TUTORIAL: DESIGNING TO EVOLVING LTE ADVANCED PRO AND PRE-5G REQUIREMENTS

Practical Deployment Considerations

Dr. Ghobad Heidari, President, GHB Intellect

Cary David Snyder, Mobile Fronthaul Architect, e2e5G.Tech

Dr. Raghu M. Rao, Principle Architect, Xilinx Inc.

Dr. Yogendra Shah, Senior Director, Interdigital Communications

http://ghbintellect.com/subject-matter-experts/expert-profiles/

Info@ghbintellect.com

Outline

- Introduction and Outline
- Business Drivers
- Network Architecture Evolution
- Practical Deployment Considerations
- Security Considerations
- IP & Design Considerations
- Q&A

SPEAKERS – *GHB Intellect* *SUBJECT-MATTER EXPERTS*

Dr. Ghobad Heidari
President, GHB Intellect
ghobad@ghbintellect.com | GHBIntellect.com | **On Brax.Me** *or* | **Twitter** @GHB_Intellect

GHB Intellect
Unparalleled Expertise | Unprecedented Service

Cary David Snyder
Mobile Fronthaul Architect, e2e 5G Technology
ca@e2e5g.tech | E2E5G.Tech | **On Brax.Me** *or* | **Twitter** @e2e5GT

e2e 5G Tech On Brax.Me

Dr. Raghu Rao
Principal Architect, Xilinx Inc.
raghu.rao@xilinx.com | Xilinx.com | **On Brax.Me** *or* | **Twitter** @XilinxInc

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Dr. Yogendra Shah
Senior Director, Interdigital Communications
Yogendra.Shah@InterDigital.com | InterDigital.com | **On Brax.Me** *or* | **Twitter** @InterDigitalCom

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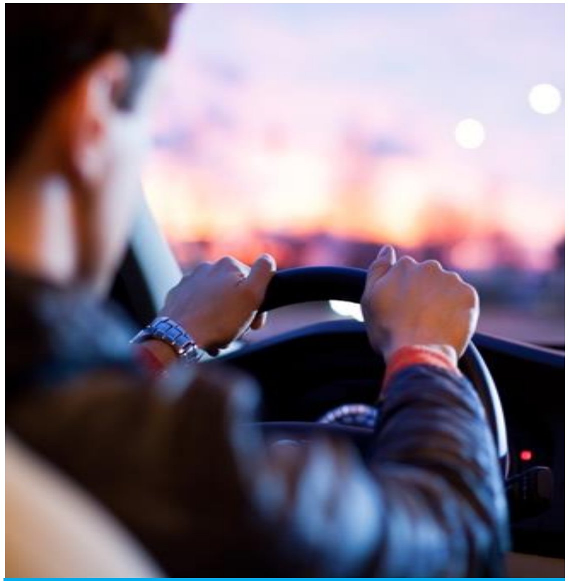
Outdoor & Indoor Use Cases Drive 5G

High Traffic Volume, Low Latency, Massive Connectivity – Required by all but vary by use case

SHOPPING MALL

DENSE URBAN INFO SOCIETY



REALTIME REMOTE COMPUTING

OPEN AIR FESTIVAL

Internet of Things (IoT)

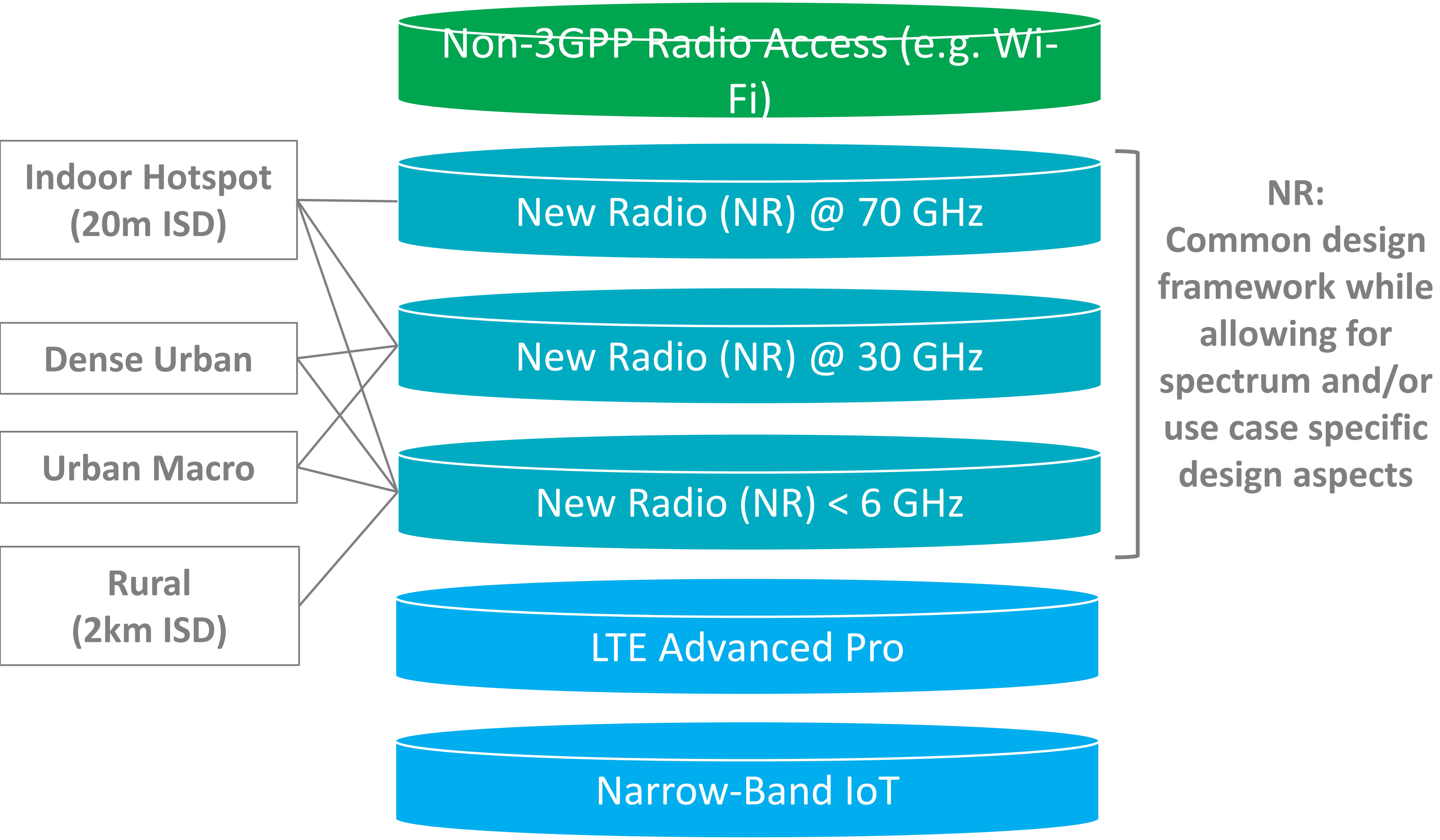
Source: METIS

What Differentiates 5G from Previous Generations?

	2G	3G	4G	4G/5G	5G
Use Cases & Services	Voice + SMS	Voice + Small Data	Mobile Broadband		Enhanced Mobile Broadband Massive Machine Type Communications Ultra Reliable and Low Latency Communications
Spectrum	200 KHz Chan Below 2 GHz	5 MHz Channels Below 3.6 GHz	Up to 20 MHz Channels Below 3.8 GHz		Up to 1 GHz Channels Below 100 GHz
Radio Technology	GSM/GPRS (Single RAT)	UMTS/HSPA (Single RAT)	LTE/LTE-A (Single RAT)		Multiple Radio Access Technologies Integrated in a 5G Network: 5G New Radio, LTE Advanced Pro, NB-IoT, Wi-Fi,…
Network Topology	Macro Cells	Macro and Small Cells	Heterogeneous Macro and Small Cells		Challenging Traditional Cell & Network Concepts: Small Cells, Mobile Edge Computing, Network Slicing, …

5G: A Multi-Layer Radio Network

5G will be designed with native support for connectivity across multiple radio layers



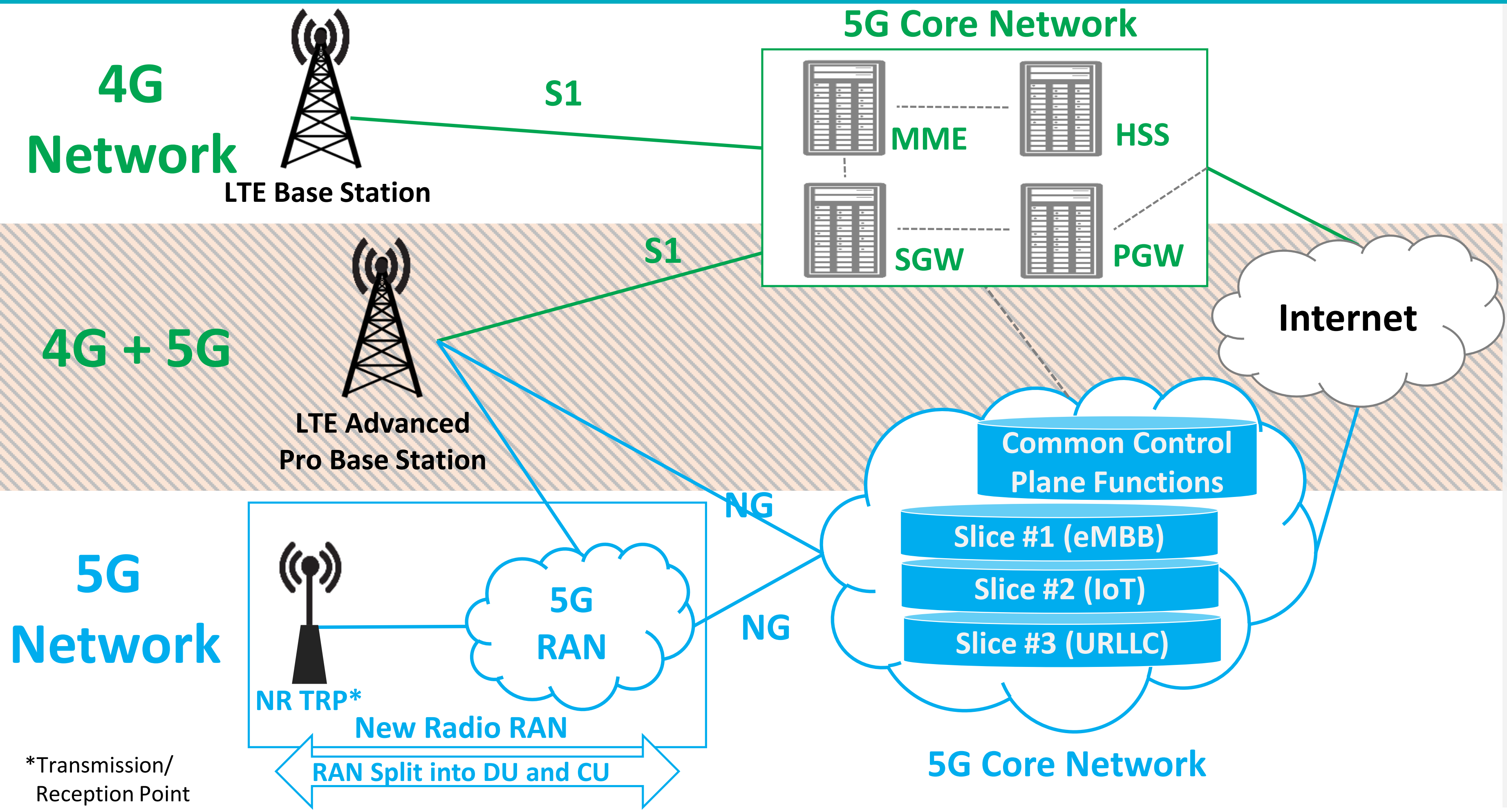
- New Radio (NR): new, non-backwards compatible air interface

  ➔ Opportunity that comes around only once every 10 years!

