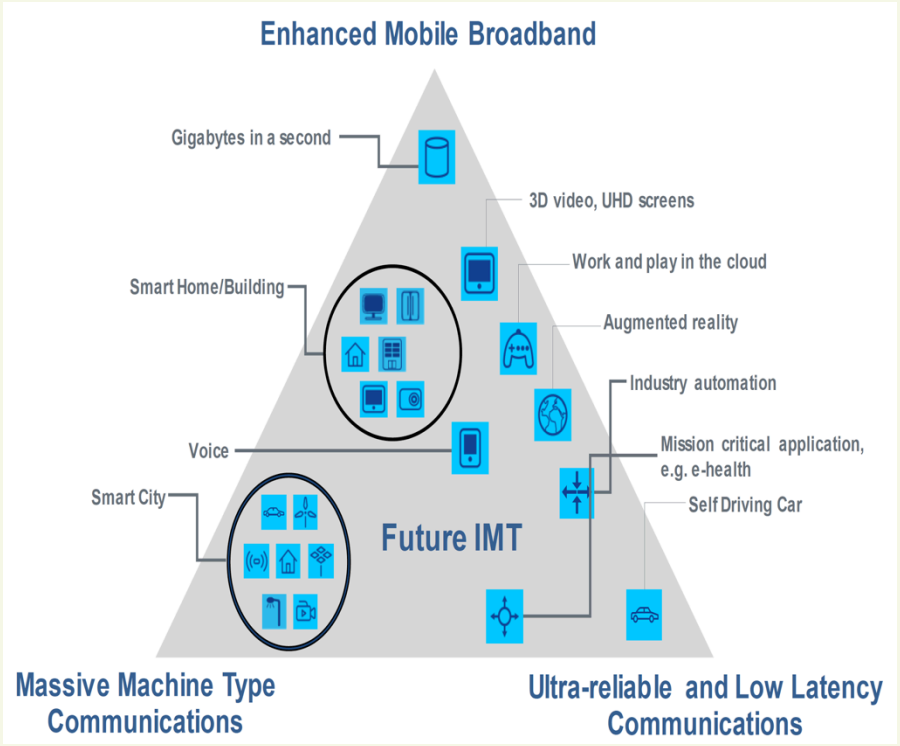
5G
Technology & Timelines & insights

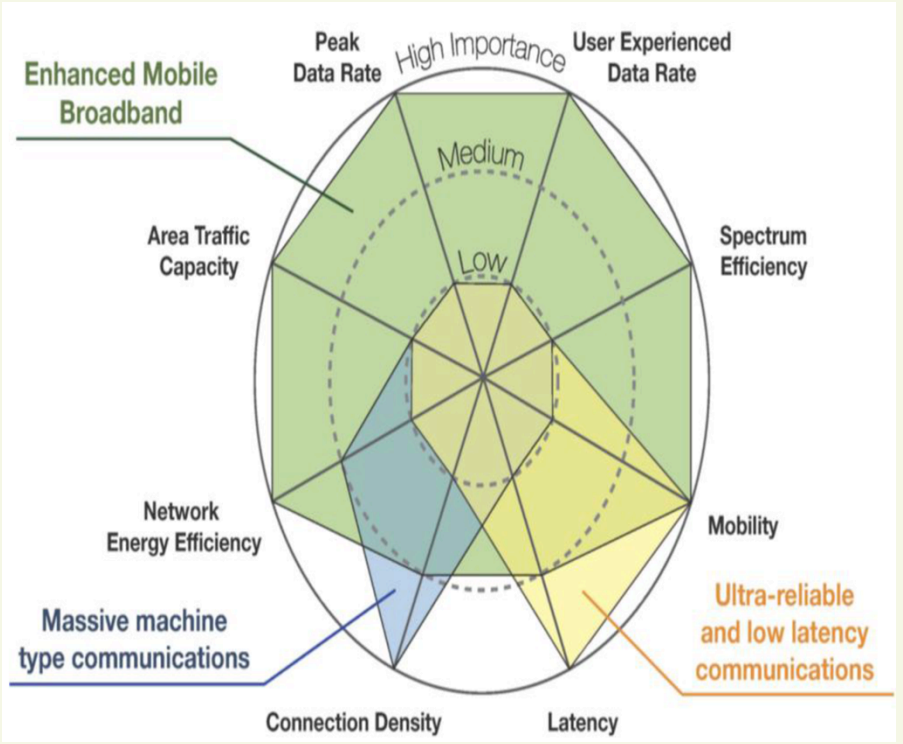
June 2016

Overview

- Three main uses cases for 5G networks
  - (Enhanced) Mobile Broadband - faster, better wireless connectivity. This will have first priority
  - Reliable IoT - device connectivity with high tolerance to key performance indicators
  - Massive IoT - connectivity of billions of devices with high tolerance to latency and data rate
- Standardization will take a phased approach
  - **Phase 1: projected 2020 for commercial availability, will leverage existing LTE networks - cannot run 5G standalone**
  - Full 5G standard (phase 2) not expected to be available until end of 2019
  - **Phase 2: projected commercial availability in 2022 at the earliest**
- This report summarizes the latest thinking and views of the wireless industry on 5G networks and technologies

ITU-R vision for IMT-2020 and beyond





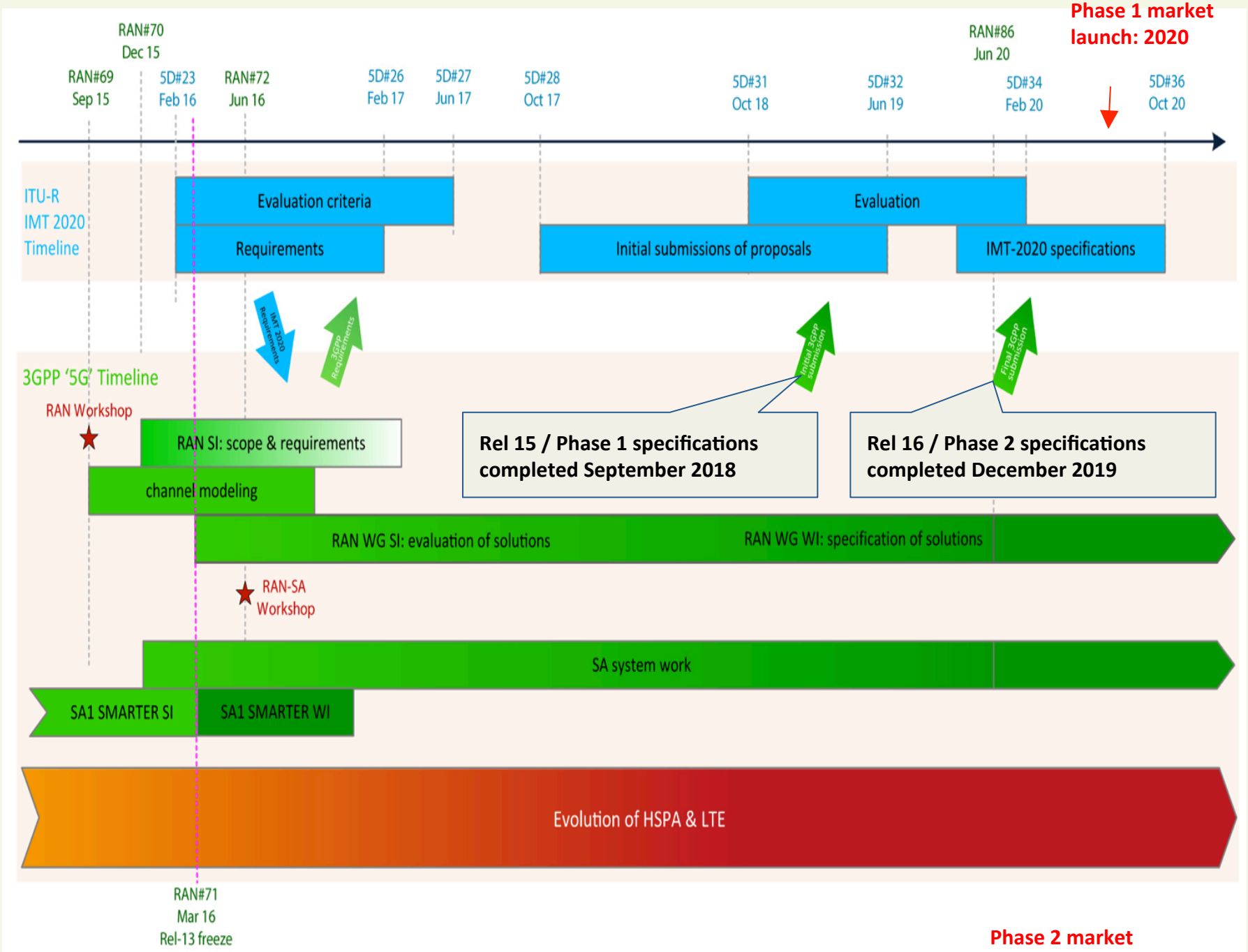
Three main use cases

Eight performance benchmarks

Note: NGMN's vision includes additional use cases, however, they are not projected to be as prominent at the three main use cases outlined here.

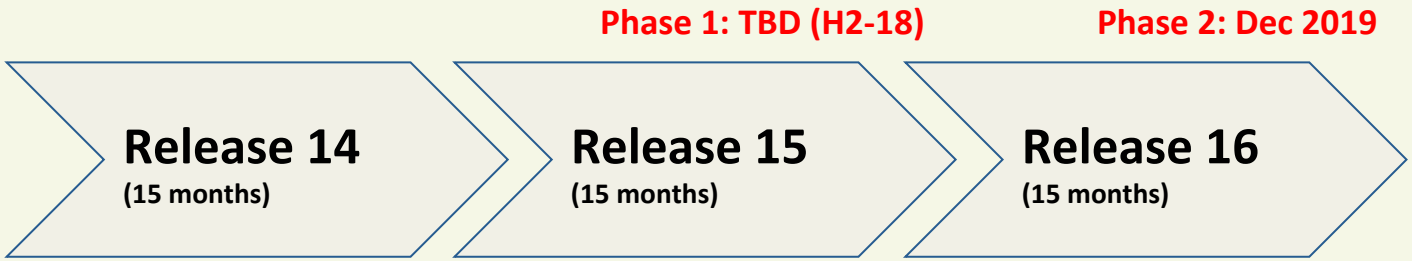
Source: ITU-R M.[IMT.VISION], Industry Vision and Schedule for the New Radio Part of the Next Generation Radio Technology (link)

3GPP Timeline and Phasing of '5G'



Source: Industry Vision and Schedule for the New Radio Part of the Next Generation Radio Technology (link)

5G Timelines & Workplan



Dates refer to 'stage 3 functional freeze of specifications (what matters to ITU-R submission). ASN 1 freeze is typically one quarter after that.

