5G: EVOLUTION TOWARDS A NETWORKED SOCIETY

Eduardo Oliva

2016-09-28

UFSCar Presentation

BEFORE SOMEONE ASKS...

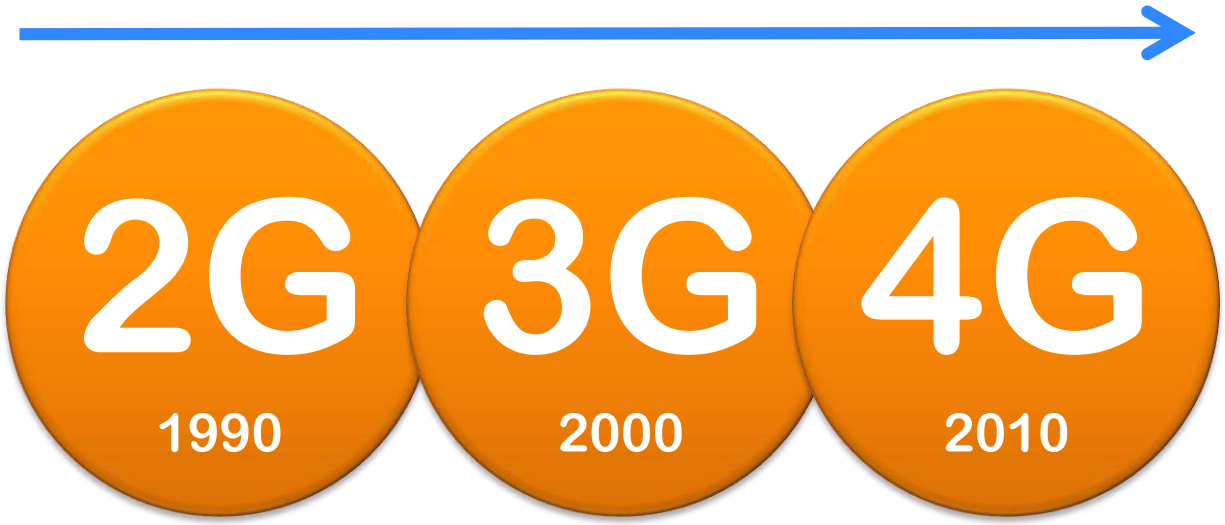
Do we (really) need 5G?

Yes!

IF YOU DON´T WANT TO WATCH THIS PRESENTATION

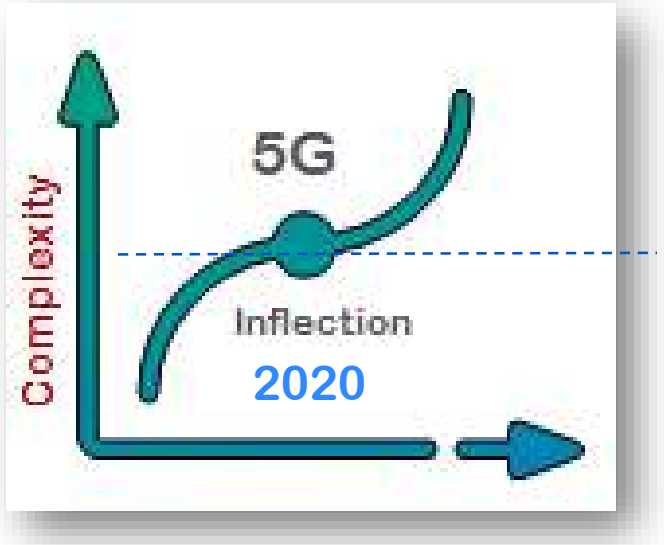
JUST KEEP THIS KEY TAKE AWAY

Evolution
Driven by communication needs from humans



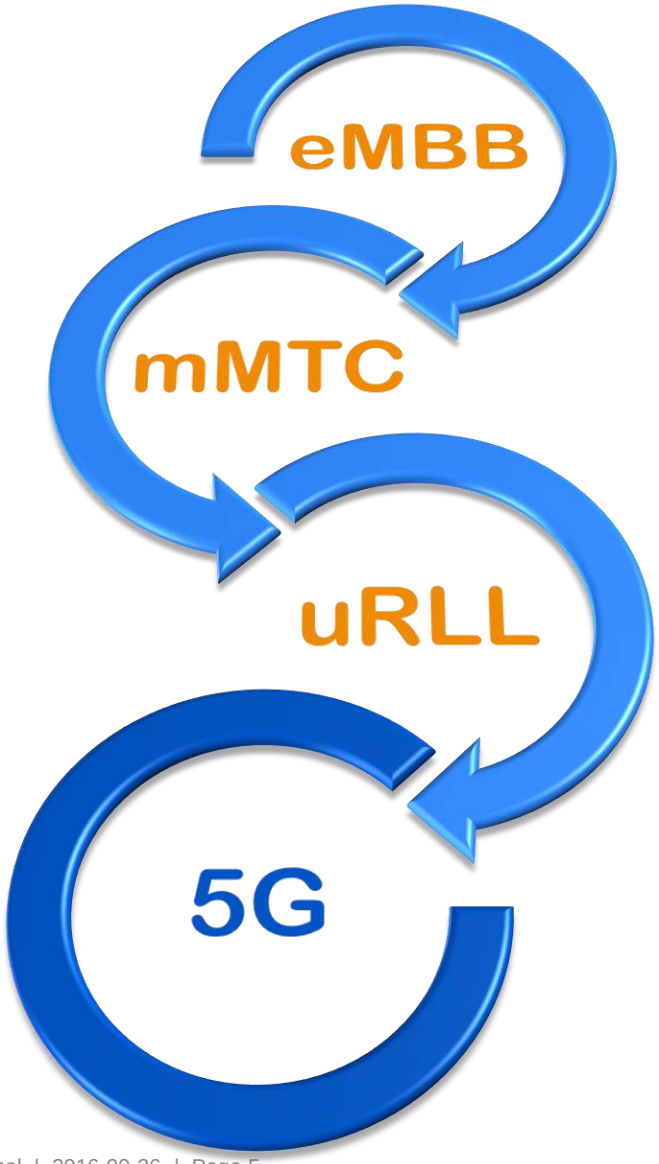
Voice&SMS | Web | Mobile Broadband

Revolution
Driven by communication needs from devices/machines and vertical industries



- ❑ Extremely Fast
- ❑ Massive Devices & Machines
- ❑ Ultra Reliable & Low Latency

JUST TO REINFORCE...



Extreme Mobile Broadband

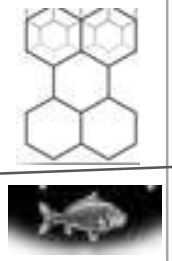
Massive Machine Type Communications

Ultra-Reliable and Low Latency

5G WILL BE DIFFERENT

80s	90s	00s	10s	20s

One Size Fits All



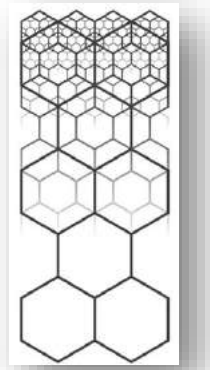
1G 2G 3G 4G

Towards BB Multimedia and "All IP"

Few and uniform use cases

Real Transformation

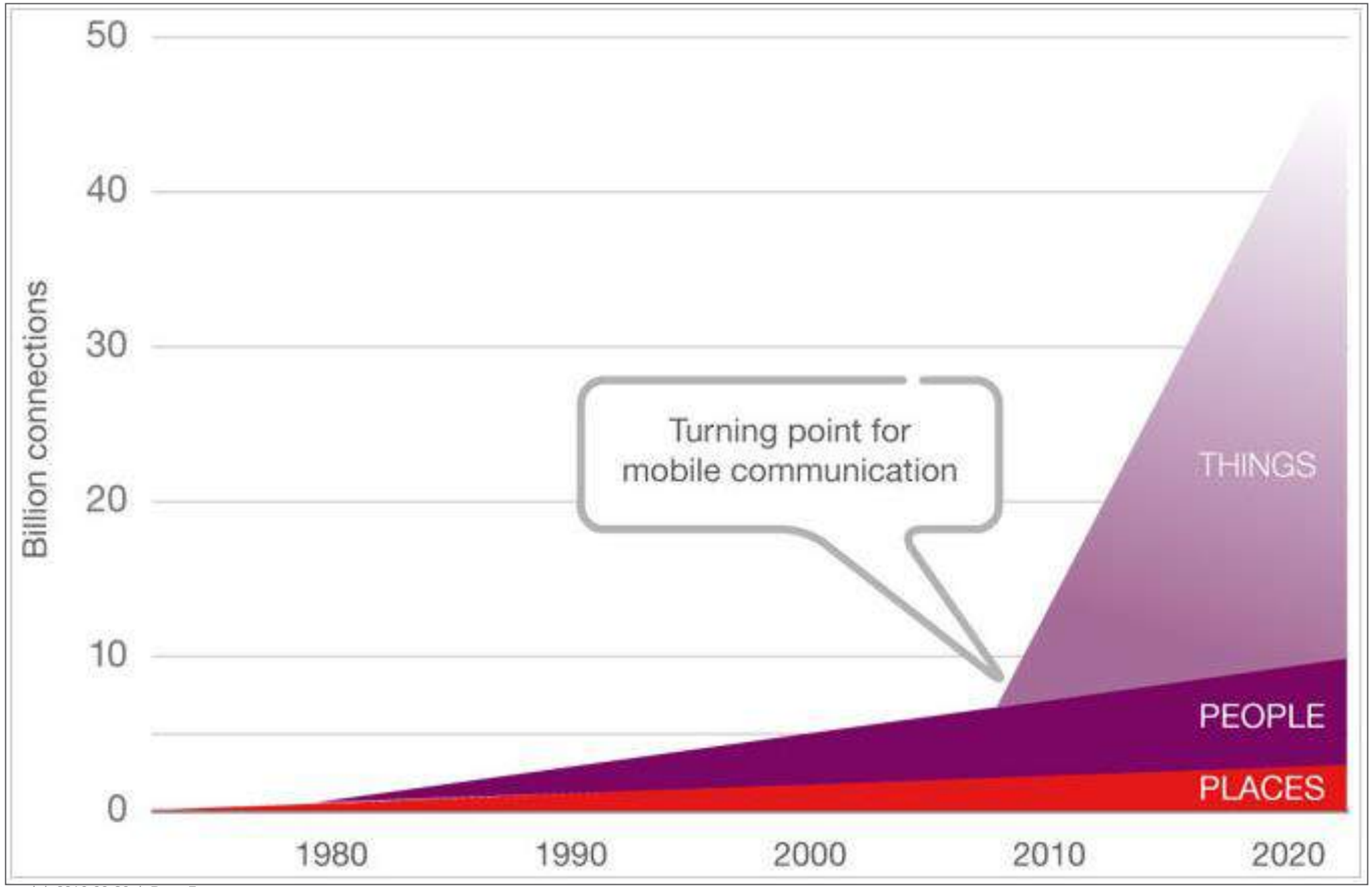
5G



Dense, Dynamic, Diversified, Different

Several use cases

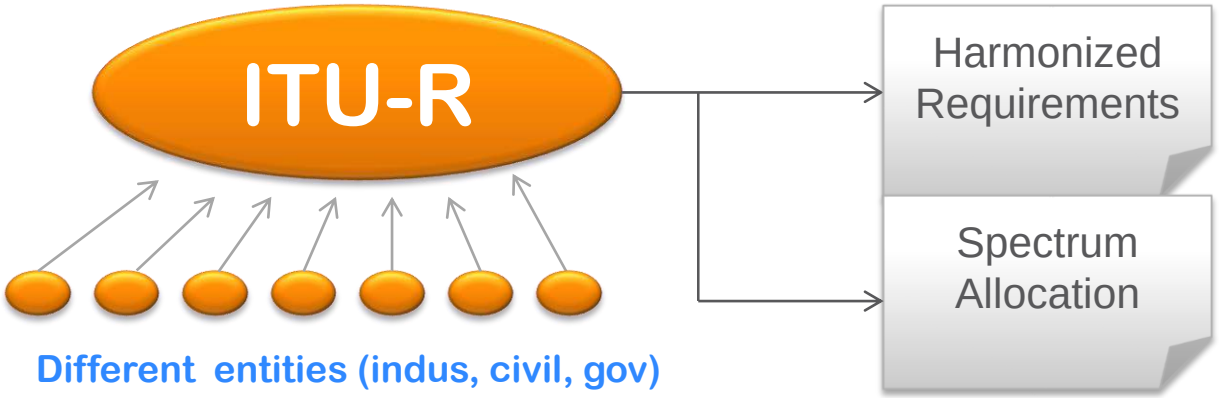
One Size Won´t Fit Any


50
40
30
20
10
0
Billion connections
Turning point for
mobile communication
THINGS
PEOPLE
PLACES
1980
1990
2000
2010
2020

What is a Wireless Generation?

WHAT DEFINES A WIRELESS GENERATION?

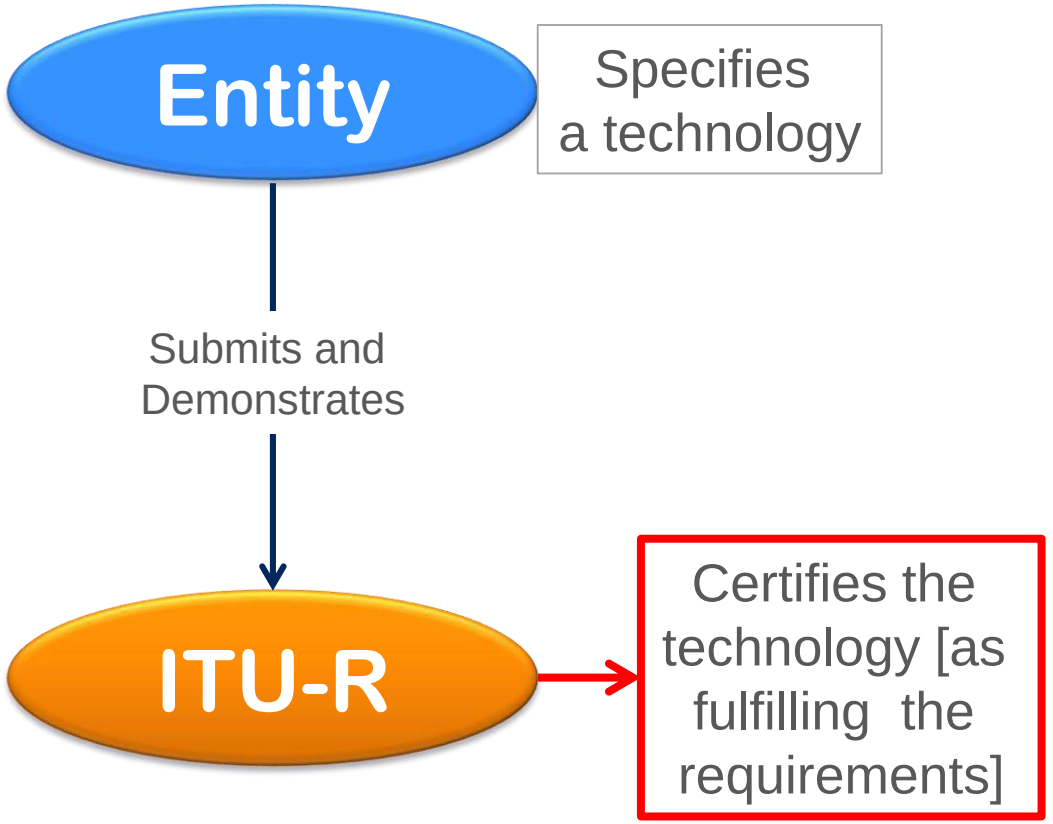
ITU Defines Vision, Requirements, Basic Use Cases and Spectrum



Different entities (indus, civil, gov) send proposals for requirements

- 3GPP
- 3GPP2
- IEEE
- ETSI
- TIA
- ARIB
- 4G Americas
- NGMN
- 5GPPP
- METIS
- NYU
- Many others

e.g. 3GPP; IEEE; …



ITU FRAMEWORK OF STANDARDS

INTERNATIONAL MOBILE TELECOMMUNICATIONS (IMT)

Question: What is ITU's role in IMT?

Over the last 25 years, ITU has developed the IMT framework of standards — or International Mobile Telecommunication system — for mobile telephony and continues to lead international efforts involving governments and industry players to produce the next generation standards for global mobile communications.

Harmonized global mobile communications standards

3G: IMT 2000

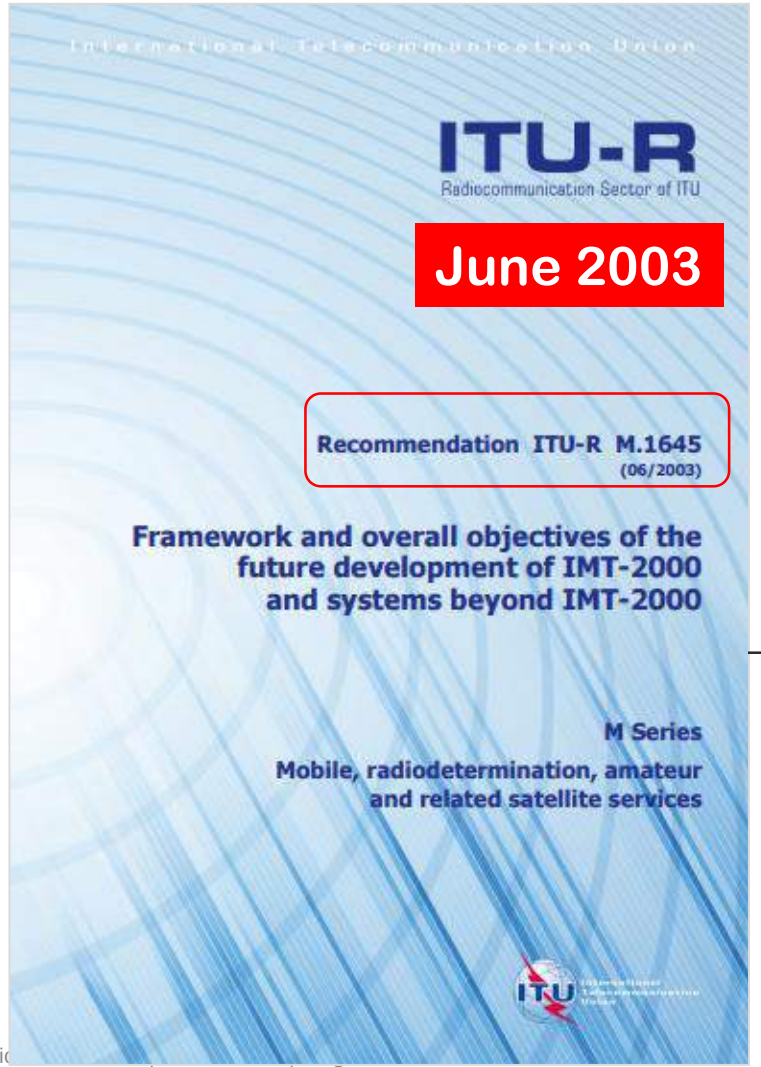
4G: IMT-Advanced

5G: IMT 2020

00s	10s	20s
3G	4G	5G

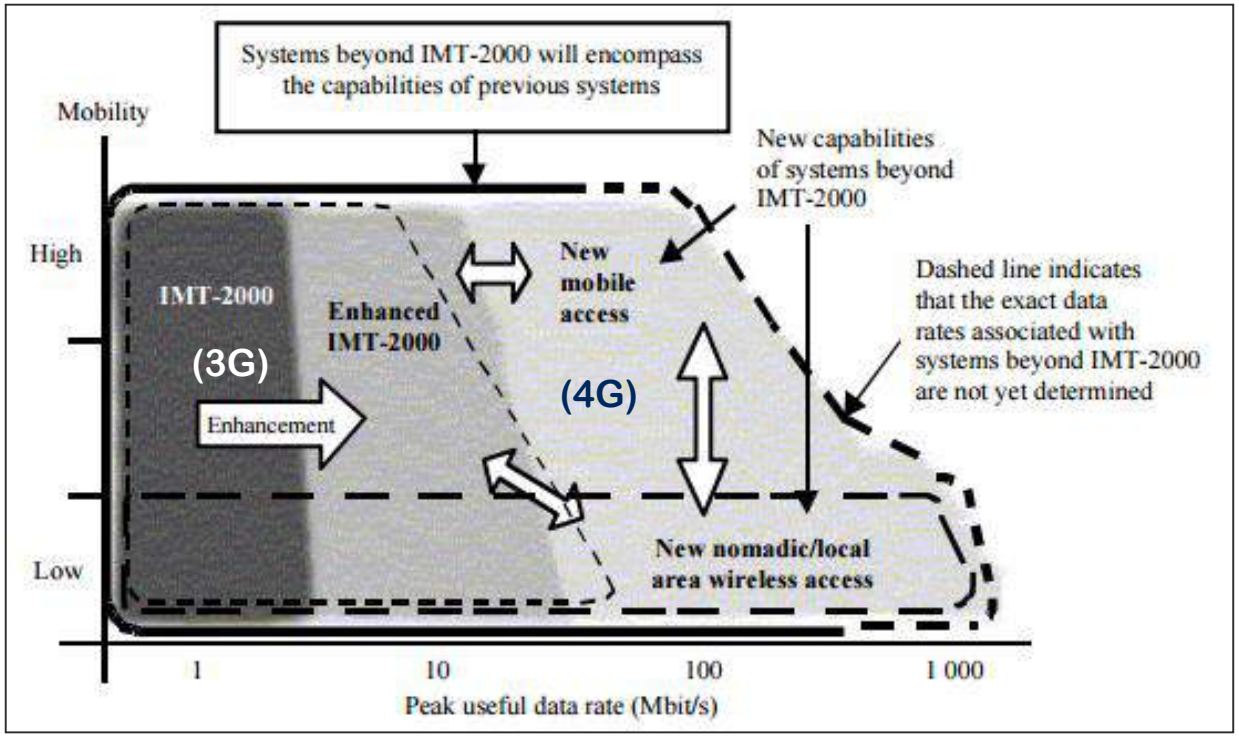
EXAMPLE: 4G (IMT ADVANCED)

http://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.1645-0-200306-I!!PDF-E.pdf



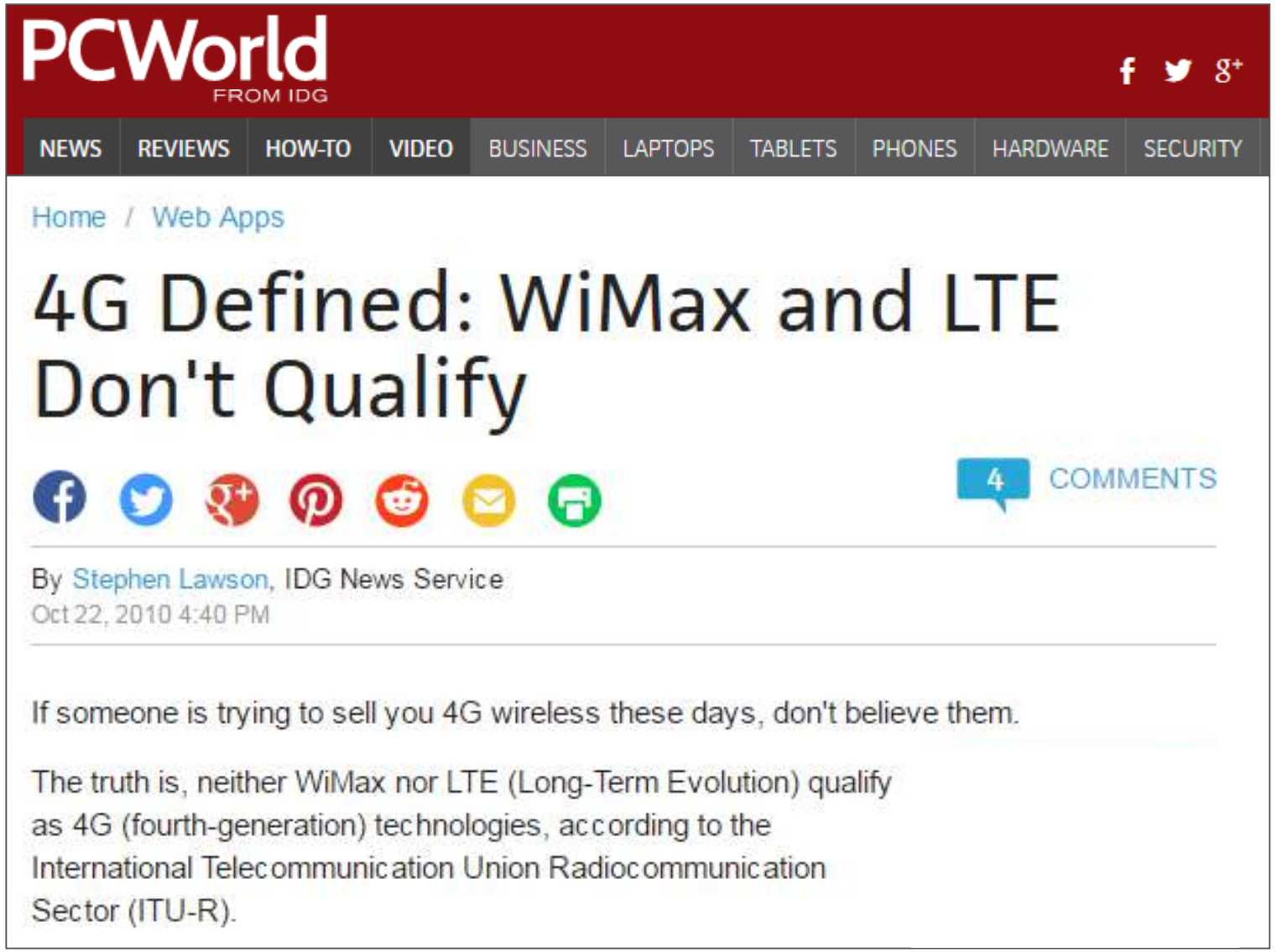
90s	00s	10s	20s
2G	3G	4G	5G

Specifies the requirements for a technology to be considered ["True"] 4G



LTE AND WIMAX ARE NOT 4G

October 2010



PCWorld
FROM IDG

NEWS | REVIEWS | HOW-TO | VIDEO | BUSINESS | LAPTOPS | TABLETS | PHONES | HARDWARE | SECURITY

Home / Web Apps

4G Defined: WiMax and LTE Don't Qualify

4 COMMENTS

By Stephen Lawson, IDG News Service
Oct 22, 2010 4:40 PM

If someone is trying to sell you 4G wireless these days, don't believe them.

The truth is, neither WiMax nor LTE (Long-Term Evolution) qualify as 4G (fourth-generation) technologies, according to the International Telecommunication Union Radiocommunication Sector (ITU-R).

LTE-ADVANCED AND WIMAX2 ARE 4G

January 2012

ITU designates LTE-Advanced as "True 4G"

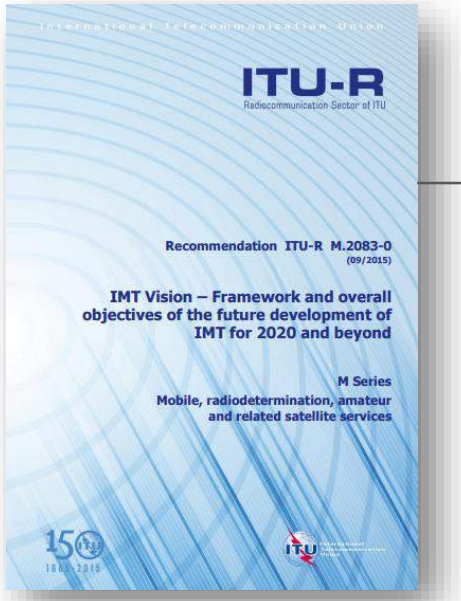
By Neal Gompa on January 23, 2012 at 9:27 am | 5 Comments

47 shares

Late last week, the ITU (International Telecommunications Union) finally agreed on which technologies qualify for the IMT-Advanced specification. The ITU has decided that LTE-Advanced (which is a collection of standards defined in upcoming UMTS Releases 9 and 10) and WirelessMAN-Advanced (commonly known as WiMAX 2) both qualify and are officially designated as IMT-Advanced technologies.

IMT 2020 (A.K.A 5G) VISION

Sep 2015



Rec. ITU-R M.2083-0 1

RECOMMENDATION ITU-R M.2083-0

IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond

(2015)

"This Recommendation defines the framework and overall objectives of the future development of International Mobile Telecommunications (IMT) for 2020 and beyond in light of the roles that IMT could play ***to better serve the needs of the NETWORKED SOCIETY***, for both developed and developing countries, in the future.