- Radio Layers could be deployed as “Standalone” or using multi-connectivity framework
- Radio layers can be deployed based on individual operator roll out plans for 5G Mature 5G networks (i.e. 2025+) envisioned to include all radio layers working together
- LTE and NB-IoT expected to evolve as components within 5G networks

Gluing 4G, 4G Evolution & 5G Together

5G System should allow for independent evolution and flexible deployment of RAN and Core Network



*Transmission/ Reception Point

Application of NFV:

- Benefits are even clearer for CN where nodes can already be centralized

Introduction of network slicing:

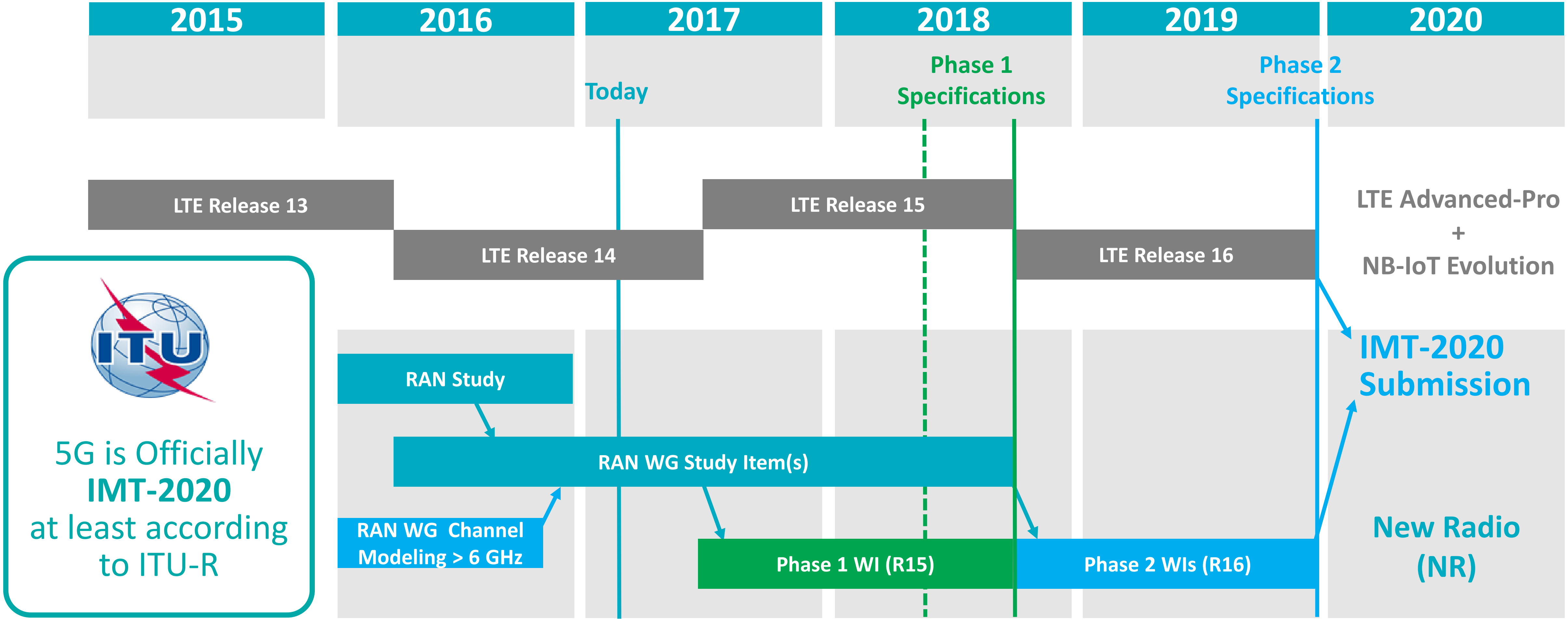
- Segmentation of resources to form a different logical CNs per service (e.g., IoT, eMBB)
- Allows dynamic scaling of resources based on service type needs

Service Capability Exposure

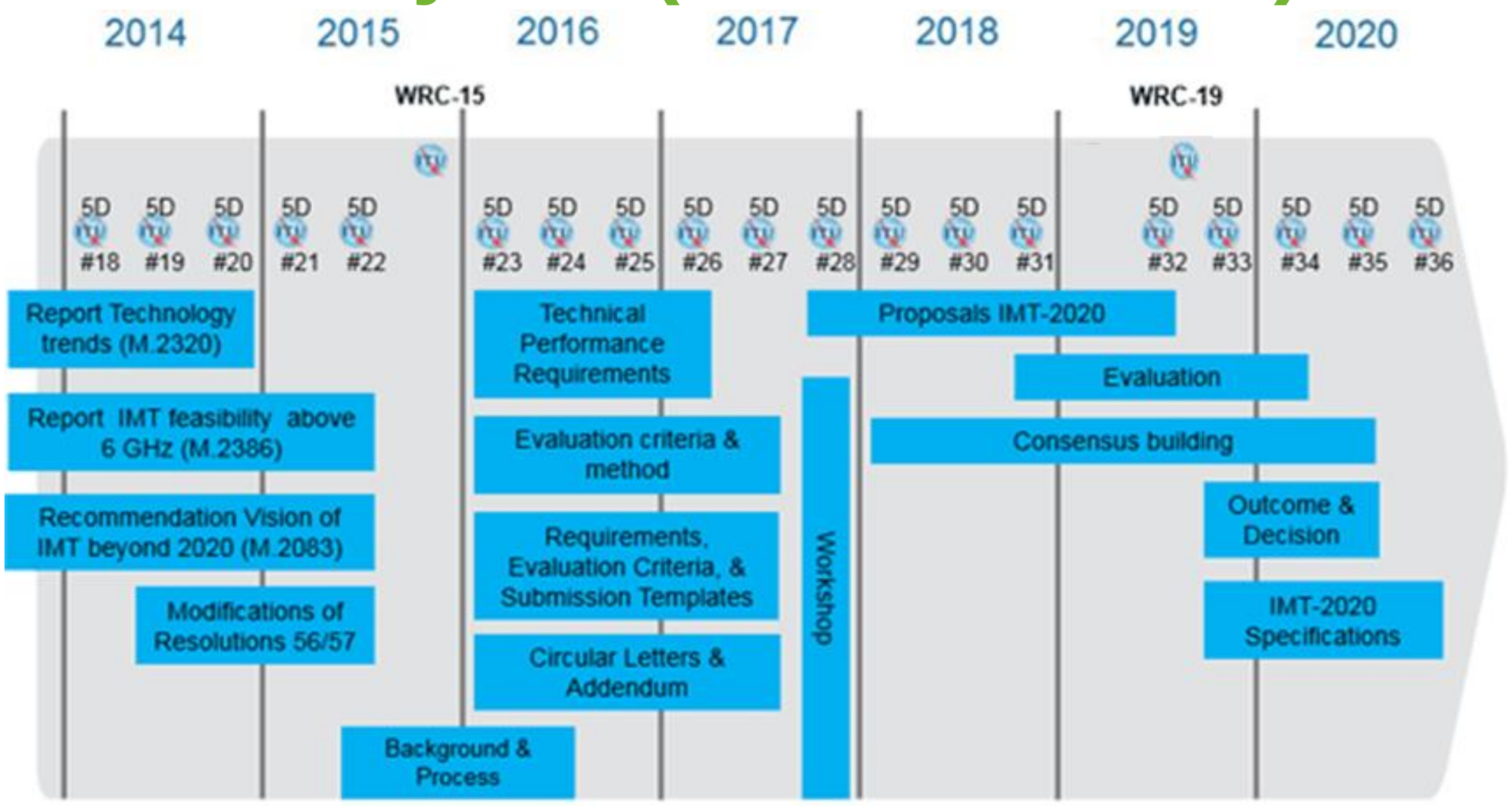
- Allowing 3rd party service/application providers access to information and service customization

Timeline: 3GPP 5G Standardization

Phased approach enables early commercial deployment of Phase 1 in 2020 and Phase 2 in 2022+



5G Timeline: ITU-R IMT-2020 and Beyond (i.e. Official 5G)



Source: ITU-R SG5 WP-5D

- Key Milestones
  - 2017 Q1: Completion of Technical Performance Requirements
  - 2020 Q1: Submission of final proposals for IMT-2020
- Who is expected to submit a proposal?
  - 3GPP already working towards proposal satisfying full set of use cases/requirements
  - 802.11 still under consideration

5G Timeline: Official vs. Commercial 5G

Early commercial 5G systems expected to be deployed ahead of "Official 5G" Standards

	What is it?	What happened for 4G?	What to Expect for 5G?
Official 5G	▪ Radio access technology recognized by ITU-R as **IMT-2020** technology ▪ Expected to meet IMT-2020 requirements ▪ Standardization must be completed and submitted to ITU-R in Q1 2020	3GPP LTE Release 10 (i.e. LTE-A) was submitted and recognized as the ITU-R IMT-Advanced (i.e. 4G) radio technology	3GPP Release 16 submitted in Q1 2020, including: ▪ New Radio (NR) ▪ LTE-Advanced Pro? ▪ NB-IoT?
Commercial 5G	▪ Whatever operators and vendors market as 5G ▪ Initial "Commercial 5G" systems will likely be deployed before completion of "Official 5G" Standards ▪ In the longer term, "Commercial 5G" and "Official 5G" will be the same thing	Initial deployments: ▪ Some early operators marketed HSPA+ (R7-R8) as 4G systems ▪ Other operators marketed LTE R8 as 4G Longer term: ▪ Majority of operators have deployed LTE R10 and expect to deploy later releases (R11-R13)	Initial deployments: ▪ Some operators will likely deploy 3GPP R15 as "Phase 1 of 5G" ▪ NR likely to require LTE-Advanced Pro for operation Longer term: ▪ 3GPP R16 and beyond

History, Technology, and Product Development Cycles Tell a Story…

5G will happen – Incrementally – Lots of Announcements – But mass market occurs well into the 2020's

Today

Announcements & Hype

- Testing of pre-standards technology
- Confirm feasibility of mmW access technology
- Continue standards study items and transition to work items