- Phase 1 to be completed by H2 2018 to address a more urgent subset of the commercial needs (to be agreed)
  - Tentatively June 2018 per latest 3GPP meeting (Dec. 2015)
  - Will not address IMT 2020 requirements
  - New RAT; OFDM-based with flexible numerology and frame structuring to accommodate wide range of frequency bands and applications
  - Focus on < 6 GHz bands (Japan, Korea MNOs, some vendors pushing to include up to 40 GHz)
- Phase 2 to be completed by Dec 2019 for the IMT 2020 submission and to address all identified use cases & requirements
  - Will address IMT 2020 requirements
  - Includes mm-Wave bands

Phased Standardization Approach

Suggestion by Ericsson

Phase 1 Early commercial deployments

- Focus on MBB
- Urban macro/micro, outdoor-to-indoor, up to ~500m ISD
- Frequency range from 3 to 30-40 GHz, licensed and unlicensed spectrum bands
- Focus on fully dynamic TDD
- Assisted by LTE (e.g. initial access)
- Forward compatible with phase 2

Phase 2 Full IMT-2020 compliance

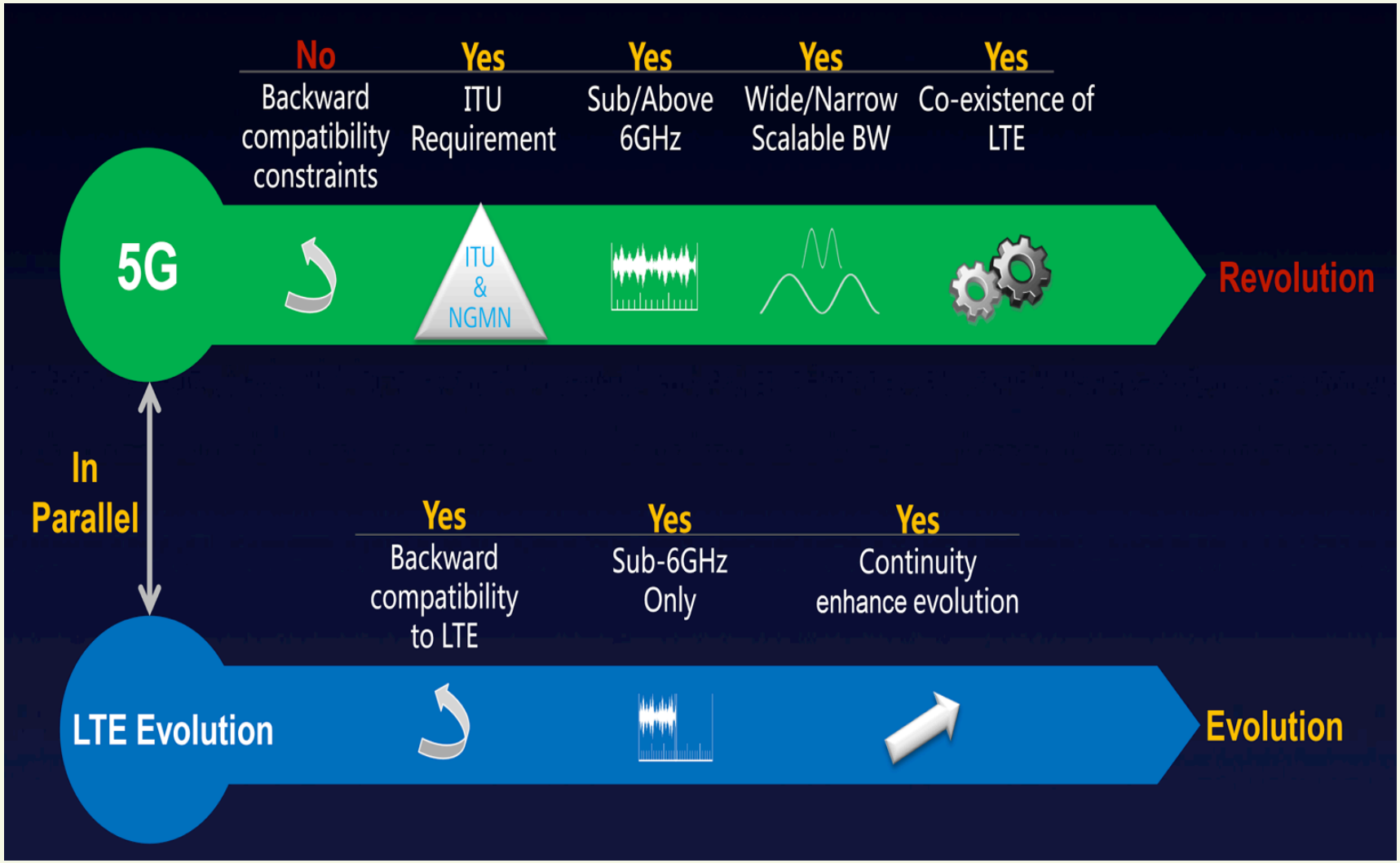
- Focus on 'all' use cases (MBB, mMTC, cMTC)
- 'All' deployments, urban/ suburban/rural, up to ~100 km range
- Full frequency range, sub-1GHz to ~100 GHz, licensed and unlicensed
- FDD and fully dynamic TDD
- Stand-alone operation

What will be in each phase of the standard is not yet determined. This is a view of Ericsson of how 5G standardization should be approached.

Source: Ericsson

Phased Standardization Approach

View from Huawei



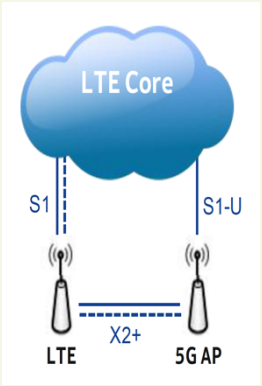
Source: Huawei

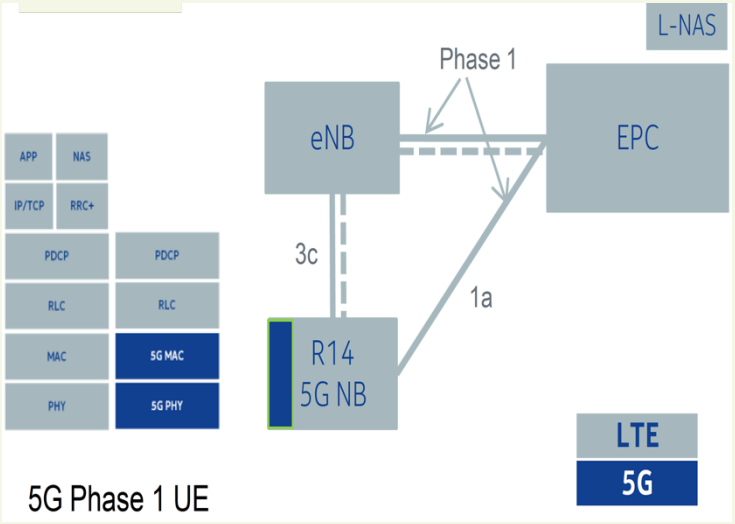
Key 5G Emerging Trends

- 5G not backward compatible with LTE; LTE-A Pro for backward compatibility
- Spectrum: < 6 GHz limited in capacity; > 6 GHz used as capacity spectrum (small cells, mmWave)
- Waveform: enhanced spectral efficiency trade off against lower OOB emissions. There is an emerging consensus that there will be a new, non-backward compatible, radio access technology as part of 5G, supported by the need for LTE-Advanced evolution in parallel. Multiple waveforms possible to cater to different applications
- Beamforming: especially for > 6 GHz spectrum to improve link budget. TDD operation most likely in > 6 GHz mmWave spectrum
  - Overhead reduction, e.g. cyclic prefix & guard bands
- Coding: LDPC to reduce decoder complexity
- Protocol splits: re-architecture to enable centralization of key functions to improve interference management; reverse distribution trend employed in LTE; allow dual-connectivity
- Energy efficiency: on both BTS and handset side (e.g. minimization of handovers, cell selection/ reselection, etc.)
- Integration among RATs - capability to support multiple radio access techniques e.g. LTE, Wi-Fi
- Massive MIMO - many antenna elements for >6 GHz spectrum

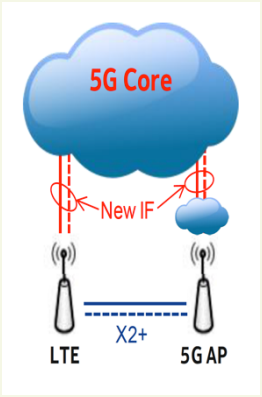
Architecture

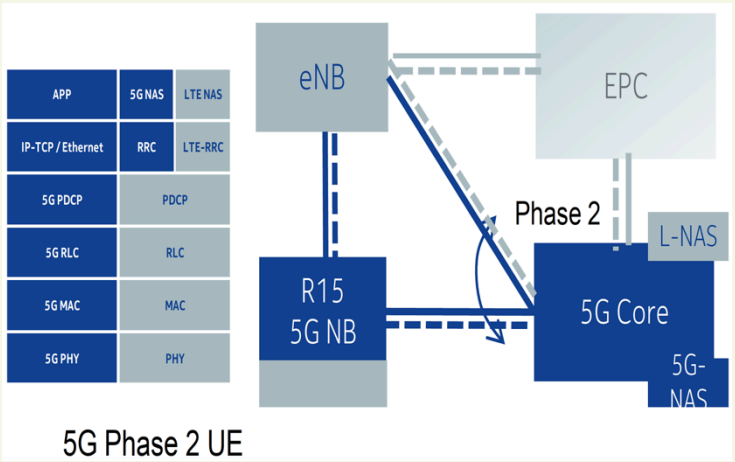
5G / Phase 1: likely to maintain LTE core and only adds RAN elements
User plane optimized only!





