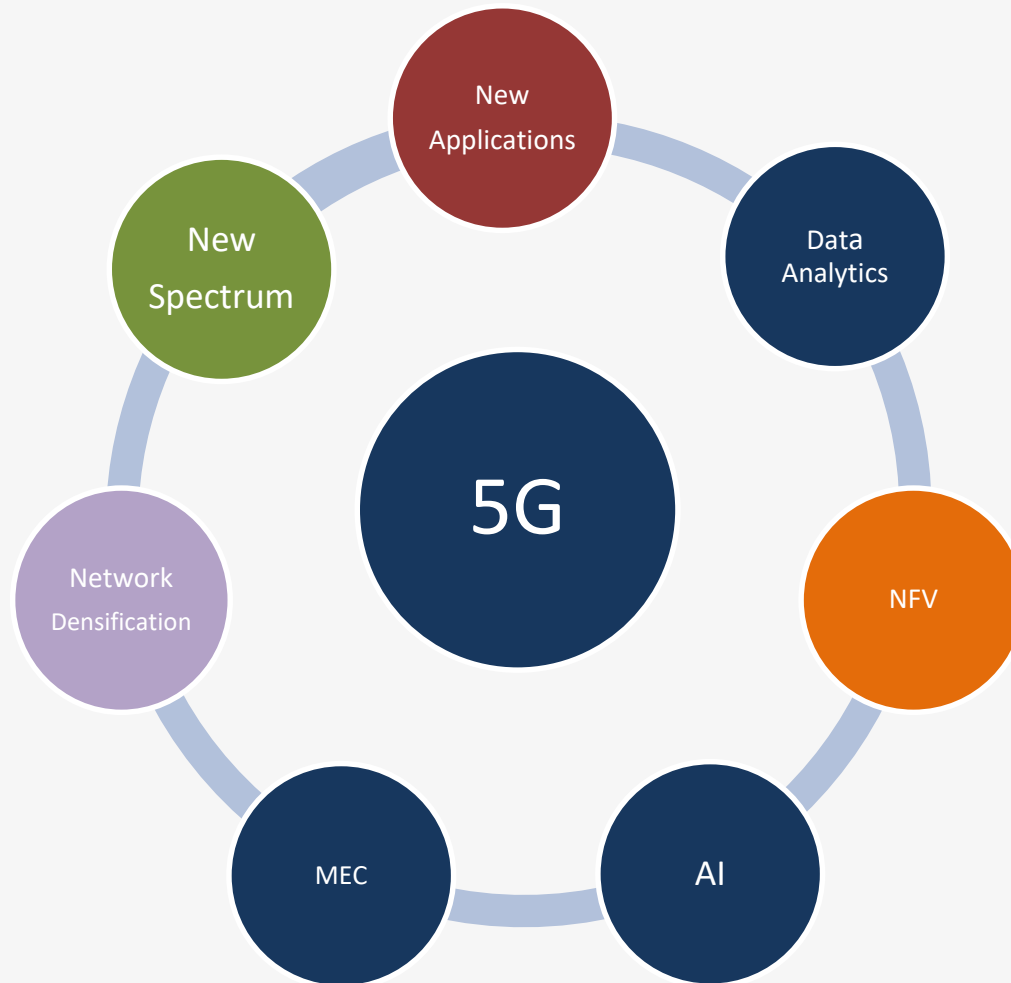
Technology Lifespans



Uptake Barriers

- eMBB - Use case - just another G /phone
 - Spectrum auctions
 - Availability of phones / devices
 - Infrastructure cost (small cells)
- IoT, LL/UR – Use case – mostly new
 - New class of devices and applications
 - High customization
 - Needs changes deep within industry process to adopt technology