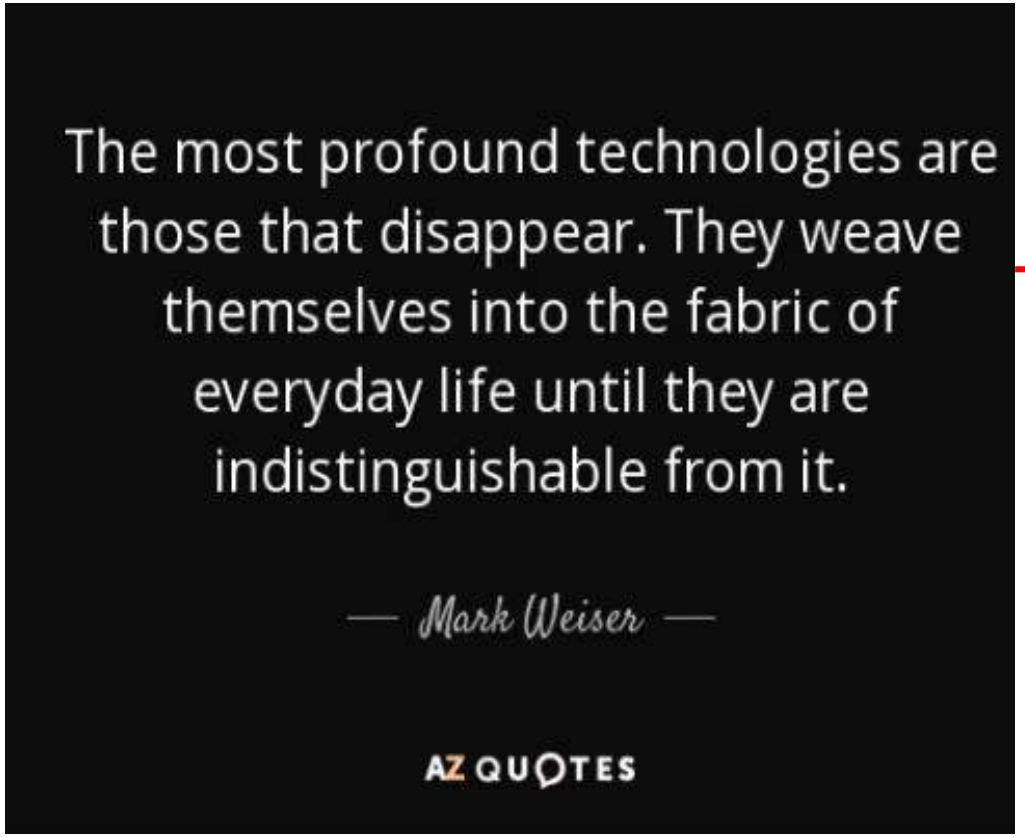
In this Recommendation, the framework of the future development of IMT for 2020 and beyond, including a broad variety of capabilities associated with envisaged usage scenarios."

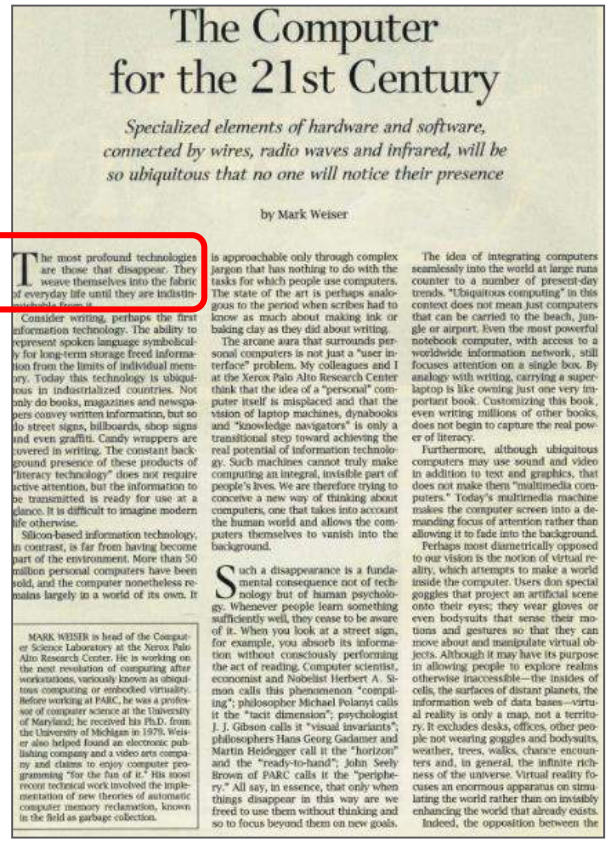
Visions

THE FATHER OF ALL VISIONS

HIS UBIQUITOUS COMPUTING VISION IS STILL EVOLVING

1991





The Computer for the 21st Century

Specialized elements of hardware and software, connected by wires, radio waves and infrared, will be so ubiquitous that no one will notice their presence

by Mark Weiser

The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.

Consider writing, perhaps the first information technology. The ability to represent spoken language symbolically for long-term storage freed information from the limits of individual memory. Today this technology is ubiquitous in industrialized countries. Not only do books, magazines and newspapers convey written information, but so do street signs, billboards, shop signs and even graffiti. Candy wrappers are covered in writing. The constant background presence of these products of "literacy technology" does not require active attention, but the information to be transmitted is ready for use at a glance. It is difficult to imagine modern life otherwise.

Silicon-based information technology, in contrast, is far from having become part of the environment. More than 50 million personal computers have been sold, and the computer nonetheless remains largely in a world of its own. It is approachable only through complex jargon that has nothing to do with the tasks for which people use computers. The state of the art is perhaps analogous to the period when scribes had to know as much about making ink or baking clay as they did about writing.

The arcane aura that surrounds personal computers is not just a "user interface" problem. My colleagues and I at the Xerox Palo Alto Research Center think that the idea of a "personal" computer itself is misplaced and that the vision of laptop machines, dynabooks and "knowledge navigators" is only a transitional step toward achieving the real potential of information technology. Such machines cannot truly make computing an integral, invisible part of people's lives. We are therefore trying to conceive a new way of thinking about computers, one that takes into account the human world and allows the computers themselves to vanish into the background.

Such a disappearance is a fundamental consequence not of technology but of human psychology. Whenever people learn something sufficiently well, they cease to be aware of it. When you look at a street sign, for example, you absorb its information without consciously performing the act of reading. Computer scientist, economist and Nobelist Herbert A. Simon calls this phenomenon "compiling"; philosopher Michael Polanyi calls it the "tacit dimension"; psychologist J. J. Gibson calls it "visual invariants"; philosophers Hans Georg Gadamer and Martin Heidegger call it the "horizon" and the "ready-to-hand"; John Seely Brown of PARC calls it the "periphery." All say, in essence, that only when things disappear in this way are we freed to use them without thinking and so to focus beyond them on new goals.

The idea of integrating computers seamlessly into the world at large runs counter to a number of present-day trends. "Ubiquitous computing" in this context does not mean just computers that can be carried to the beach, jungle or airport. Even the most powerful notebook computer, with access to a worldwide information network, still focuses attention on a single box. By analogy with writing, carrying a superlaptop is like owning just one very important book. Customizing this book, even writing millions of other books, does not begin to capture the real power of literacy.

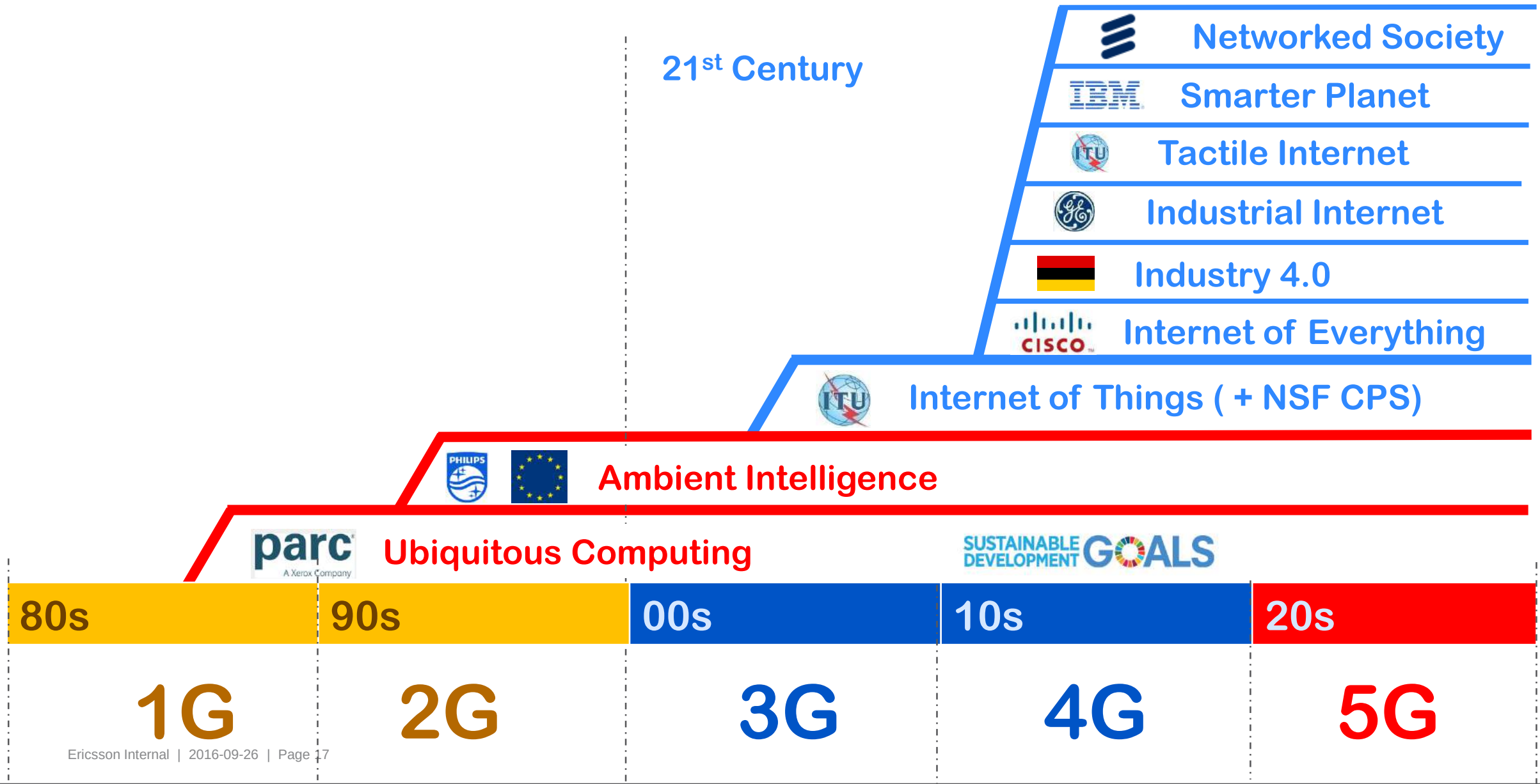
Furthermore, although ubiquitous computers may use sound and video in addition to text and graphics, that does not make them "multimedia computers." Today's multimedia machine makes the computer screen into a demanding focus of attention rather than allowing it to fade into the background.

Perhaps most diametrically opposed to our vision is the notion of virtual reality, which attempts to make a world inside the computer. Users don special goggles that project an artificial scene onto their eyes; they wear gloves or even bodysuits that sense their motions and gestures so that they can move about and manipulate virtual objects. Although it may have its purpose in allowing people to explore realms otherwise inaccessible—the insides of cells, the surfaces of distant planets, the information web of data bases—virtual reality is only a map, not a territory. It excludes desks, offices, other people not wearing goggles and bodysuits, weather, trees, walks, chance encounters and, in general, the infinite richness of the universe. Virtual reality focuses an enormous apparatus on simulating the world rather than on invisibly enhancing the world that already exists.

Indeed, the opposition between the

MARK WEISER is head of the Computer Science Laboratory at the Xerox Palo Alto Research Center. He is working on the next revolution of computing after workstations, variously known as ubiquitous computing or embodied virtuality. Before working at PARC, he was a professor of computer science at the University of Maryland; he received his Ph.D. from the University of Michigan in 1978. Weiser also helped found an electronic publishing company and a video arts company and claims to enjoy computer programming "for the fun of it." His most recent technical work involved the implementation of new theories of automatic computer memory reclamation, known in the field as garbage collection.

EMBRIOLOGY AND MORPHOLOGY OF A VISION



DIFFERENT VISIONS, SAME WORLD

Video, APPs, APIs, msging and virtualization explosions

Facebook Youtube

SOA&WS Mega DCs Web2.0

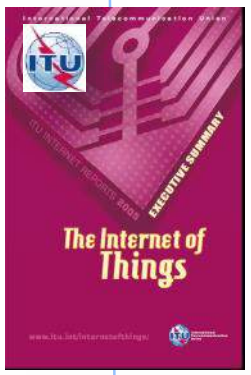
iPhone

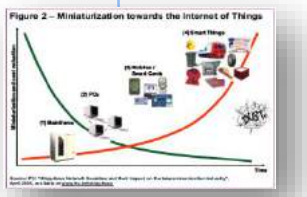
App Store REST APIs

Cloud Hype

2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015

Internet of Everything Report





"When Everything Connects"

Smarter Planet

IBM

50b@2020 Vision

ERICSSON

Networked Society

ERICSSON

Industry 4.0

Knee of exponential

Internet of Everything

CISCO

Industrial Internet

GE

Tactile Internet

ITU

Future X Network

SUSTAINABLE DEVELOPMENT GOALS

5G Vision

Blended Vision

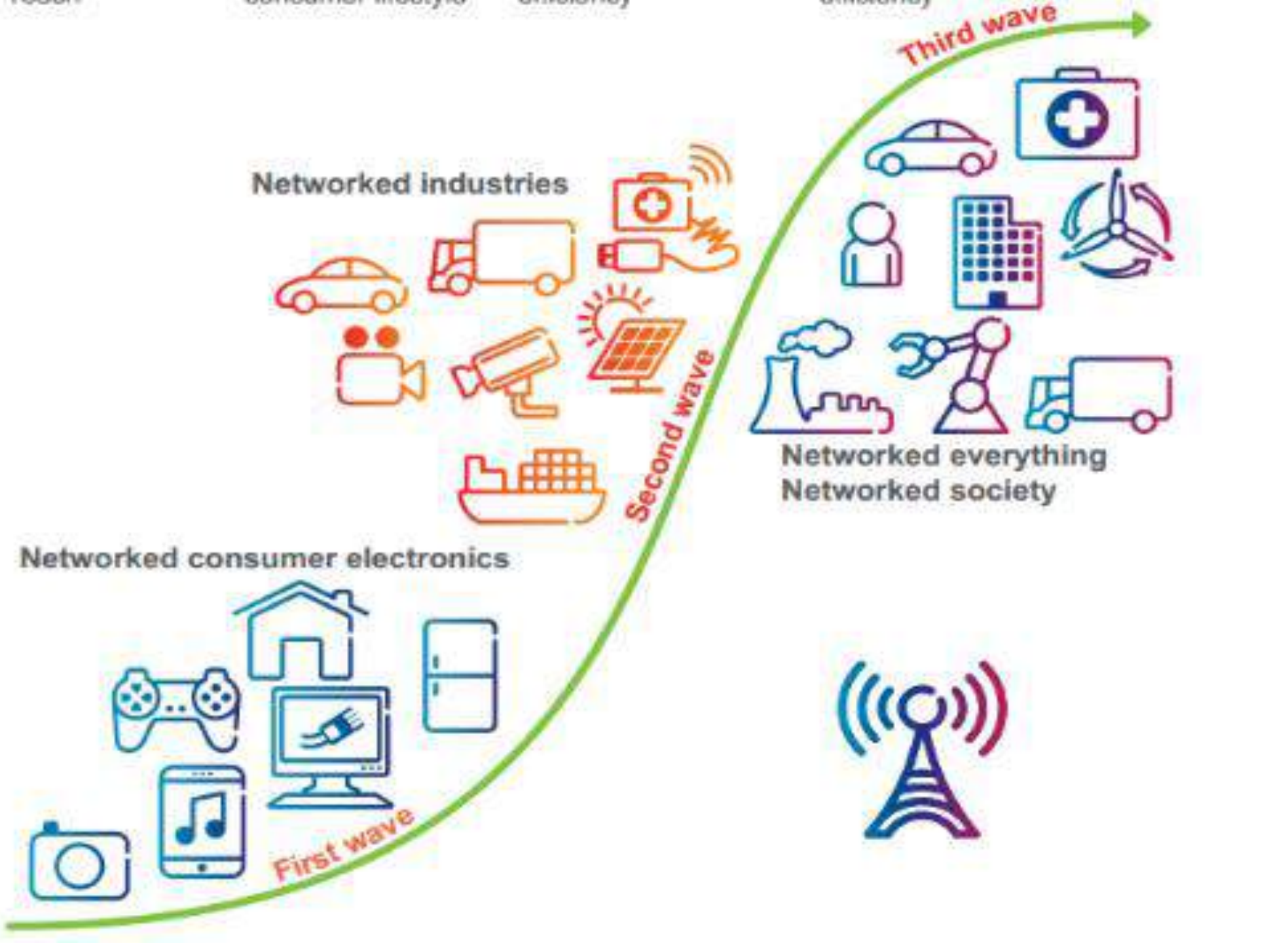
[utopian flavor]

Networked Society

Living in a Smarter, Sustainable Planet

Enabled by Intelligent and

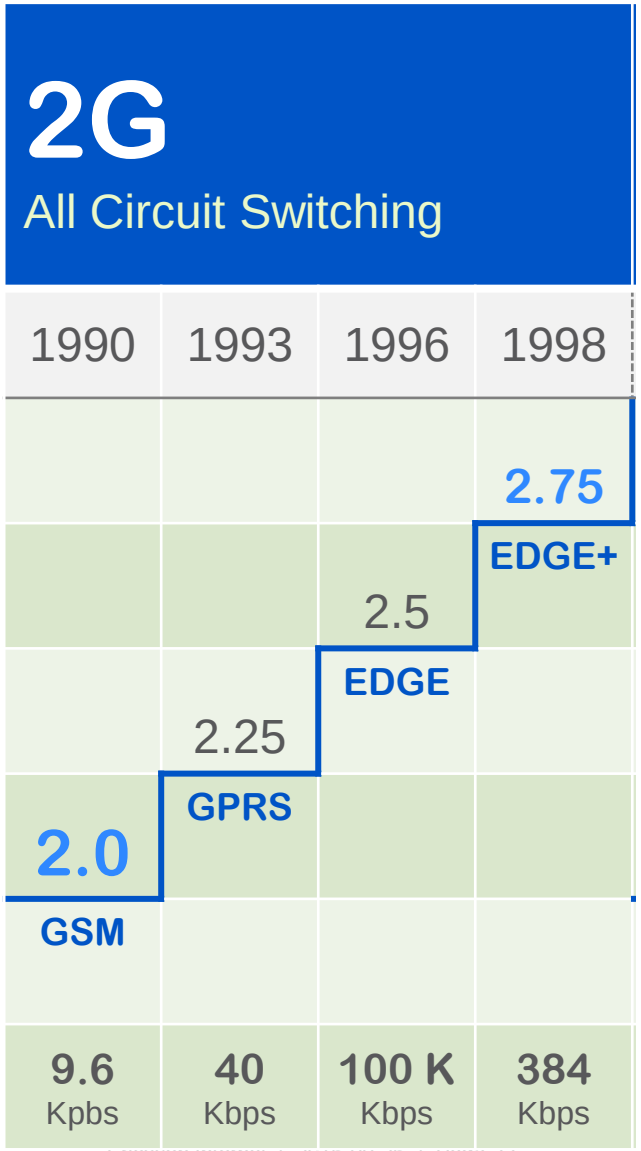
Cognitive Technologies


Third wave
Networked industries
Second wave
Networked everything
Networked society
Networked consumer electronics
First wave

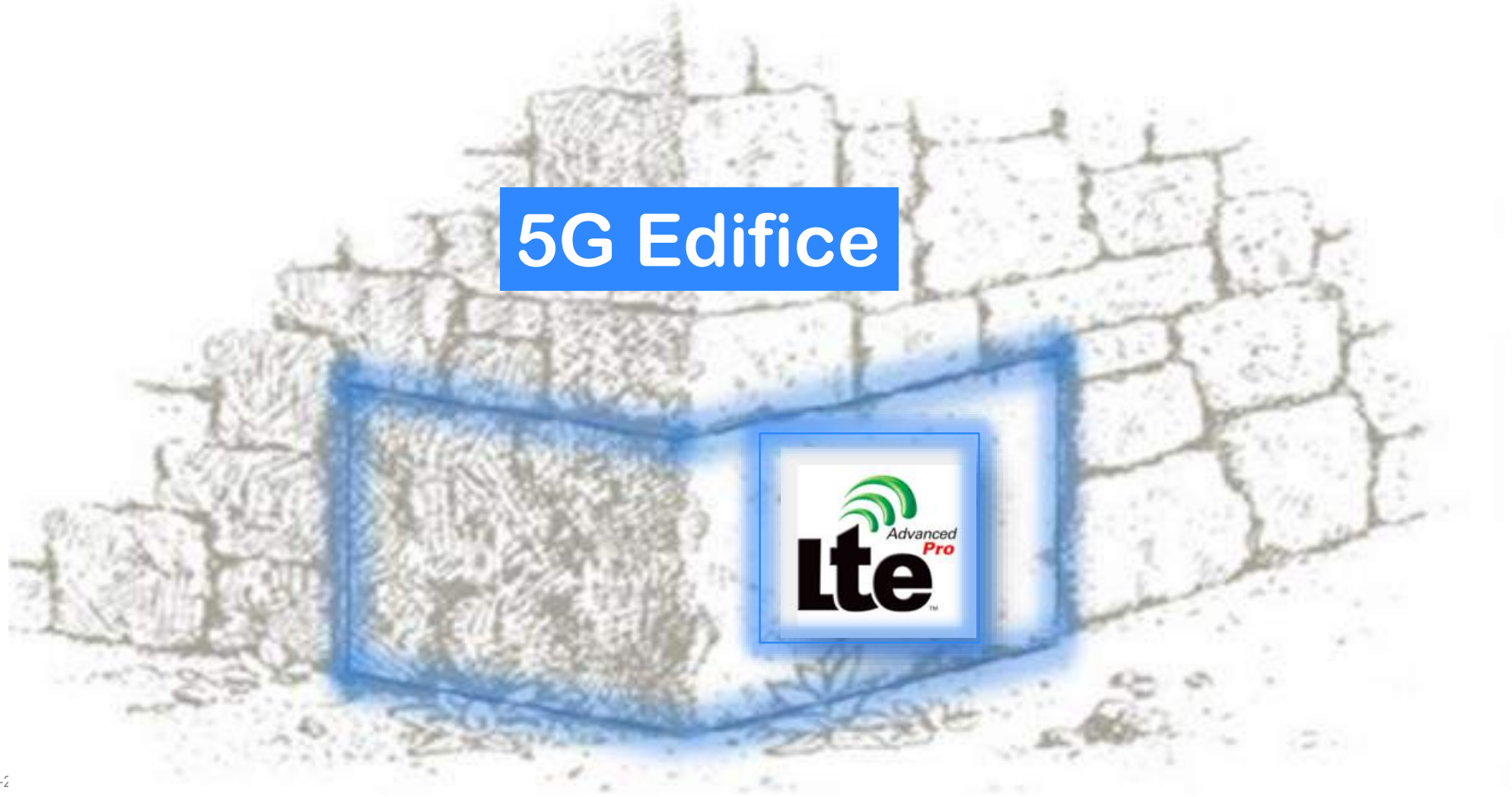
"ANYTHING THAT BENEFITS FROM BEING CONNECTED WILL BE CONNECTED"