2017 to 2020

Incremental 4.75/5G Deployment, Demos, & Business Plans

- Deployment of sub-6 GHz 3GPP stds compliant 4.75G (LTE-A, LTE-A Pro)
  - Growing availability of Ph 1 compliant terminal devices
- Demos of pre-standards & proprietary mmW systems
  - Up to 40 GHz in 5G NR Ph 1
  - Ad hoc terminals
- Proprietary "5G-like" fixed wireless access & small cell deployments
  - Backhaul, self config mesh, SDN network management
- LTE-U/LAA/MulteFire Trials

2020 to 2025

Pilot Deployment & Tech Winners Emerge

- Pilot deployment of stds compliant 5G
  - mmW and sub-6 GHz
  - Growing availability of stds compliant 5G terminal devices w/ mmW
- Tech Winners Emerge
  - Indoor air interfaces
  - LTE-U/LAA/MulteFire
  - Backhaul / fronthaul
  - Neutral host
- Cost effective fixed wireless access and dense small cell deployments
  - Self config mesh
  - SDN network management

2025 and beyond

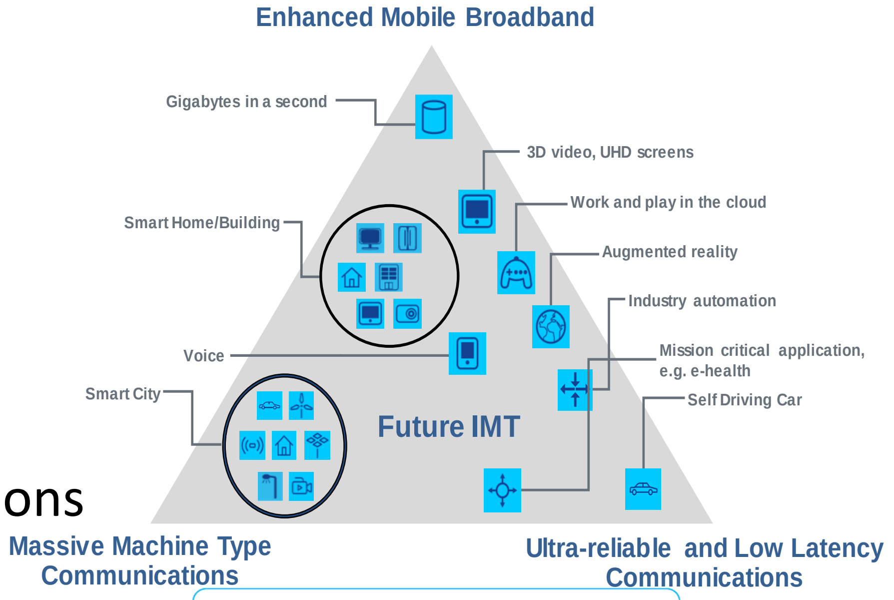
Mass Deployment

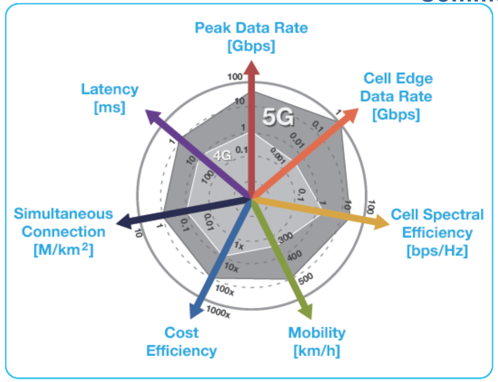
- Mass deployment of stds compliant 5G
  - mmW and sub-6 GHz
  - Indoors and outdoors
- Mass market availability of standards compliant 5G terminal devices w/ mmW
- Mature fixed wireless access & dense small cell deployment technologies

Performance as a 5G Driver

5G KPI's Require End-to-End System Technology Enhancements

- Lower Latency
  - Network delays must be <10msec to enable 5G new applications (4G end-to-end delays are 50-100msec)
  - AR/VR, autonomous driving, tactile internet
  - TCP data rates inversely proportional to latency
- Higher Data Rate and Capacity
  - Insatiable demand for capacity & multi-Gbps 5G applications
  - AR/VR, office-in-the-cloud, wireline equivalence
- More Mobility Uses
  - A key differentiator for cellular vs. Wi-Fi
  - Connected Cars, Trains, Aircraft including Drones





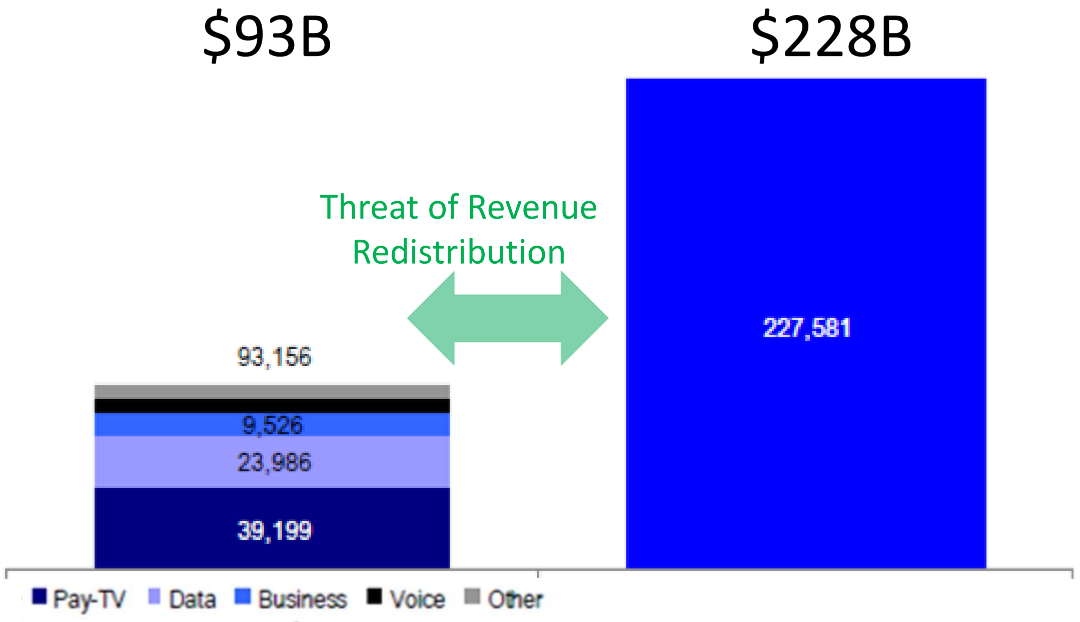
5G KPI (Rainbow) Requirements

Cost and Revenue as a 5G Driver

Architecture Changes for Cost Reduction Enable Denser Deployments

Cellular – Wi-Fi Competition Drives Cost Reductions

2015 Cable vs. Cellular USA Revenue ($B)*



Cable
- Indoor/fixed dominance
- High Video QoE
- 80% of Wireless Data

Cellular
- Outdoor/mobile dominance
- High non-Video QoE

*J.Chaplin, "Cable Entering Wireless," Catalysts for Change - Cable and the Future of Wireless, NYC, 13 April 2016.

- Reducing Cost with New Network Architecture
  - **Centralization**: Baseband processing enables sharing of hardware, easier repairs and upgrade (e.g. Cloud-RAN)
  - **Software Defined Networking (SDN & NFV)**: Architectures for flexible networking, eliminating need to for dedicated hardware for each network function
  - **Flexible Transport** to integrate fronthaul and backhaul over Ethernet, eliminating need for dedicated fiber
  - **Mobile Edge Computing**: Distributing content and application processing closer to the user reduces network congestion
- Adding Revenue with New Network Services
  - **Network Slicing** enables custom networks for new and diverse services
  - **Mobile Edge Computing** enables new applications that leverage low-latency networks

Competition as a 5G Driver

Fixed Broadband considered an early 5G use case, with interesting emerging landscape

- Operators: AT&T, Verizon, CableCo’s
  - Verizon and AT&T looking to make fixed residential wireless the first 5G deployment. Verizon leasing/purchasing 28 GHz spectrum from XO
  - Interest from Cable for rapid plant extensions and “curb-jumping”
- Big Newcomers: Google and Facebook
  - Facebook Terragraph : Facebook has built a 60 GHz, WiGig-based, low-cost, street furniture based, Gigabit small-cell/Wi-Fi AP mesh backhaul and Ethernet delivery to buildings system
  - Google Fiber announced in August they are moving to wireless in 12 major cities – fiber is too expensive
  - Google files with FCC in August to test 3.5 GHz in 24 major cities
- Start-ups: Starry and Vivint
  - Starry: Fixed mmW wireless
  - Vivint: Offering wireless Internet

Starry Window-mounted broadband mmW access

http://www.fiercewireless.com/wireless/at-t-5g-mostly-about-fixed-wireless-for-next-two-to-three-years
http://www.rcrwireless.com/20160525/carriers/verizon-looks-to-wireless-delivery-of-home-broadband-service-tag4
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Network Architecture Evolution

- Introduction
- 5G Imperatives
- 5G Network Evolution
- Functional Splits
- CPRI Fronthaul
- Packet-based Fronthaul
- Time Sensitive Networking
- FPGAs for Fronthauling
- Summary

Evolution of Cellular Communication

5G Architectural Requirements and Use cases

Enhanced Mobile Broadband
- Higher data rates
- Higher density
- Higher mobility

Massive Internet Of Things
- Massive number of devices
- Ultra low power

Critical Communications
- Ultra reliable
- Low latency
- Anywhere, anytime

Network Operations
- Network Slicing
- Reconfiguration
- Security

	5G	4G
Peak data rate	10 Gbps	1 Gbps
Spectral efficiency	120 b/s/Hz	30 b/s/Hz
Transmission Time Interval (TTI)	Varying; min 100us, max 4ms	1ms
Mobility	500kmph	350kmph
Latency	<1 ms (radio)	10 ms (radio)
Connection density	1000,000/km2	1000/km2
Energy efficiency	100x better than 4G	
Configurability	Per network slice and per TTI	

Enabling Technologies

	Peak data rate	Connection Density	Energy Efficiency	Spectral efficiency	Configurability	Latency	Mobility
Spectrum (mmWave communications)	√	√	√	√		√	
Carrier aggregation, multi RAT	√	√	√		√		√
Multi/Dual connectivity, Unlicensed LTE	√			√	√	√	
CloudRAN, Edge Clouds			√		√	√	√
Massive MIMO		√	√	√			
New air interfaces		√		√	√	√	√
Advanced Network Operation	√		√		√	√	√