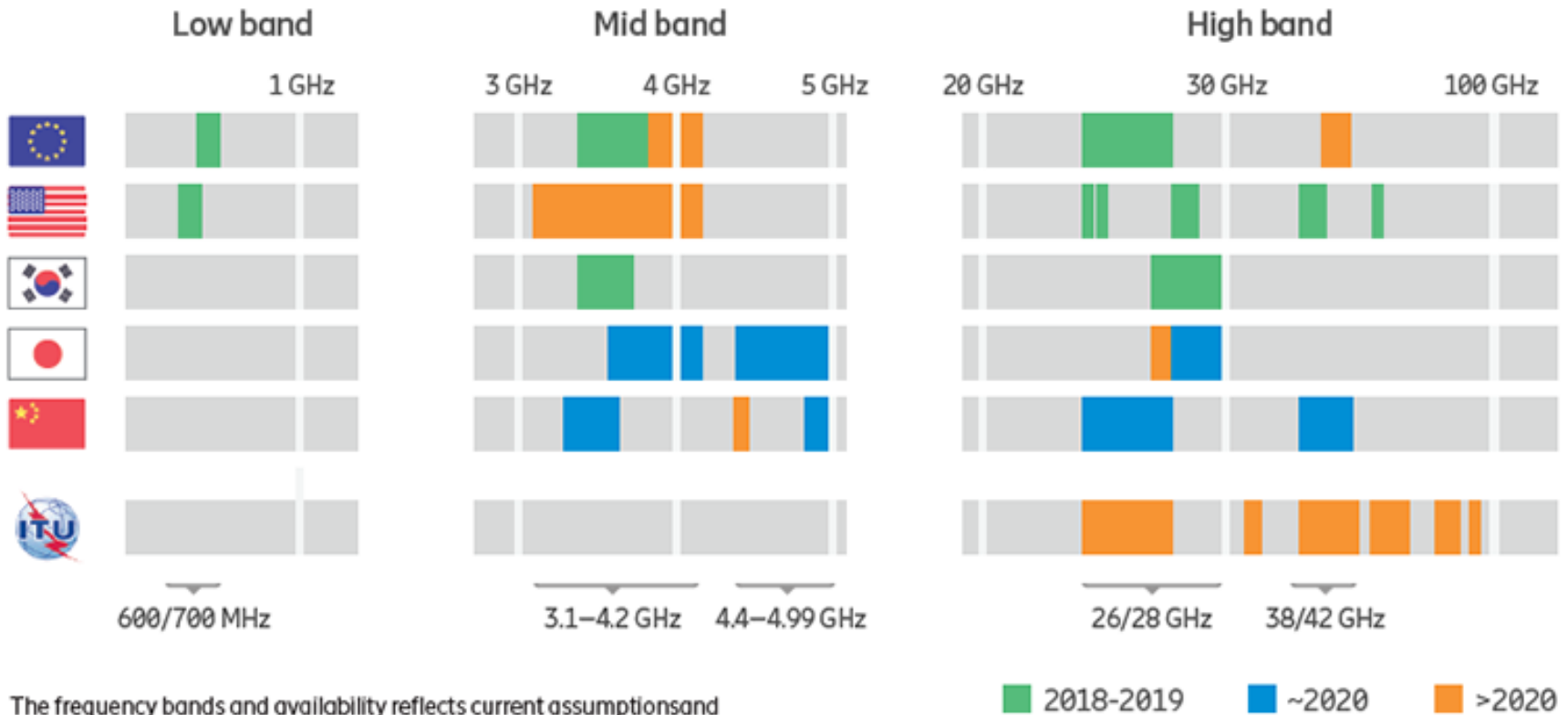
What's New in 5G



Frequency Bands

Low < 1 GHz	Mid 3.5 GHz	24–40 GHz
IoT Large cells	Phones Macro cells	Phones, FWA, Small cells

Spectrum Roadmap



The frequency bands and availability reflects current assumptions and are based indications from different countries/regions

mm-Band

- Bands
 - 24, 28, 37, 39 GHz
- Propagation mode
 - Generally LOS / single bounce LOS
 - No significant loss in free space
- Deployment
 - Smaller cells ~200 - 400 M
- Beamforming essential



5G Cell Radius – Fixed Aperture

Freq band	3.5 GHz	24 GHz	28 GHz	39 GHz
Beam Width	25 Deg	3 Deg	2.5 Deg	2 Deg
Cell Radius	620 M	460 M	400 M	380 M
Array Size	5x5	34 x34	40x40	55x55