Wireless Evolution

WIRELESS GENERATION LADDER

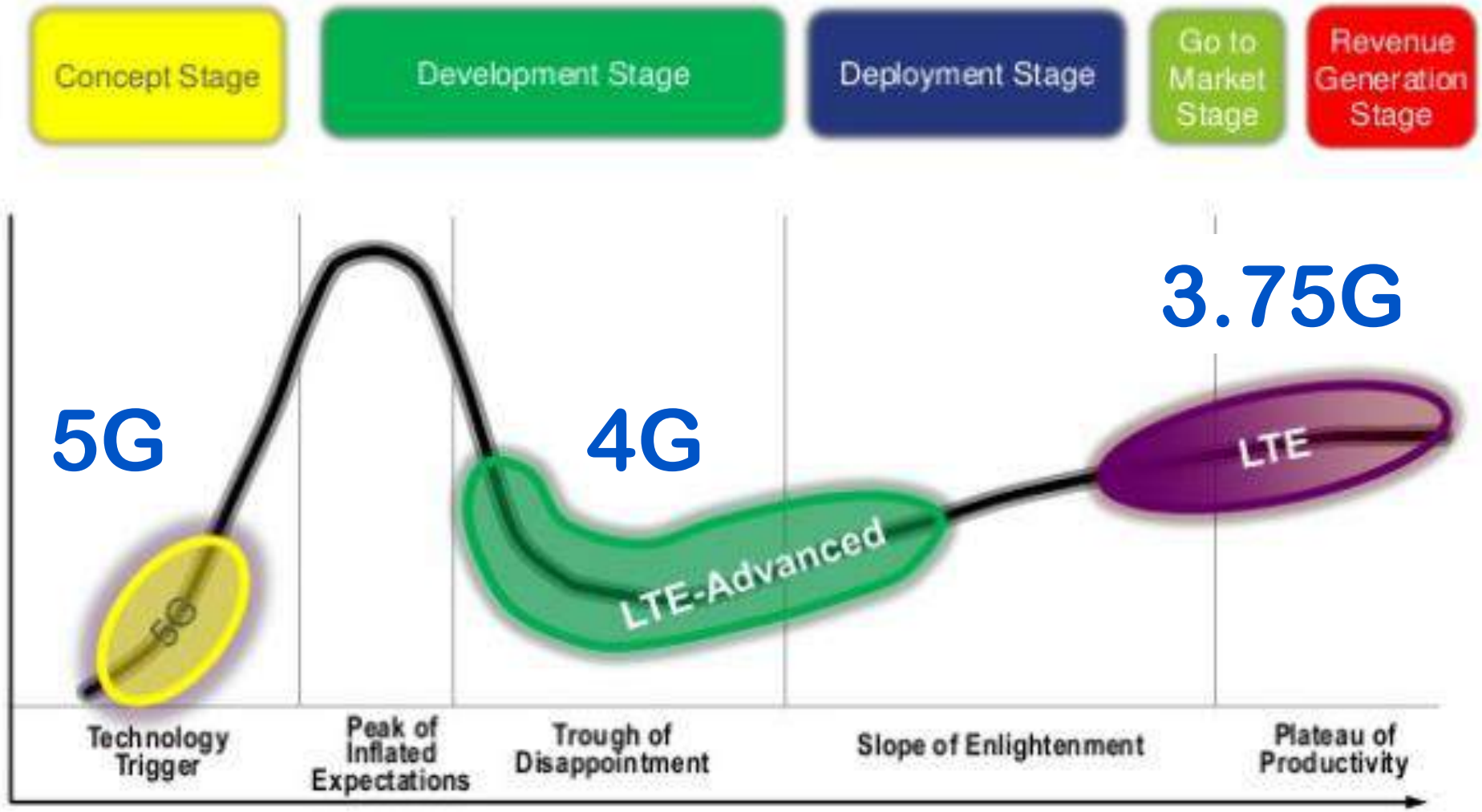


4.5G: THE FOUNDATION OF 5G EDIFICE



Recortar slide

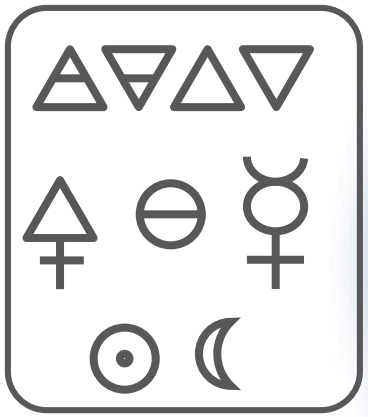
Technology Lifecycle

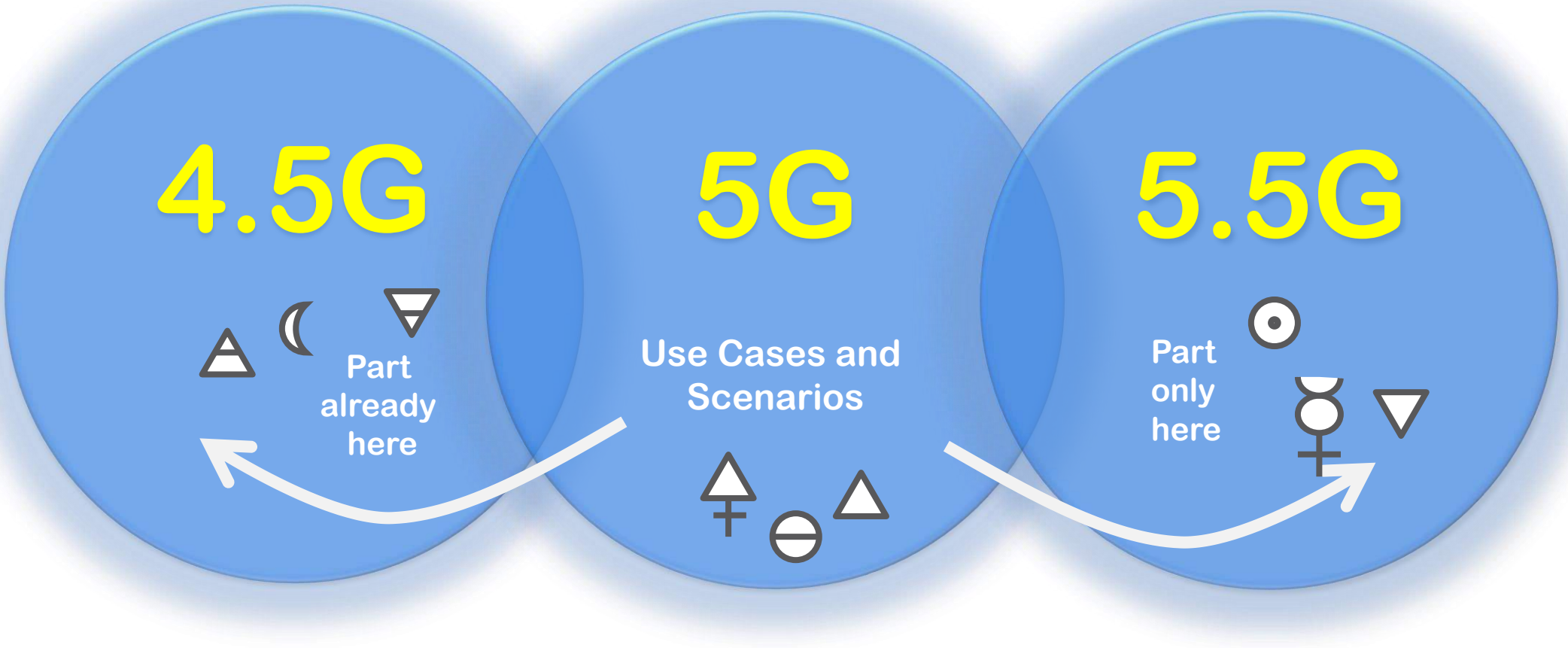


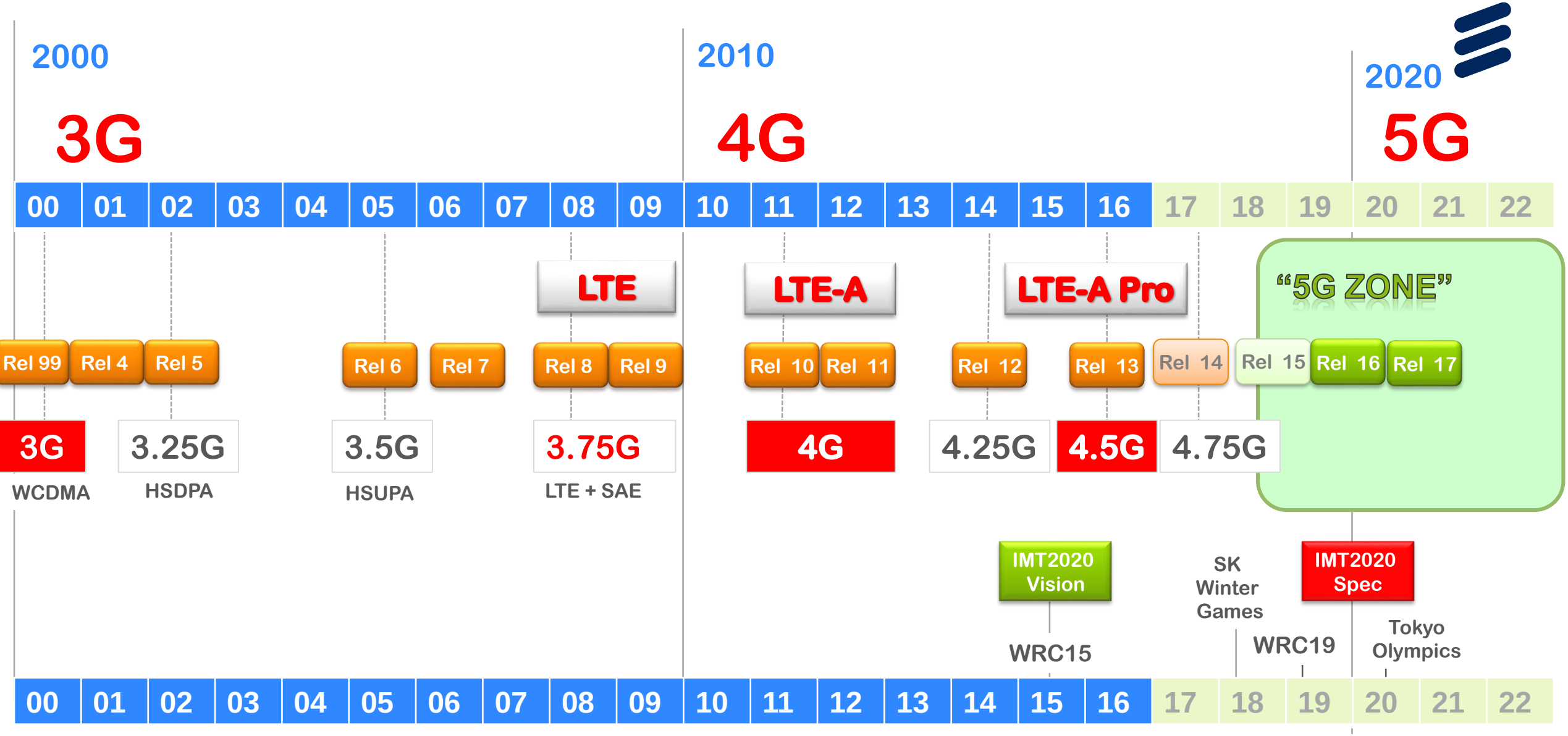
KEYSIGHT TECHNOLOGIES

4.5G & 5.5G NEEDED TO UNDERSTAND 5G

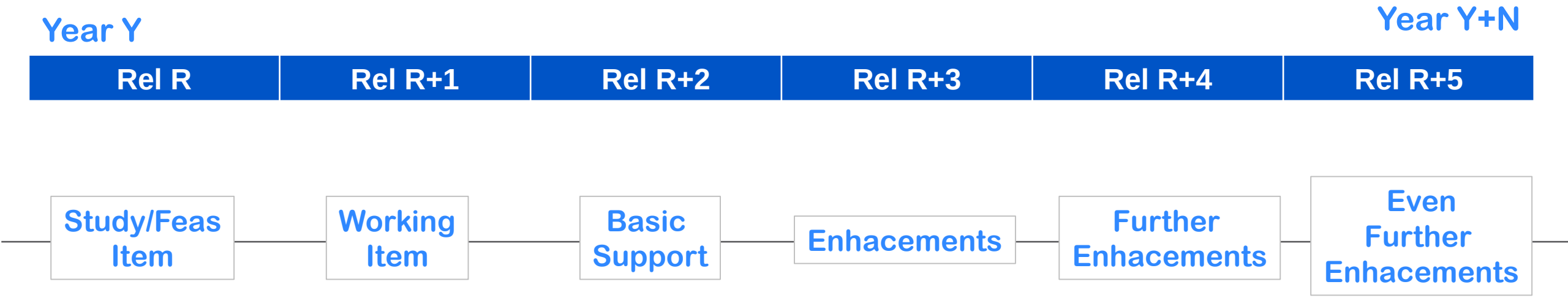
5G Use Cases & Requirements





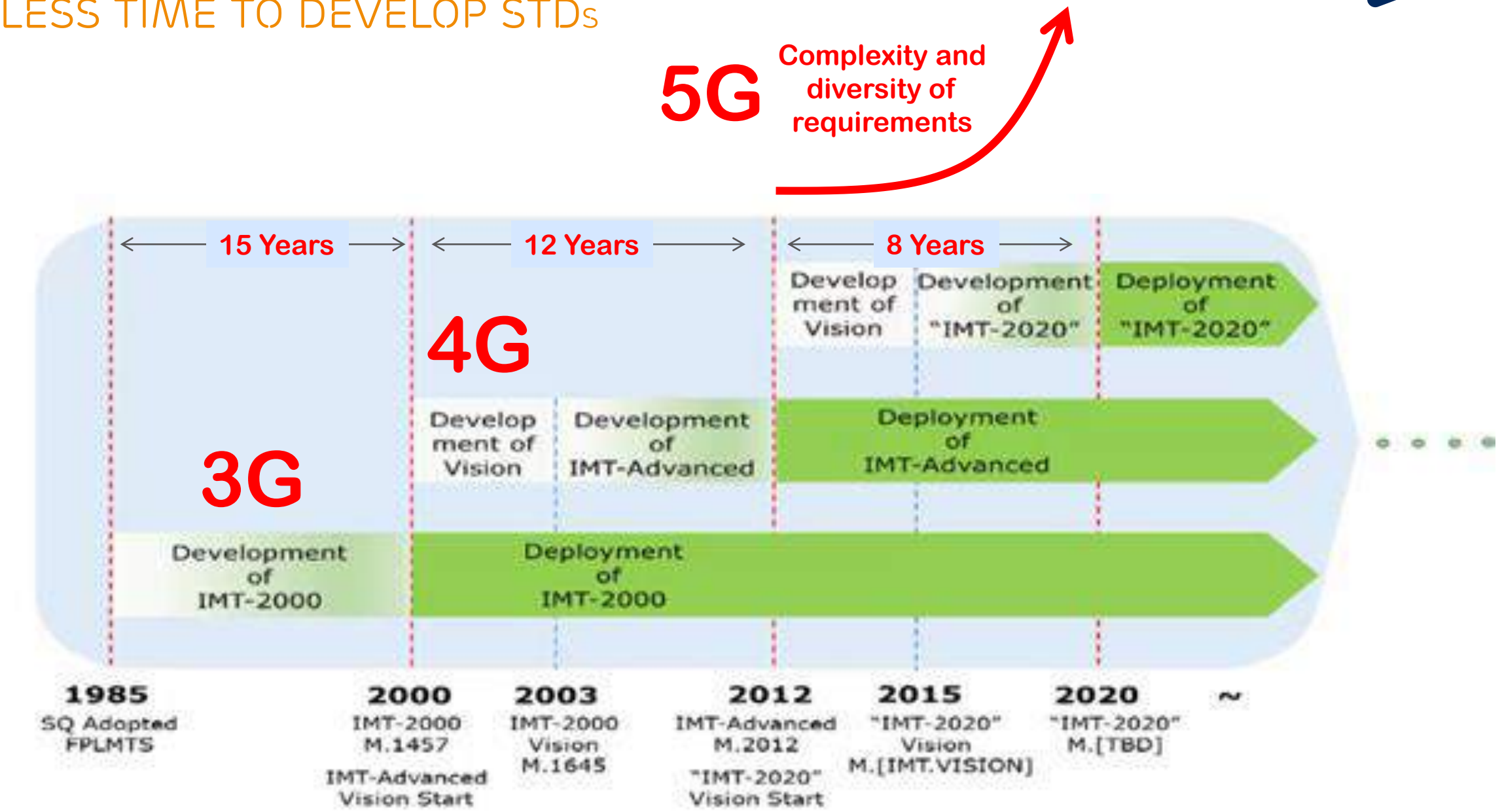

2000
3G
2010
4G
2020
5G
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22
LTE
LTE-A
LTE-A Pro
"5G ZONE"
Rel 99
Rel 4
Rel 5
Rel 6
Rel 7
Rel 8
Rel 9
Rel 10
Rel 11
Rel 12
Rel 13
Rel 14
Rel 15
Rel 16
Rel 17
3G
3.25G
3.5G
3.75G
4G
4.25G
4.5G
4.75G
WCDMA
HSDPA
HSUPA
LTE + SAE
IMT2020 Vision
WRC15
SK Winter Games
WRC19
IMT2020 Spec
Tokyo Olympics
00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22

STANDARDIZATION IS A LONG PROCESSES

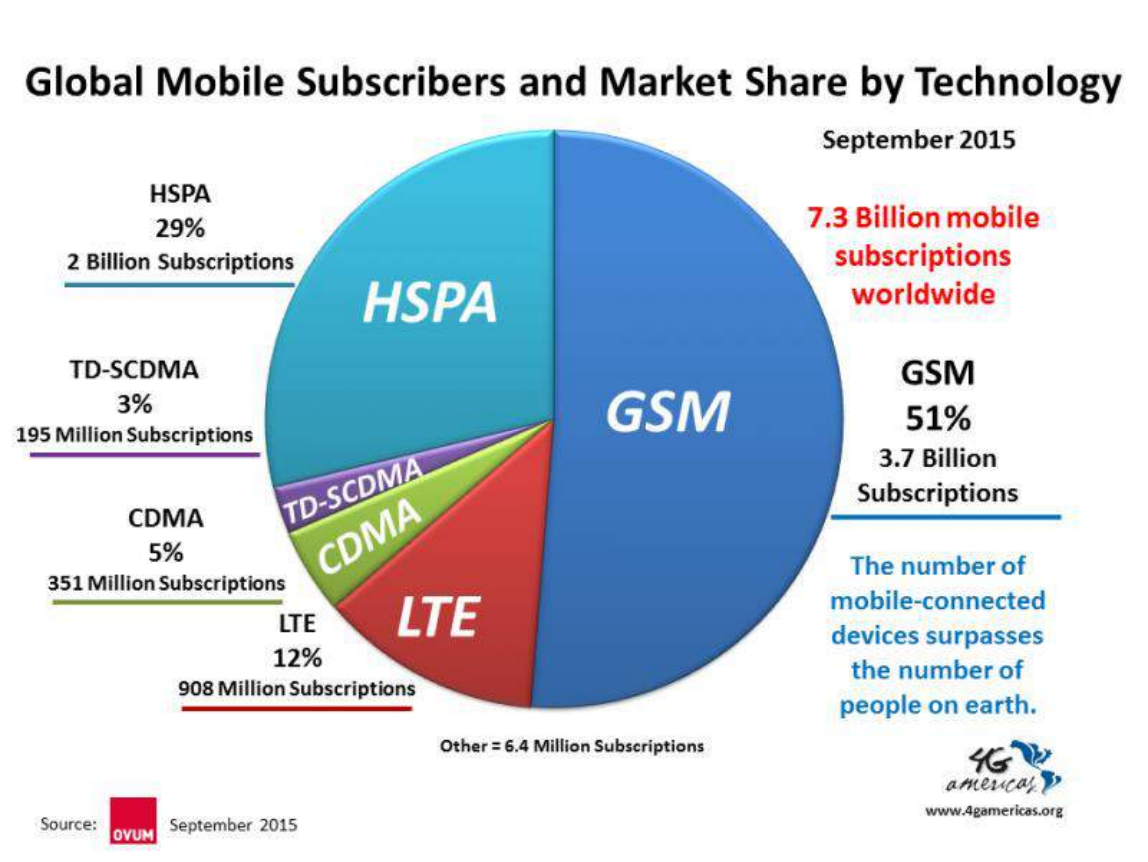


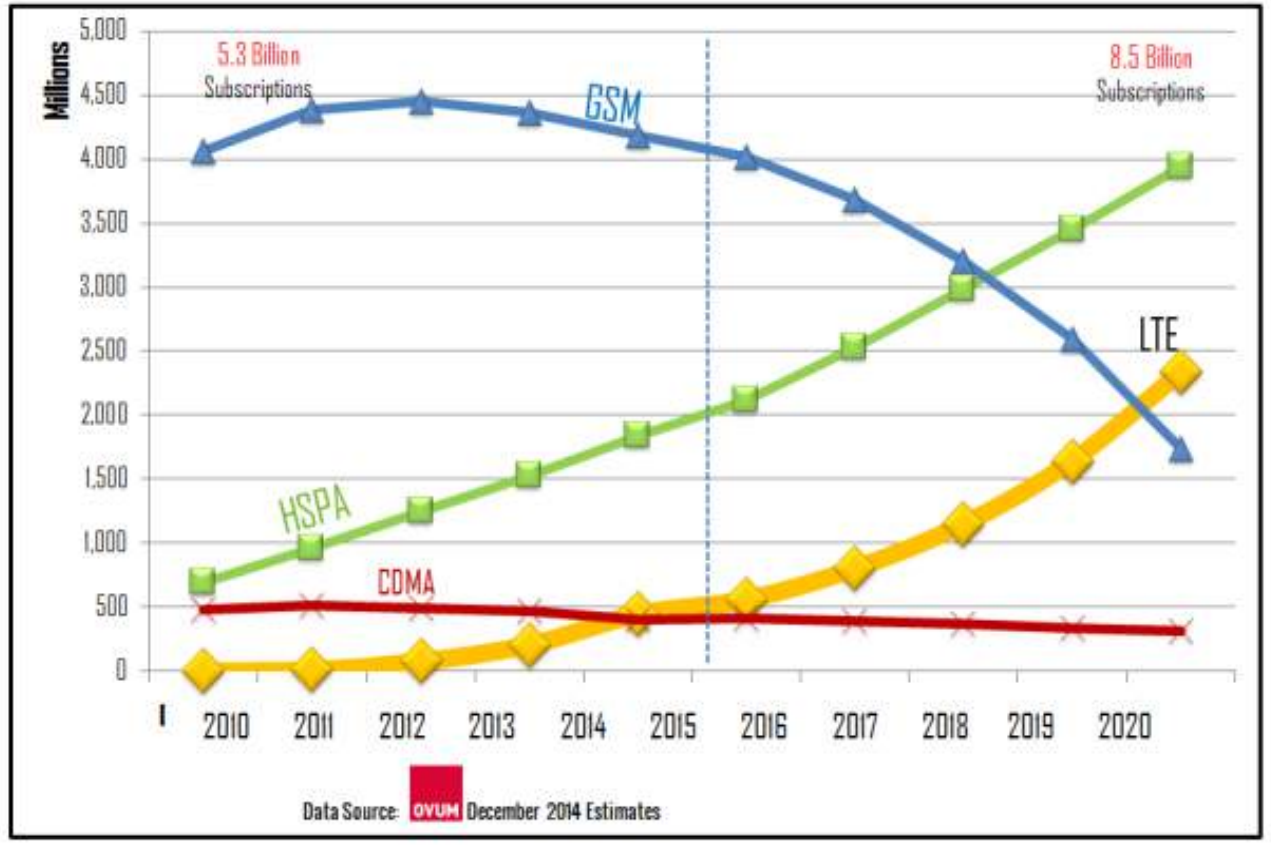
5G WILL BE MUCH MORE COMPLEX

AND LESS TIME TO DEVELOP STDs



THE TYRANNY OF LEGACY



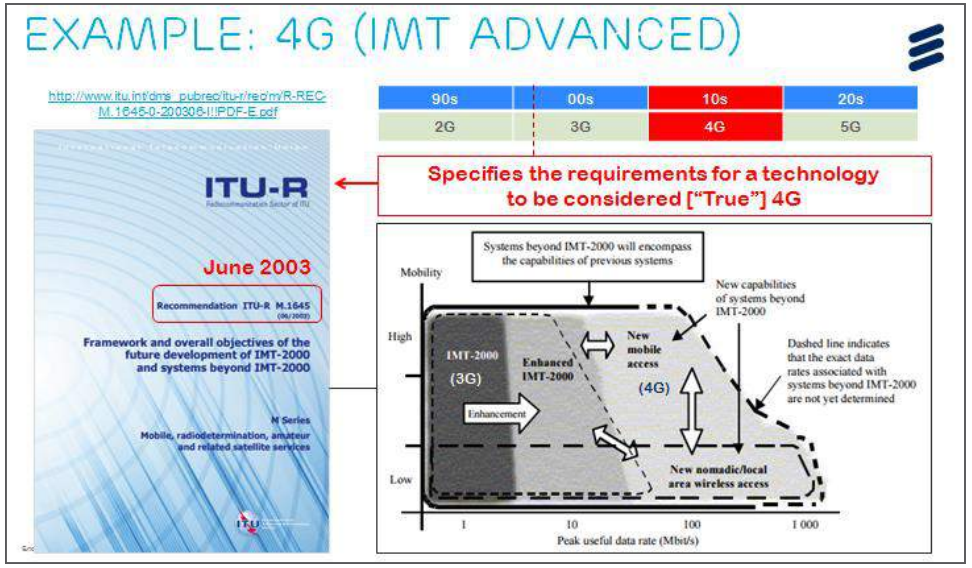


Why 5G?

5G MAIN DRIVING FORCES

- Explosions in smartphones, video&mobile broadband, APPs and APIs
- Massive growth in number and diversity of connected things;
- Industry 4.0; Industrial Internet, Smarter Planet; Dig Transformation ; Networked Society;
- Increased Automation and Smart Technologies, from devices to cities.
- New users: increased ICT literacy, aware, conscious, much higher expectations and demands
- Traditional Telcos threatned by OTTs; growing demands for efficiency, agility and flexibility
- Energy efficiency and sustainability demands
- Softwarization of ICT networks (SDE) and complexification of OAM / MANO

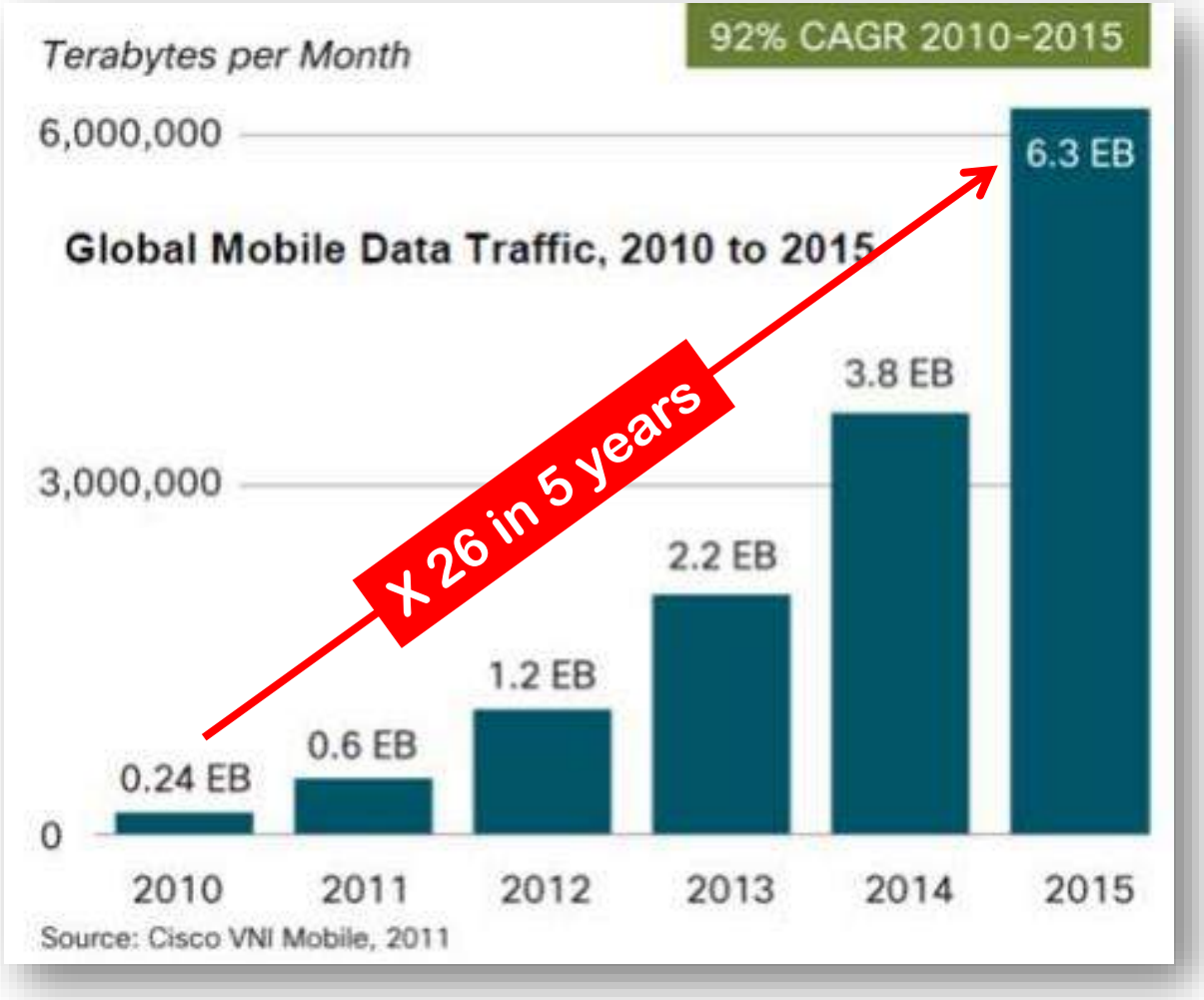
2007: THE UNEXPECTED HAPPENED



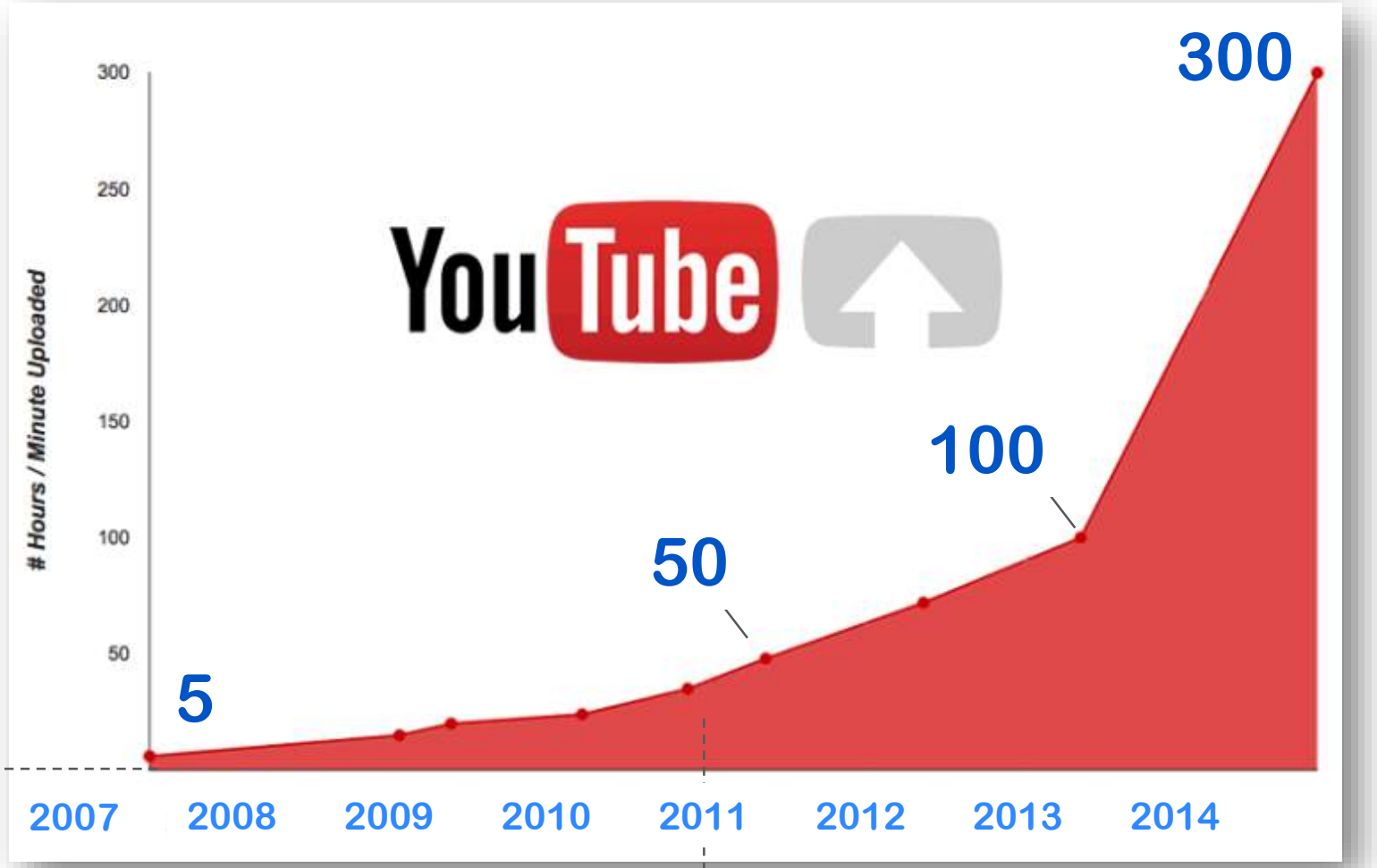
4G was defined before iPhone, APPstore, Youtube and Facebook. *The demands on the network from these innovation was beyond anyone´s imagination.*

As the new demands materialized, several improvements were being proposed, but they many times added new functional components and complexity to existing components.