5G / Phase 2:
Evolve the 5G radio to support stand alone operation and optimize architecture to enable new services





Radio Access Technology Evolution

- A new radio access technology (RAT) for Phase 1 and Phase 2 is under discussion
- The radio access technology needs to also address low spectrum (e.g. < 6 GHz) and high spectrum (e.g. mm-Wave)
  - Phase 1 will most likely cover on < 6 GHz bands
  - The boundary between 'low' spectrum and 'high' spectrum is not fully defined
- A new and different RAT physical layer is required for the mm-Wave spectrum bands because the requirements will mandate it
- For the < 6 GHz bands, it is not clear how different the RAT will be from LTE
  - Some argue that it make sense to adopt some form of enhanced LTE as an intermediate step, before the full implementation of Phase 2 5G
- Operators will always have the option to pursue LTE-Advanced which opens the question as the the benefits of the new RAT over LTE
- The new RAT would need to have some incremental improvement over LTE and also provides a roadmap to evolve further in spectral efficiency and performance targets

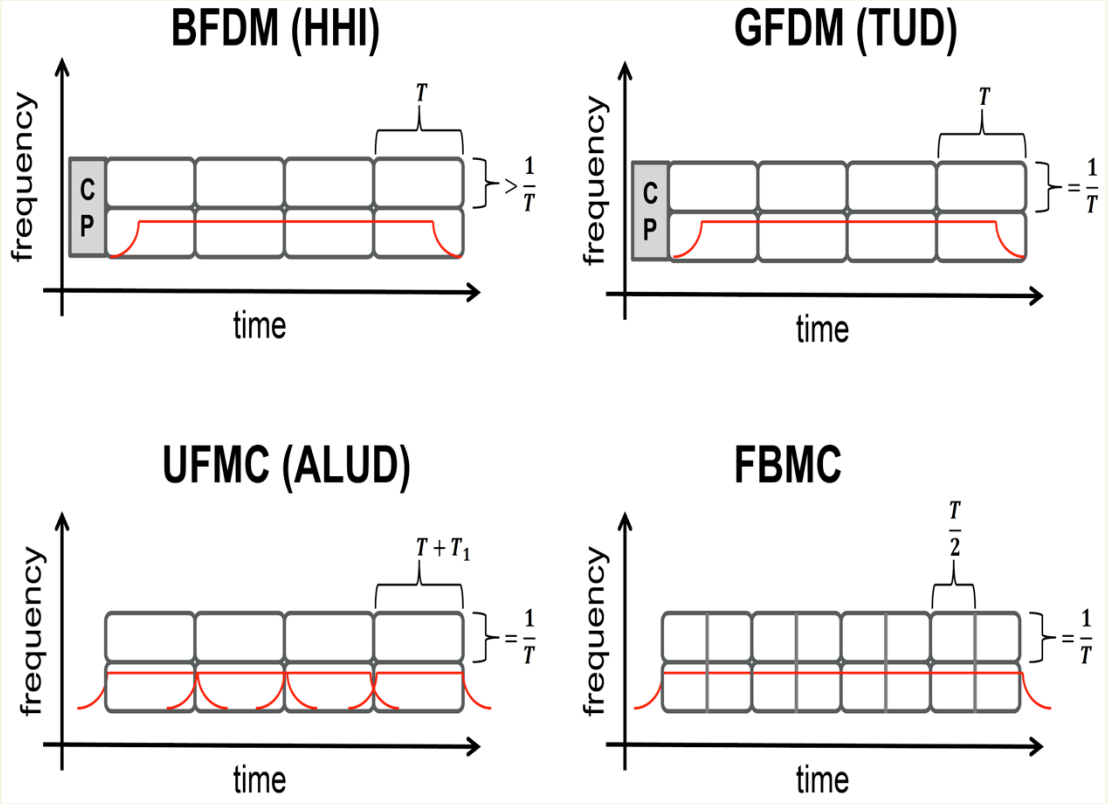
New Waveform

- Area widely debated
  - OFDM works well, tried, tested…
  - OFDM has challenges supporting wide bandwidth in mmWave. Can efficient PAs be developed?
  - OFDM performance for asynchronous access required in M2M?
- Some form of OFDM-based multi-carrier technology will be used in 5G in order to:

a. Improve spectral efficiency by using tighter packing of carriers

b. Improve out-of-band emissions

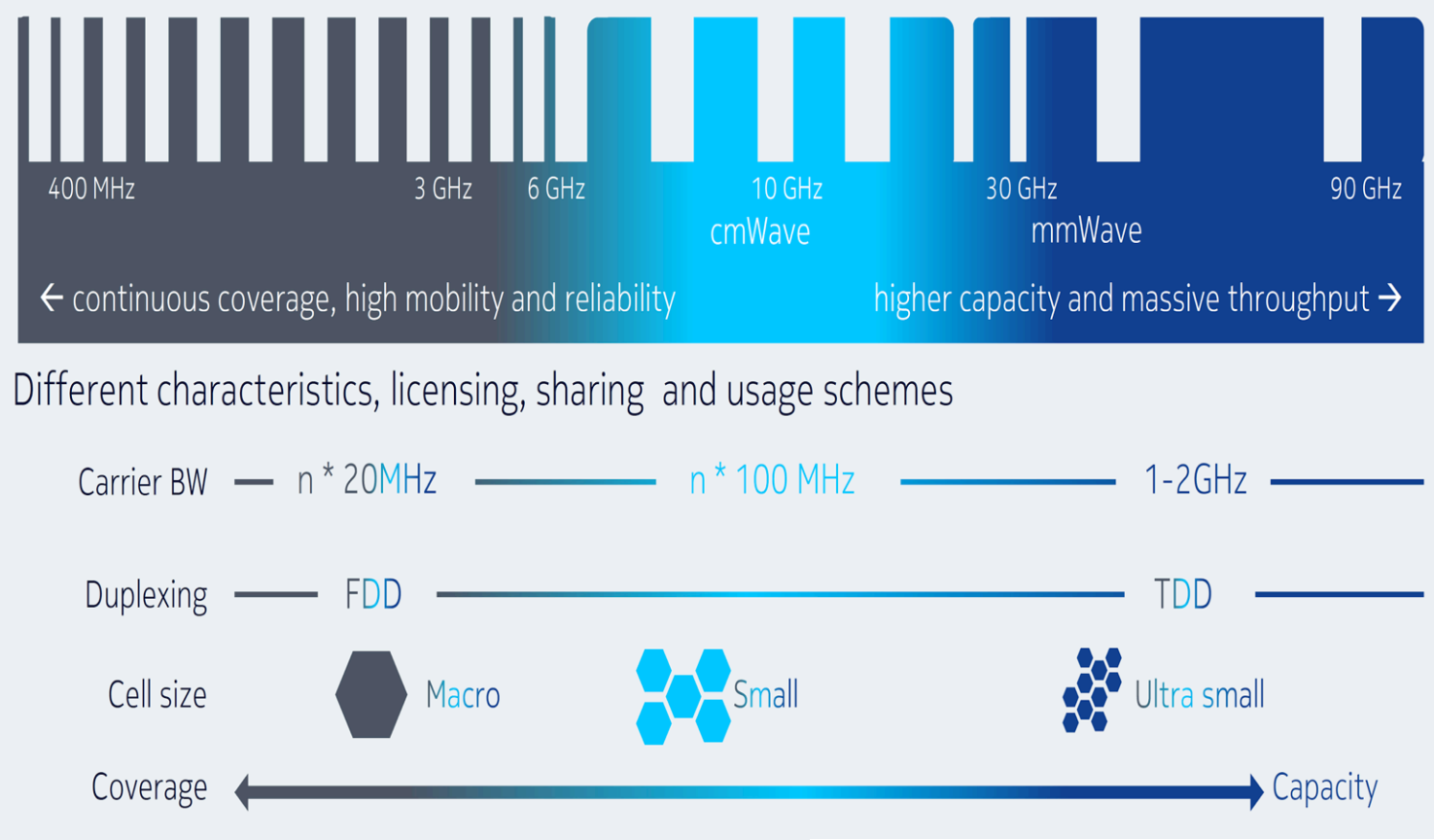
- Tradeoffs have to be made to achieve a balance between these two objectives
- More than one physical layer may be used depending on application



OFDM is suitable for broadband connectivity but fails in highly synchronous access scenarios such as massive M2M. Therefore, ther can be multiple waveforms in 5G to support different services.