33 dBm
Tx Power

20 x 20 cm
array

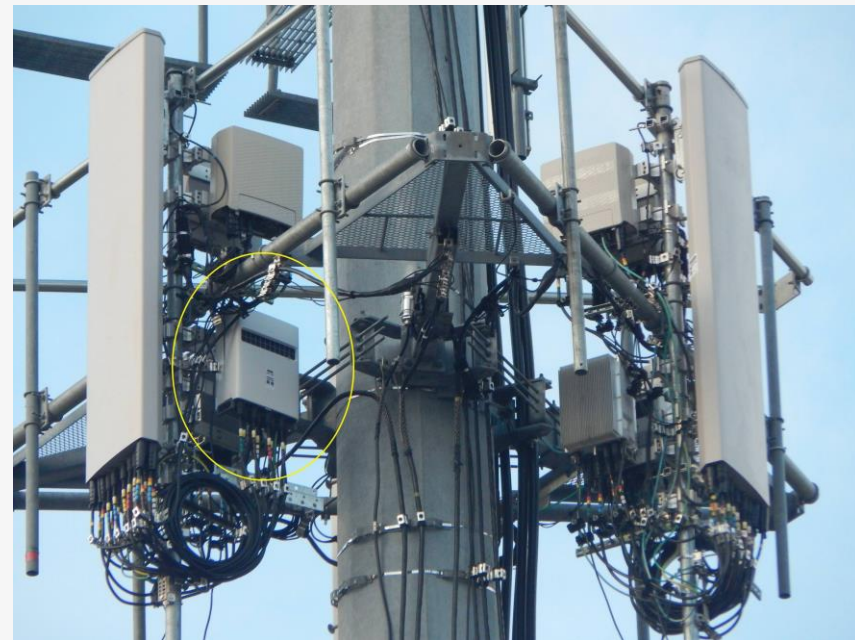
With a Fixed Aperture, Higher Frequencies Suffer Minimal Range Penalty



eMBB

eMMB (Another G)

- Service to phones, MyFi and CPEs
- 2-20 Gbps peak
- NSA initially, going to SA later
- 5G NR radio
- Mid and High Bands
- 20X lower cost/bit



5G FWA

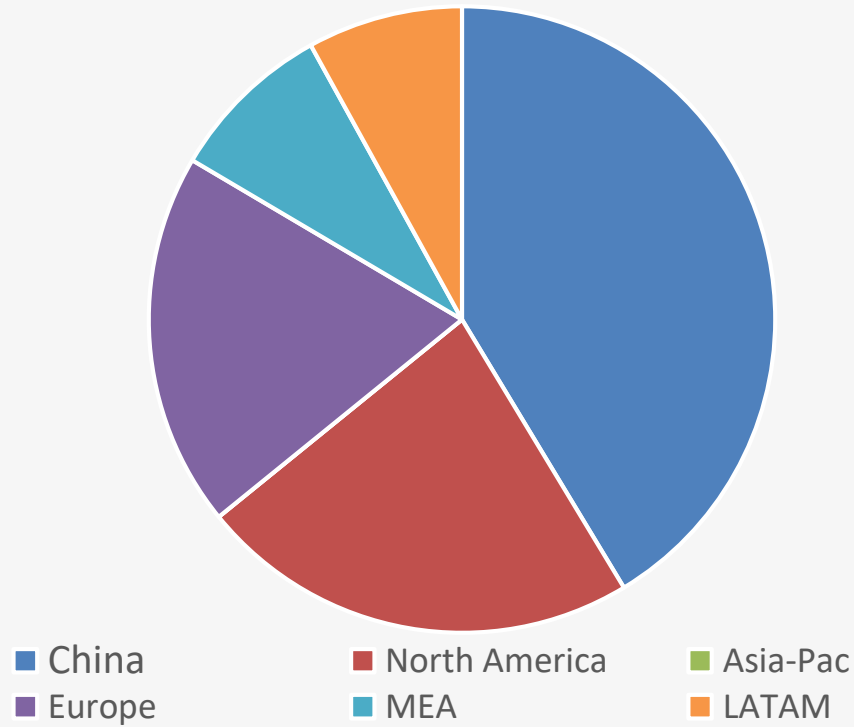
- Delivers G bit access
- CPE terminals
- Verizon and AT&T roll out in US
- Low foliage
- Competition from 60 GHz Mesh (WeLink,..)