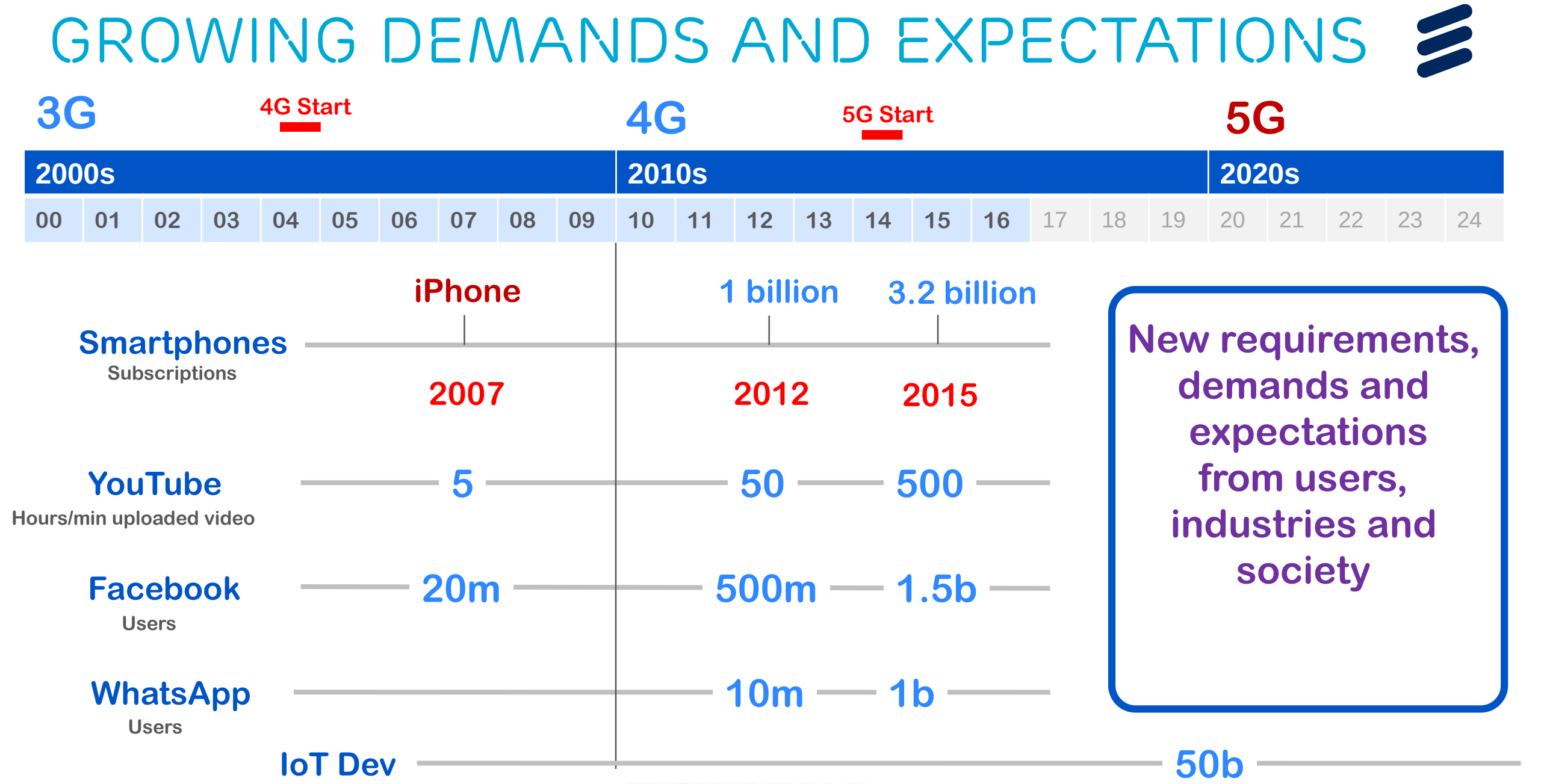
MOBILE DATA TSUNAMI



HOURS OF VIDEO UPLOADED PER MINUTE



GROWING DEMANDS AND EXPECTATIONS



New requirements, demands and expectations from users, industries and society

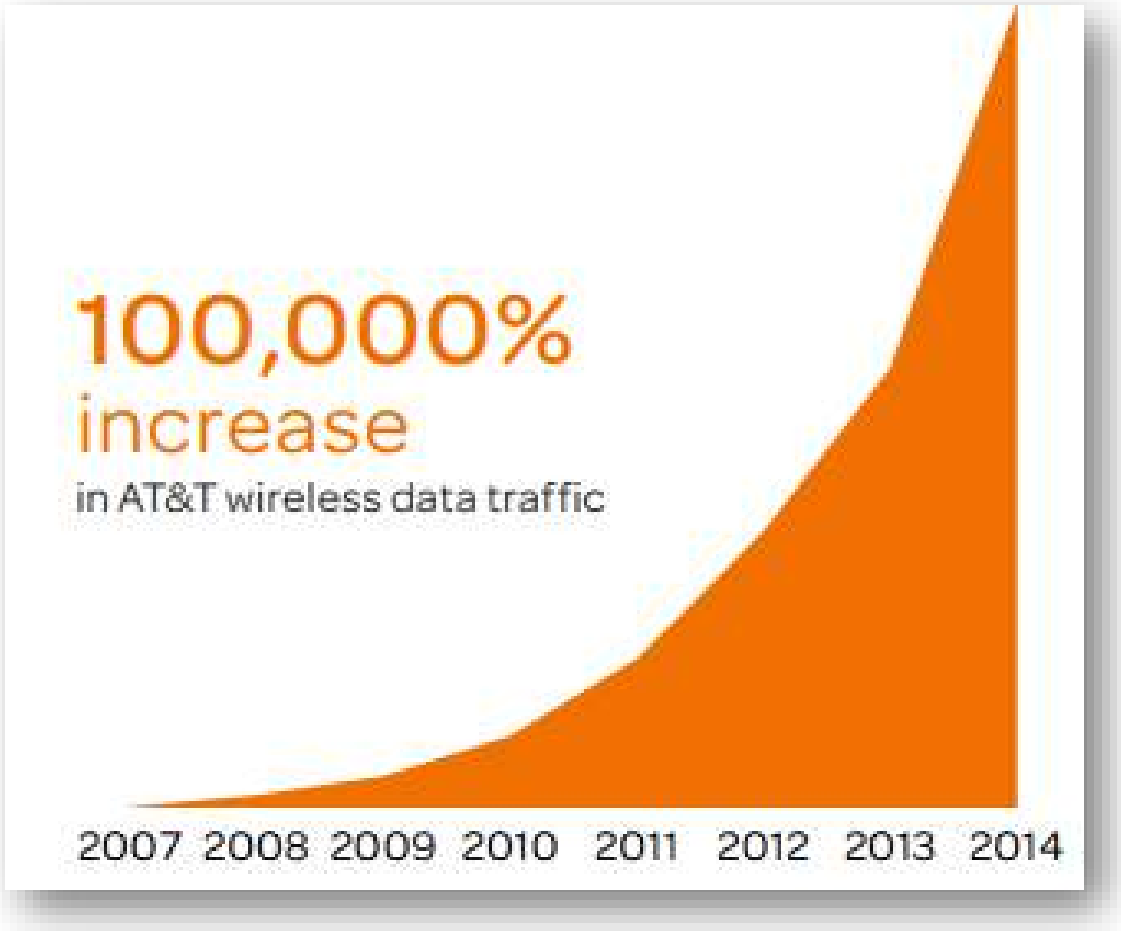
SUSTAINABLE DEVELOPMENT GOALS

VATICAN CITY 2005

VATICAN CITY 2013

EVIDENCE: AT&T WIRELESS DATA TRAFFIC

FROM AT&T ANNUAL REPORT 2015



iPhone +

AppStore +

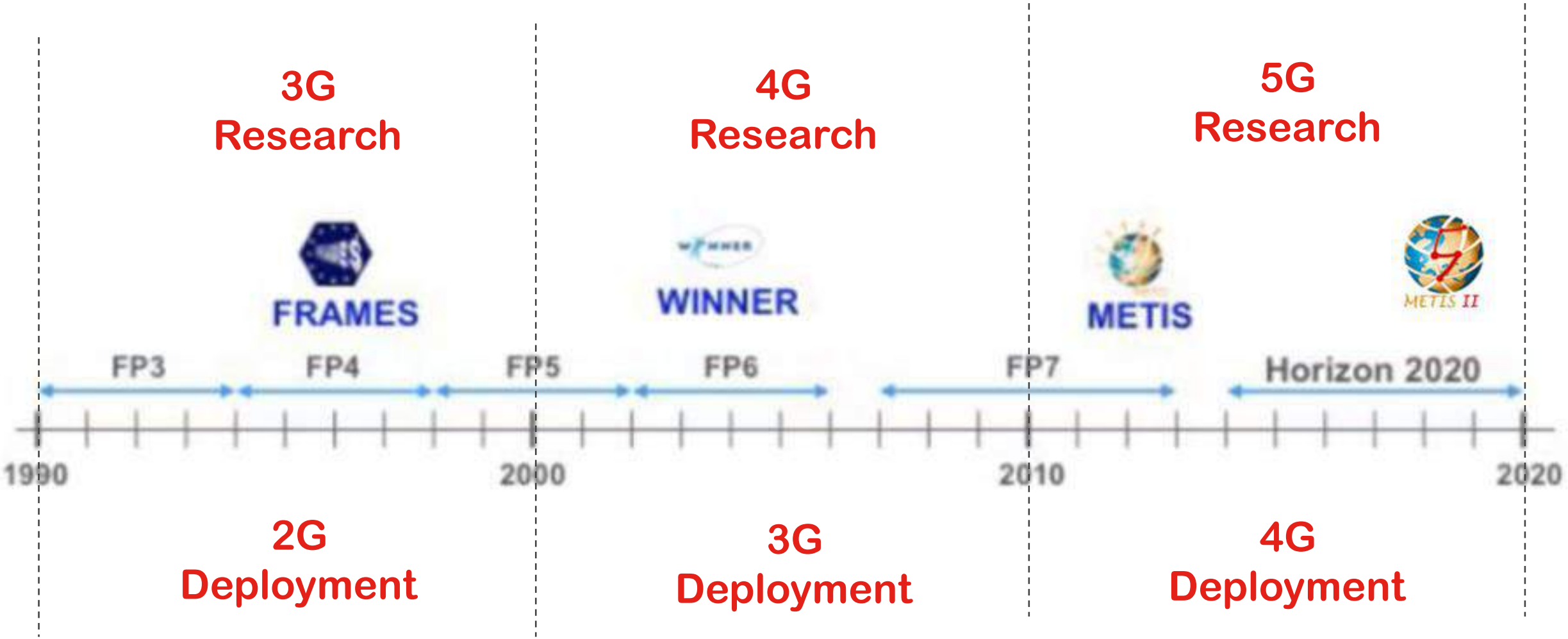
Netflix + Youtube +

Messaging =

Explosion

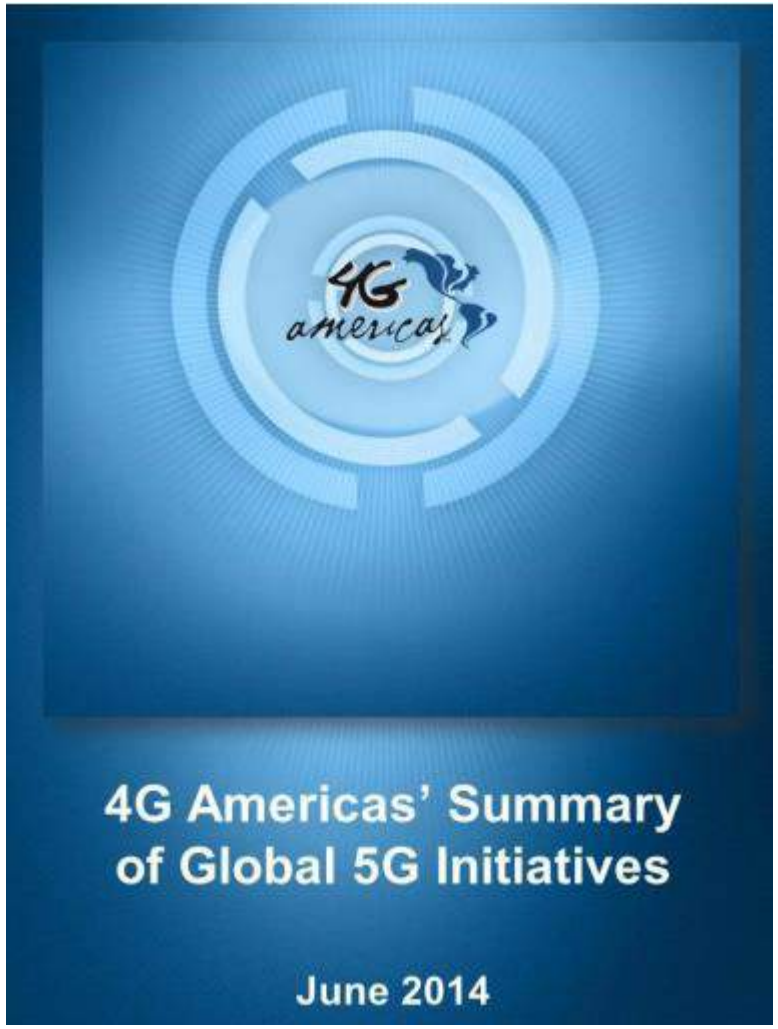
Wireless Races

ACTUALLY A NEVER-ENDING RACE



5G GLOBAL INITIATIVES / RACE

http://www.4gamericas.org/files/2114/0622/1680/2014_4GA_Summary_of_Global_5G_Initiatives__FINAL.pdf



5G R&D Activities – pre-standardisation (examples)

America: 4G Americas: Recommendations on 5G Requirements and Solutions" published on Oct 2014

NYU
WRI

China: International Mobile Telecommunications IMT-2020 (5G) promotion association established in February 2013.

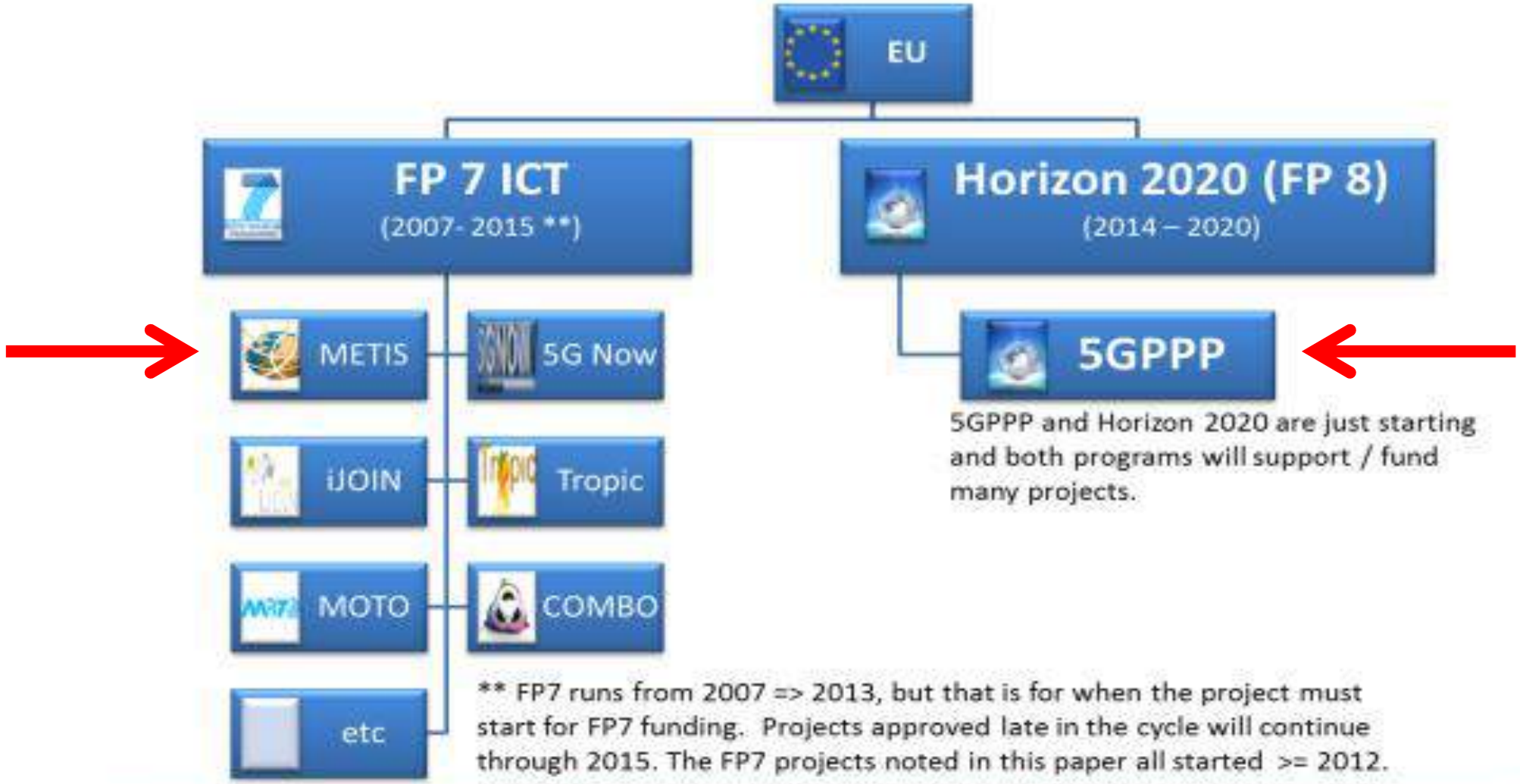
Europe: European Commission 5G-Public Private Partnership (5G-PPP) established in 2013

Japan: Fifth Generation Mobile Communications Promotion Forum (5GMF), since September 2014 has been participated in by 60 companies as well as a large number of academic experts.

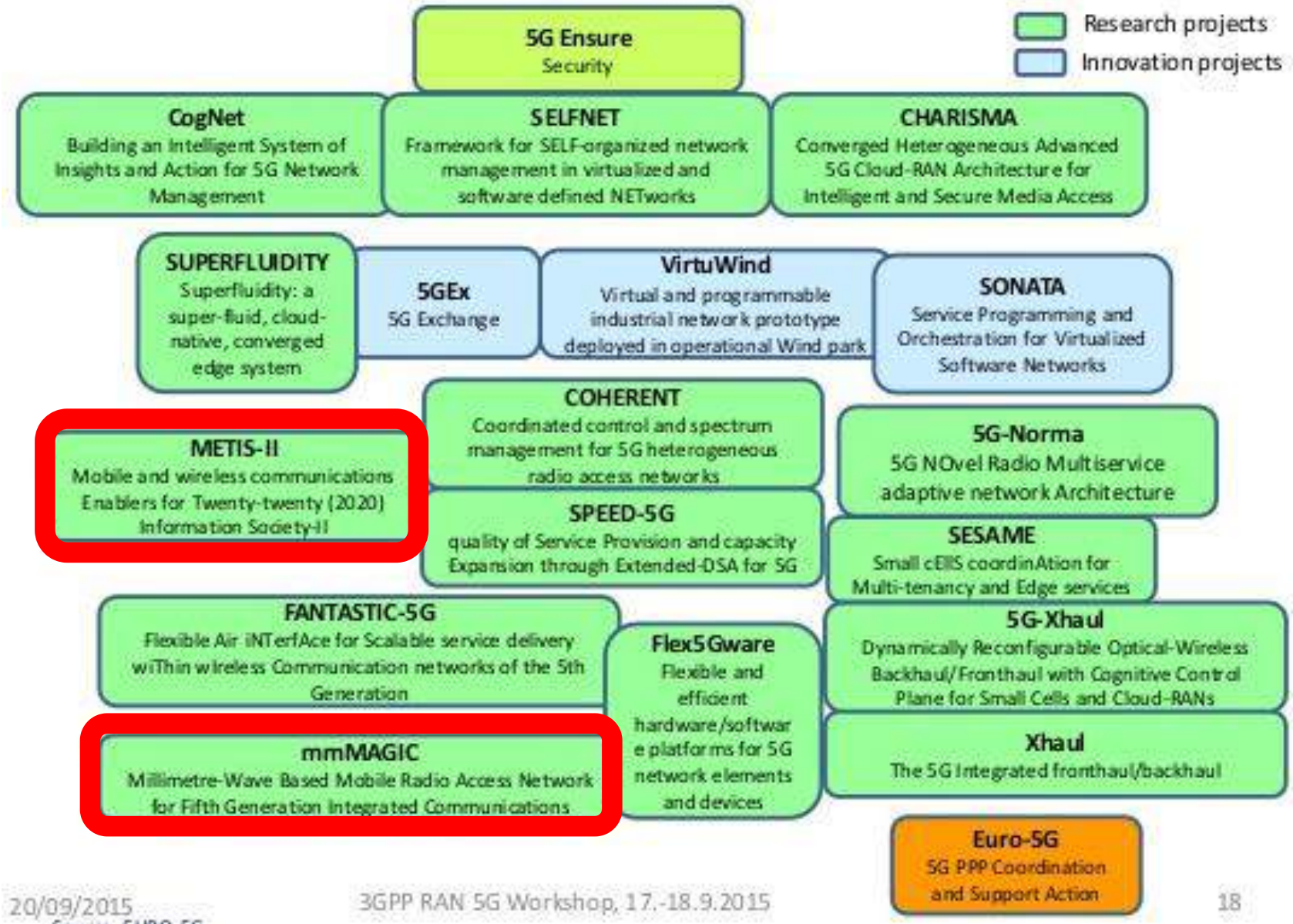
Global: International Telecommunications Union (ITU) and **3rd Generation Partnership Project (3GPP)** look to spectrum allocation and technical standardisation of 5G.
Next Generation Mobile Network (NGMN) Alliance released white paper at MWC 2015 Barcelona

Korea: 5G Forum of Korea published "2015 5G White Paper", including
- 5G New Wave towards Future Societies in the 2020s
- 5G Vision, Requirements, and Enabling Technologies
- 5G Spectrum Issues in Korea

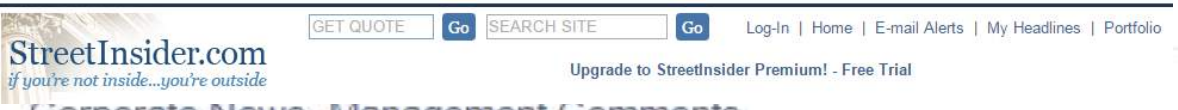
5G EUROPEAN INITIATIVES



H2020 5GPP CALL 1 PROJECTS



Back to mobile site



Ericsson (ERIC) Will Lead METIS-II EU Project for 5G Deployment

Article | Stock Quotes (1) | Comments (0)

July 9, 2015 7:12 AM EDT

Tweet | Share | E-mail

Ericsson continues to spearhead 5G system development as coordinator of the new METIS-II EU project to develop the overall 5G radio system design and roadmap recommendation for 5G standardization.

On a strategic level, METIS-II will provide the 5G collaboration framework within the 5G Infrastructure Public Private Partnership (5G-PPP) for a common evaluation of 5G radio access network concepts and a recommended 5G spectrum roadmap. It will also lead to the preparation of concerted actions toward regulatory and standardization bodies.

The project centers on a strong international consortium, consisting of 23 partners from all regions with strong 5G R&D initiatives (China, the EU, Japan, South Korea and the US) and involving most of the major international vendors, major operators, and key researchers.

As the main driver and coordinator of the METIS-II project together with the global consortium, Ericsson will integrate technologies into a radio access design and provide a platform for concerted actions toward regulatory and standards bodies. The METIS II project will leverage the success of METIS, the first integrated 5G project also driven and coordinated by Ericsson.

In addition, Ericsson will take the lead as the technical coordinator of the mmMAGIC (Millimetre-Wave Based Mobile Radio Access Network for Fifth-Generation Integrated Communications) project. This project will develop and design new concepts for mobile radio access technology for deployment in the 6-100 GHz range.