Additional Spectrum for 5G

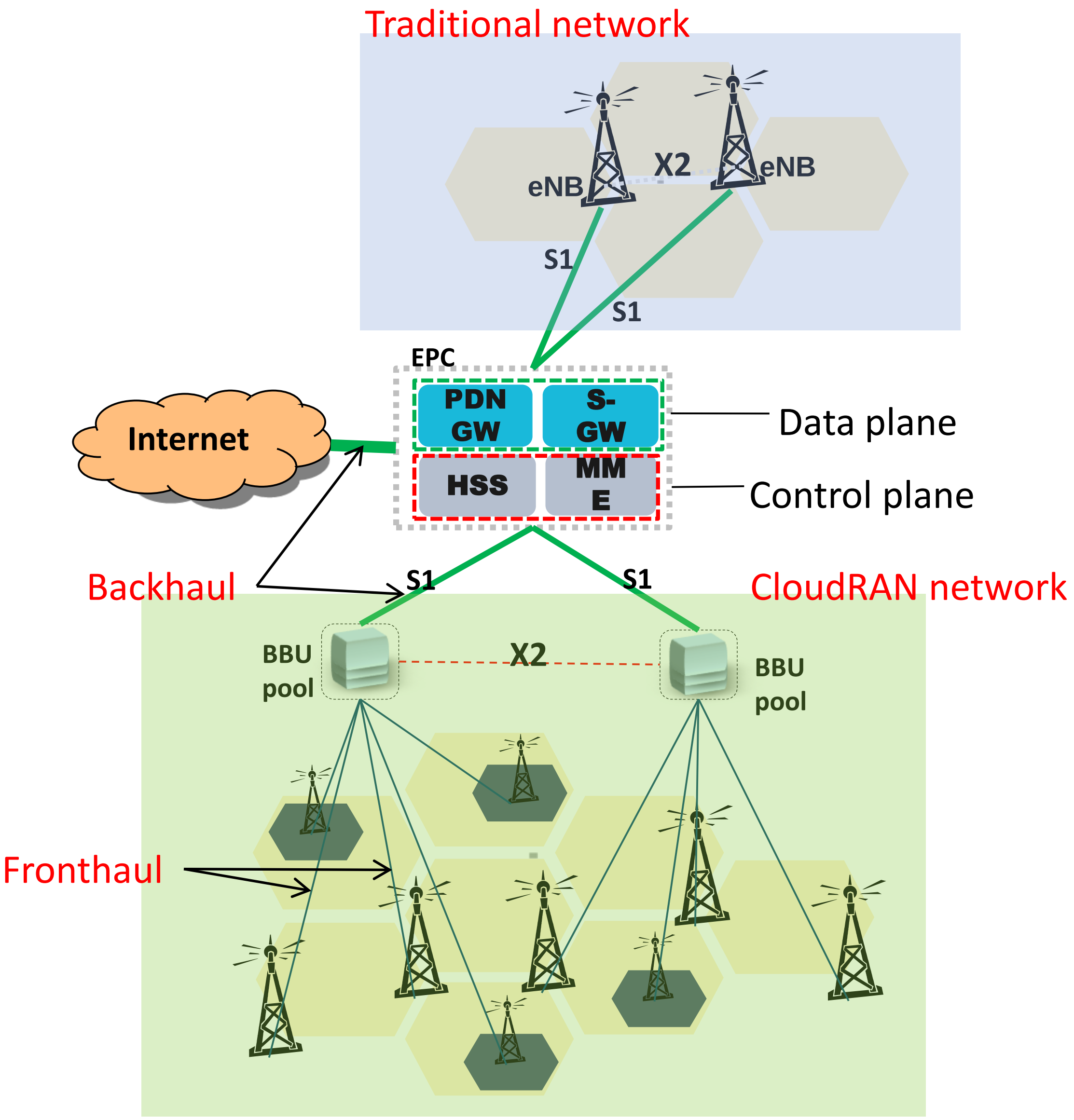
- FCC released new spectrum in 3.5 GHz, 28 GHz and 39 GHz bands for cellular access and fixed wireless access (last mile access)
- Verizon 5G spec address this spectrum and number of companies developing products around this spec
- The V-band (60-70 GHz), E-band (70-80 GHz) and W-band (90-110GHz) provide large chunks of unlicensed or lightly-licensed spectrum

	Spectrum	Available BW	Auctioned chunk	Carrier BW
3.5 GHz	3.55-3.70 GHz	150 MHz	Shared spectrum	10 MHz
28 GHz	27.5-28.35 GHz	850 MHz	425 MHz	100 MHz
37 GHz	37-38.6 GHz	1.6 GHz	200 MHz	100 MHz
39 GHz	38.6-40 GHz	1.4 GHz	200 MHz	100 MHz
V Band (60GHz)	57-71 GHz	14 GHz	Unlicensed	NA
E Band (70GHz)	71-86 GHz	15 GHz	Lightly licensed	NA
W Band (90GHz)	92 – 114.5 GHz	22.5 GHz	Unlicensed	NA

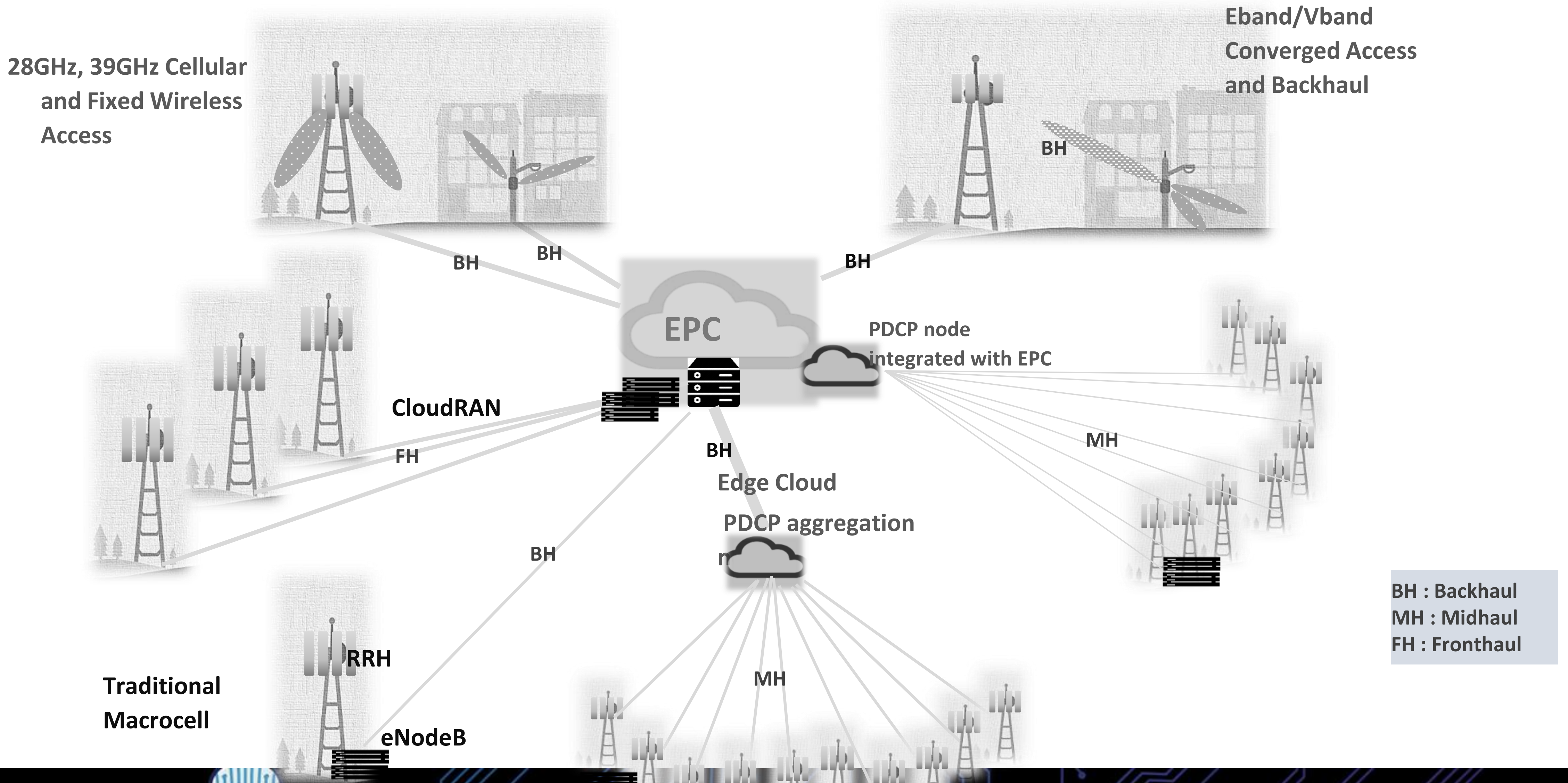
The 4G Network View

- SGW - Serving Gateway (Demarcation point between RAN and Core networks).
- PDN – Packet Data Network Gateway
- MME – Mobility Management Entity
- HSS – Home Subscriber Server
- EPC – Evolved Packet Core

- S1 – Interface from eNodeB or CloudRAN BBU pool to EPC.
- X2 – Interface between various eNodeBs and BBU pools