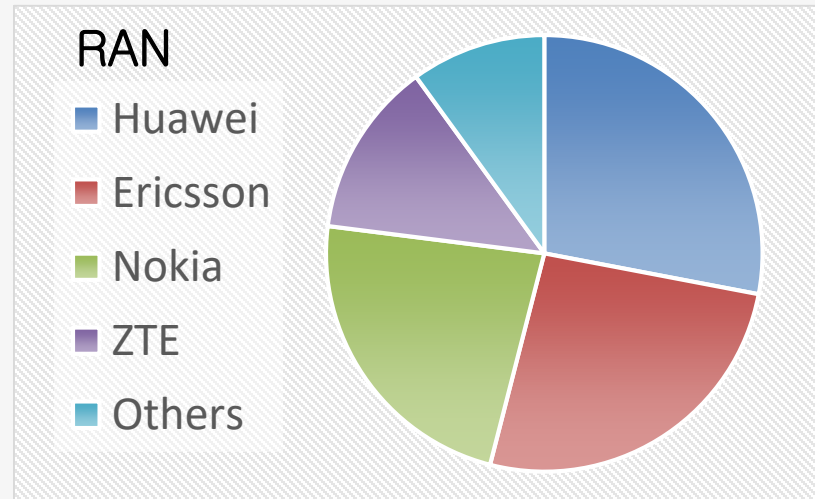
5G Americas

5G Phone Subs

1.9 B by 2024



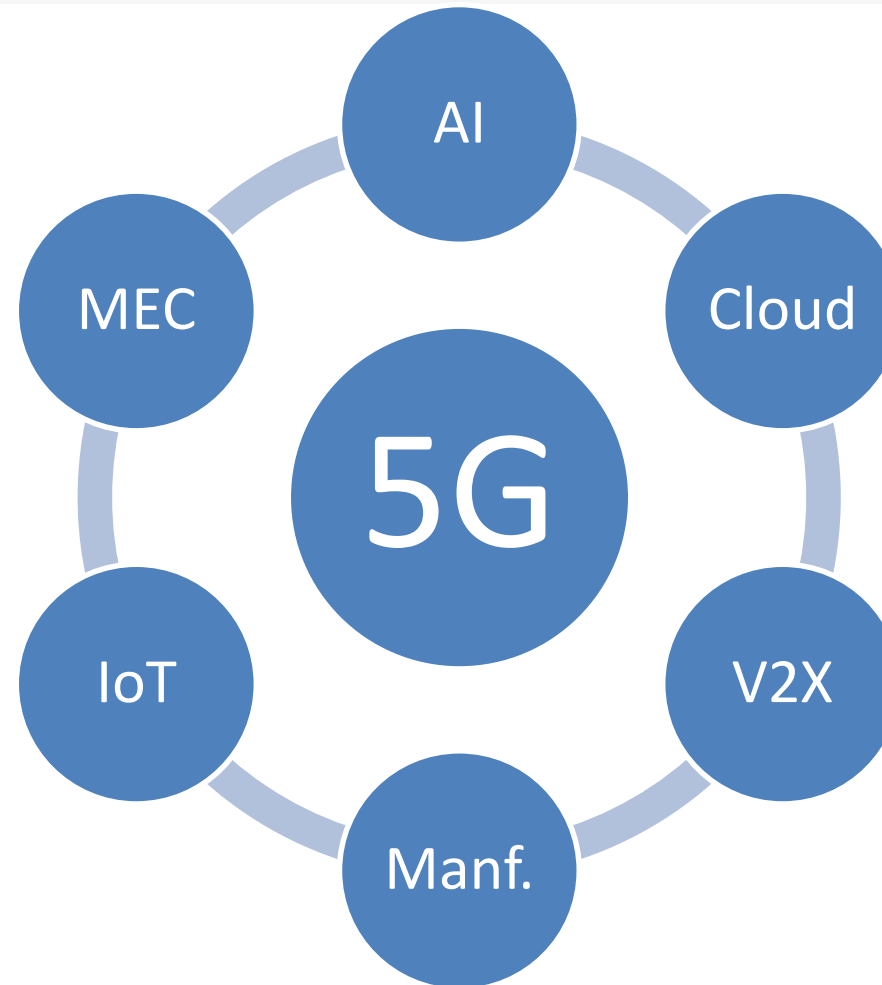
Current Eqpt Market Share



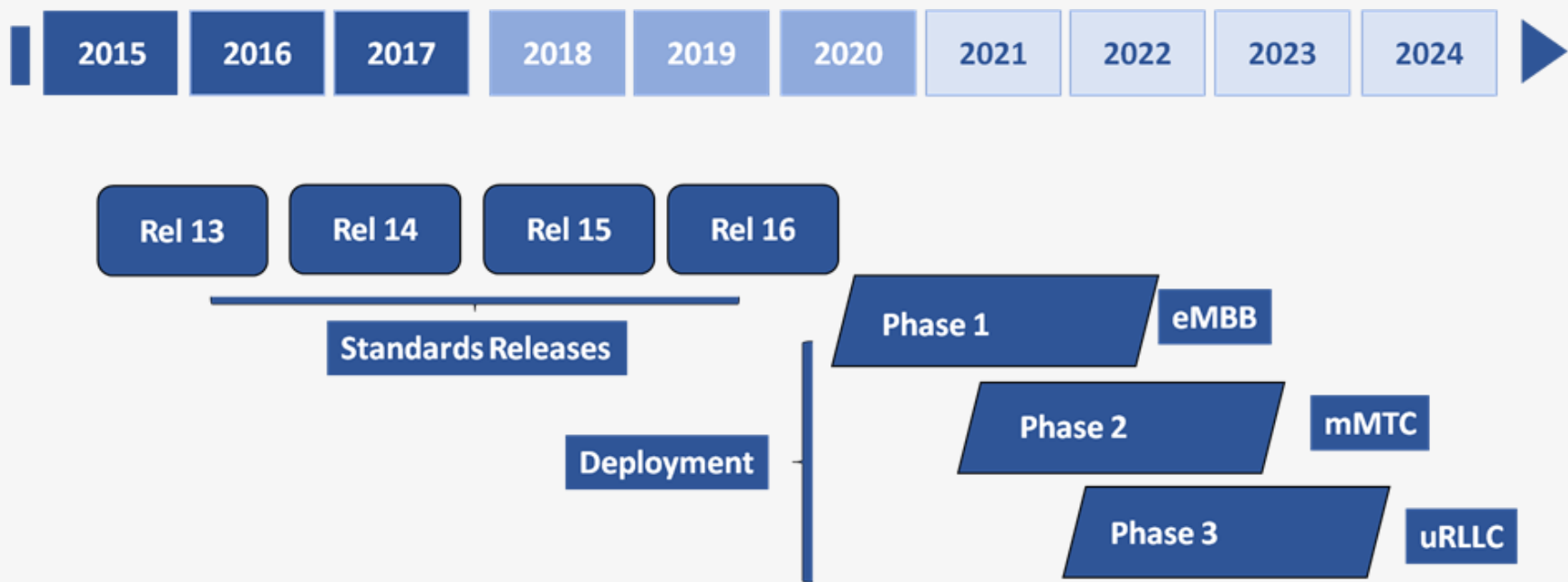
5G Phones

	Xiaomi	Huawei	ZTE	LG	Samsung
Band GHz	3.5	3.5/28/ 39	3.5	3.5 / 28	28/39

IoT/LL-UR Fabric



Standards and Deployments

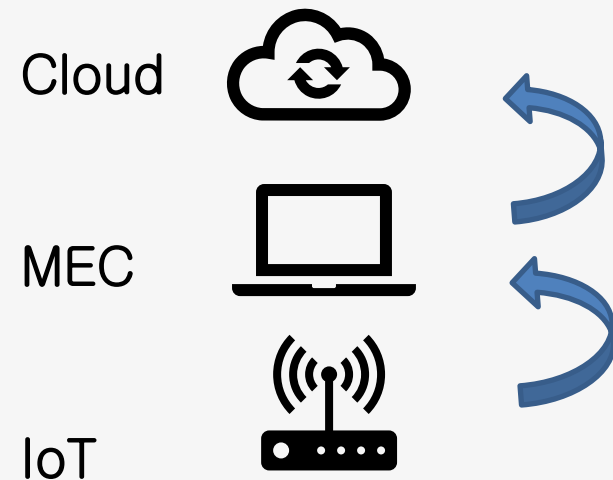


Uptake Barriers

- eMBB - Use case - just another G /phone
 - Spectrum auctions
 - Availability of phones / devices
 - Infrastructure cost (small cells)
- IoT, LL/UR – Use cases – mostly new
 - New class of devices and applications