METIS II – CONTINUED LEADERSHIP

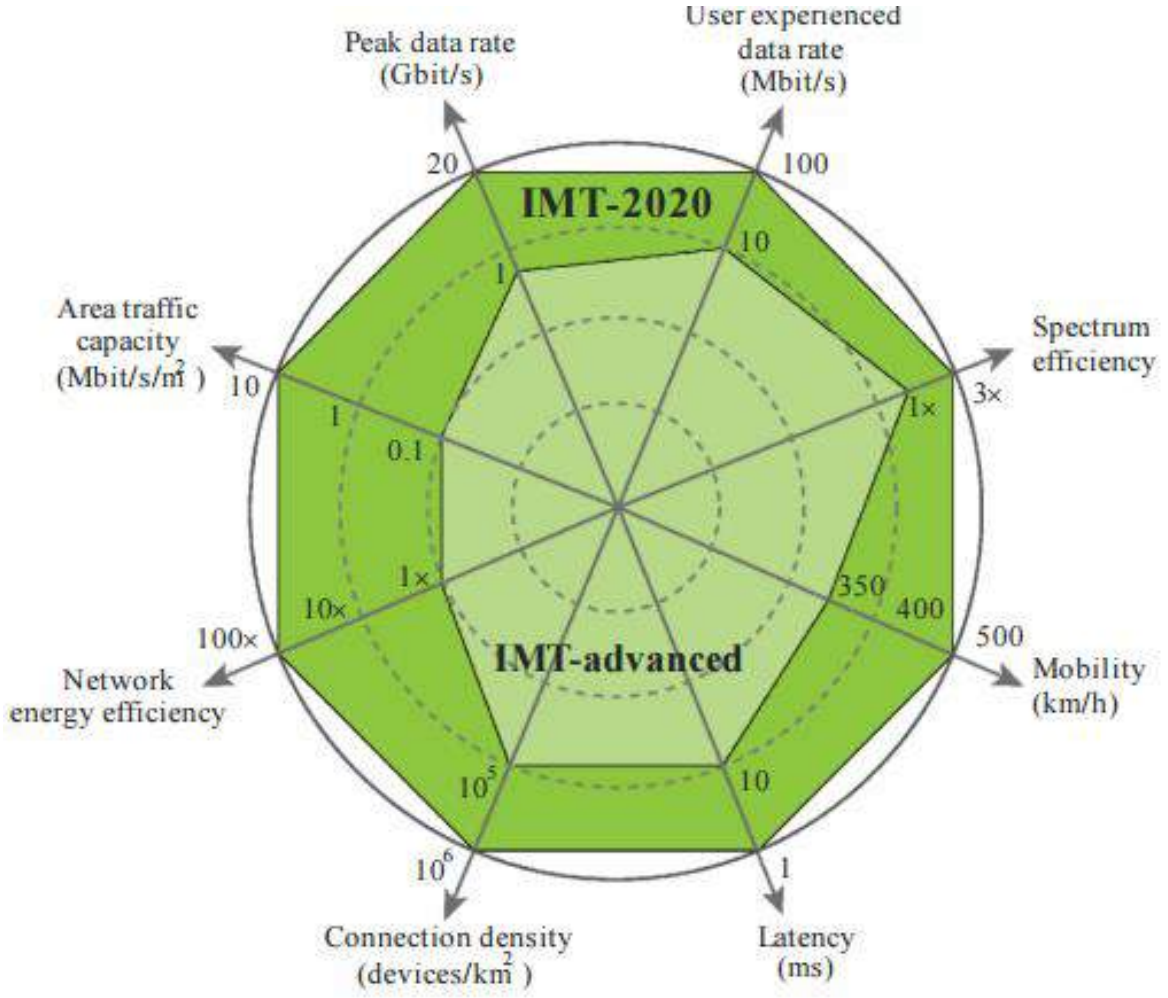
5G Requirements, Use Cases and Scenarios

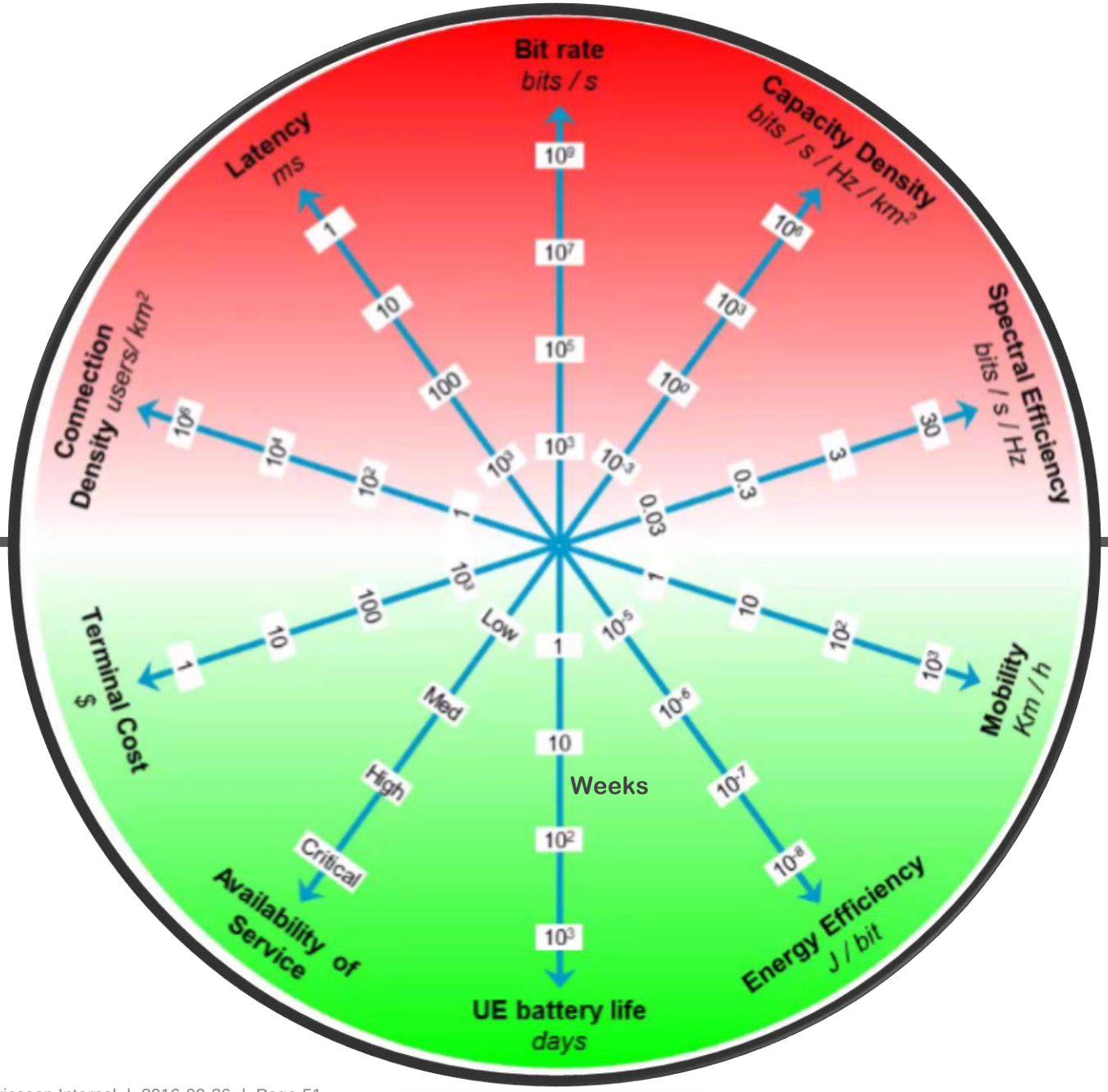
THREE MAIN BASIC SCENARIOS (ITU)

- **Enhaced Mobile Broadband**
- **Massive Machine Type Communications**
- **Ultra-Reliable and Low Latency Communications**

EIGHT MAIN PARAMETERS (ITU)

- Peak data rate
- User experienced data rate
- Spectrum efficiency
- Mobility (km/h)
- Latency (ms)
- Connection density (devices/sq km)
- Energy efficiency
- Area traffic capacity (Mbps/sq m)



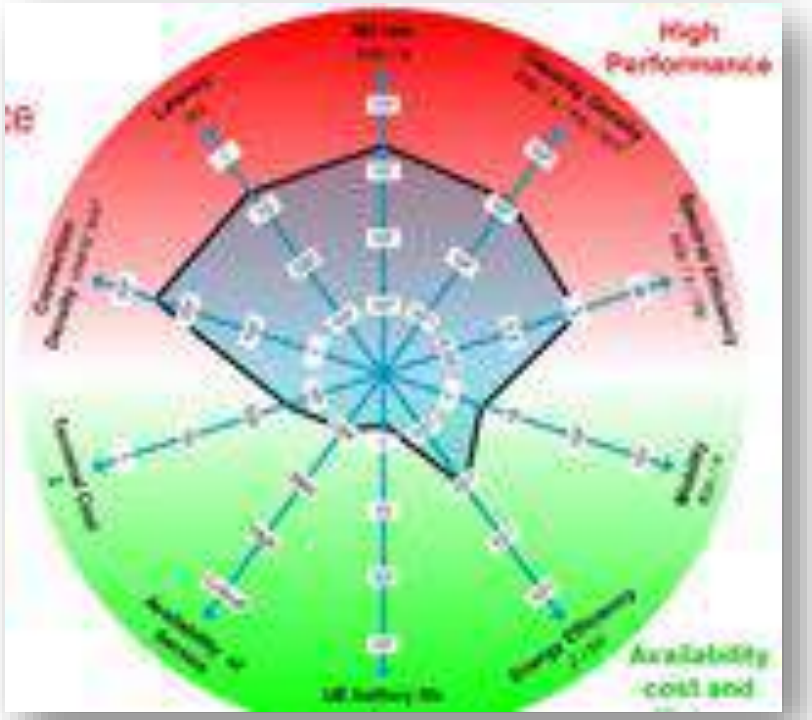


High Performance and Capacity Requirements

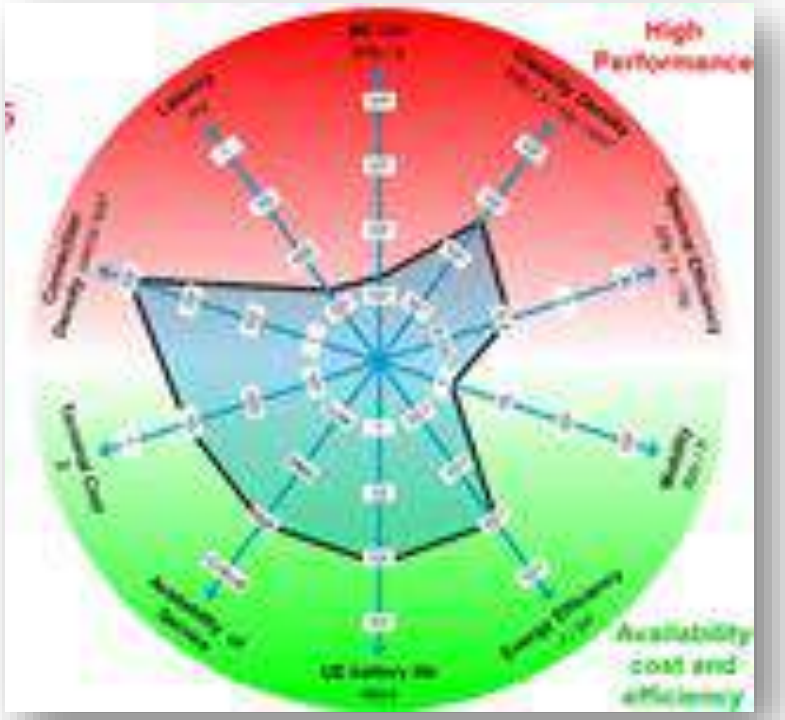
Conflicting Requirements

Efficiency, Cost, and Availability Requirements

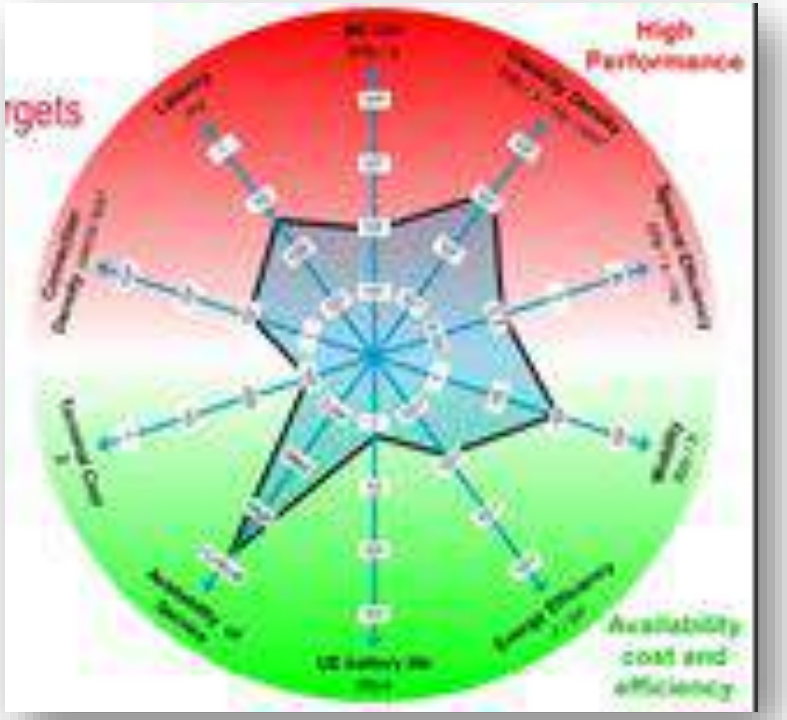
High Performance Scenarios

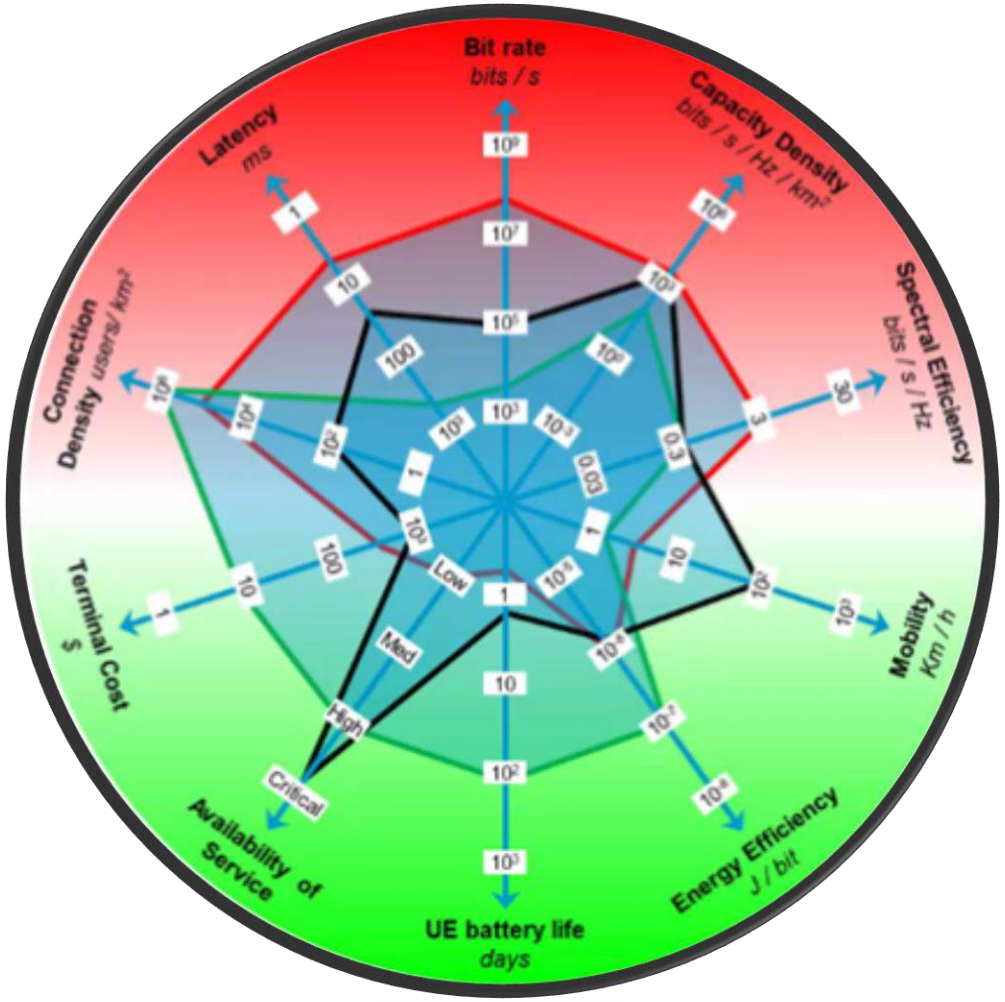


MTC/IoT Scenarios



Public Safety Scenarios





Simply not possible with a single technology standard or network.

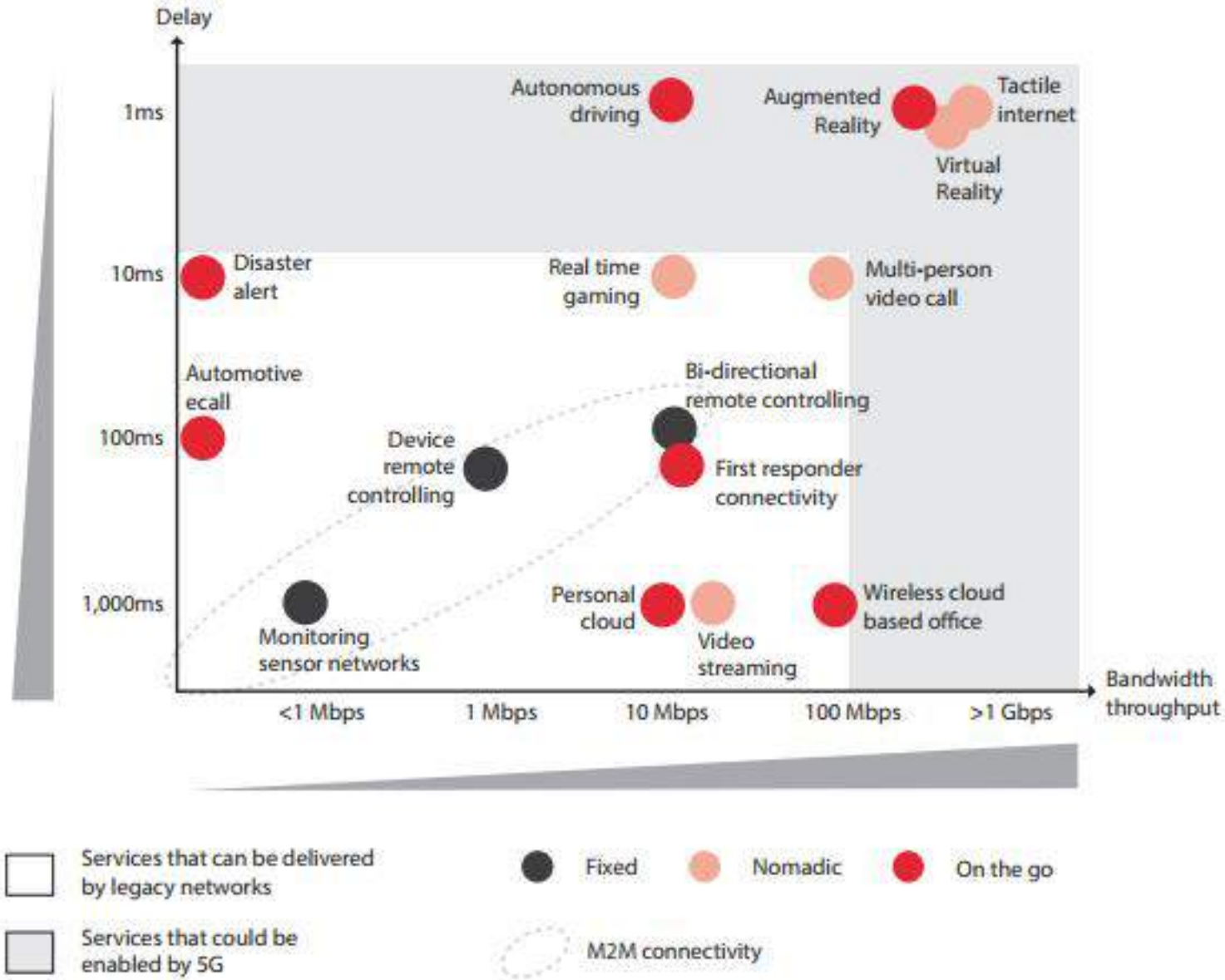
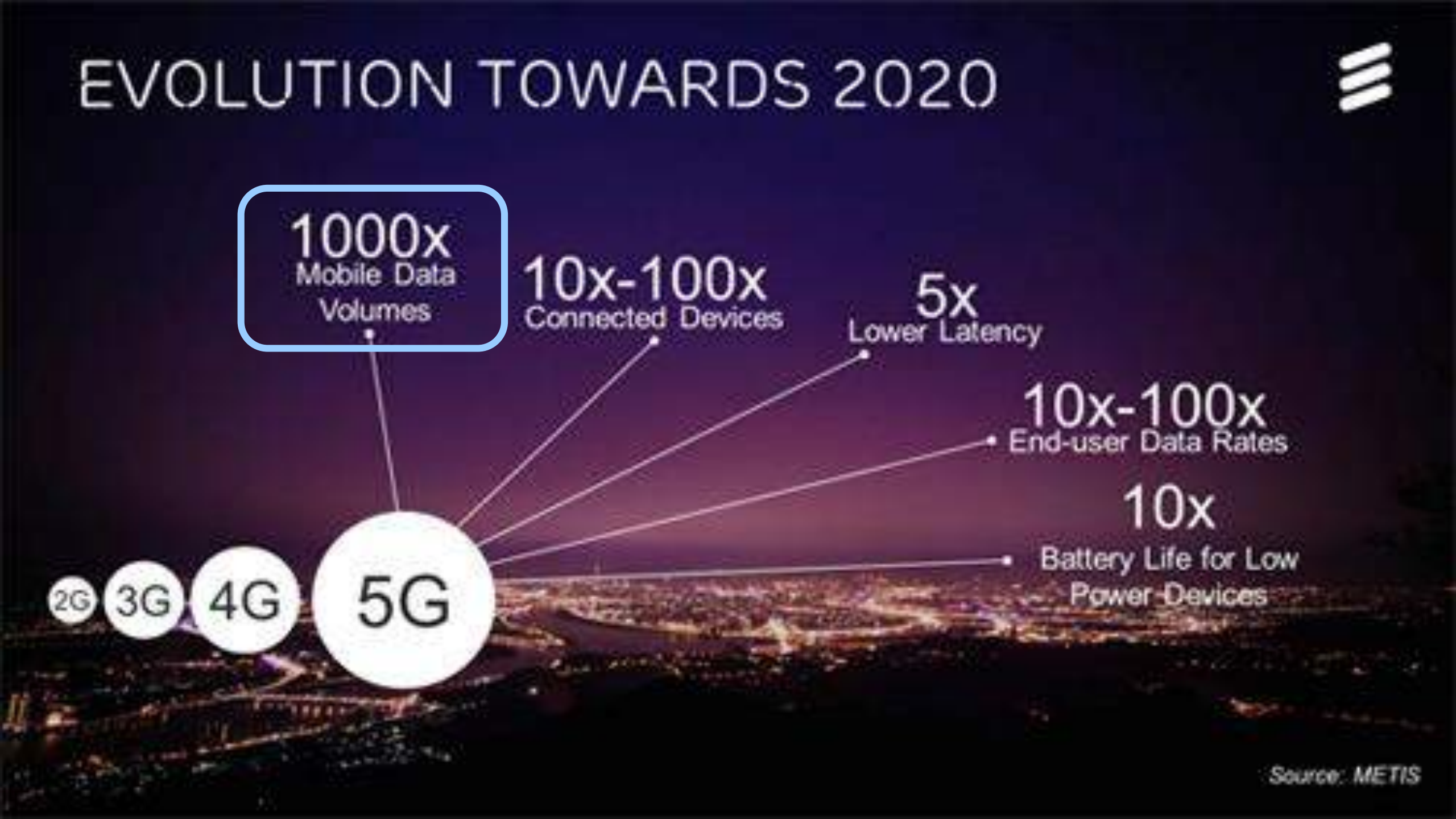
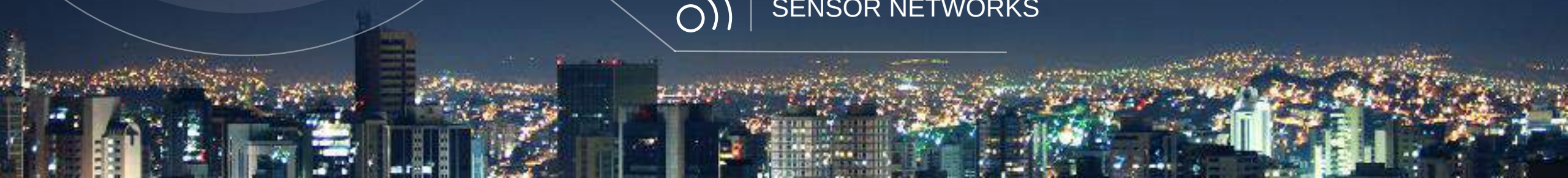


Figure 1: Bandwidth and latency requirements of potential 5G use cases

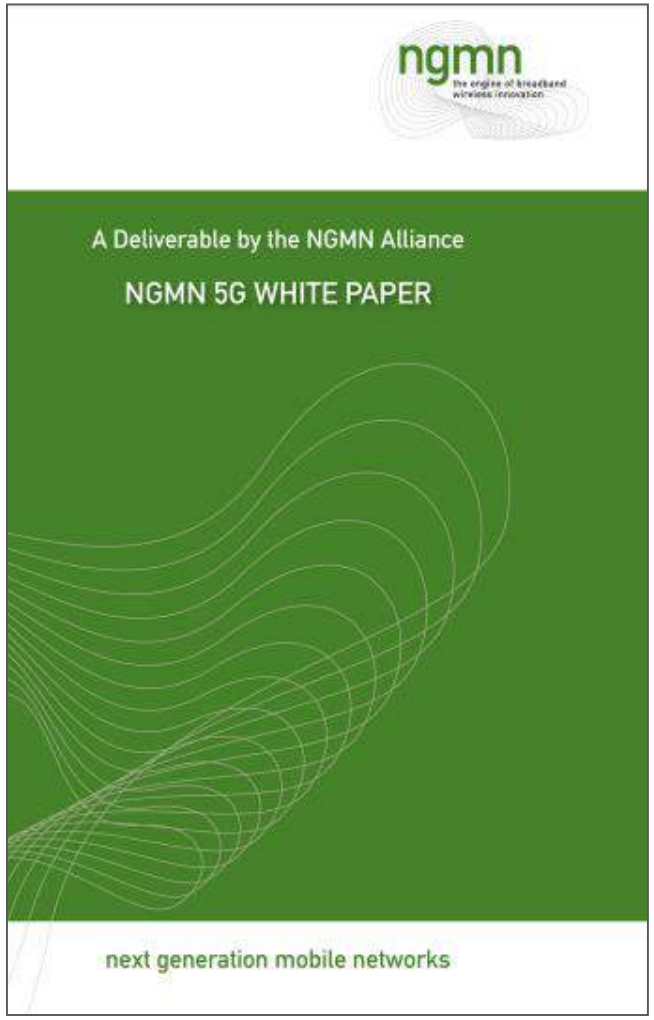

EVOLUTION TOWARDS 2020
1000x
Mobile Data
Volumes
10x-100x
Connected Devices
5x
Lower Latency
10x-100x
End-user Data Rates
10x
Battery Life for Low
Power Devices
2G
3G
4G
5G
Source: METIS

5G USE CASES

- BROADBAND AND MEDIA EVERYWHERE
- SMART VEHICLES, TRANSPORT
- CRITICAL SERVICES AND INFRASTRUCTURE CONTROL
- CRITICAL CONTROL OF REMOTE DEVICES
- HUMAN MACHINE INTERACTION
- SENSOR NETWORKS