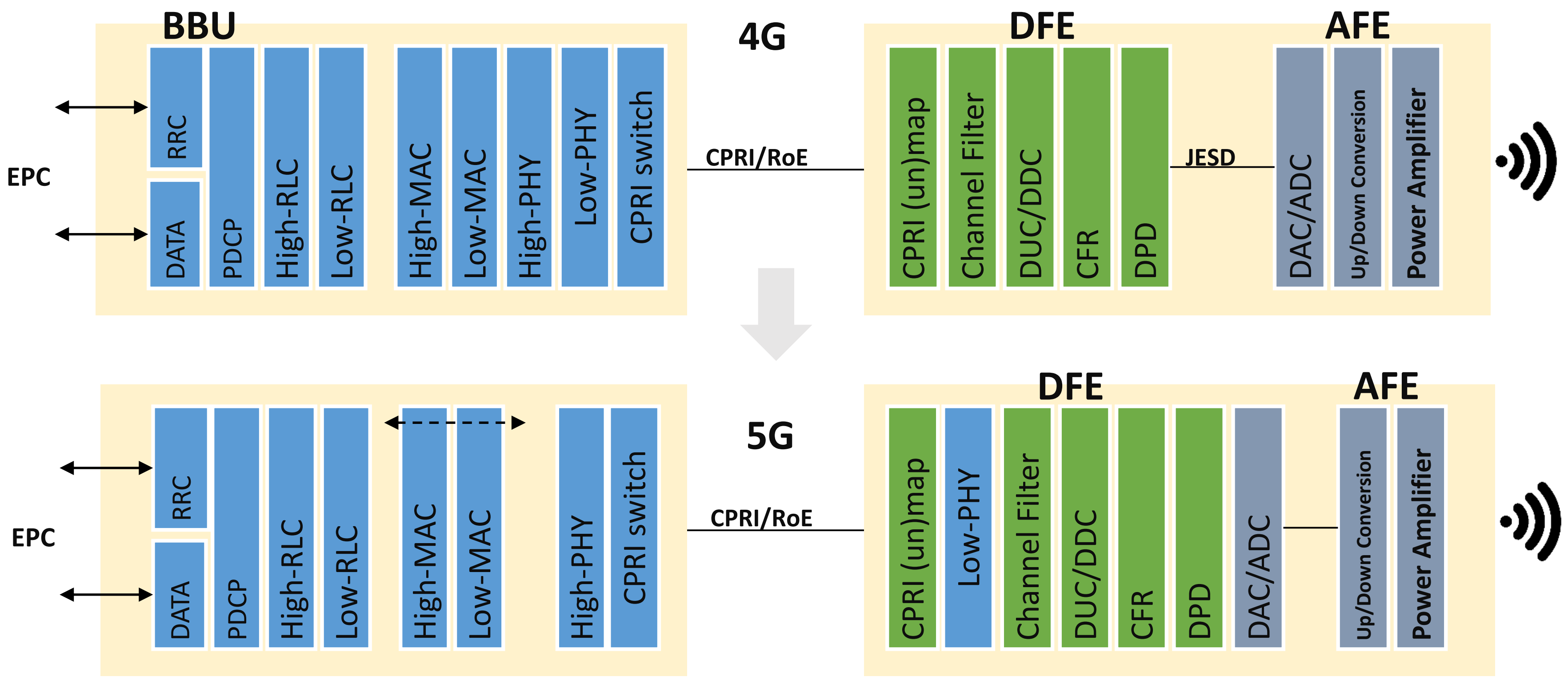
The Changing Radio Access Network



Functional Splits

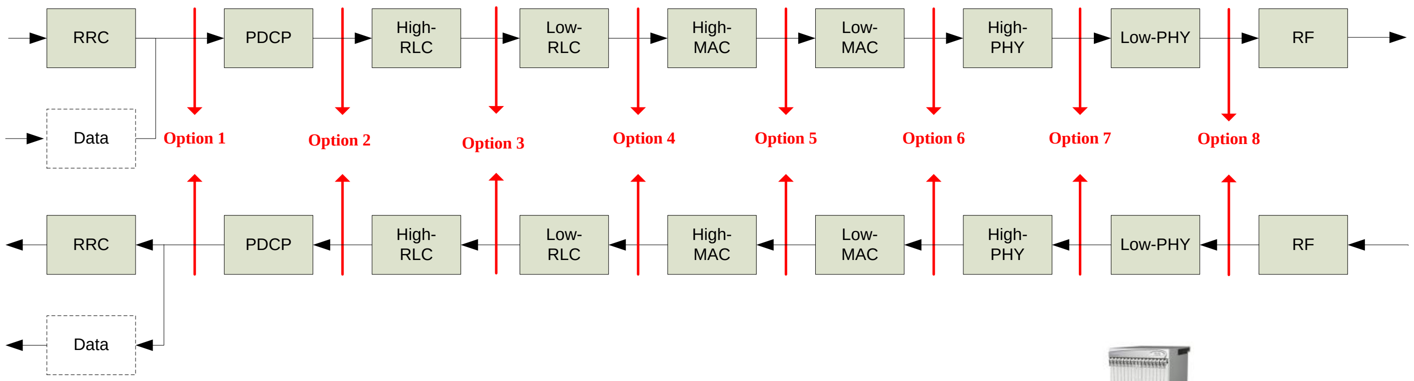
- With growing complexity of the baseband the fronthaul bandwidth also increases significantly.
  - Increased carrier aggregation
  - Increased Spectrum
  - Massive MIMO
- To contain the capacity requirements of the fronthaul, the physical layer (L1) is being split and some of the functionality moves to the radio.
- There are also aggregation nodes in the L2/L3 (PDCP Aggregation Node) which split the baseband in the upper L2 and create a new aggregation unit to facilitate low latency handovers and multi-connectivity (ex. LTE-U, LAA, etc.)

Trend : Emerging Functional Partition Of The Basestation



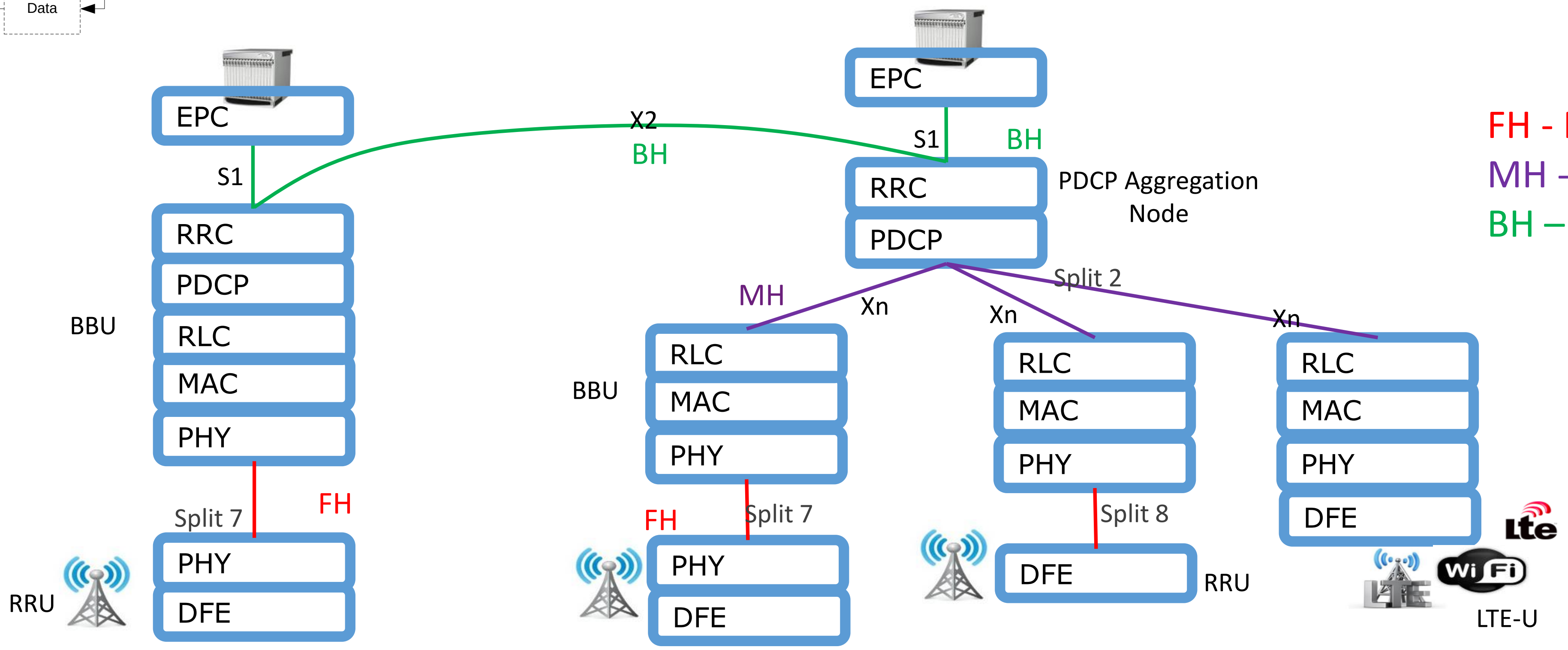
- **Portions of L1 migrating to remote radio head (RRH) in an effort to contain fronthaul bandwidth requirements**
- **Complexity of RRH increases**

Examples of Functional Splits



3GPP TSG RAN defined functional splits that cover the entire baseband (L1, L2, L3)

Deployment examples



FH - Fronthaul
MH - Midhaul
BH – Backhaul

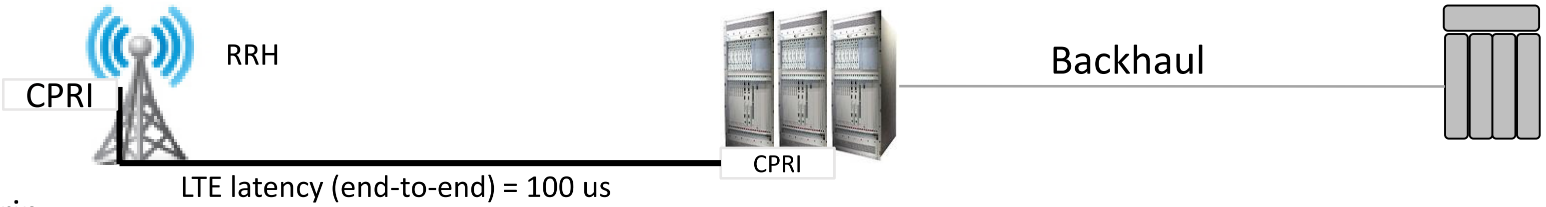
Fronthauling

- Transport of I/Q signals from the baseband unit to the radios is known as "Fronthaul".
- Common Public Radio Interface (CPRI) is a popular standard for transporting baseband I/Q signals to the radio unit in traditional BS.
- Timing and frequency synchronization are critical elements for front-hauling.

- LTE-A and LTE-A Pro systems have some strict latency and delay constraints on transporting I/Q signals.

CPRI round trip latency

- Speed of light = 2.99*10^8 m/s. This creates a latency of 3.33 us/km.
- Light travels slower in fiber due to the fiber's refractive index, so latency increases to 5us/km.
- This limits the range of fiber to about 15km-20km for LTE.
- Overall latency determined by link latency and hence range of front-haul.

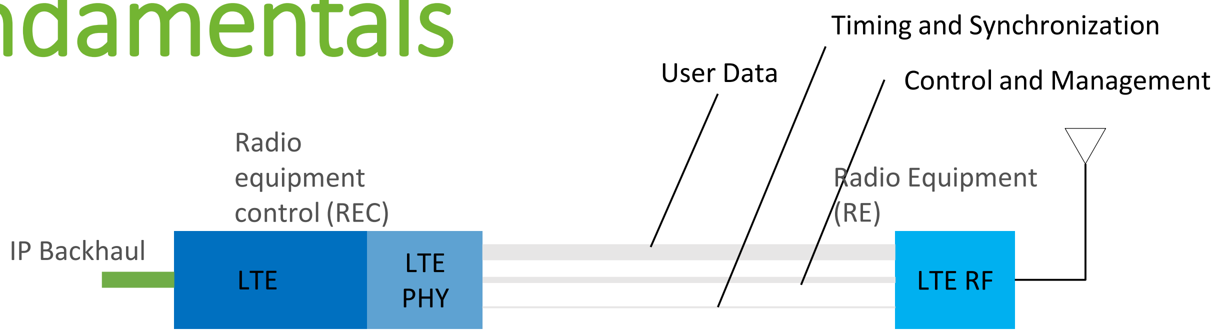


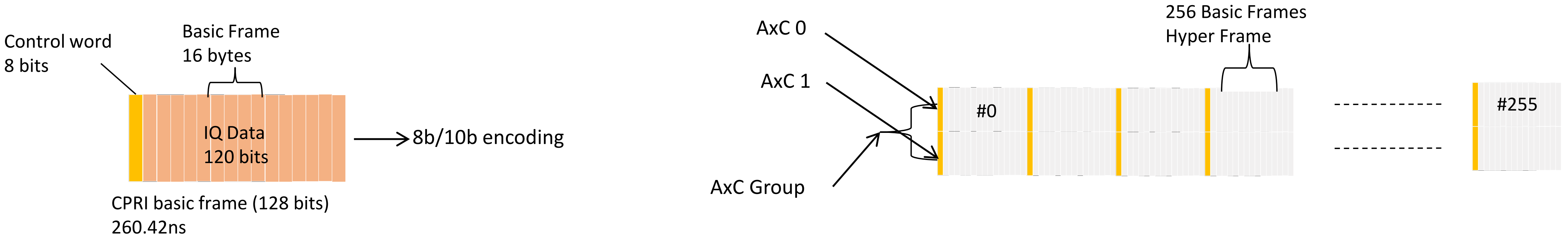
CPRI latency = 5us round trip

Scenario	WCDMA 5 MHz	LTE 10 MHz	LTE 20 MHz
3 Sector, 4x4 MIMO, 1 Carrier	922 Mbps	7.4 Gbps	14.7 Gbps
1 Sector, 2x2 MIMO, 1 Carrier	246 Mbps	1.2 Gbps	2.5 Gbps

RAT	Frequency Accuracy (Network/Air i/f)	Phase Accuracy (Time-of-Day)
TD-SCDMA	16 ppb/50 ppb	1.5 us
WCDMA	16 ppb/50 ppb	
LTE-FDD	16 ppb/50 ppb	1.5 us (LTE-A only)
LTE-TDD	16 ppb/50 ppb	1.5 us

CPRI Fundamentals





- CPRI allows an efficient, flexible I/Q data interface for various standards such as LTE, WCDMA, GSM, etc.
- It uses one physical connection for user data, management and control signaling and synchronization.
- CPRI transports I and Q data of a particular antenna and a particular carrier and this "unit" is called an AxC (Antenna-Carrier) unit.
- For example, in an LTE system, if I=16 bits and Q=16 bits, then one AxC is 32 bits.
- Data is organized into basic frames of 16 words each. The first word of each basic frame is the control word.
- Each word could be 8, 16, 32 bits, etc. The width of the word depends on the CPRI line rate.