Source: 5GNOW

High Frequencies / mmWave

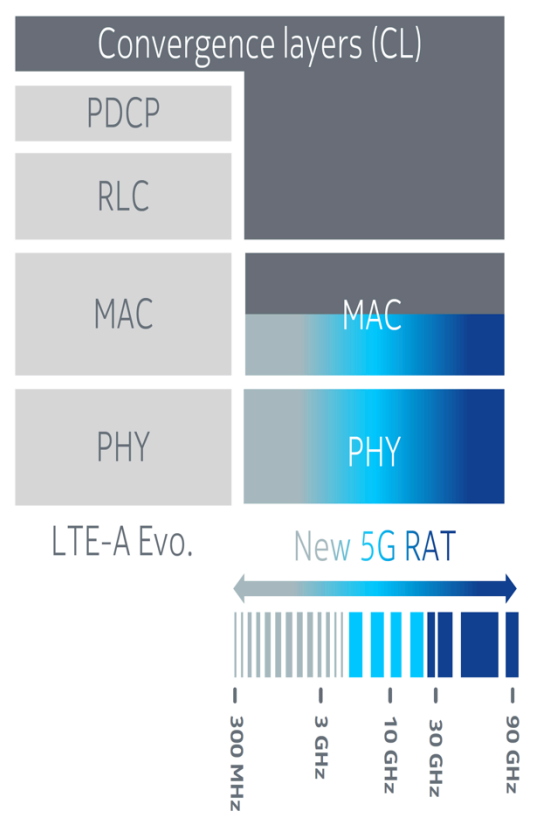


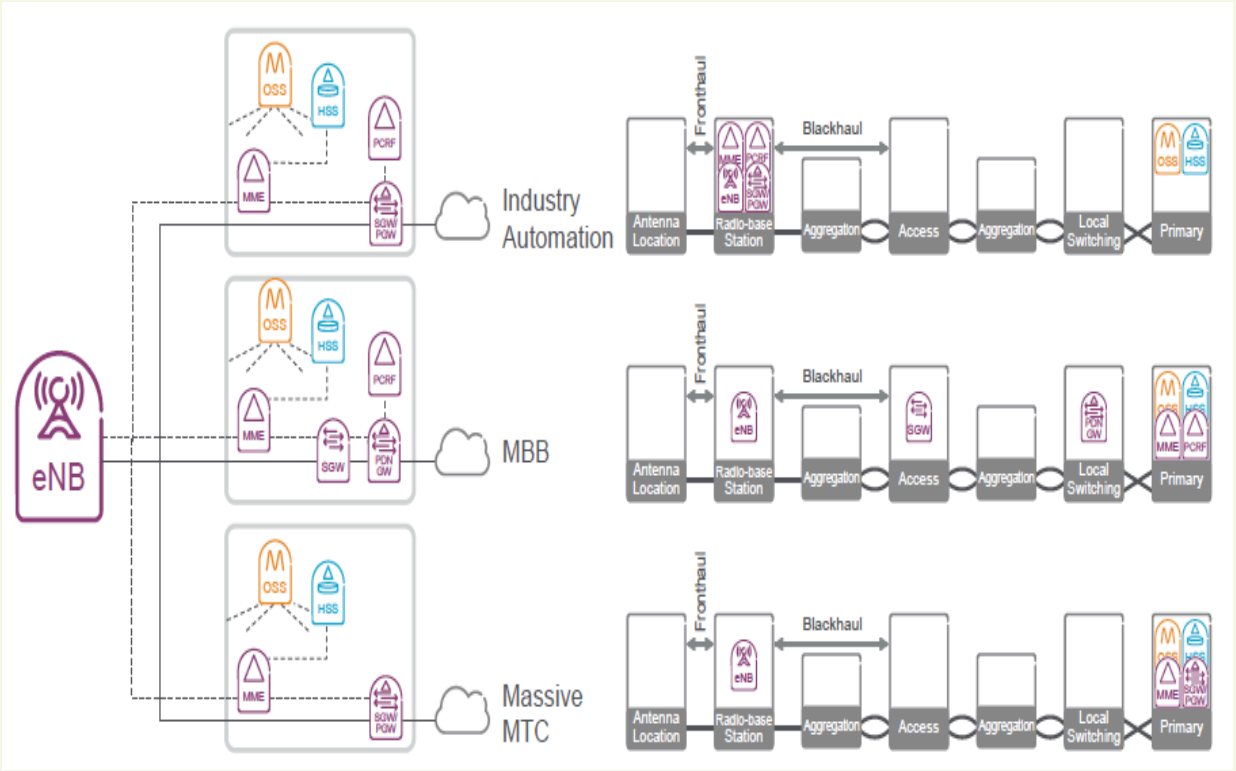
28 dB Free-space path loss difference

Distance	2.4GHz	28GHz	60GHz
d = 1m	-40 dB	-62 dB	-68 dB
d = 100m	-80 dB	-102 dB	-108 dB

Source: Nokia

Multiple Radio Access Technologies and Core Network Slicing

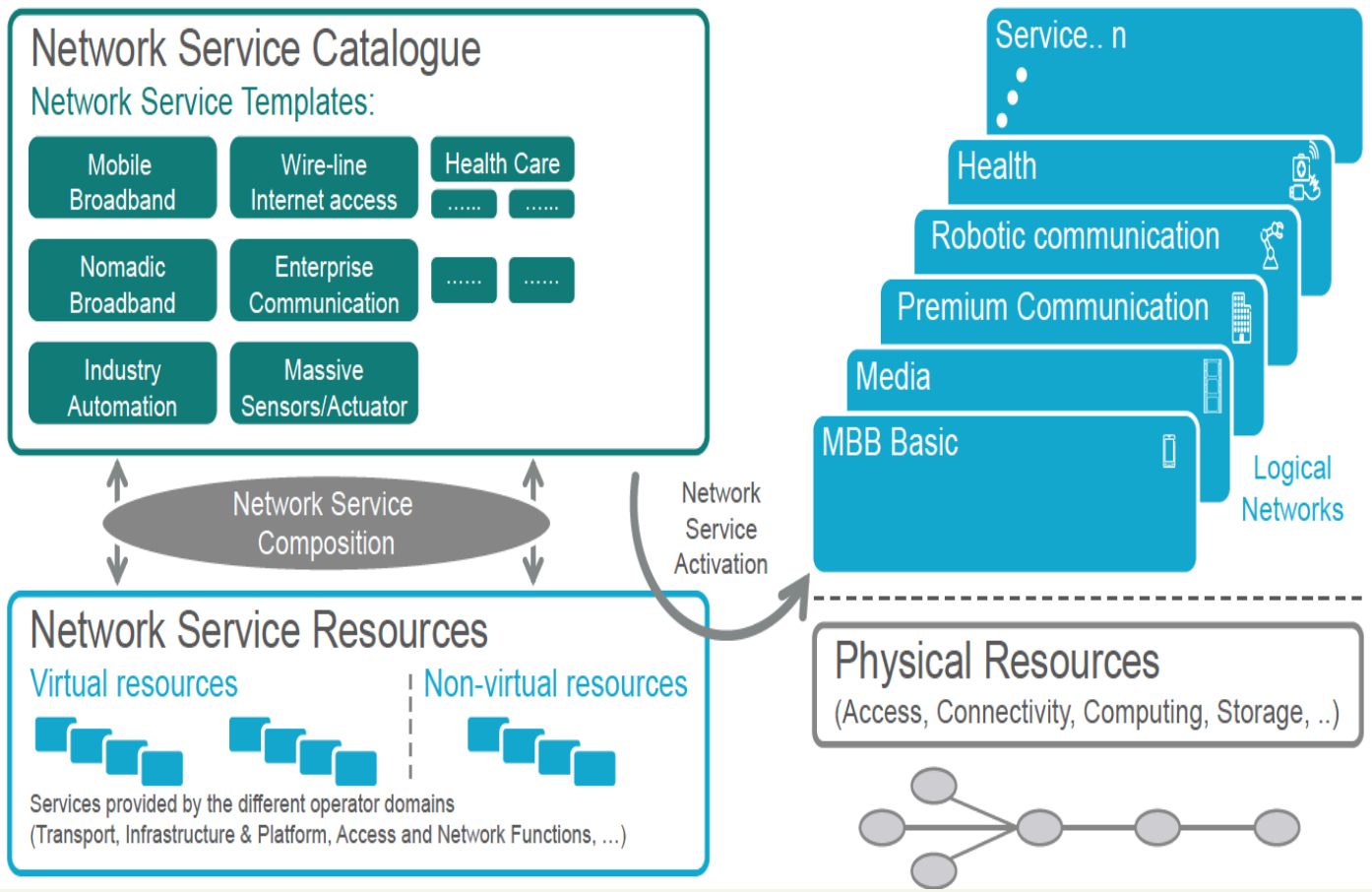




RAN: Multiple technologies (MAC/PHY) with unified convergence layers

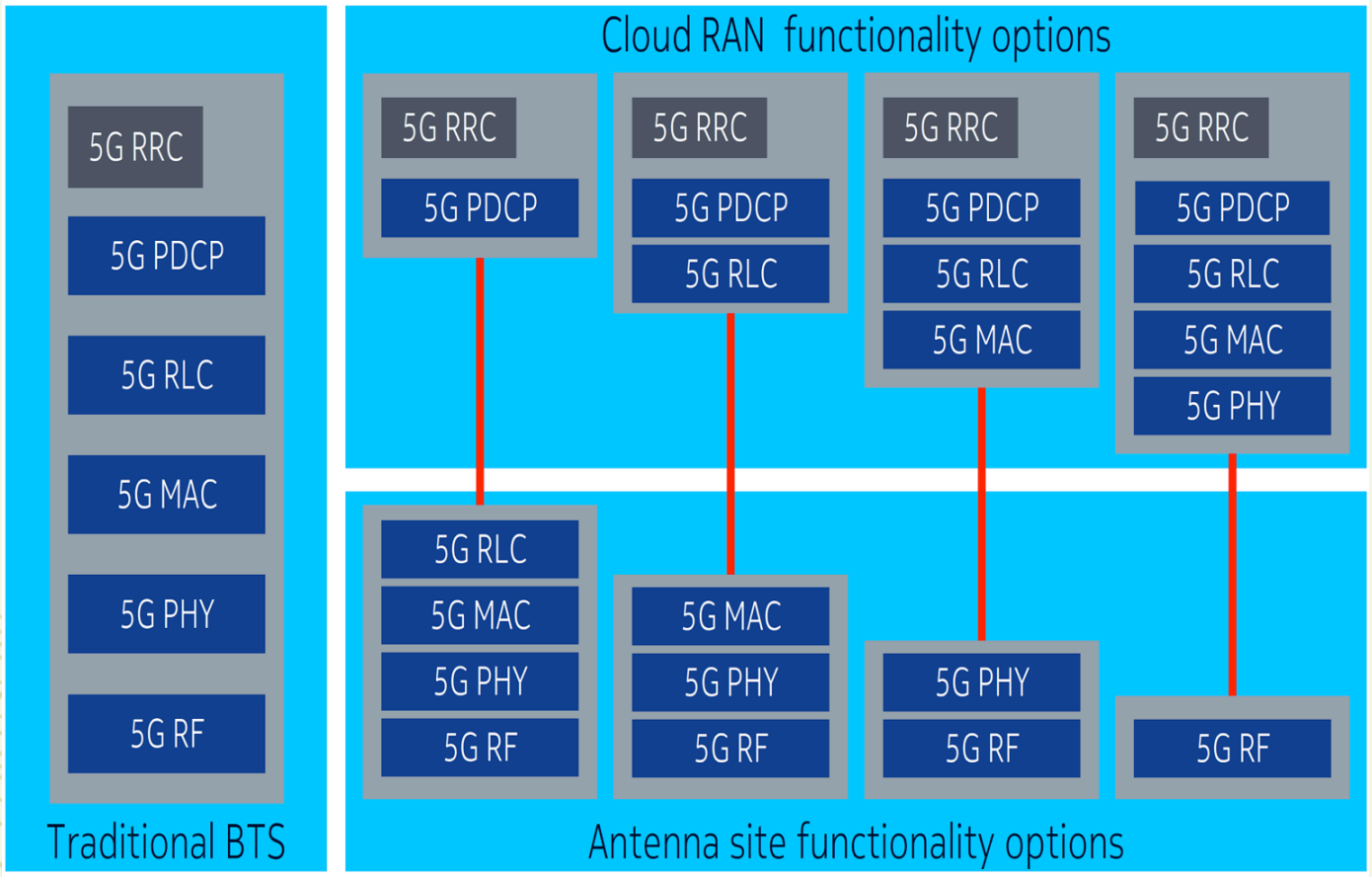
Core: 'Network slicing' to support multiple use cases and technology requirements.