NGMN 5G REQUIREMENTS AND USE CASES



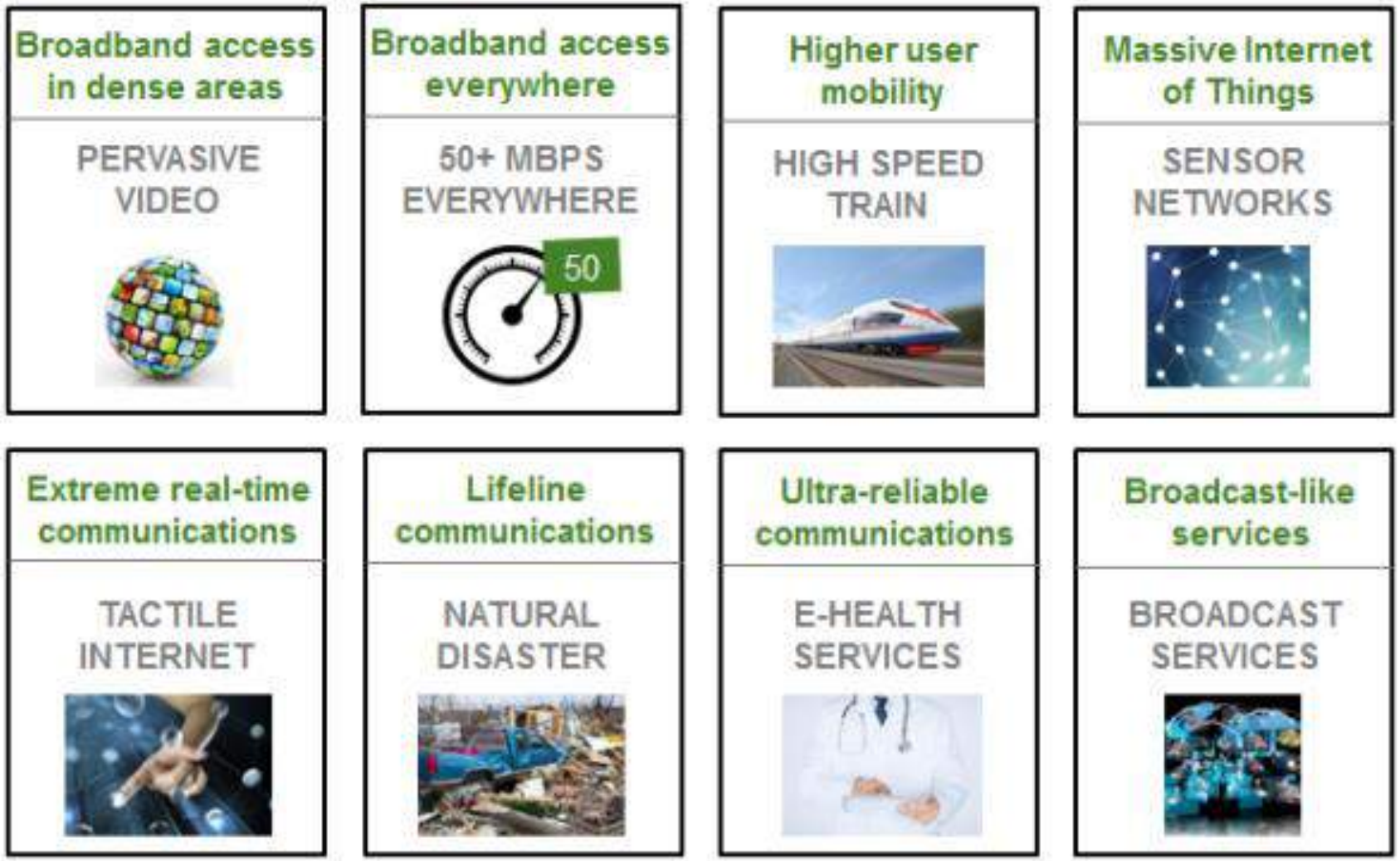
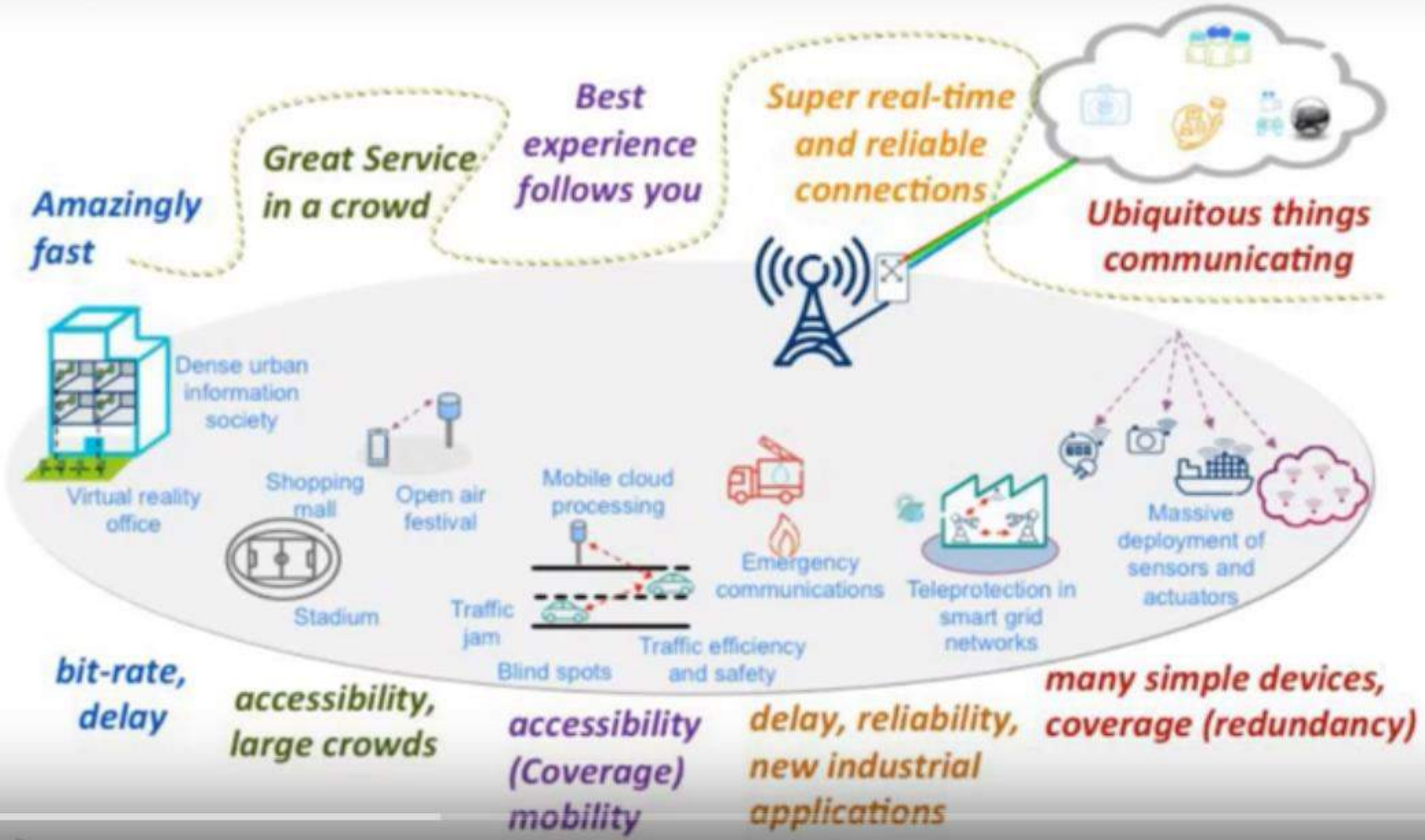


Figure 1: 5G use case families and related examples

Hugo Tullberg, Ericsson, 5G architecture, METIS and 5G PPP

METIS 5G SCENARIOS

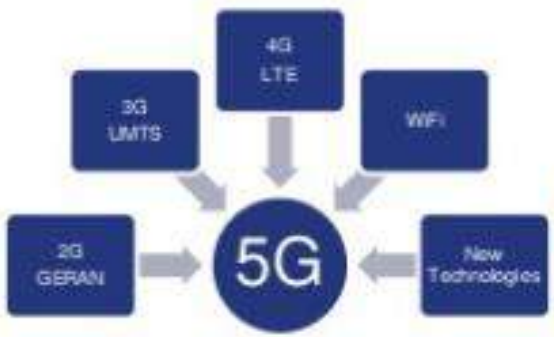


1:10 / 17:33

The 5G Network is not a replacement.

Recortar slide

It is a revolutionary enhancement.



- **What will it be? (Courtesy of METIS):**

- **Amazingly fast** focusing on high data-rates for future mobile broadband users – **Speed: 10 Gbps**
- **Great service in a crowd** focusing on mobile broadband access even in very crowded areas and conditions – **Multiplying Coverage/Cells**
- **Super real-time** focusing on new applications such as augmented reality and tactile feel for virtual realities calling for stringent requirements on latency - **1 msec Latency**
- **Ubiquitous things communicating** focusing on efficient handling of a very large number of devices with widely varying requirements, Mobiles, M2M, Internet of Things - **>30 Billion Devices**
- **Low cost, low energy** – Operators need to make it more efficient and cost effective

KEYSIGHT TECHNOLOGIES

Page 7

Numerous 5G use cases from different sources

EU projects

- 21 use cases from METIS-I
- 6 use cases from 5GNOW
- 10 use cases from COMBO
- 7 use cases from MiWEBA
- 5 use cases from MAMMOET
- 9 use cases from MOTO
- 9 use cases from TROPIC
- 4 use cases from iJoin

Standardization bodies and fora

- 25 use cases from NGMN
- 59 use cases from 3GPP
- ITU-R also proposes a number of use cases
- 4G Americas, ARIB, etc.

There is a need for a consolidation of use cases into a small number of representative ones

Objectives of METIS-II WP1

- Refine the 5G scenarios that have been defined in the METIS project:
  - taking into account recent activities by bodies such as ITU-R or NGMN,
  - and in discussion with other 5G-PPP phase 1 projects.
- Generate from the refined scenarios a low number of precise 5G use cases
  - that are suitable for usage in 5G standardization
  - define corresponding KPIs and requirements
- Perform a qualitative and quantitative techno-economic feasibility assessment
  - to determine whether the 5G scenarios and use cases can be feasibly addressed by different 5G RAN design concepts developed in METIS-II.

Technical Corner – Key Problems

THE MOTHER TROUBLE OF ALL TECHNIQUES

Peak Performance

Single car in cell

Clean Signal

No noise nor interference

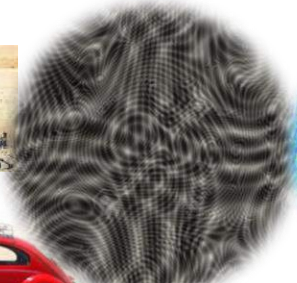
SNR and interference decreases capacity dramatically

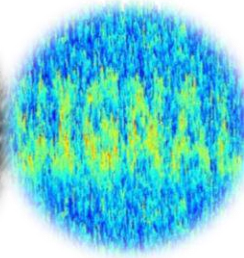
Capacity & QoE

Several cars in cell

Interference

Noise





Interference and noise (non-linear, non-intuitive)

Average Performance

Cell Edge

Cell Edge

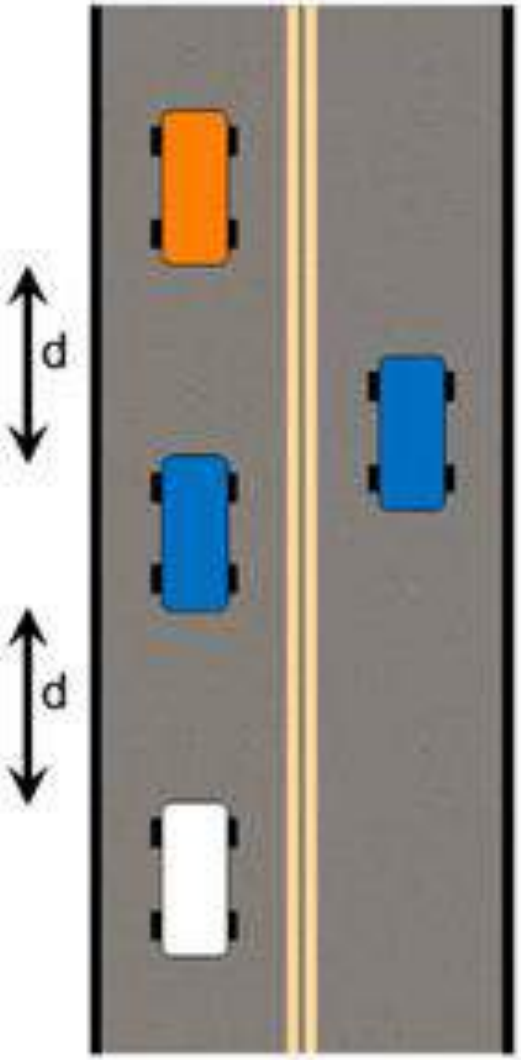
Cell Center

Building an intuitive understanding of cellular performance
Variation of throughput across a cell in a loaded network

Format \ Throughput	Occupied Bandwidth	Peak (Single user)	Average (10 users/cell)	Cell Edge (10 users/cell)	Raw Peak/ edge ratio*
GSM (1 slot) (10 users, freq. reuse = 4)	1 MHz	9.6 kbps	9.6 kbps	9.6 kbps	1
GPRS (4 slot)	4 MHz	81.6 kbps	50 kbps	36.2 kbps	2.3
EDGE (4 slot)	4 MHz	236.8 kbps	70 kbps	36.2 kbps	6.5
UMTS (Rel-99)	5 MHz	384 kbps	100 kbps	30 kbps	12.8
HSDPA (Rel-5)	5 MHz	3.6 Mbps	250 kbps	80 kbps	45
HSDPA (Rel-7)	5 MHz	42 Mbps	350 kbps	120 kbps	350
HSDPA (Rel-8)	10 MHz	84 Mbps	800 kbps	240 kbps	350
LTE (Rel-8) 4x4	20 MHz	300 Mbps	5.34 Mbps	1.6 Mbps	187
LTE-A (Rel-10) 4x4	20 MHz	600 Mbps	7.4 Mbps	2.4 Mbps	250

* Ratio can be reduced at expense of cell capacity with proportional fair scheduling and fractional frequency reuse

Building an intuitive understanding of cellular performance
Speed versus capacity



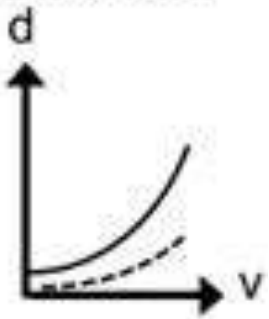
At what average speed does the capacity (i.e. cars per hour) of a typical road reach its peak?

- ☐ 10 mph ?
- ☑ 40 mph ?
- ☐ 70 mph ?
- ☐ 100 mph ?
- ☐ 1000 mph?

This has been the case since motoring began!

This result is not immediately obvious but we can understand it.

The reason is that the relationship between the speed v and the safe distance d is non-linear.



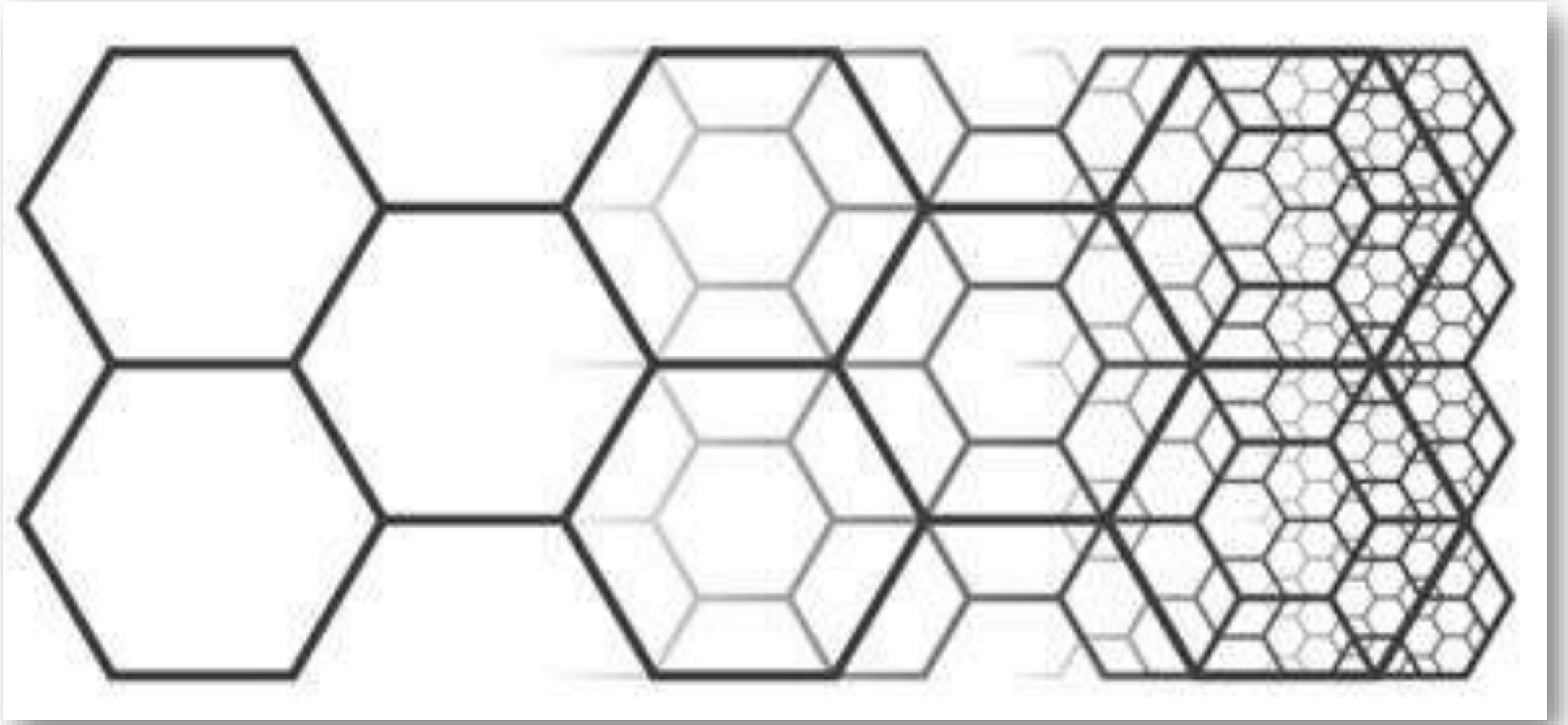
So operating at speeds above 40 mph is good for some but reduces capacity

Capacity will only increase with a new control system like driverless cars

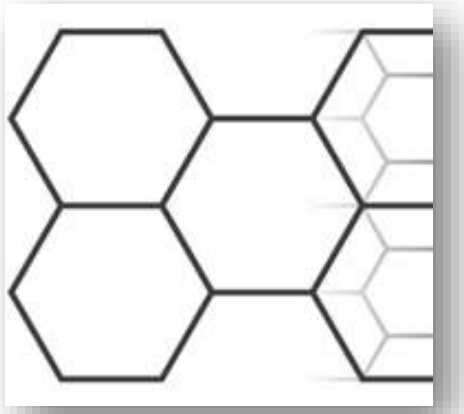
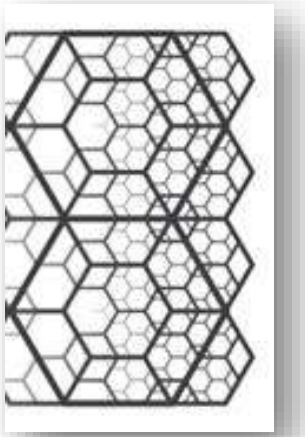
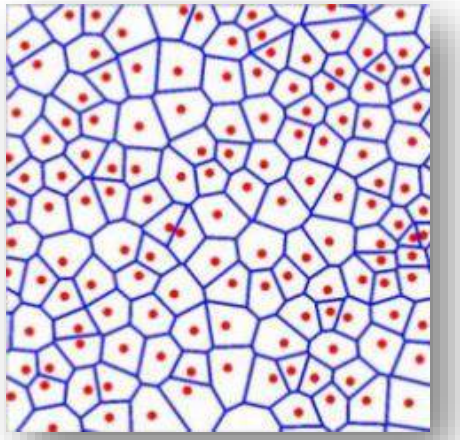
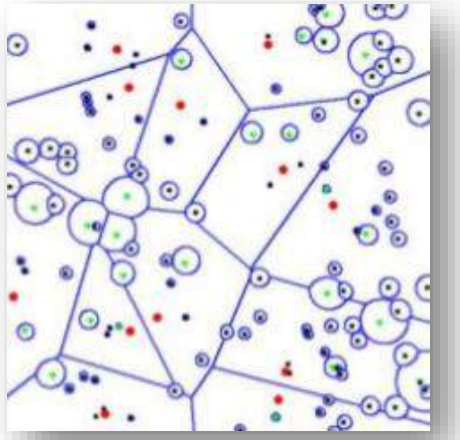
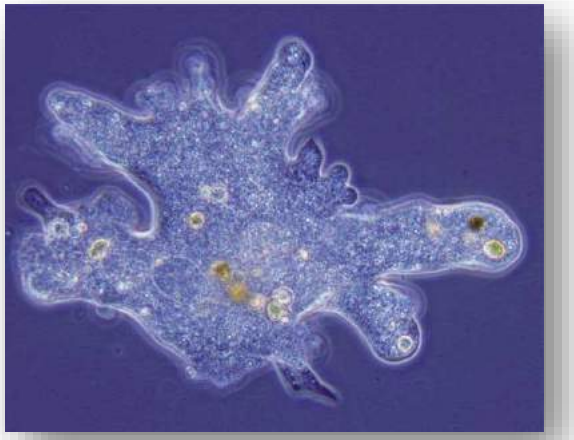
In cellular "d" equates to interference

Principle: Top speeds grab headlines
Capacity generates revenue

DENSIFICATION MAKES LIFE HARDER



THE VANISHING CELL CONCEPT

SAMPLE 5G RELATED TECHNOLOGIES

- Massive, MU and FD MIMO, 3D BF
- Centimeter and Millimeter Waves
- Ultra-desnification
- New Waveforms and Modulations
- Wireless backhaul/access integration
- Spectrum Aggregation and Sharing; L&U
- Multi-RAT Integration and Mgt
- Advanced Internode/cell Coordination
- Advanced Interference Management
- Advanced Multi-carrier Transmission
- Small Cells and HetNets
- Flexibility of Core and Access Dev.
- SDI: SDN, NFV, SFC, Slicing
- Cloud, MEC, CORD
- ICN / CCN, NDN
- D2D/MTC/CelloT Communications
- Efficient small data transmission
- Cognitive Radio and Networks
- 120+ other tech topics (METIS)

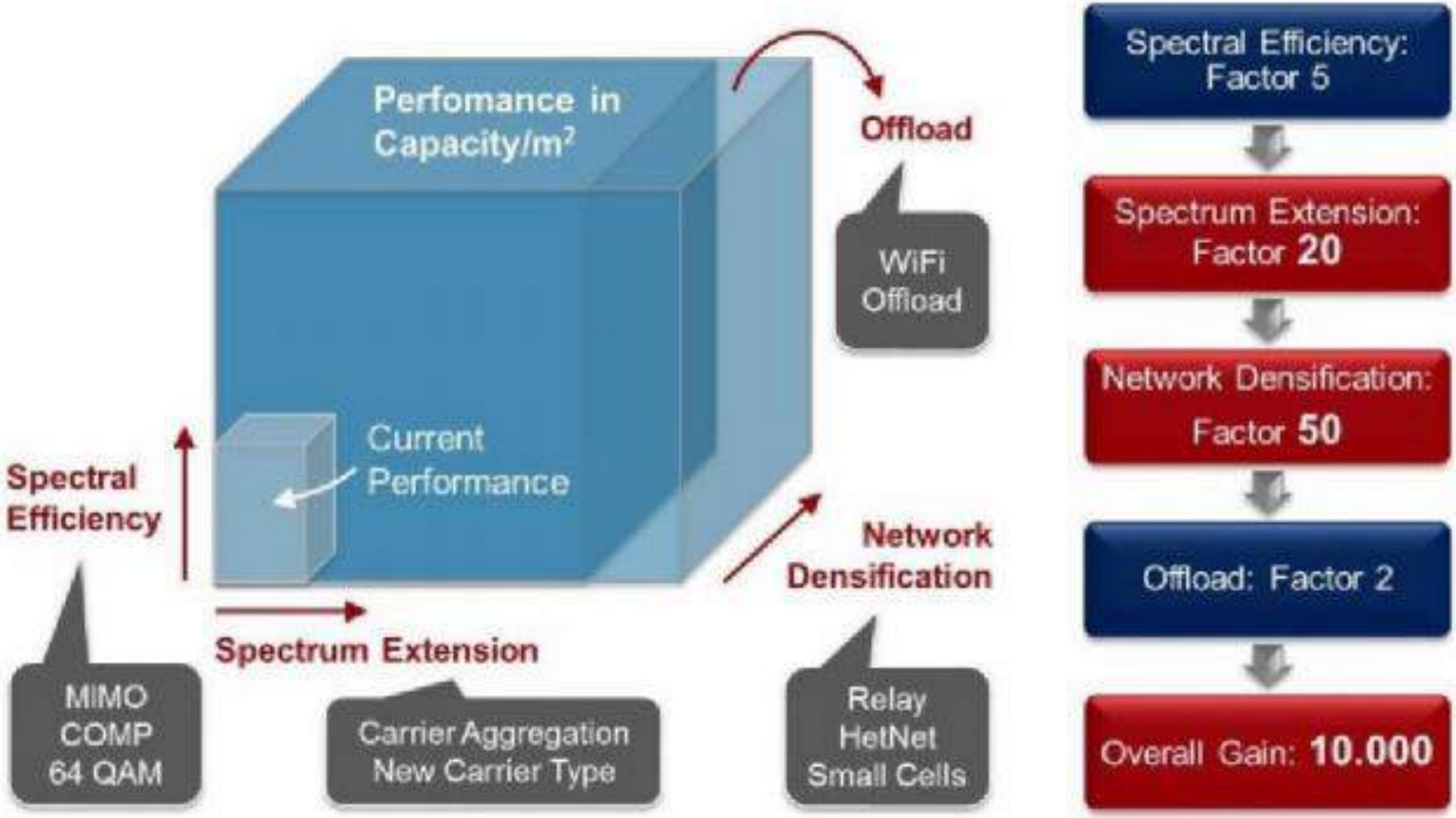


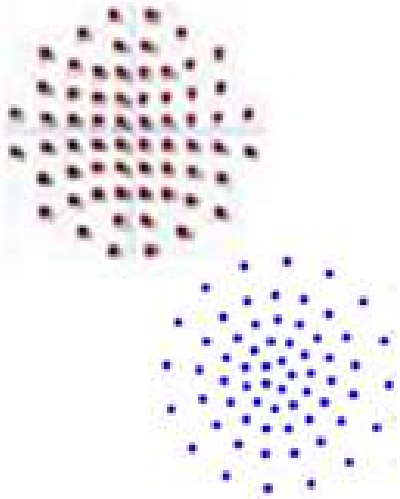
Fig. 2. Degrees of freedom for areal capacity increase.

Sample Topic
Modulation & Waveforms

SAMPLE TOPIC – MODULATION FORMATS

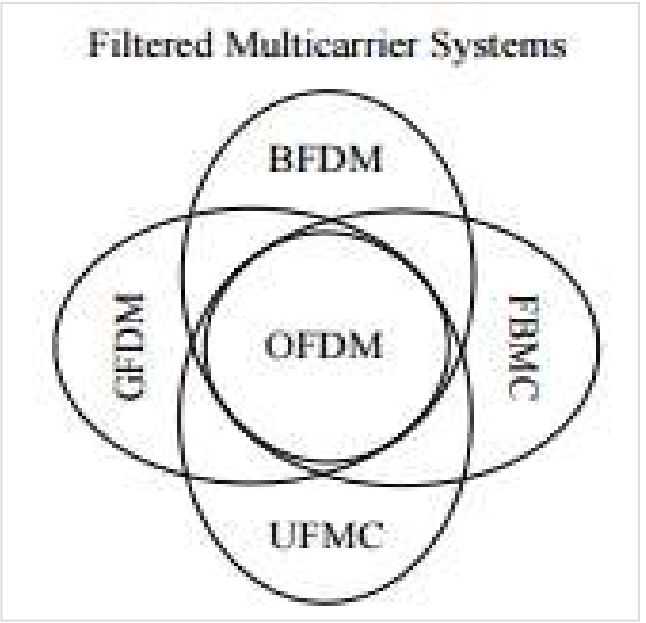
There are many factors to consider when evaluating new modulation formats

- Spectral efficiency (For large & small packets e.g. M2M or control plane)
- Latency
- Computational complexity
- Energy efficiency - µJ / information bit
- Adjacent channel performance for co-existence
- Synchronization requirements
- Implementation costs
- Resistance to narrow and broadband interference



New formats being studied include:

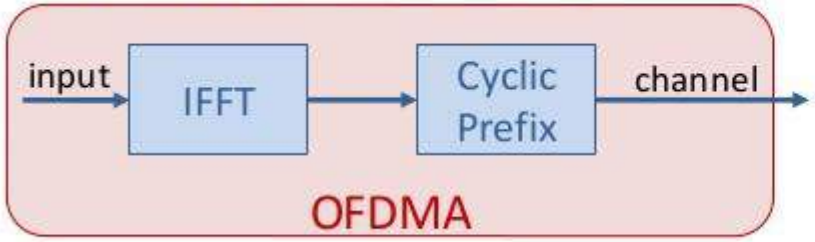
FBMC – Filter Bank Multi Carrier
UFMC – Universal Filtered Multi Carrier
GFDM – Generalized Frequency Division Multiplexing
BFDM – Bi-orthogonal Frequency Division Multiplexing
FQAM – Frequency Quadrature Amplitude Modulation
NUCs – Non-uniform constellations

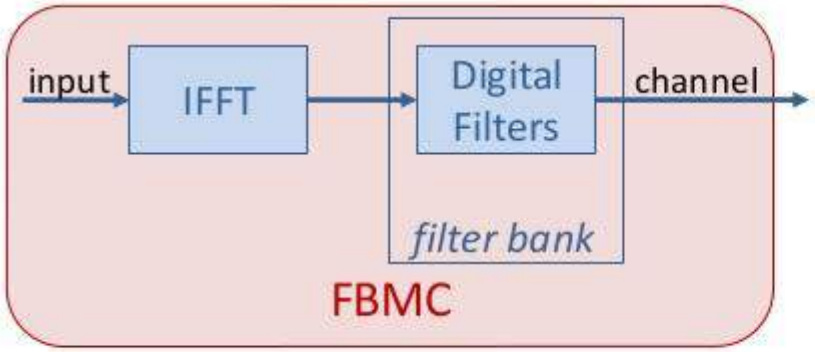


What is Filter Bank Multicarrier (FBMC)?

FBMC is an alternative approach to OFDMA since it has a higher spectral efficiency

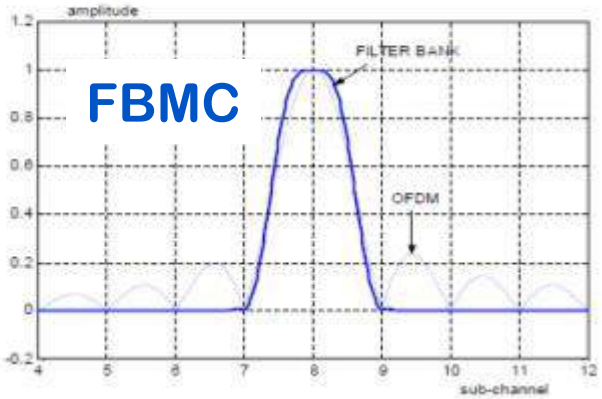
FBMC uses common FDMA without subcarrier overlap while lack of sidelobes allow increased spectral efficiency.