CPRI Line Rates and Transport Capacity

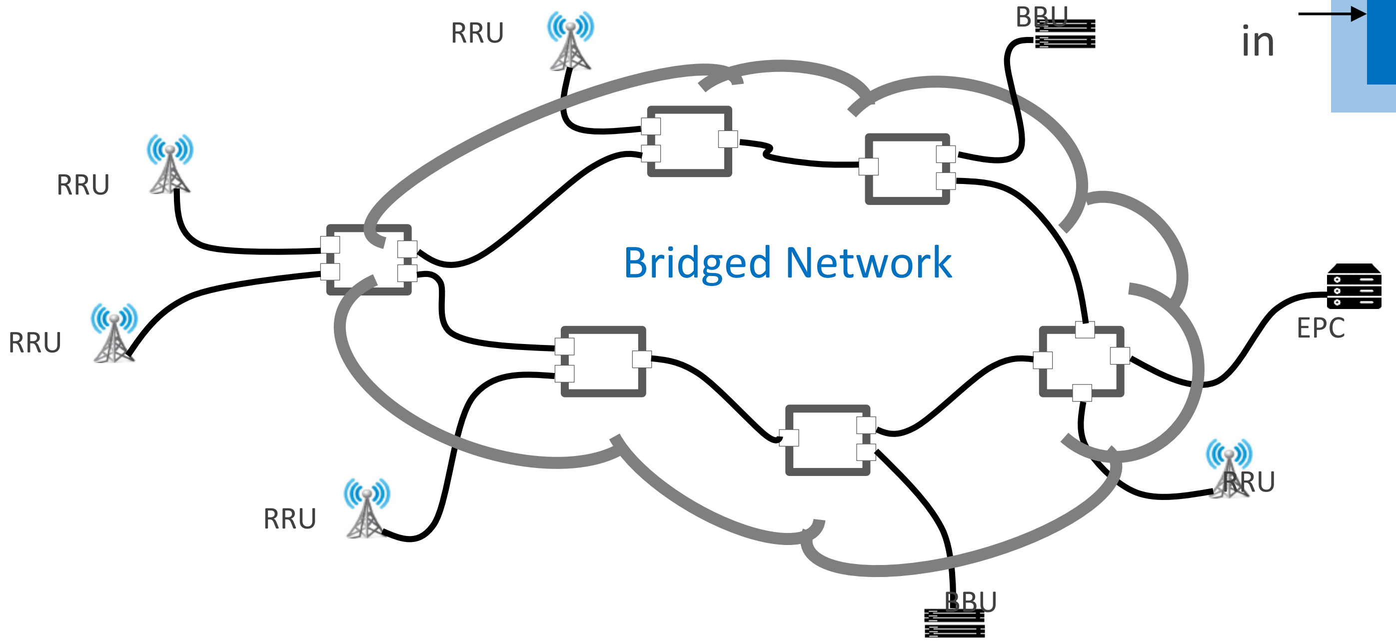
CPRI Rate	Line Bit Rate	Line Coding	Bits per word	Transport Capacity (#WCDMA AxC)	Transport Capacity (#20MHz LTE AxC)	SerDes
Rate 1	0.6144 Gbps	8B/10B	8	4	--	GTH/GTY
Rate 2	1.2288 Gbps	8B/10B	16	8	1	GTH/GTY
Rate 3	2.4576 Gbps	8B/10B	32	16	2	GTH/GTY
Rate 4	3.0720 Gbps	8B/10B	40	20	2	GTH/GTY
Rate 5	4.9152 Gbps	8B/10B	64	32	4	GTH/GTY
Rate 6	6.1440 Gbps	8B/10B	80	40	5	GTH/GTY
Rate 7A	8.1100 Gbps	64B/66B	128	64	8	GTH/GTY
Rate 7	9.8304 Gbps	8B/10B	128	64	8	GTH/GTY
Rate 8	10.1376 Gbps	64B/66B	160	80	10	GTH/GTY
Rate 9	12.1651 Gbps	64B/66B	192	96	12	GTH/GTY
Rate 10	24.3302 Gbps	64B/66B	384	192	24	GTY

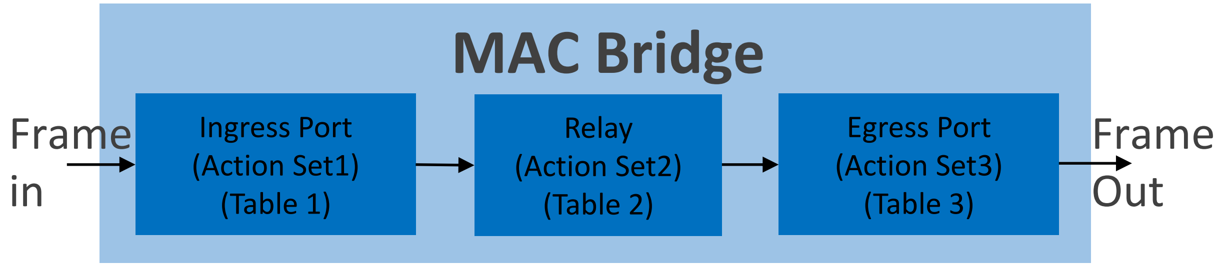
Ethernet Rate	Line Bit Rate	Closest CPRI rate	Approx number of WCDMA AxC	Approx number of LTE AxC	SerDes
10G	10.3125 Gbps	Rate 8	80	10	GTH/GTY
25G	25.7812 Gbps	Rate 10	192	24	GTY

From Circuit Switched to Packet Switched

- Traditional fronthaul infrastructure to transport I/Q data encapsulated in CPRI frames is circuit switched
  - This has a dedicated path and bandwidth reserved for it
  - Might be overprovisioned and inflexible but there are no issues regarding delay and time synchronization
- The move to packet based fronthaul with Ethernet technology needs to address the issue of worst case delay
  - Ethernet is "best effort delivery"
  - Adaptive and robust but timing is very sloppy
- What is needed is bounded delay and accurate timing synchronization and these are the topics of Time Sensitive Networking (802.1CM)
- This is the move towards a "Deterministic Ethernet"

Packet Based Fronthaul



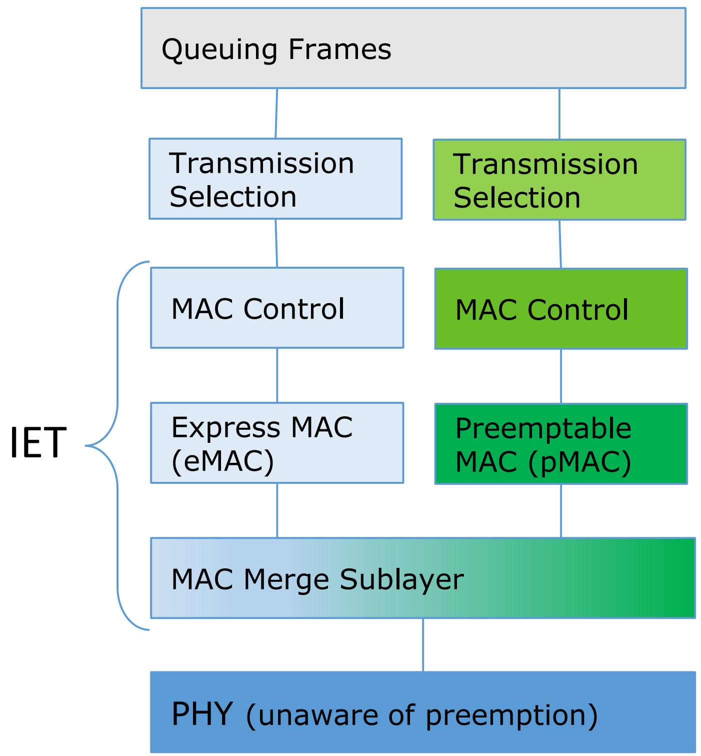


- Ingress port
  - Filtering, (un)tagging, VID translation, de/en-capsulation
- Relay
  - Forwarding, filtering
- Egress port
  - Filtering, (un)tagging, VID translation, de/en-capsulation, metering, queuing, transmission selection

- Needs to meet the tight timing constraints of fronthaul networks
- However, this paves the way for converged fronthaul and backhaul
- A dynamically configured network with a centralized orchestrator

Time Sensitive Networking – 802.1 CM Frame Preemption/Interspersing Express Traffic

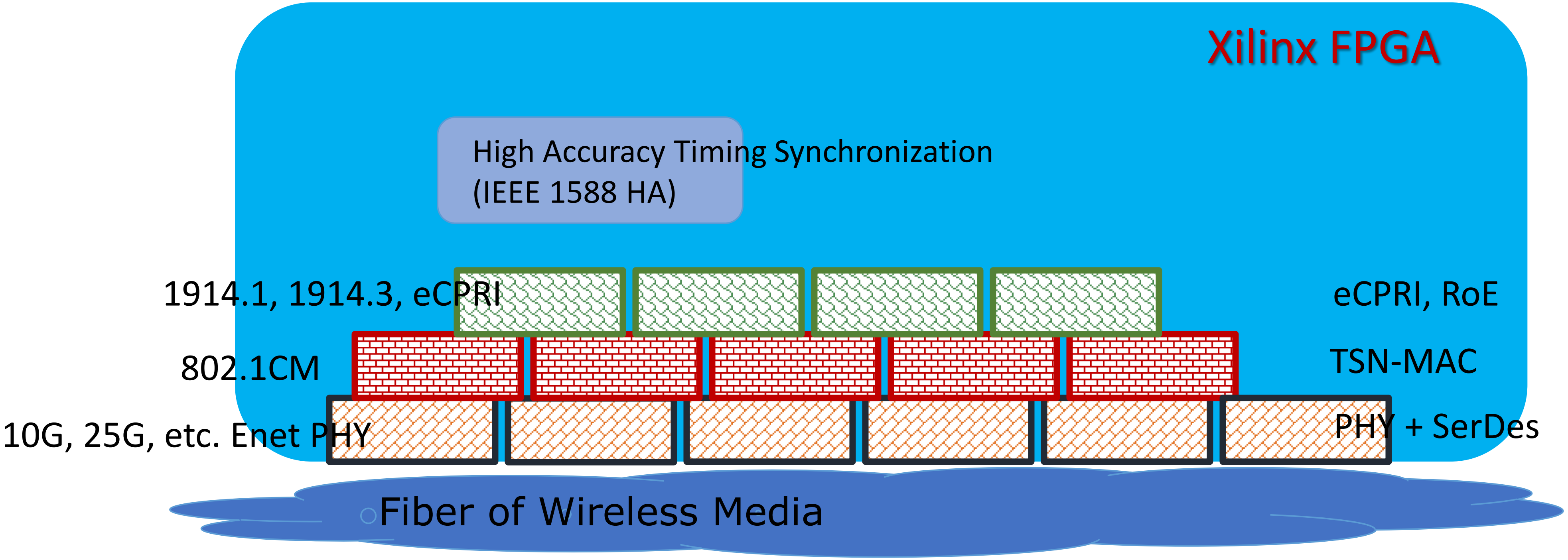
- Time-critical frames can suspend the transmission of non-time-critical frames.
- Specified by
  - 802.3br (Interspersing Express Traffic – (IET))
  - 802.1Qbu (Frame Preemption)
- Minimum fragment size if 64 bytes
- 802.1Qbu makes the adjustments needed in 802.1Q in order to support 802.3br such as assign a status for frame preemption, ex. Express or preemptable.