Virtualization



Virtualization serves multiple purposes including quick service creation and financial savings

Coud RAN and Functional Centralization



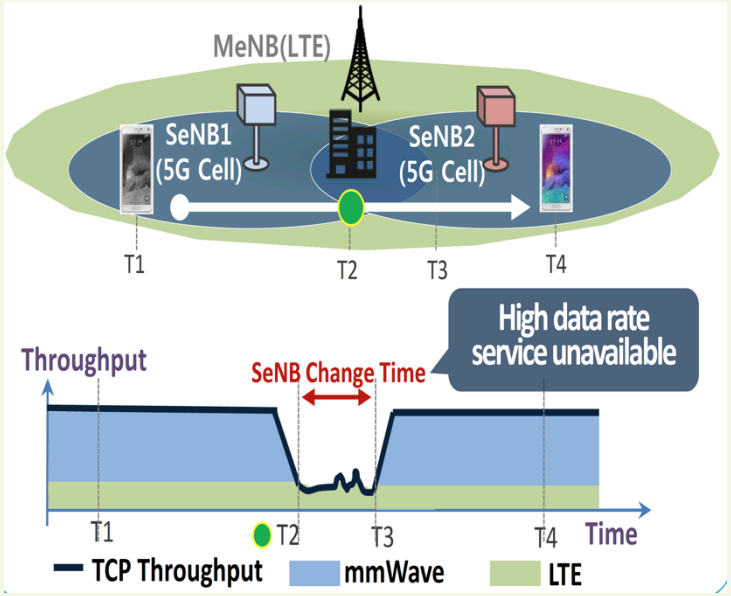
Centralization is important for Coordinated Multipoint techniques. LTE has limitation in

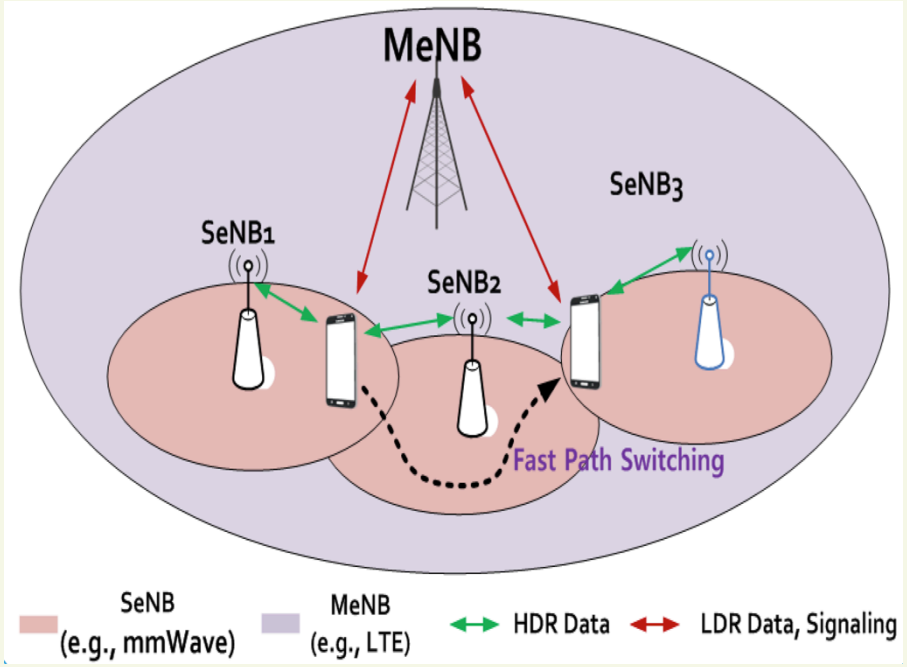
1. CSI reporting:
   - In a dense deployment too many CSI processes are needed
   - CQI from different nodes cannot be linearly combined - a Central Coordinator has limited possibilities to preview the interference status in short time
1. Existing X2 support for a Central Coordinator is limited to coordination of protected resources

5G provides a flexible framework to distribute and centralize functions which reverses LTE's distributed architecture. Centralization is critical to reduce interference and improve mobility robustness in hetnets

Multi-Connectivity for Service Continuity

- When using high spectrum, we can achieve areas of high throughput which would have rapid drop of Tput at cell edge → use 4 G as coverage to 'glue' 5G islands initially
- Severe signal drop on the move at 28 GHz even with dual-connection: high data rate service is not guaranteed → use multicell connectivity
- Multiple eNBs Connection - 1 MeNB (RRC control) + more than 1 SeNB(s) (user plane data) SeNB serves packet transmission/reception which requires ultra high data rate. Additional SeNB(s) is ready for a case that serving SeNB is unavailable

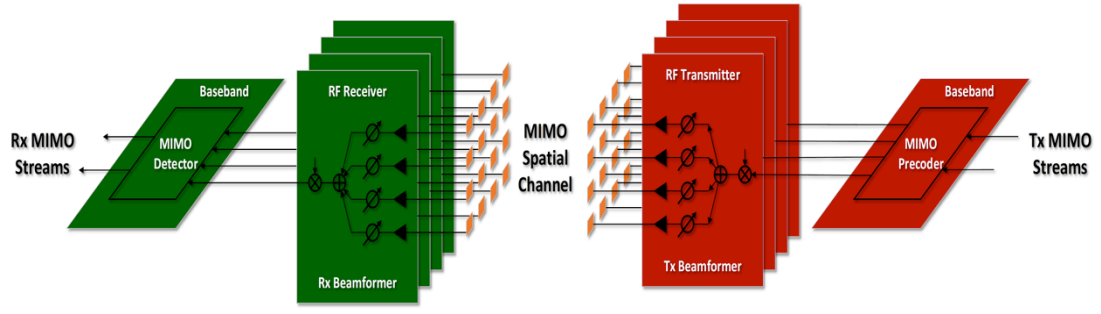




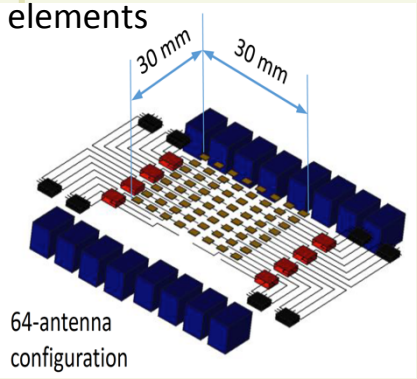
Source: Samsung, Vision and Schedule for 5G Radio Technologies (Link)

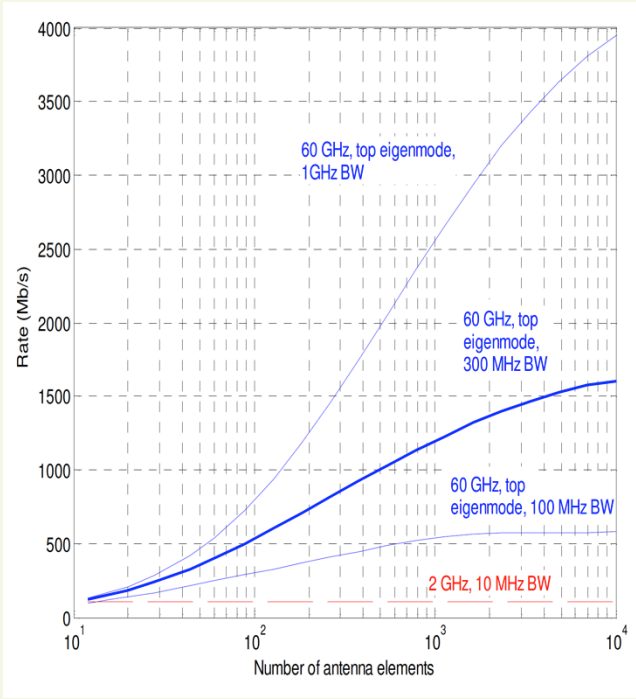
Massive MIMO & Advanced Antenna Techniques

- Massive antenna arrays (MAA) are key technology enabler at higher frequencies - multiple technologies can be combined:
  - Beamforming (analog, digital or hybrid)
  - SU-MIMO (channel rank tends to be lower in mmW)
  - MU-MIMO / SDMA