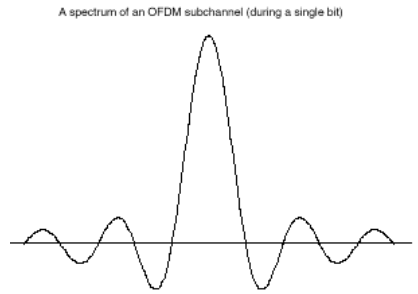


Comparing OFDM and FBMC

Sub-channel frequency response



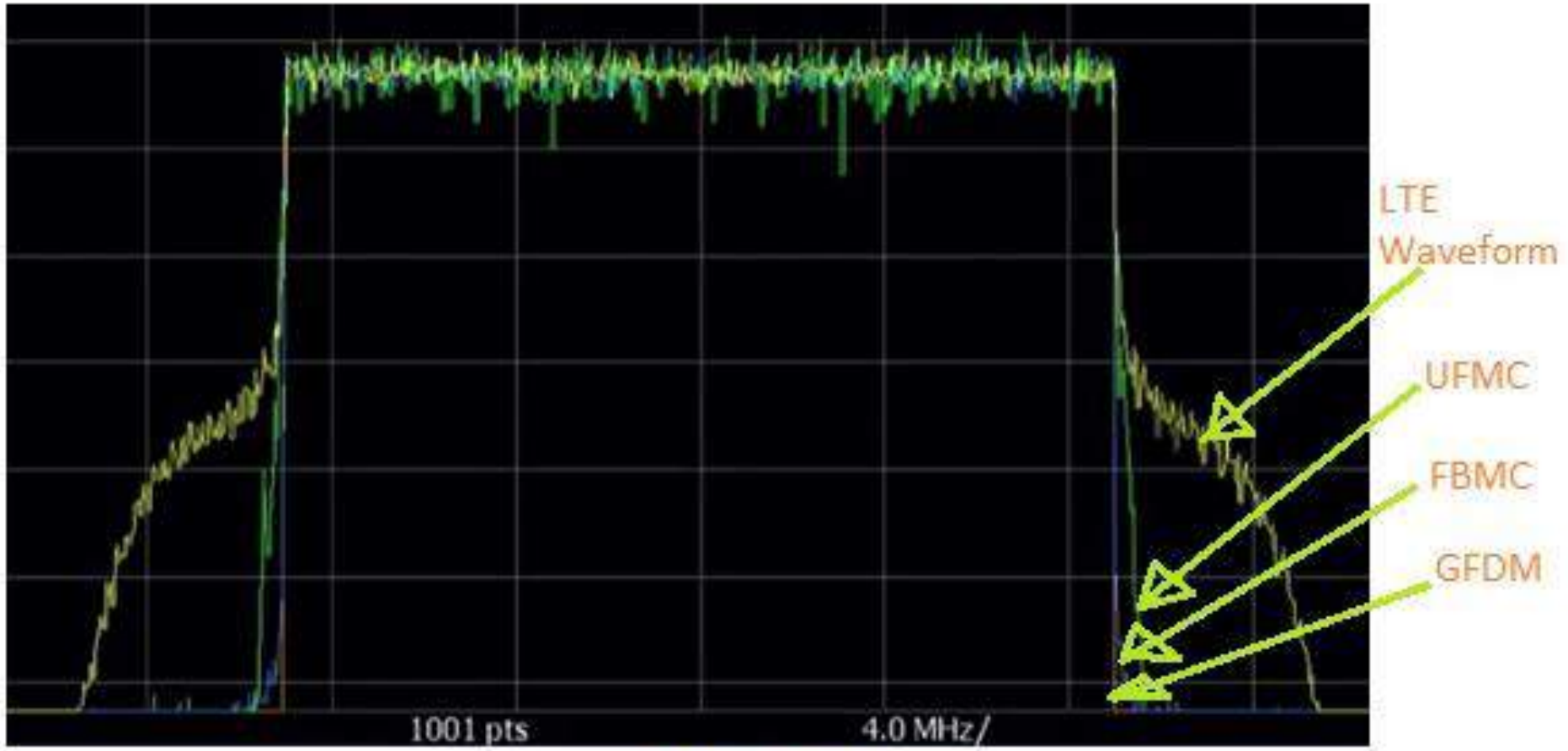
OFDM



- no sidelobes with the filter bank
- no cyclic prefix : increased spectral efficiency

Picture source: FBMC physical layer – principle by Maurice Bellanger, Phydyas

FBMC BETTER THAN OFDM, RIGHT?



5G Waveforms

WELL...

FBMC Merits(Advantages)

- Provide spectrum efficient and more selective system
- CP(Cyclic Prefix) is not needed
- Provide robust narrowband jammers

FBMC Demerits/Challanges

- The development of MIMO based FBMC is very limited and is non-trivial.
- to design wider BW and higher dynamic range system will have more challenges in achieving RF performance
- More complex as compared to OFDM. It introduces overhead in overlapping symbols in the filter bank(in time domain).

Sample Topic
5G Spectrum & Wireless Access

3GPP 5G RATs

3GPP 5G RAT(s) = LTE Evolution + New RAT

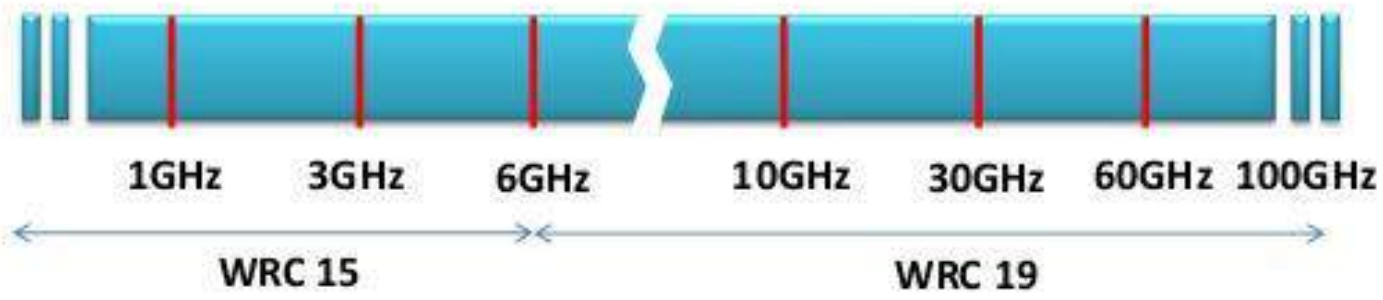
5G RATs

Backward Compatible RAT
(LTE Evolution)

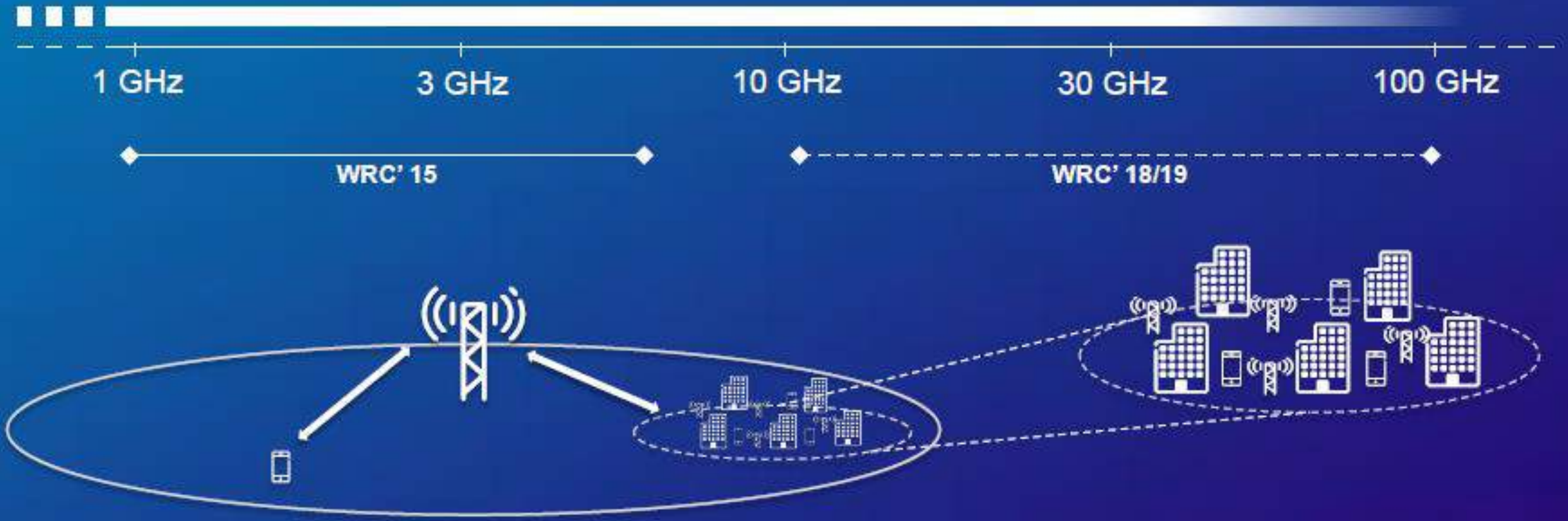
lower frequencies(<6GHz)

Non-backward compatible RAT
(5G new RAT)

Whole 5G spectrum range



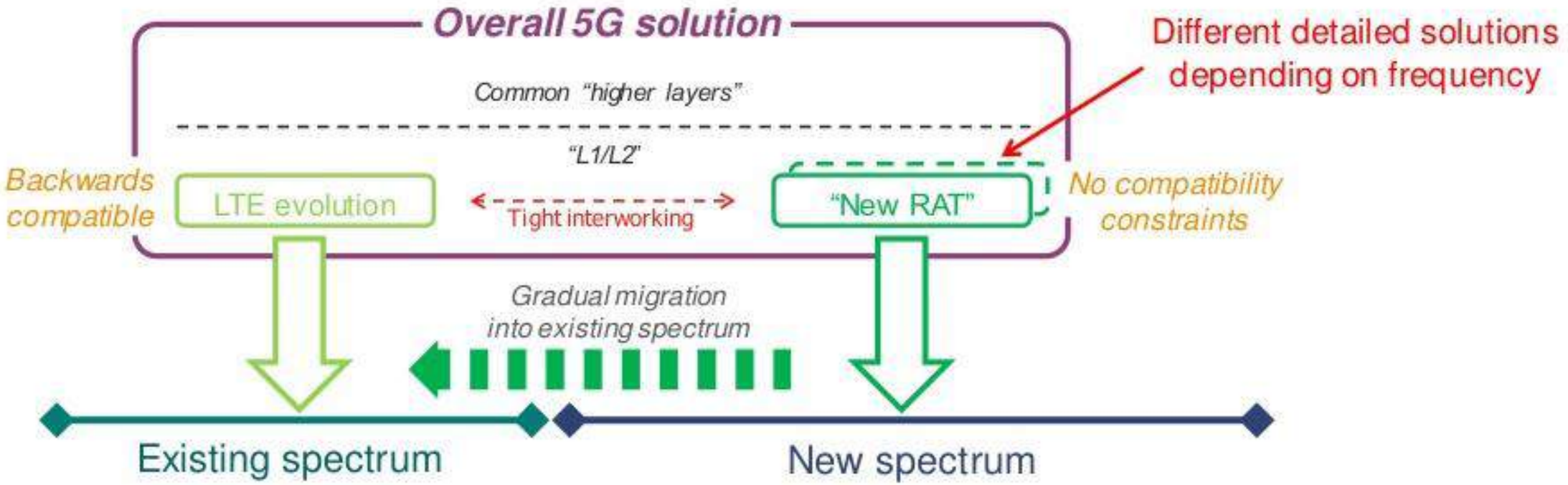
5G SPECTRUM



Lower frequencies for full-area coverage…

…complemented by high frequencies for extreme capacity and data rates in dense scenarios

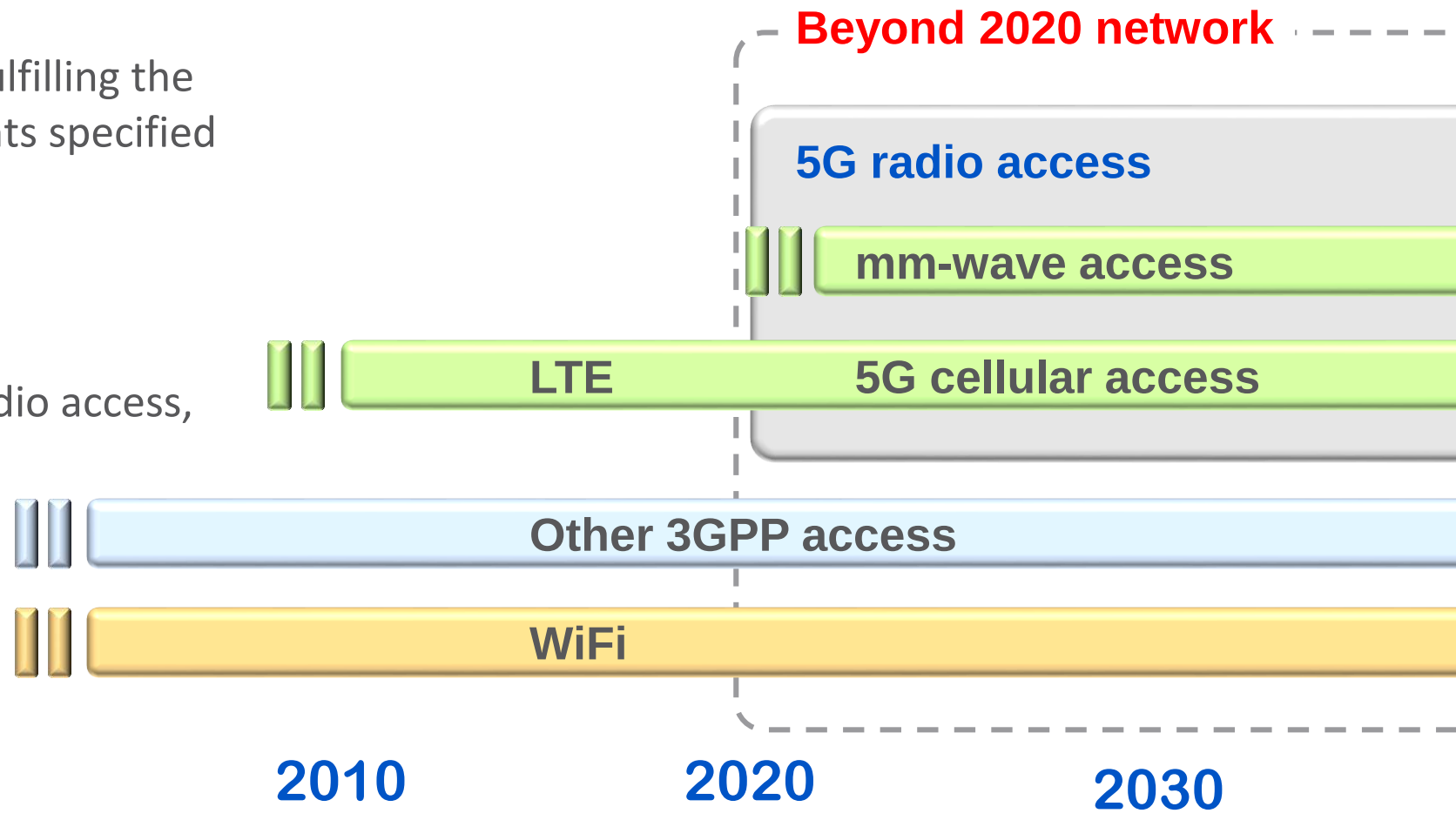
5G SPECTRUM - OVERVIEW



5G WIRELESS ACCESS

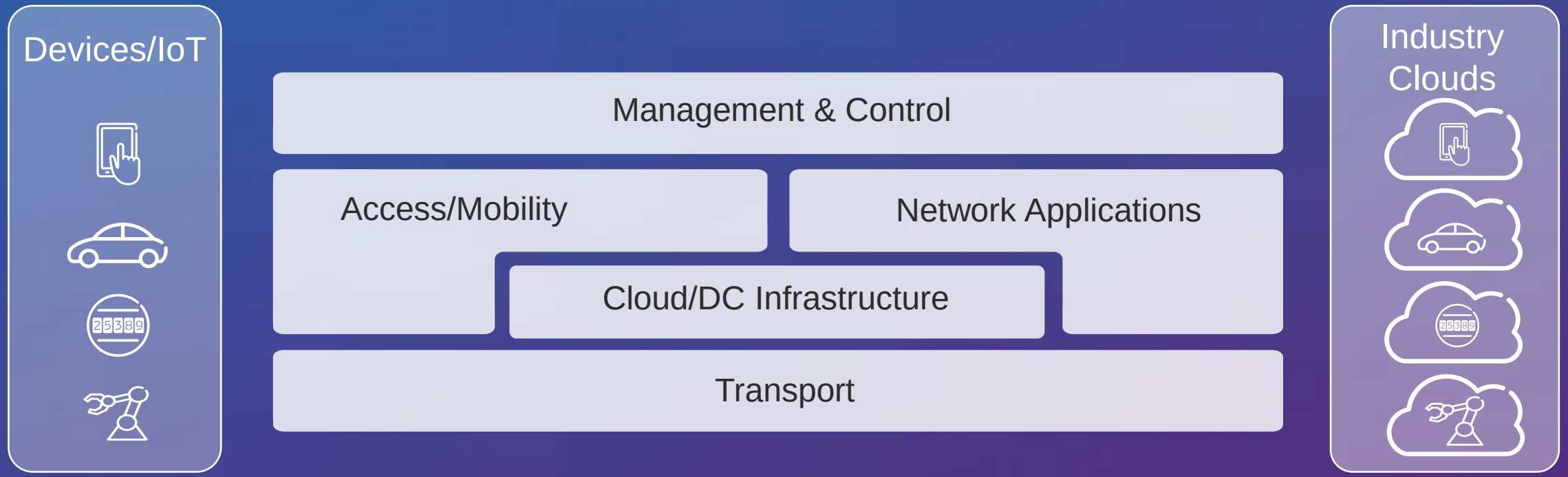
› 5G radio access
  – A set of technologies jointly fulfilling the "5G" radio-access requirements specified by ITU]

› Beyond 2020 network
  – Seamless integration of 5G radio access, other 3GPP accesses and WiFi



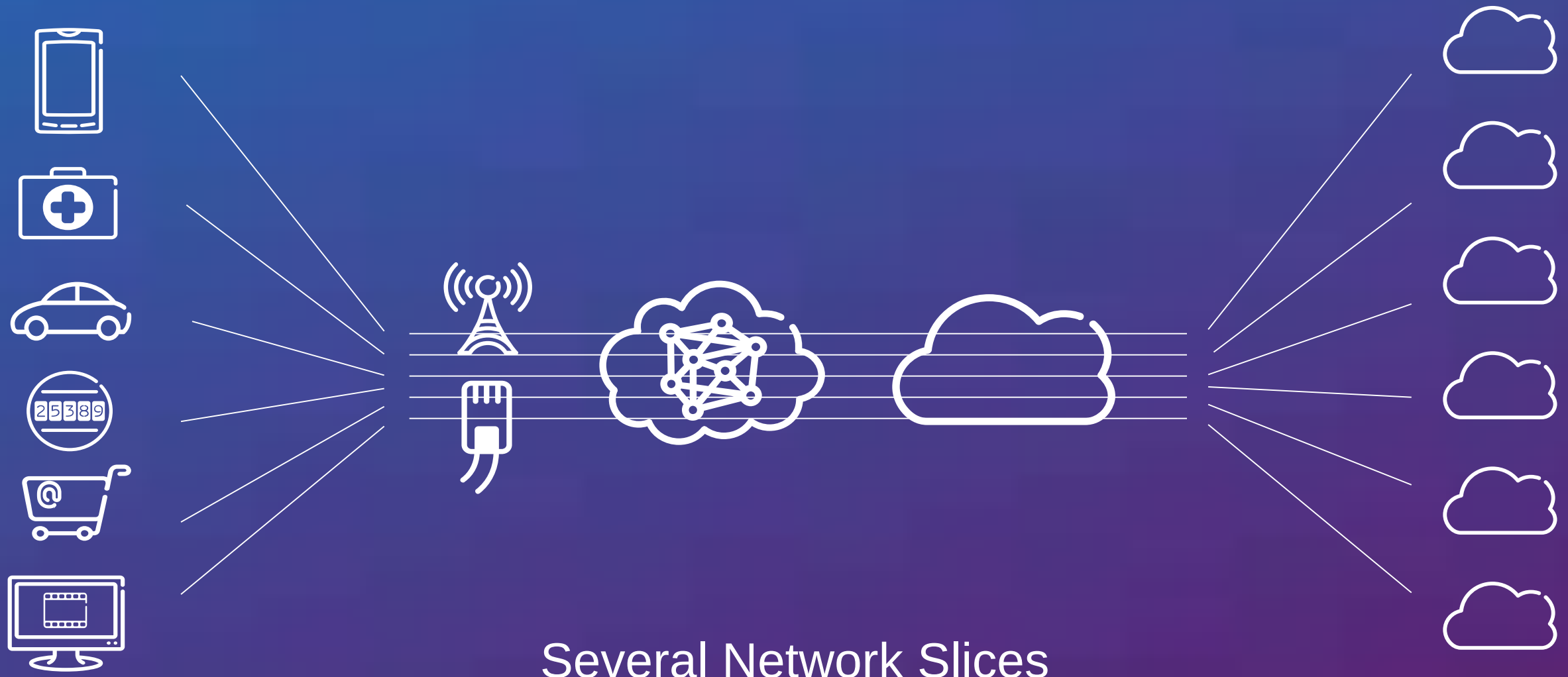
Sample Topic
5G Architectures / Slicing

5G ARCHITECTURE



source: Ericsson

ONE NETWORK – MULTIPLE INDUSTRIES



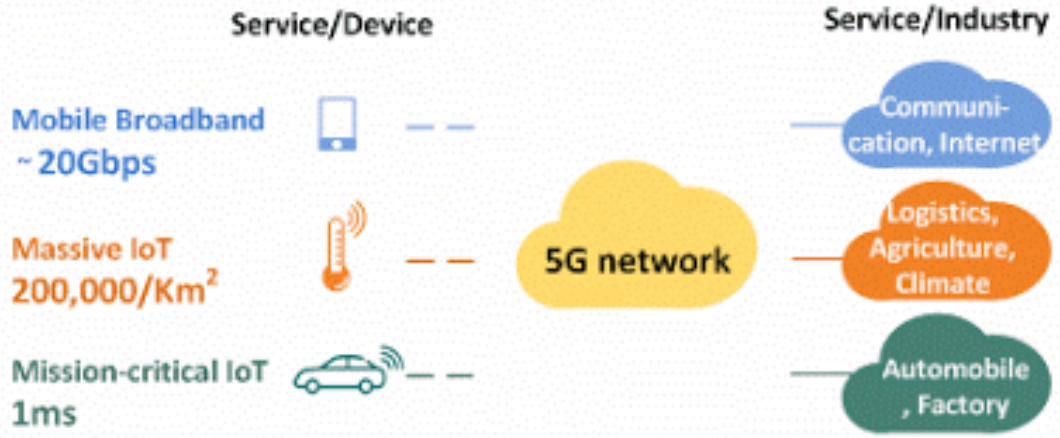
Several Network Slices

source: Ericsson W.P. on 5G Systems

4G Network: communication service via phones in the communication industry

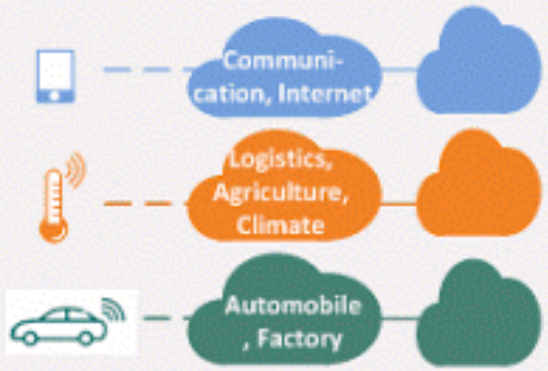
Communication service
(voice, text and Internet)

5G network: all mobile services via all types of devices across all industries

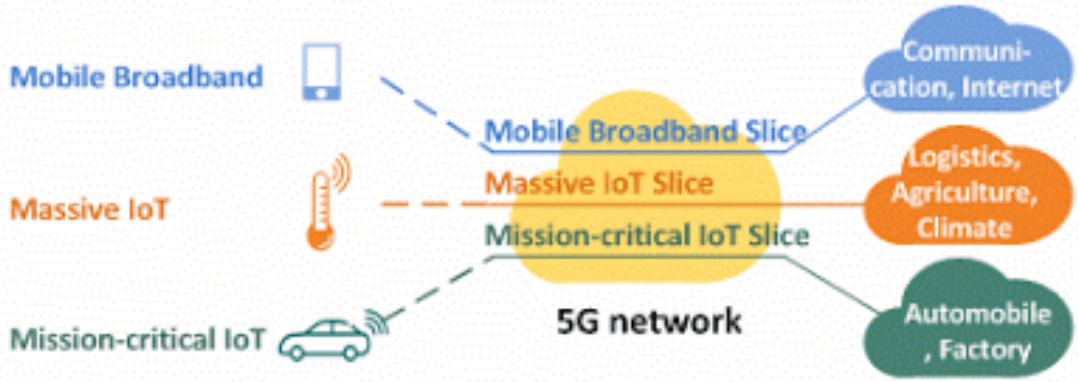


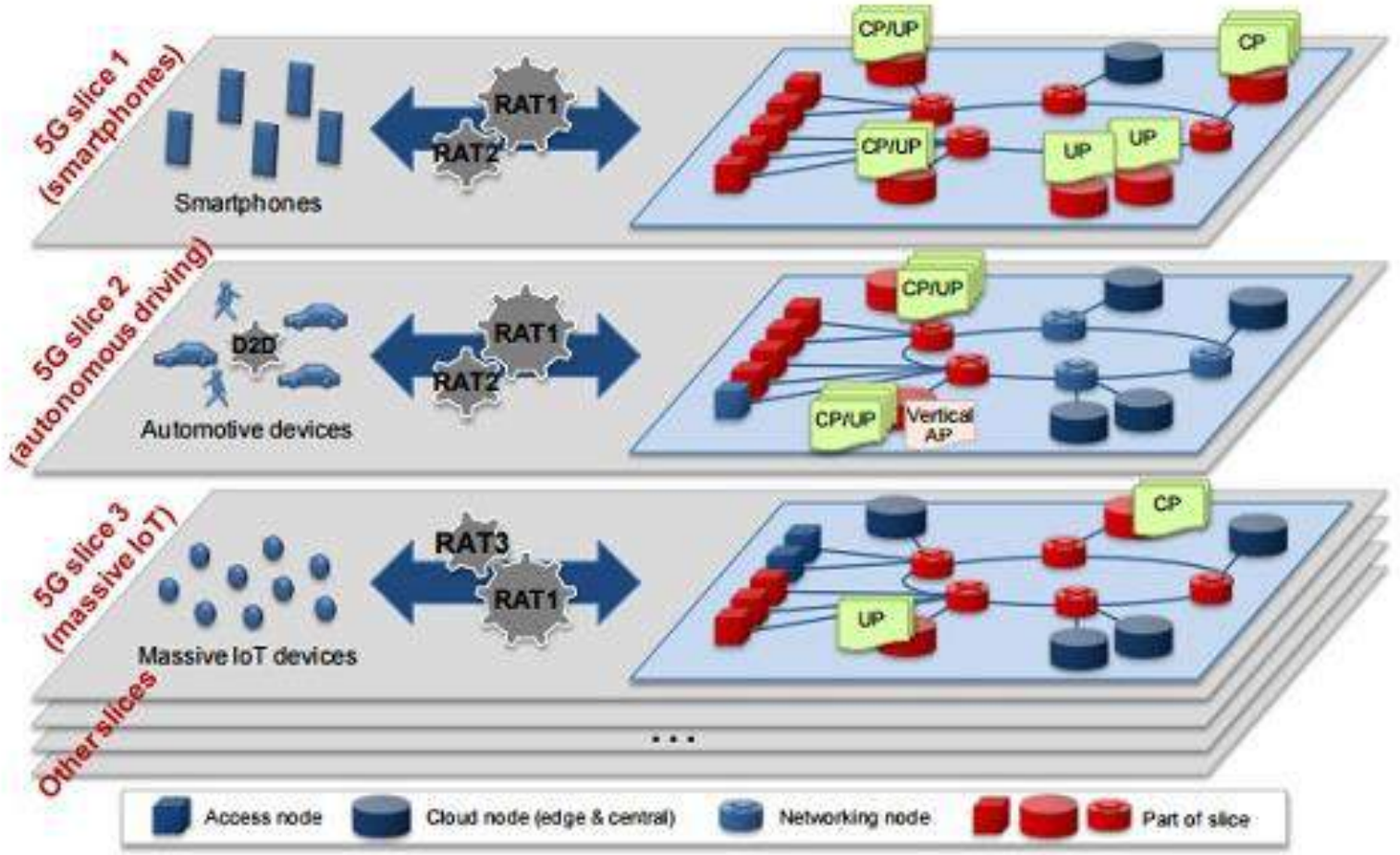
how?