 - High customization
 - Needs changes deep within industry process to adopt technology

MEC

- Necessary for low latency
- Data localization
- Security
- Faster Analytics



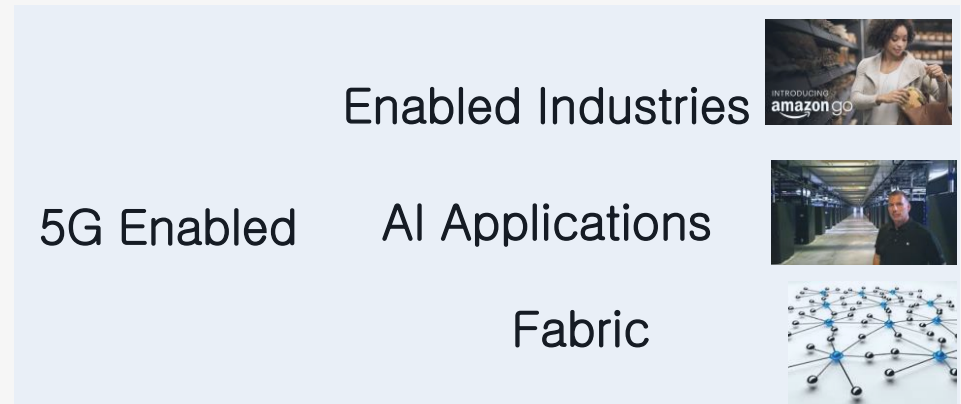
IoT

- IoT market slow to develop
- 5G IoT is outdoor focused
- Rel 16 will define first cut (Dec 2020)

Short Range	Local Area	Wide Area
Bluetooth	WiFi	nB-IOT, CatM
Z-Wave	Zigbee	5G
BLE	SigFox	Lora

AI

- 5G is the fabric to deliver AI Applications and Enabled Industries
- AI increasingly used in delivering 5G fabric



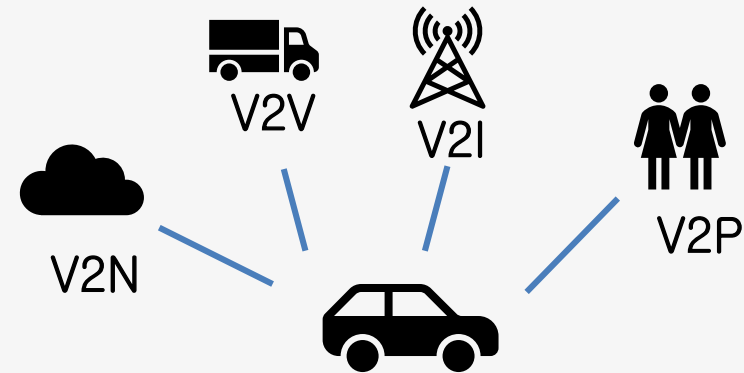
Manufacturing

- Wireless adds many benefits
 - Loc Flexibility
 - Lower cost
 - Reconfigurability
 - Faster integration to MEC / Analytics



V2X

- Intelligent transportation
 - Enhanced safety
 - Reducing congestion
 - Energy efficiency
 - Autonomous driving
- Also DSRC and IEEE standards



Summary

- 5G will be in service till around 2035
- Full maturity in 6-7 years
- Deployments of mobile and fixed services just beginning
- Real potential of 5G lies in the services enabled by MTC and LL/UR applications
- Perhaps only 1% of eventual 5G applications are now visible