Source: Intro to IEEE 802.1CM by Janos Farkas

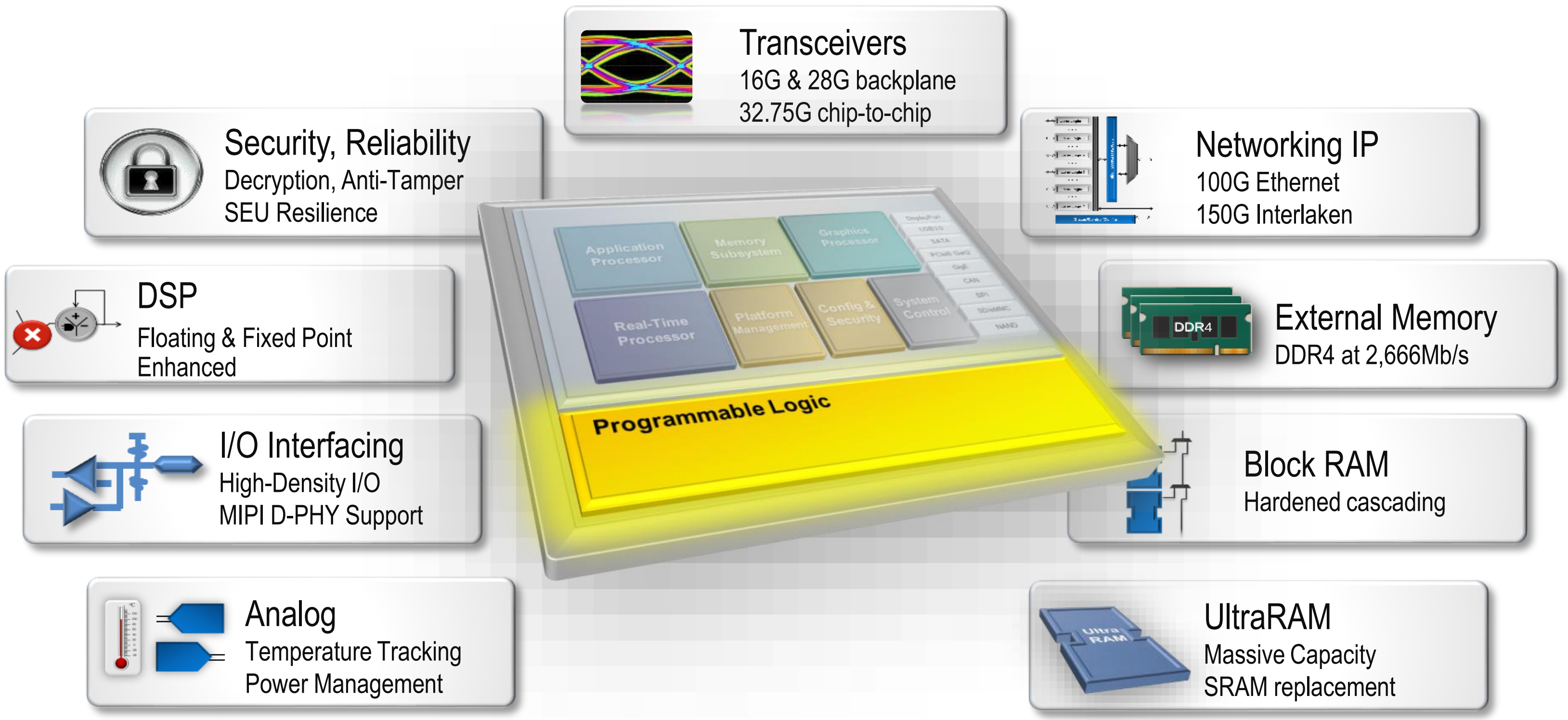
Bricks That Comprise The Transport Interface

- ➢What are the underlying technologies related to packet based fronthaul?



FPGAs for Fronthauling

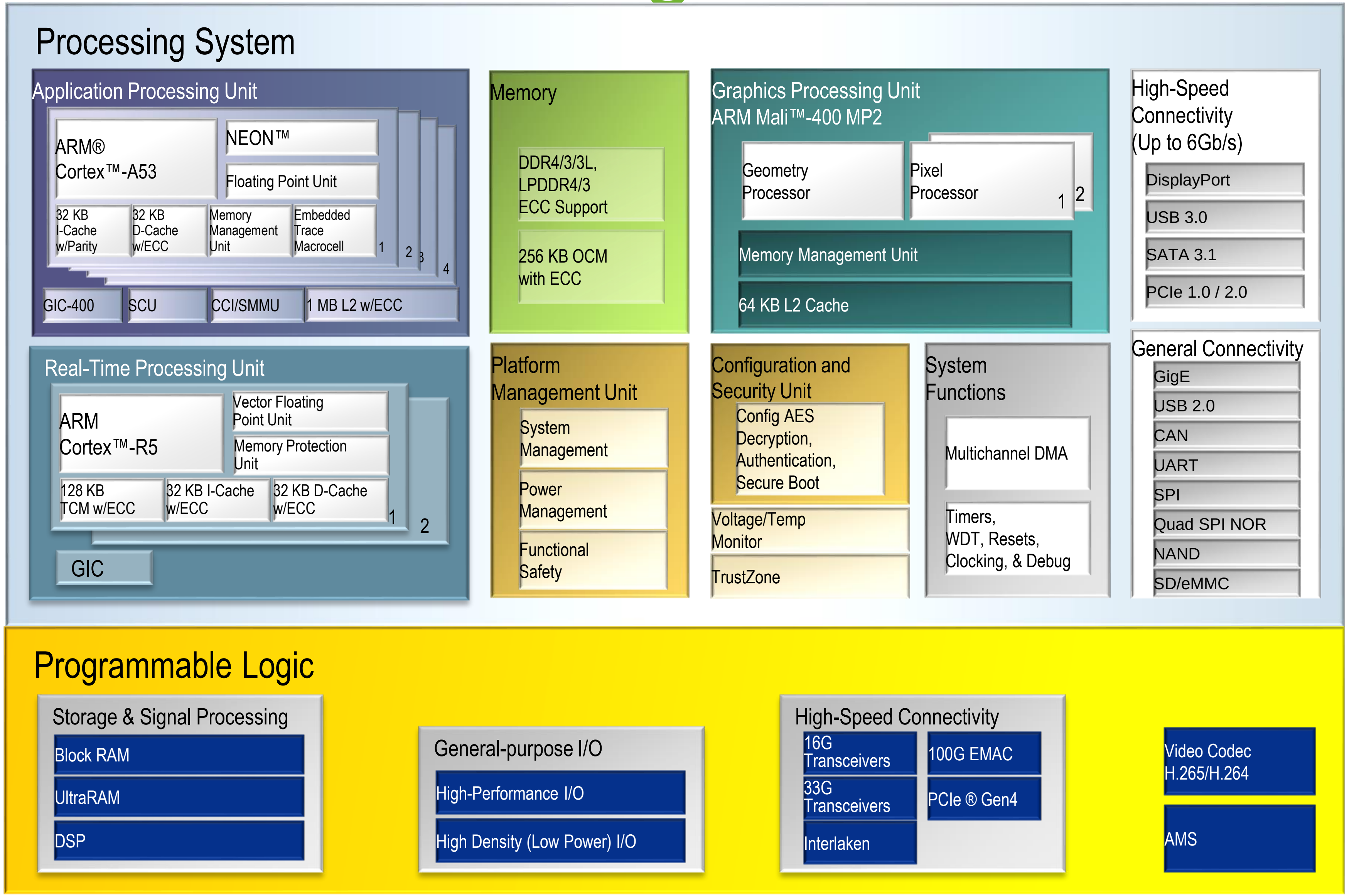
Xilinx UltraScale+™ Programmable Logic



The right resource mix for developing Fronthaul systems

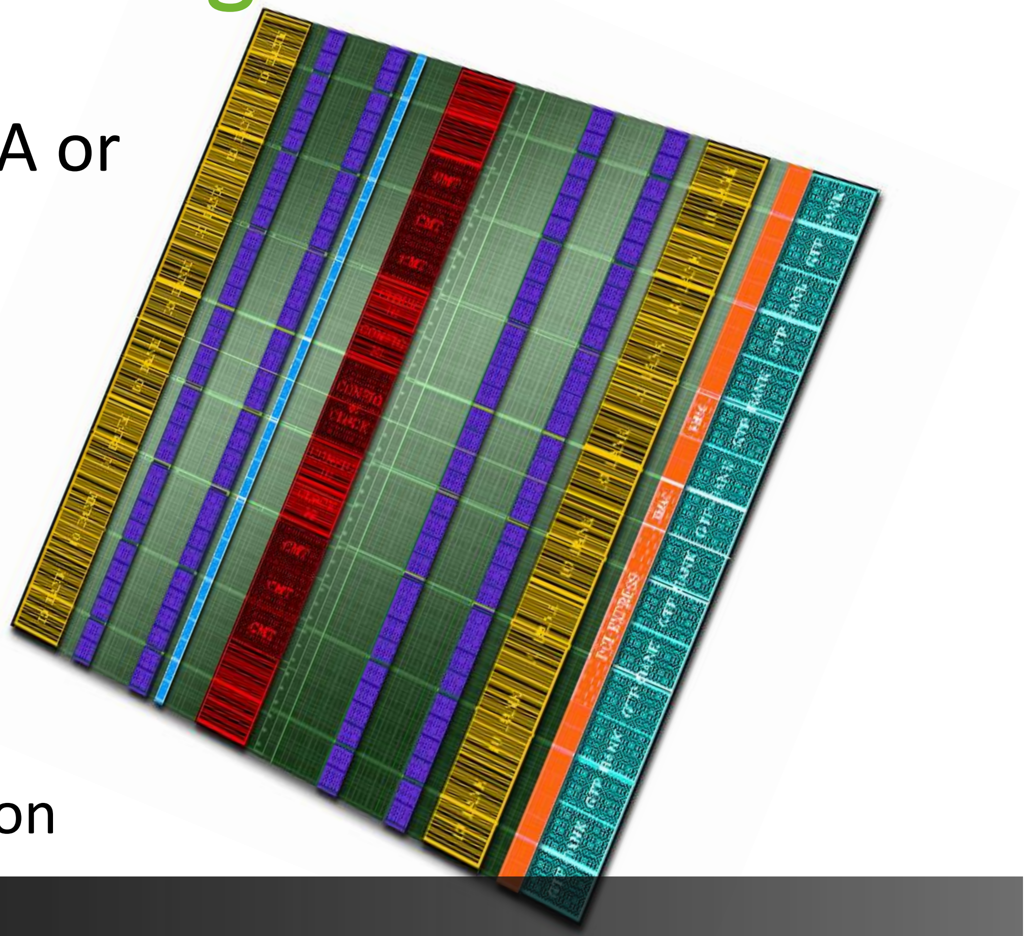
- Efficient Fabric Resources for Fronthaul Switches and protocol processing
- Networking IP for Backhaul and Packet based front haul
- High Quality High Speed Transceivers
- High-Performance Block Memory