Short wavelength at high frequencies allow packing more antenna elements

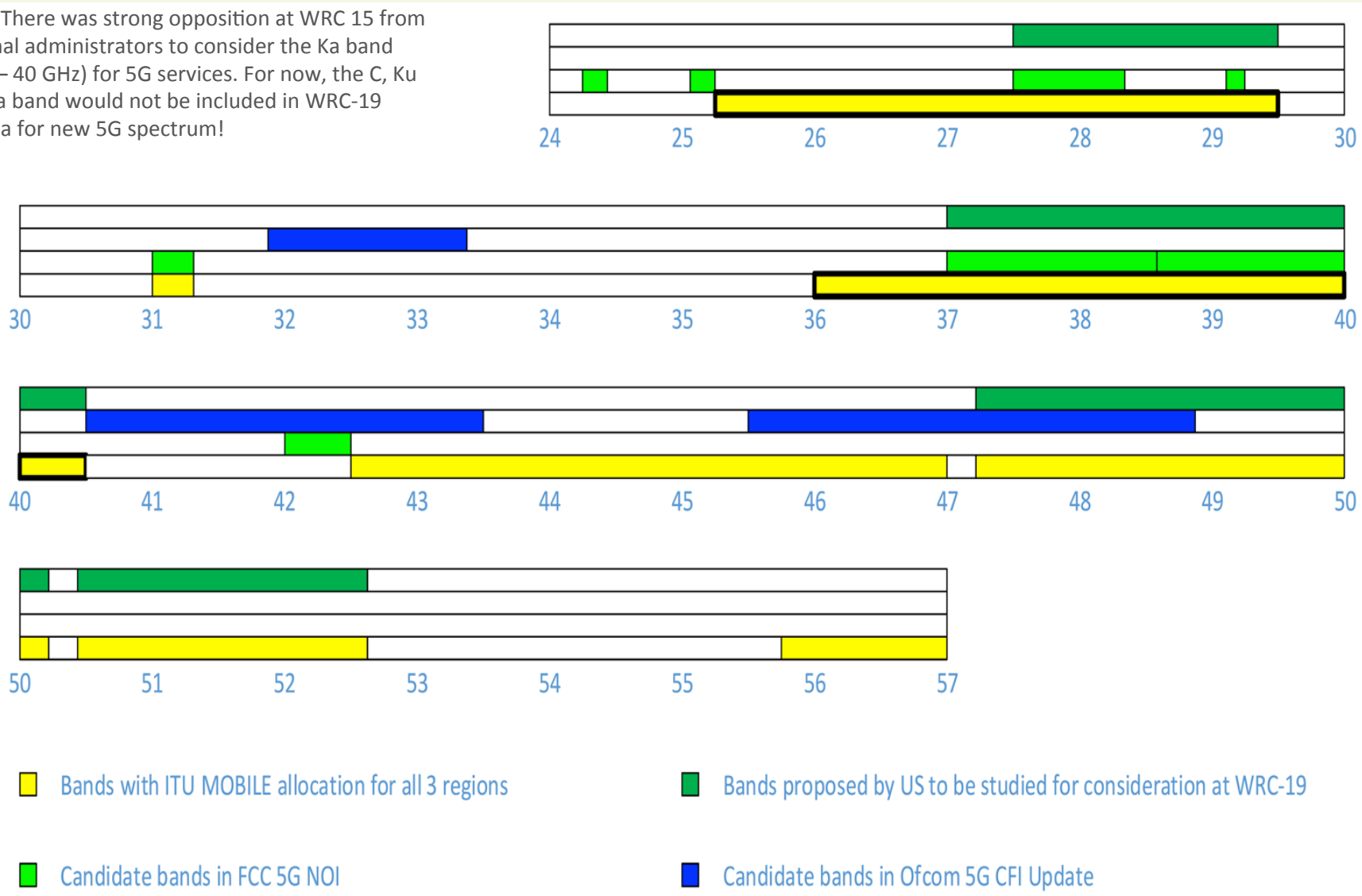




1 GHz BW at mm waves brings 10x capacity of a reference low-band LTE link (using ~128 joint elements, e.g. 32 AP x 4 UE)

mmWave Spectrum for 5G: 24 - 57 GHz

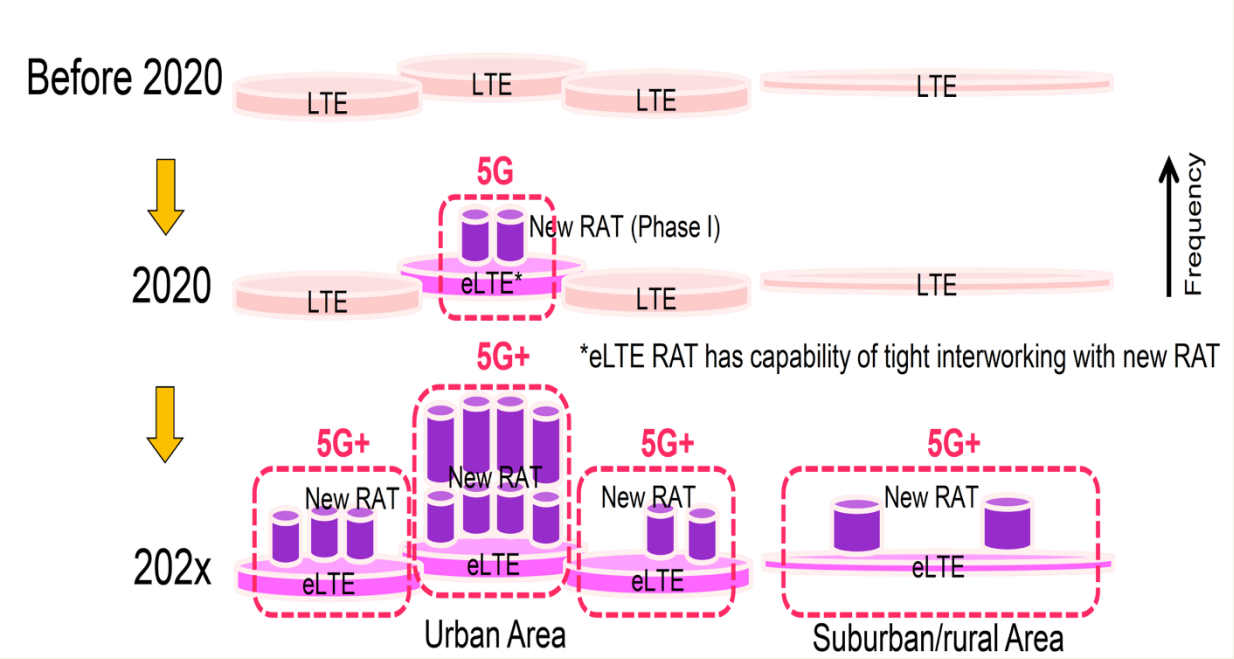
Note: There was strong opposition at WRC 15 from regional administrators to consider the Ka band (26.5 – 40 GHz) for 5G services. For now, the C, Ku and Ka band would not be included in WRC-19 agenda for new 5G spectrum!



Operator Views

- Japan (DoCoMo) & Korea (SKT, KT) operators are most vocal and aggressive on 5G plans
- North American operators present no view (Verizon, AT&T) or generic view (Sprint)
- European operators present NGMN view

NTT DoCoMo Deployment Outline

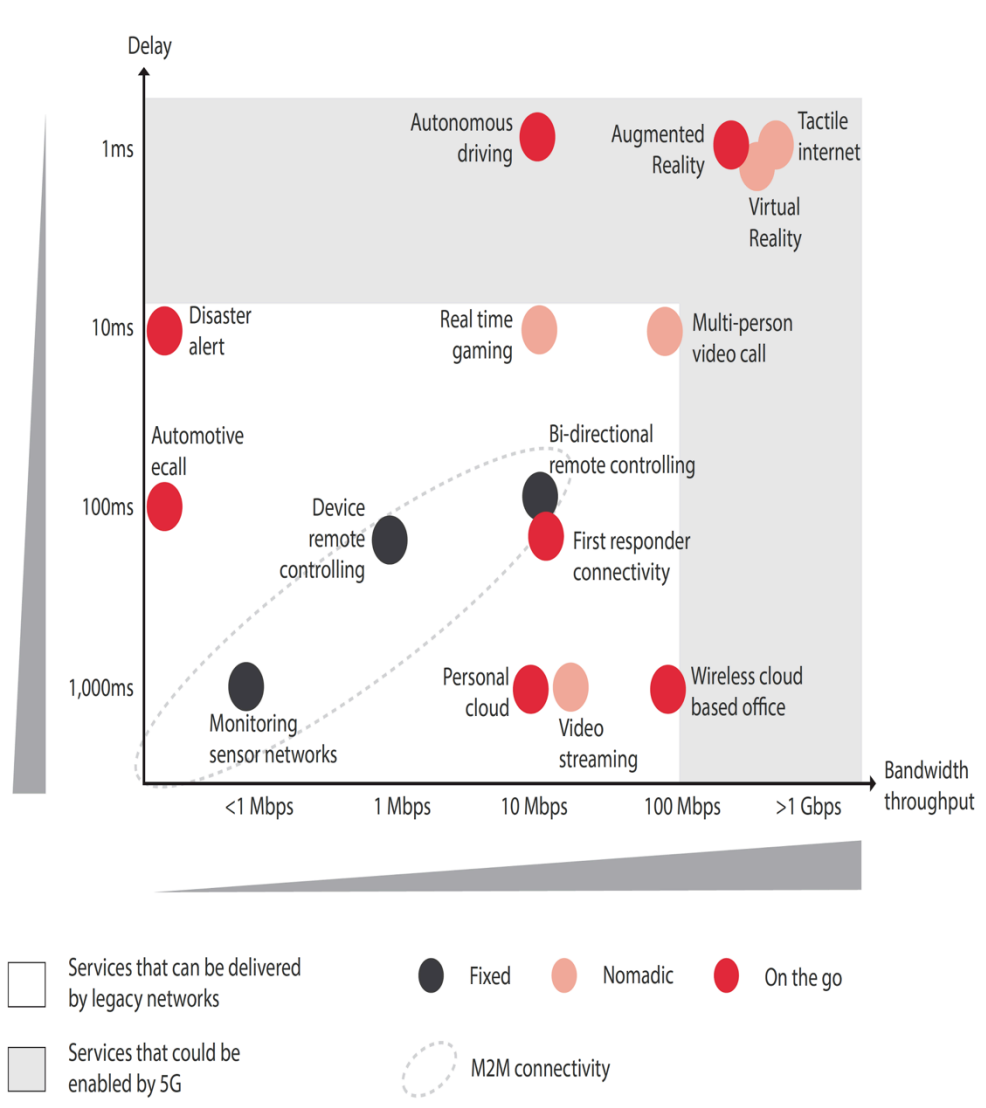


Technologies / Buzz Words Used in 5G

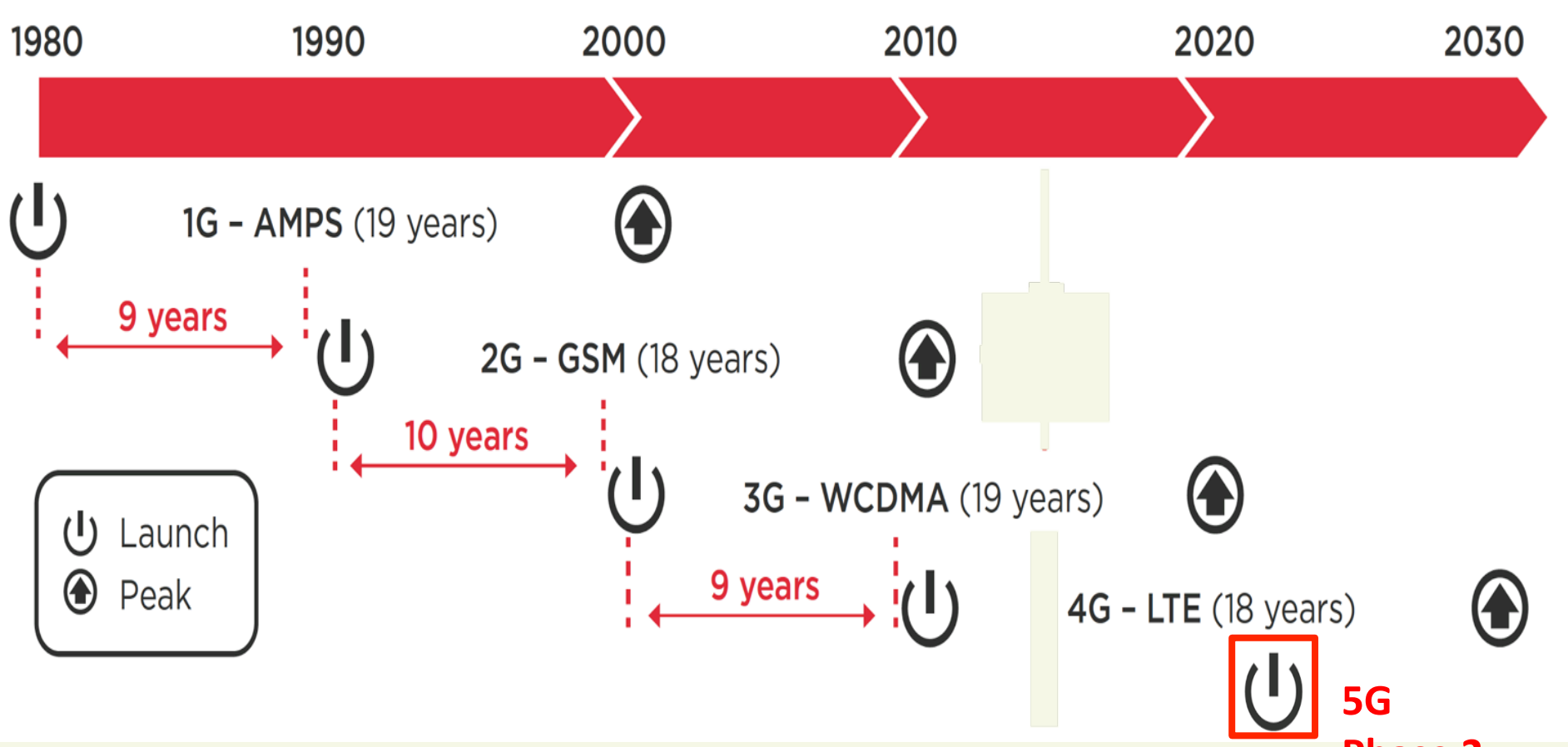
- Device-to-device communications
- Flexible PHY
- Massive multi-antennas
- Access/backhaul integration
- Polar codes for M2M connectivity (reliability & low energy consumption)
- Adaptive frame structure
- Filtered-OFDM and flexible subcarrier parameterization
- Multi-connectivity / licensed and unlicensed spectrum
- Forward compatibility
- Millimeter waves
- New physical layer