Multiple 5G networks ? X



Network Slicing !

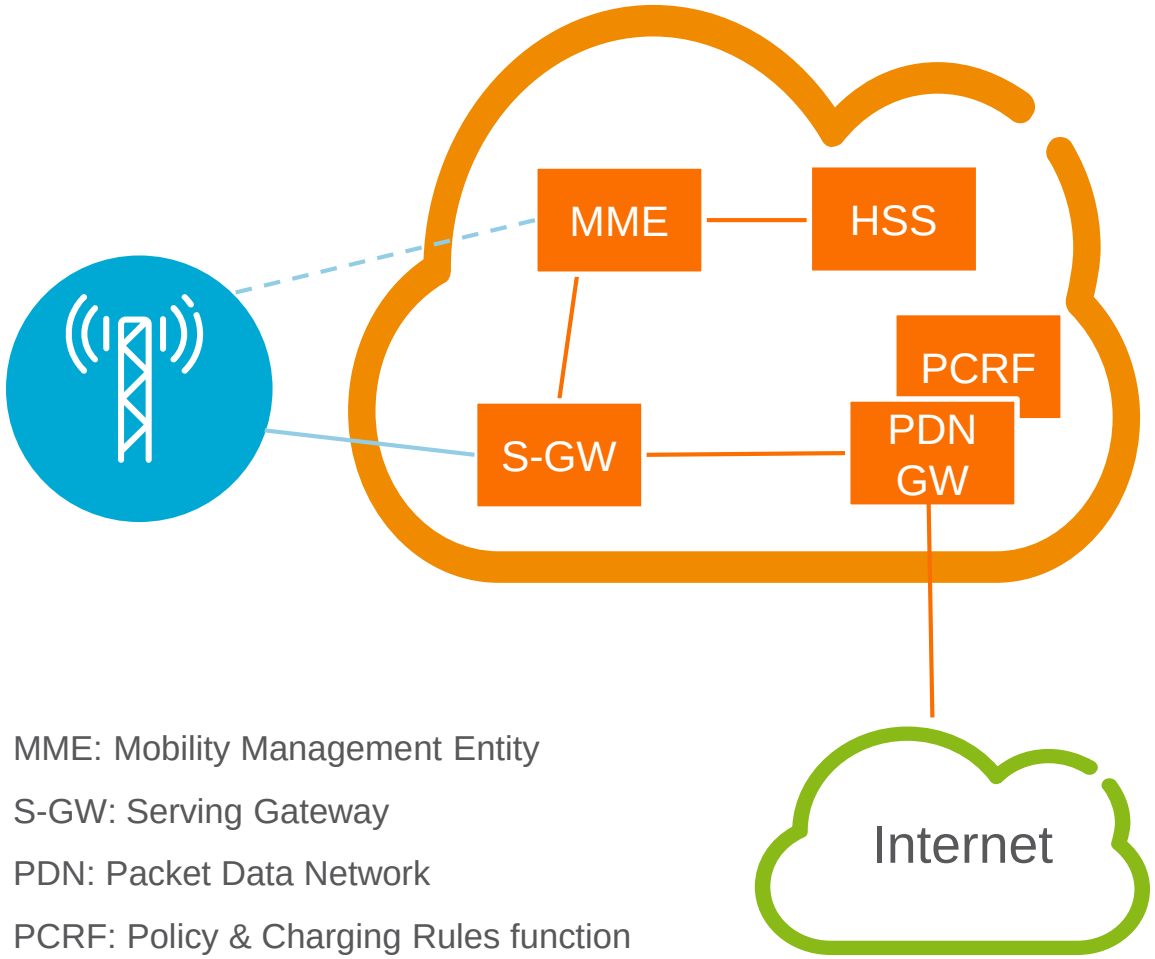




This figure shows 5G network slices implemented on the same infrastructure.
(*Source: NGMN 5G White Paper*)

- **Network Slicing**: Multiple independent and dedicated virtual sub-networks (network instances) are created within the same infrastructure to run services that have completely different requirements for latency, reliability, throughput and mobility.

CURRENT MOBILE CORE ARCHITECTURE



- A single network architecture for multiple services
- Mix of control and use plane functions
- Appliance-based realization

- Difficult to customize
- Scalability issues

MME: Mobility Management Entity

S-GW: Serving Gateway

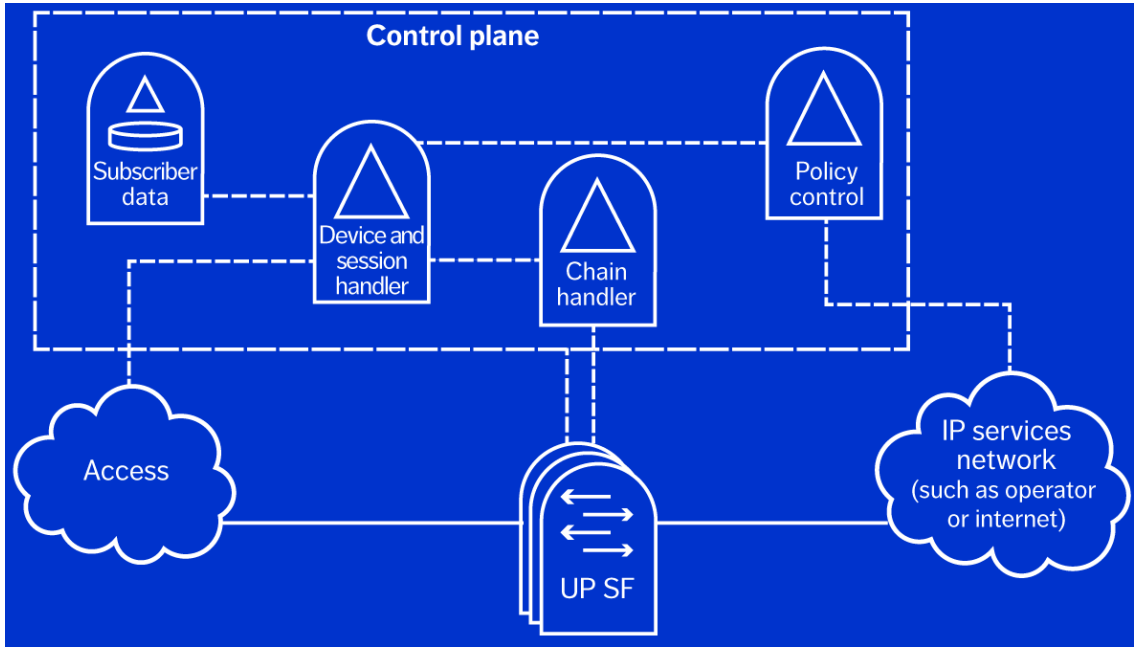
PDN: Packet Data Network

PCRF: Policy & Charging Rules function

HSS: Home Subscriber Server

FLEXIBLE CORE ARCHITECTURE

- Separation of control and user-plane functions
- Decompose core functionality into granular functions
- Virtualize network functions

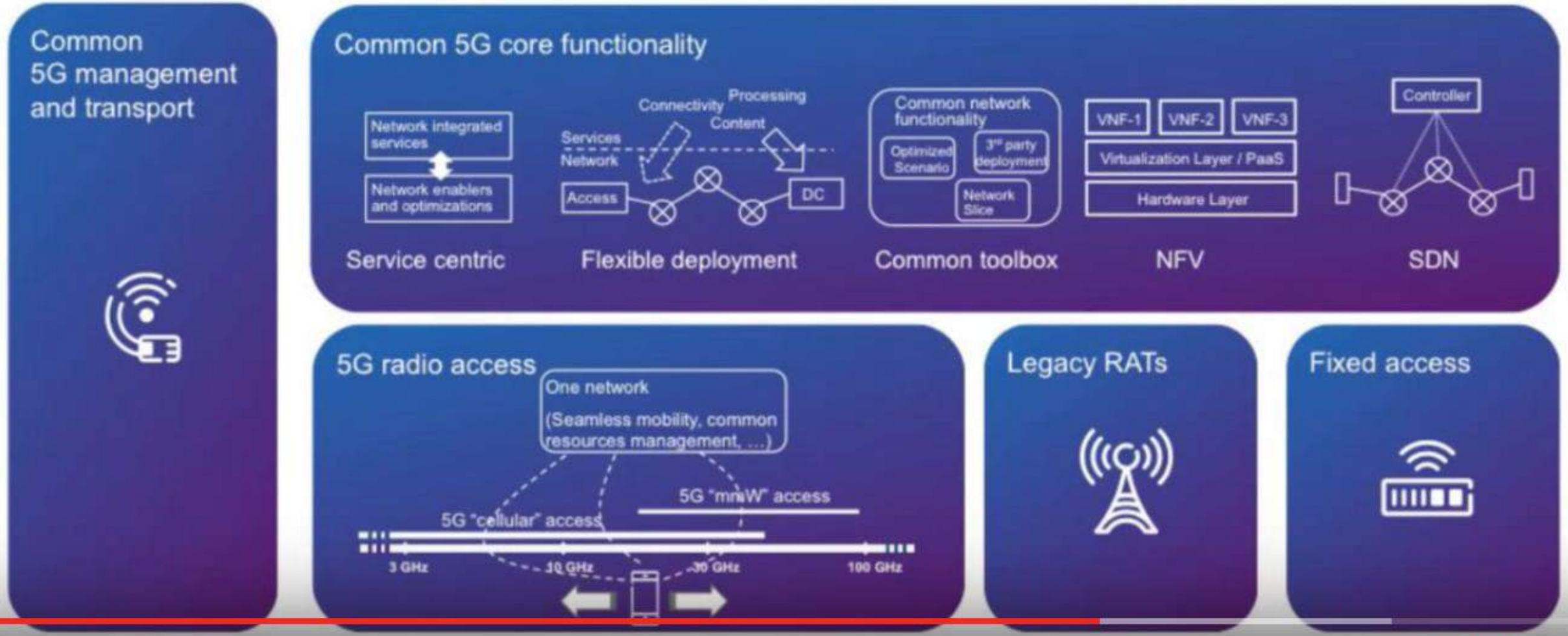


- Customize realization per service/slice
- Centralized control functions
- Selective scaling
- Utilize Cloud Environment
- Flexible placement of functions

Source of fig.: Ericsson Review on 5G Core Flexibility

Hugo Tullberg, Ericsson, 5G architecture, METIS and 5G PPP

5G NETWORK ARCHITECTURE



Cloud technologies together with software-defined networking (SDN) and Network Functions Virtualization (NFV) provide the tools that enable architects to build systems with a greater degree of abstraction – which enhances network flexibility. Cloud, SDN and NFV technologies allow vertical systems to be broken apart into building blocks, resulting in a horizontal network architecture that can be chained together – both programmatically and virtually – to suit the services being offered and scaled.

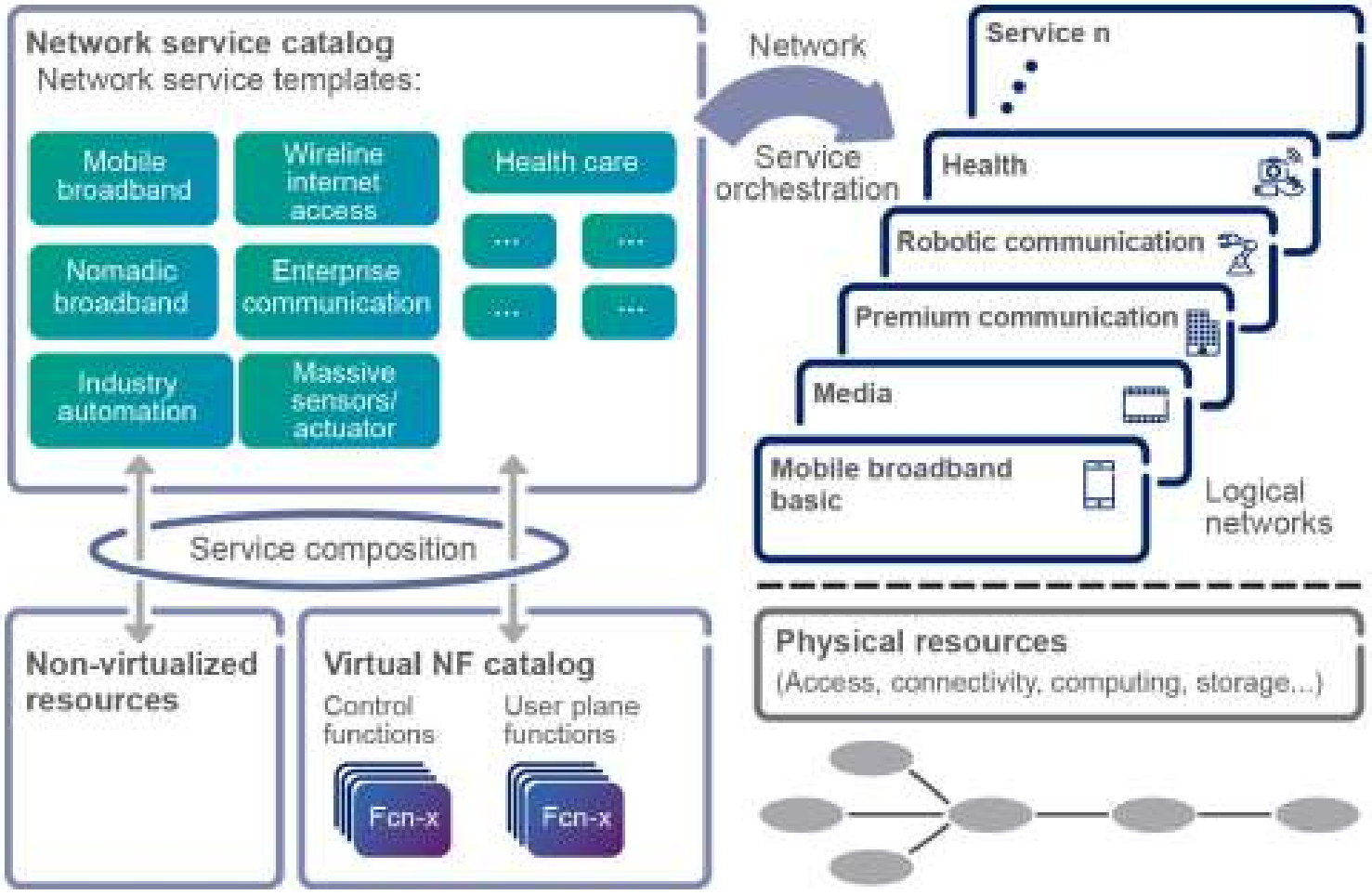
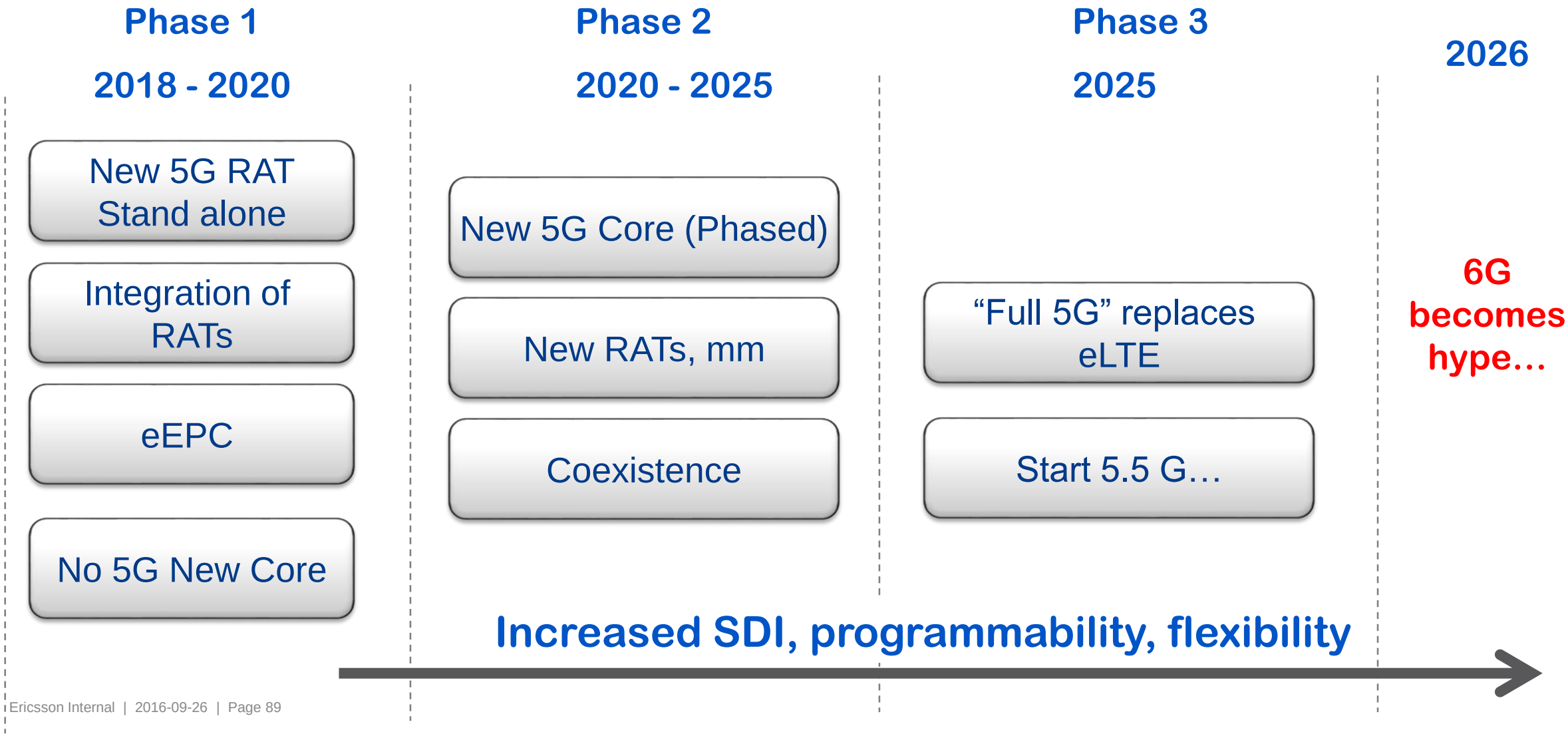


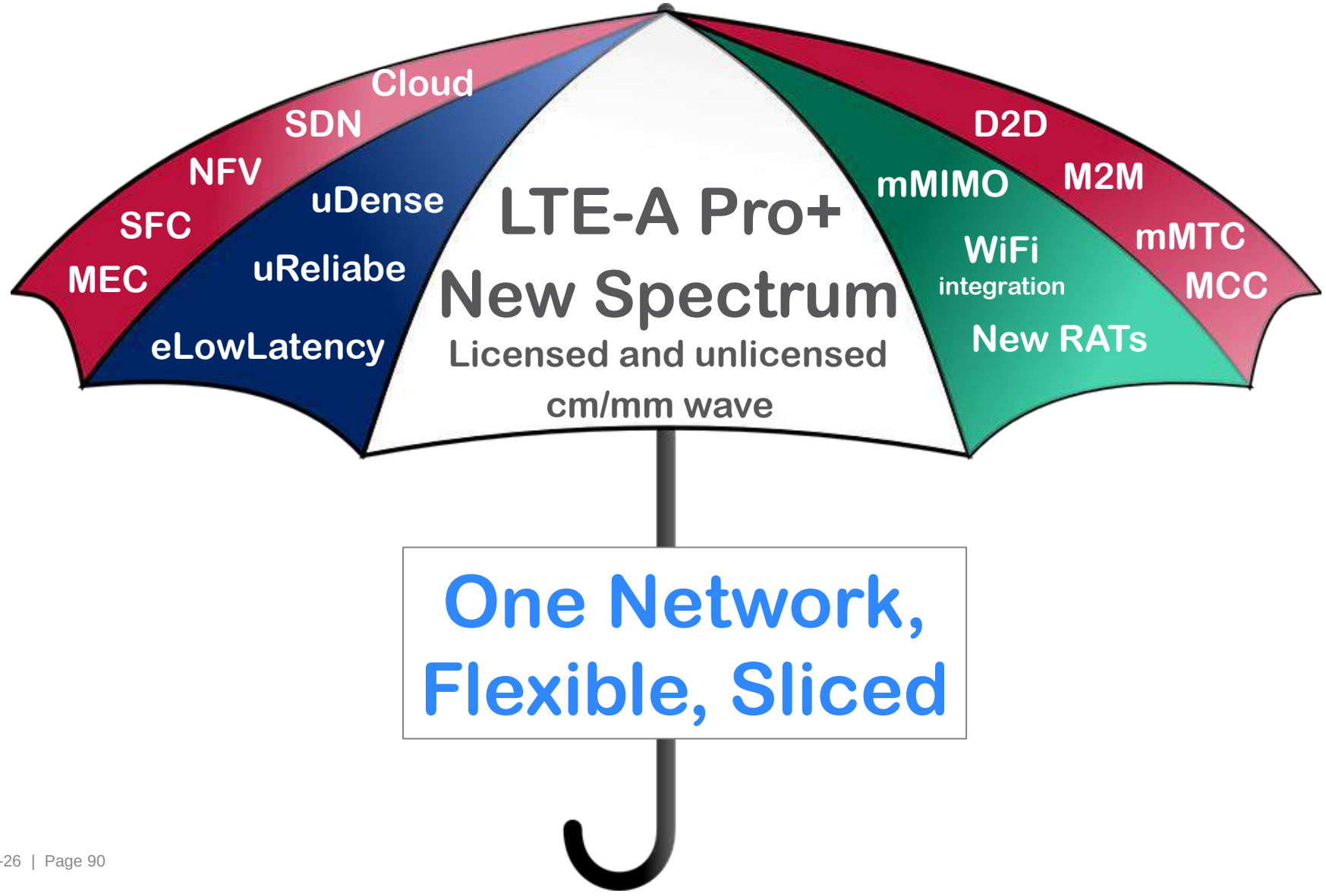
Figure 3: Service creation using network slices.

PHASED FUTURE ACCESS AND CORE

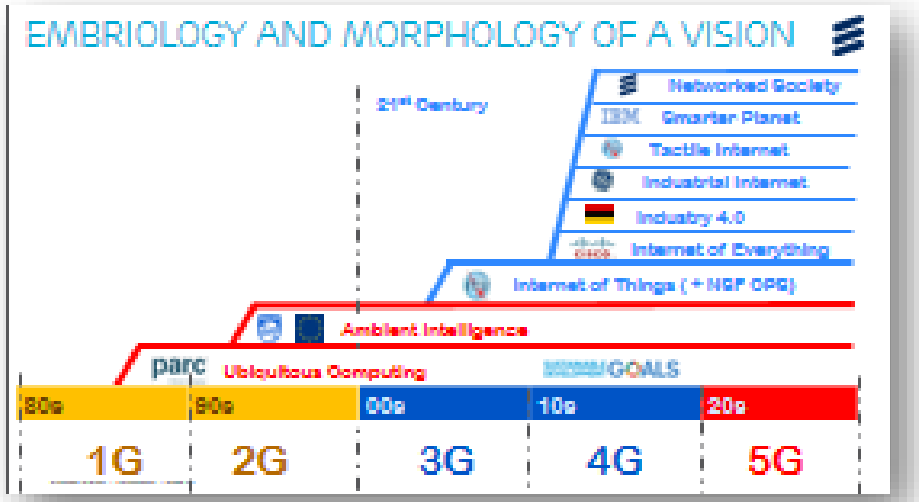
APPROXIMATE DATES - SPECULATIVE

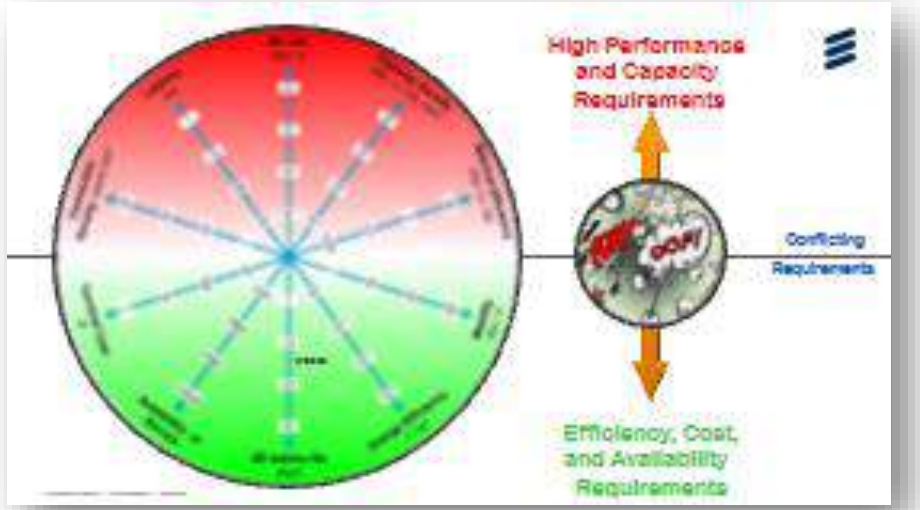


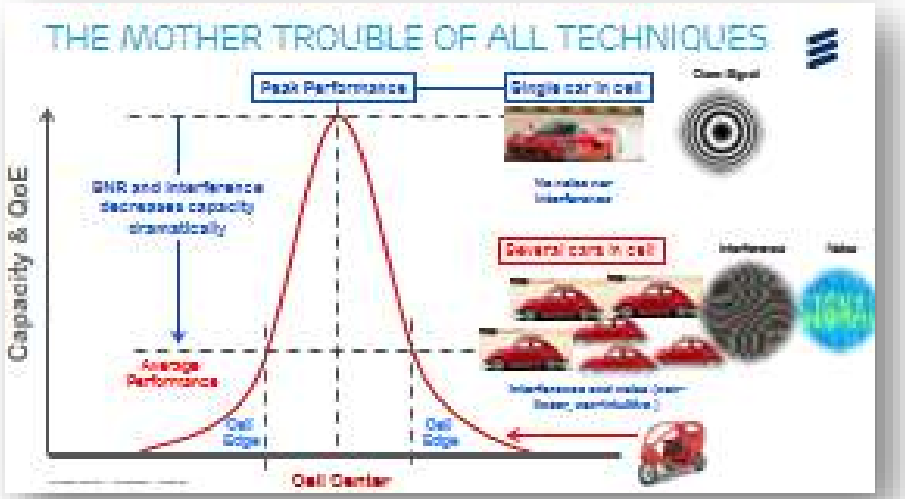
SUMMARY: 5G AN UMBRELLA OF TECHNOLOGIES



KEY TAKEWAYS







A SELF-GUIDED TOUR TOWARDS 5G UNIVERSE

MWC 2016

https://www.youtube.com/watch?v=xjB-zwDiet4 UlfE, SaraM

Johannesberg Summit

https://www.youtube.com/watch?v=6oqUa_kW73E Sara Masur
https://www.youtube.com/watch?v=9NwDEzumkUQ Erik Ekkuden

Amazon – Look inside
https://www.amazon.com/Fundamentals-Mobile-Networks-Jonathan-Rodriguez/dp/1118867521
https://www.amazon.com/5G-Mobile-Wireless-Communications-echnology/dp/1107130093/ref=pd_sim_14_2?ie=UTF8&psc=1&refRID=43KXKPA4VJ0SJ7H7F5XA

Increasing technical content

Ericsson White Papers

https://www.ericsson.com/res/docs/whitepapers/what-is-a-5g-system.pdf
https://www.ericsson.com/res/docs/whitepapers/wp-5g.pdf

4G/5G Americas White Papers

http://www.4gamericas.org/files/2714/1471/2645/4G_Americas_Recommendations_on_5G_Requirements_and_Solutions_10_14_2014-FINALx.pdf
http://www.4gamericas.org/files/2414/4431/9312/4G_Americas_5G_Technology_Evolution_Recommendations_-_10.5.15_2.pdf
http://www.4gamericas.org/files/7814/4606/7589/4G_Americas_5G_Spectrum_Recommendations_White_Paper-2015.pdf

Questions

ERICSSON