5G Applications

- Improve the performance of existing applications
- Enable new use cases
- Provide a unified platform for wireless connectivity



Perspective on Wireless Technologies



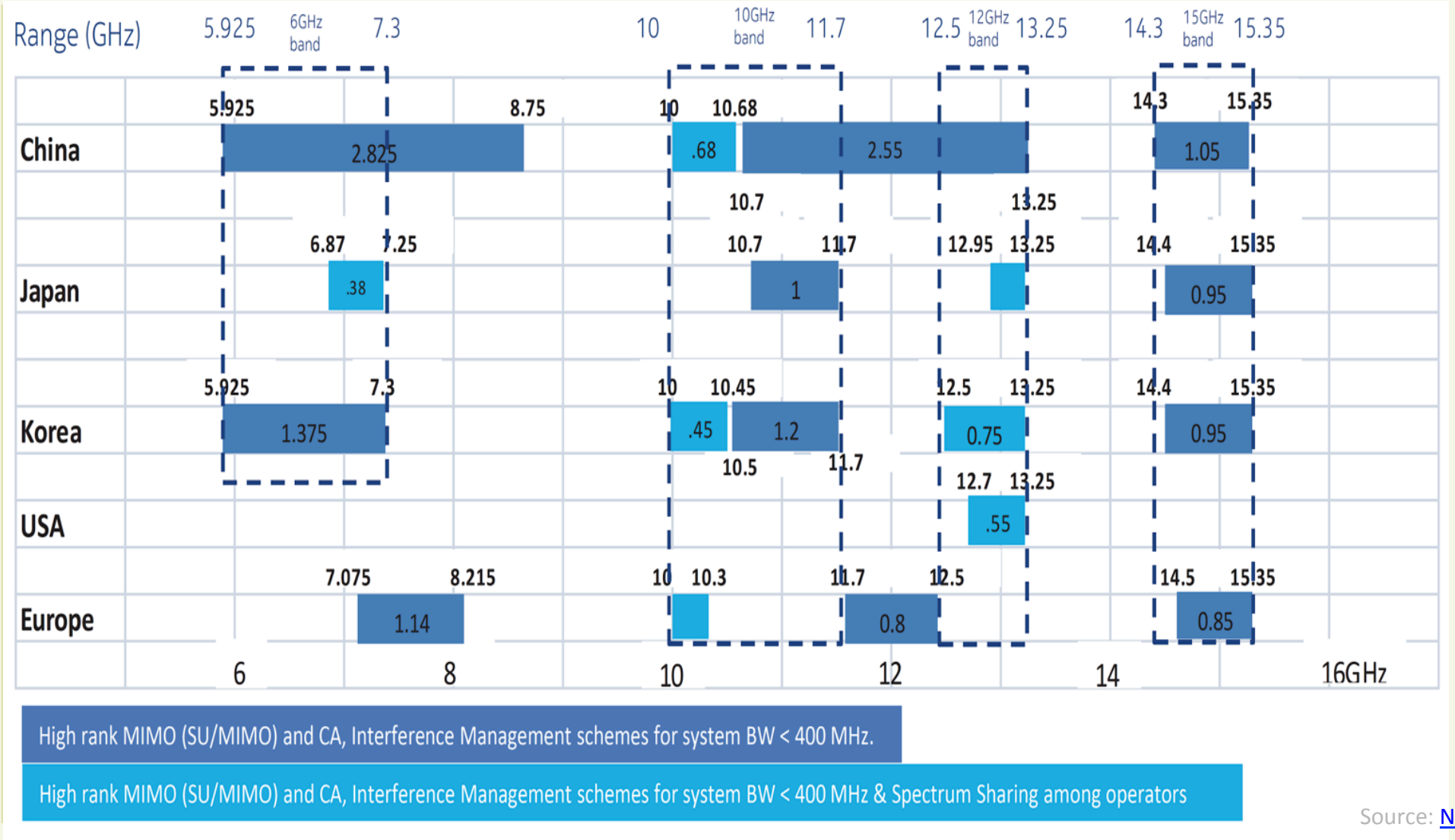
- It takes about 20-years from launch for a technology to peak in penetration
- LTE connections projected to peak by end of next decade ~2030

Source: GSMA

Spectrum Details

6-16GHz Co-Primary Mobile Allocation

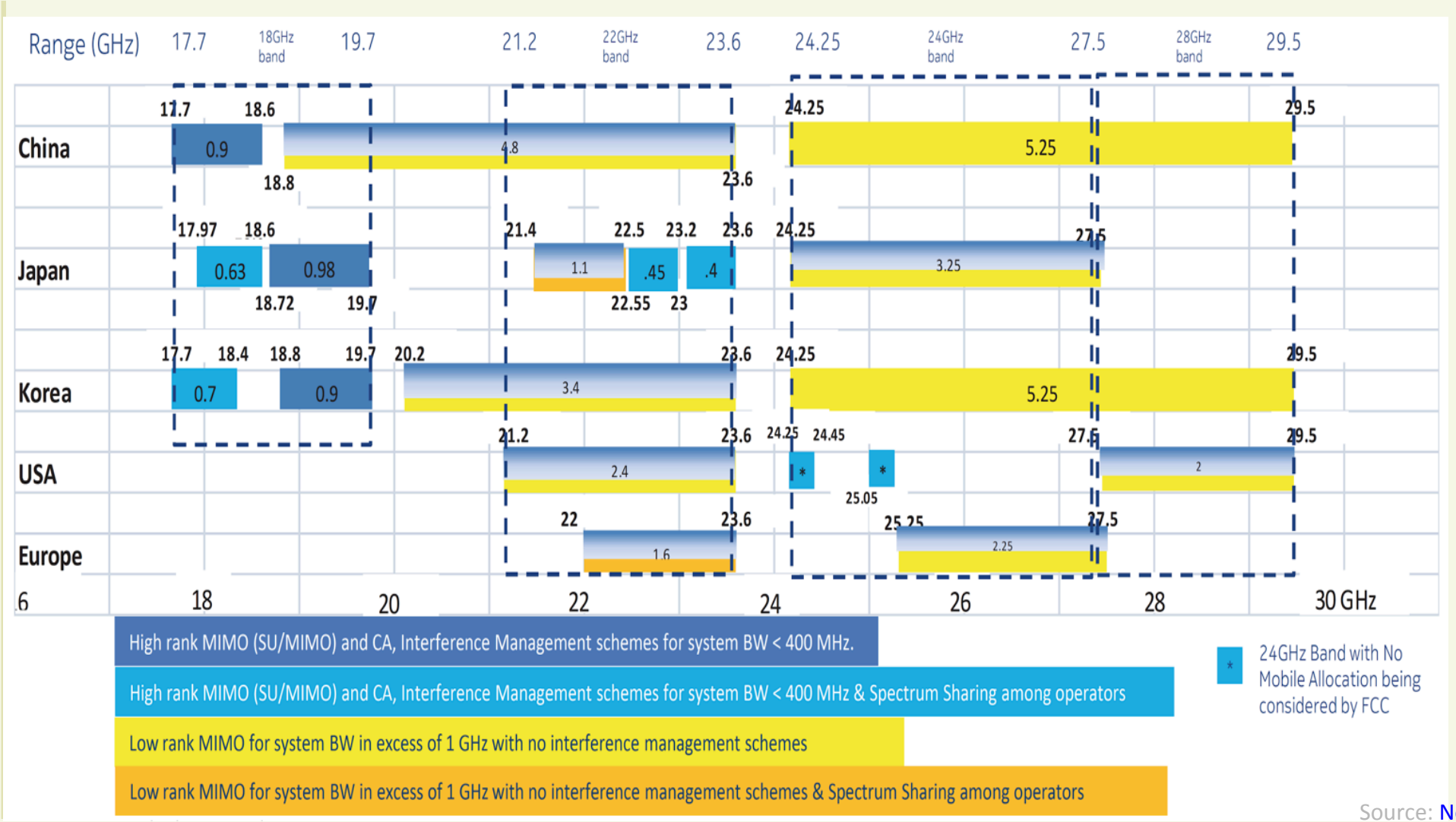
min. 300MHz Contiguous Spectrum



Source: Nokia

16-30 GHz Co-Primary Mobile Allocation

Min. 300MHz Contiguous Spectrum



Source: Nokia

30-54 GHz Co-Primary Mobile Allocation

Min. 300MHz Contiguous Spectrum

Source: Nokia

54-100 GHz Co-Primary Mobile Allocation

Min. 300MHz Contiguous Spectrum

Source: Nokia

Overview

- Founded in 2012 by Silicon Valley startup founders and managing directors in global ventures, renowned technologists and investment advisors
- Fusion of multiple advisory firms, global references with the top mobile, media and Internet players, top venture capitalists and private equity firms
- Core team of partners across all key tech/finance/media hubs. Unique blend of cross functional expertise, covering end-to-end lifecycle management

Xona Partners In Brief

Team

Dan Cauchy
San Francisco

Eric Chan
San Francisco

Dr. Riad Hartani
San Francisco, Hong Kong, Dubai

Richard Jeffares
London, Hong Kong, Sydney

Dean Sirovica
San Francisco

Mats Vilander
Stockholm

Rolf Lumpe
Tokyo, Hong Kong, Seoul

Dr. Anurag Maunder
San Francisco

Mano Vafai
San Francisco

Ashish Wadhwani
Singapore, Mumbai

Frank Rayal
Toronto, Ottawa

Ritendra Roy
New York, Calcutta

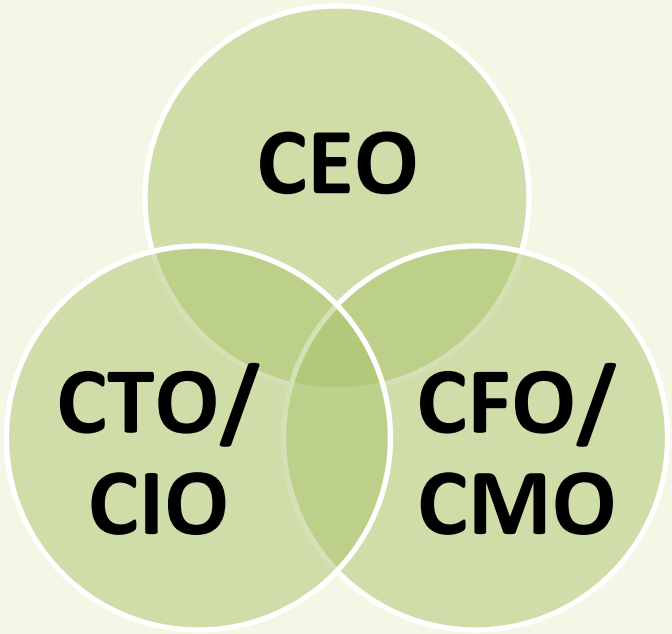
Ananda Sen Gupta
New Delhi, San Francisco,Hong Kong

Dr. James Shanahan
San Francisco, London, Beijing

Malik Si Hassen
Paris, Dubai, London

Focus

A Boutique Advisory Firm Specialized in Technology Businesses Incubation & Growth Strategies



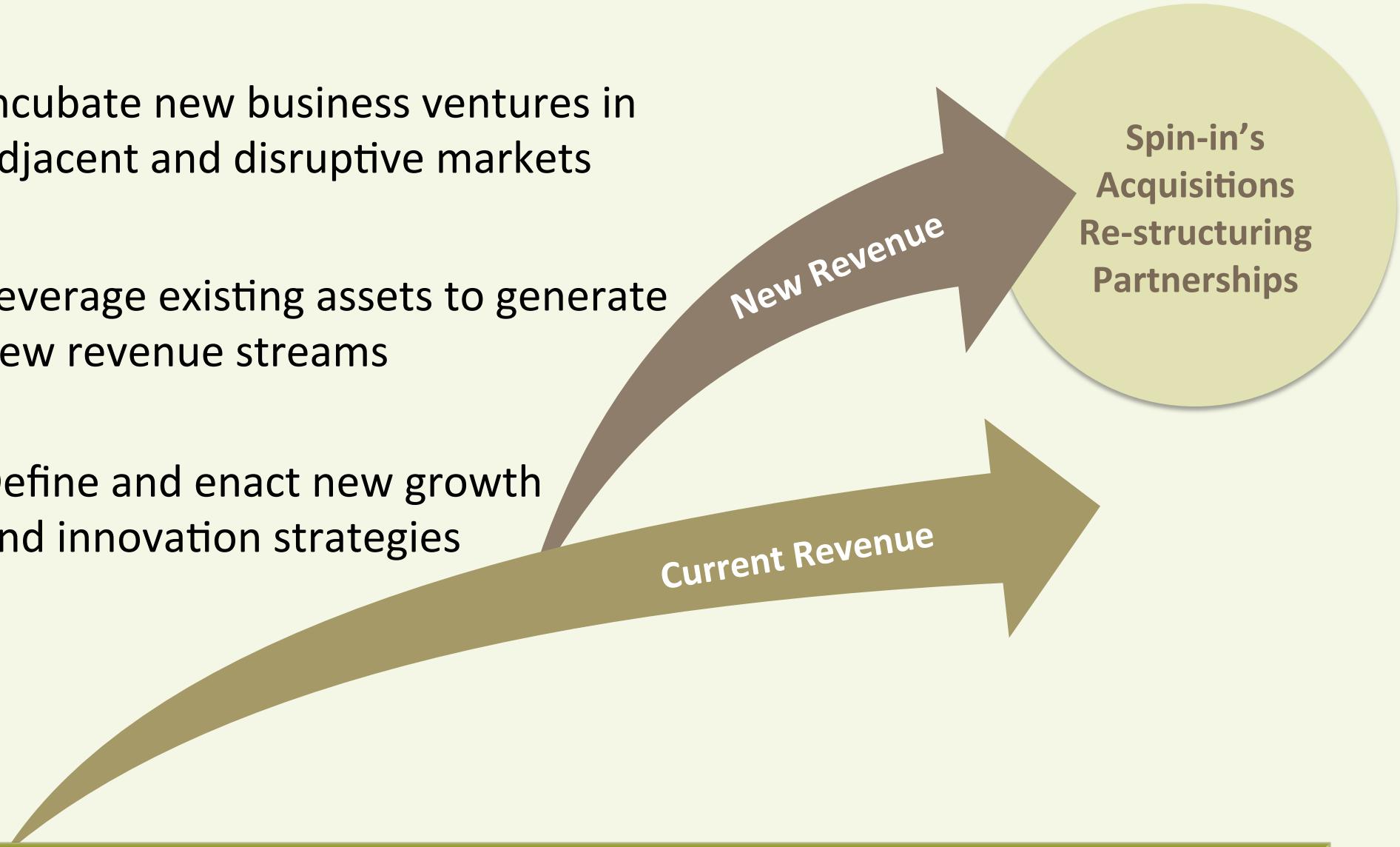
Xona Partners Assists CxOs in Developing New Streams of Revenue

- **Multi-Disciplinary Integrative Approach**
- **Global Reach**
- **Exclusive Expertise in Internet, Telecom & Information Technologies**

XONA PARTNERS

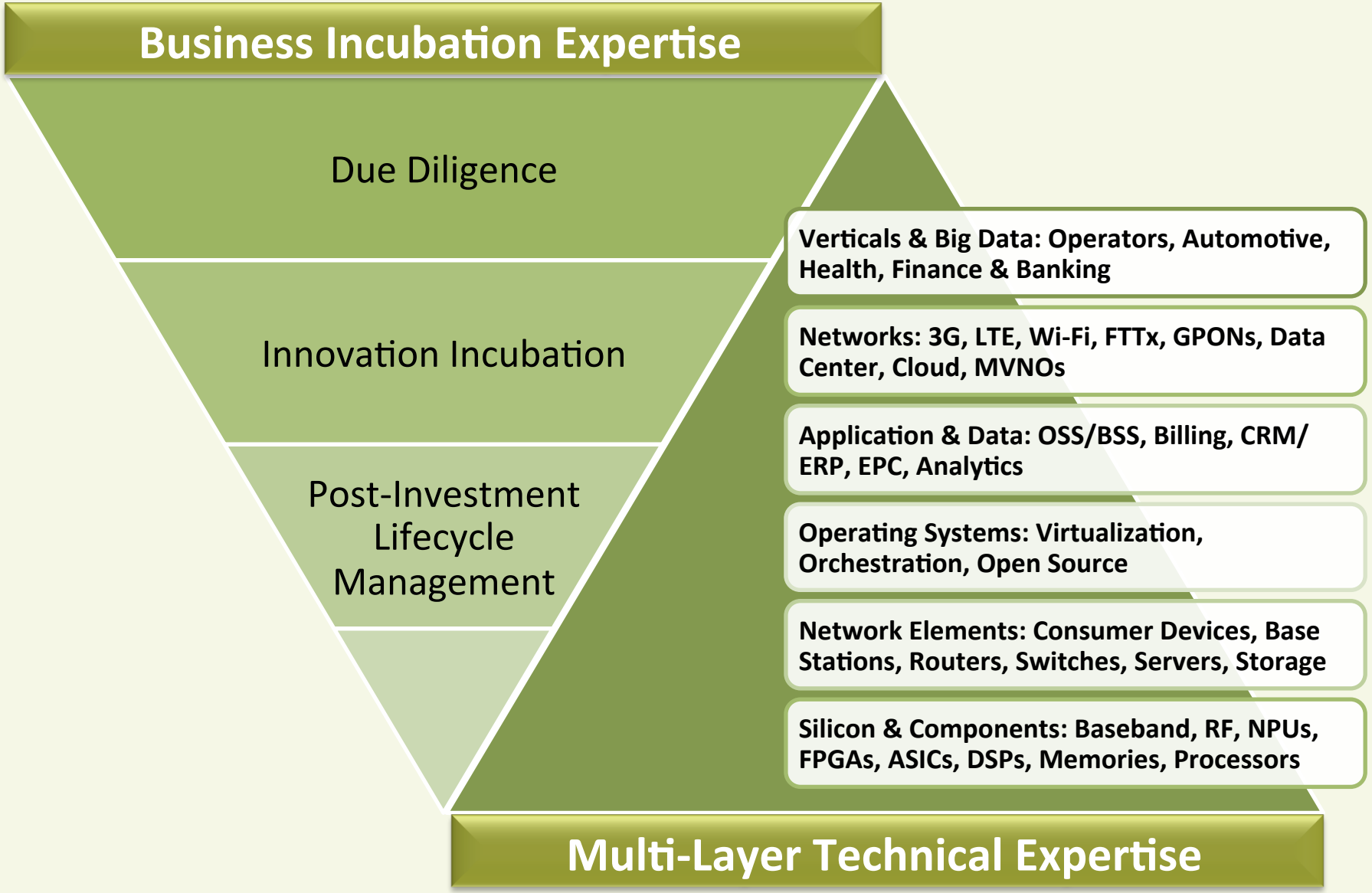
New Business Incubation & Growth

- Incubate new business ventures in adjacent and disruptive markets
- Leverage existing assets to generate new revenue streams
- Define and enact new growth and innovation strategies



XONA PARTNERS

Expertise Through the Value Chain



XONA Partners

Innovate. Enable.

Contact: advisors@xonapartners.com

Web: www.xonapartners.com

Partners & Advisors: www.xonapartners.com/team

San Francisco • Singapore • Dubai • Paris