Zynq UltraScale+ Block Diagram



Logic Architecture is the Foundation of Programmable Logic Devices

- It defines the overall effectiveness of the FPGA or MPSoC
  - Defines performance
  - Defines density
  - Defines productivity
- Users always demand
  - More performance
  - Higher logic capacity
  - Lower power consumption

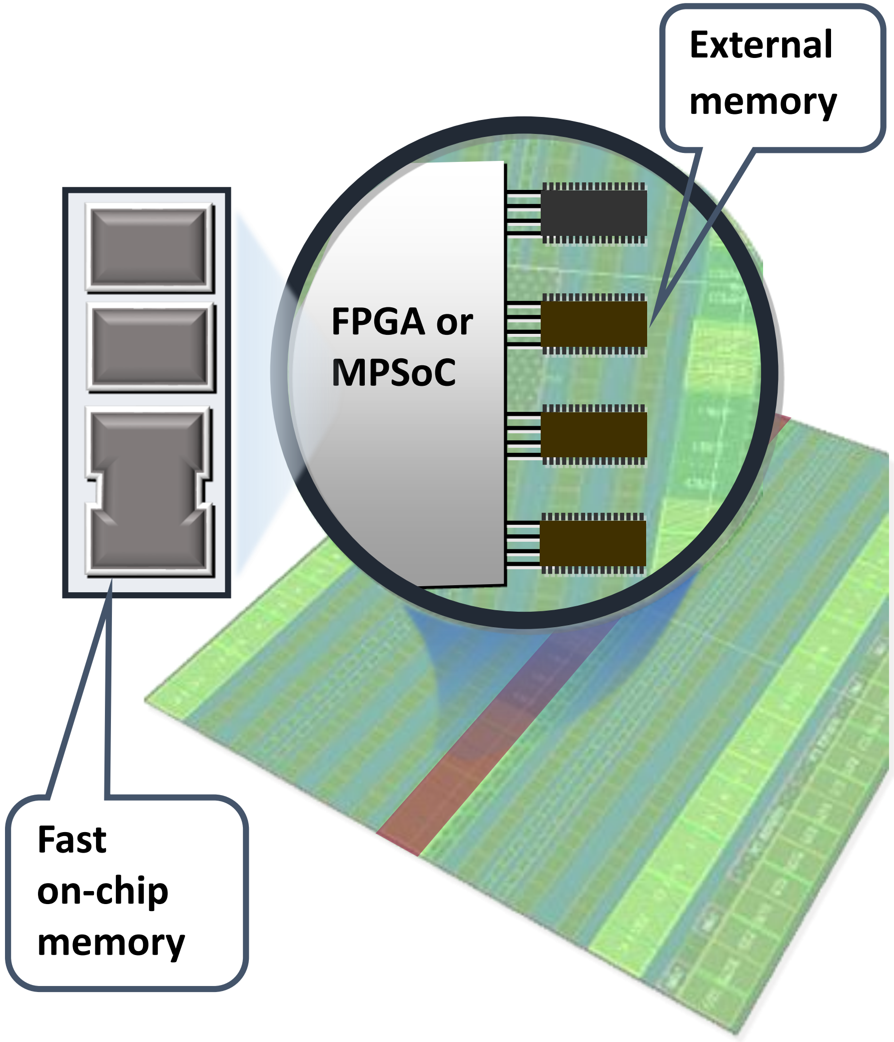


Programmable System Integration

- Meeting Users’ Demands on Logic Capacity and Performance

Every Design Uses Memory

- On-chip memory for:
  - Local data/coefficient storage
  - Shift registers
  - State machines
  - Data buffering
  - FIFO
- On chip memory must be fast and flexible
- External memory for larger data storage
  - Must support evolving standards

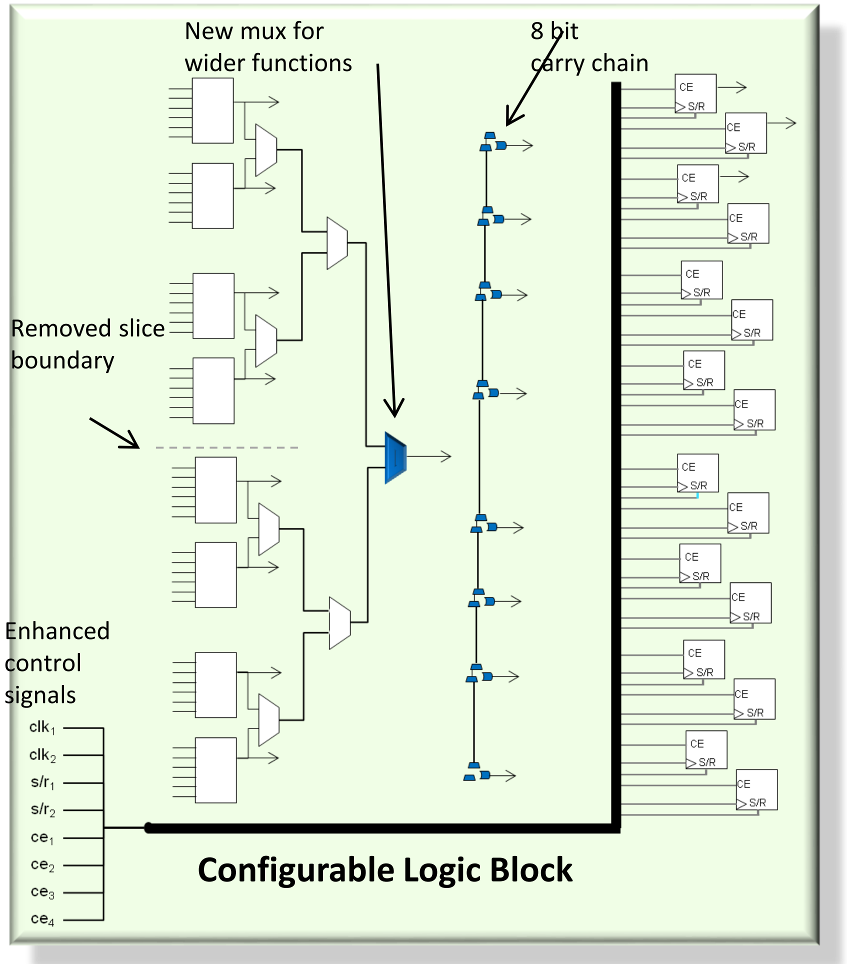


$ BOM Cost Reduction

- Integration of High-Performance Block Memory

UltraScale Architecture CLB
Enhanced Device Packing & Utilization

- Removed slice boundaries
- Wider function in single level
- Extends carry chain to 8 bit
- Improved routing directly to FF
- Enhanced control signals
  - Doubled CEs
  - Added S/R and CE ignore
    - 4 FF granularity
  - Added Reset inversion
    - 8 FF granularity

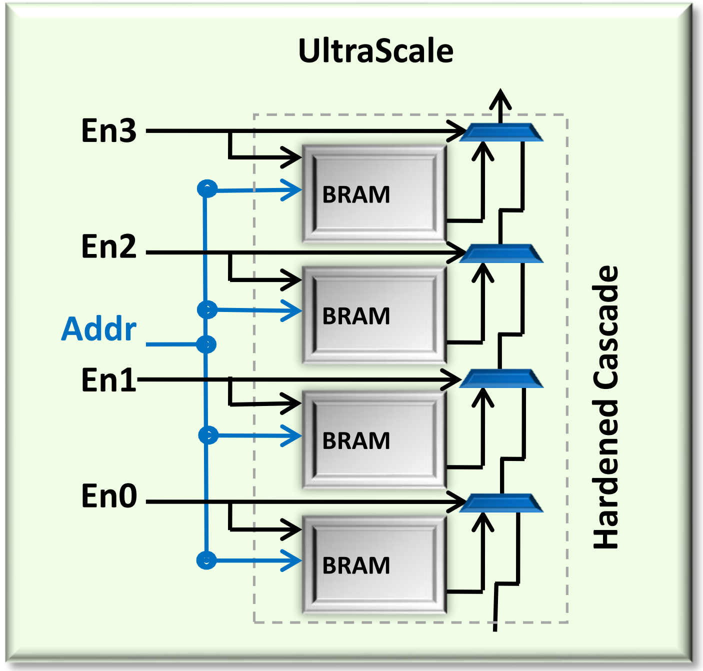


Accelerated Design Productivity

- CLB Enhancements Greatly Increase Resource Utilization

UltraScale Architecture Block RAM Enhancements

- Performance increase to alleviate bottleneck for many applications
  - 737Mhz in -2 speed grade
- Built-in high speed memory cascading
  - Build larger RAMs, deeper FIFOs
  - Spans up to 12 block RAMs
  - Eliminate CLB usage while reducing routing congestion and power
- Enhanced FIFO to match soft FIFO
  - Synchronous & Asynchronous Mode
  - Asymmetric read and write port widths
- New block level power saving modes
- Key for memory buffering applications, e.g., wireless, imaging

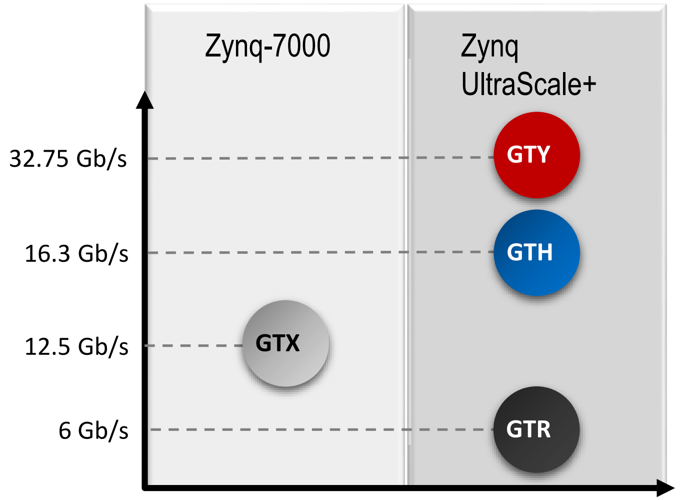


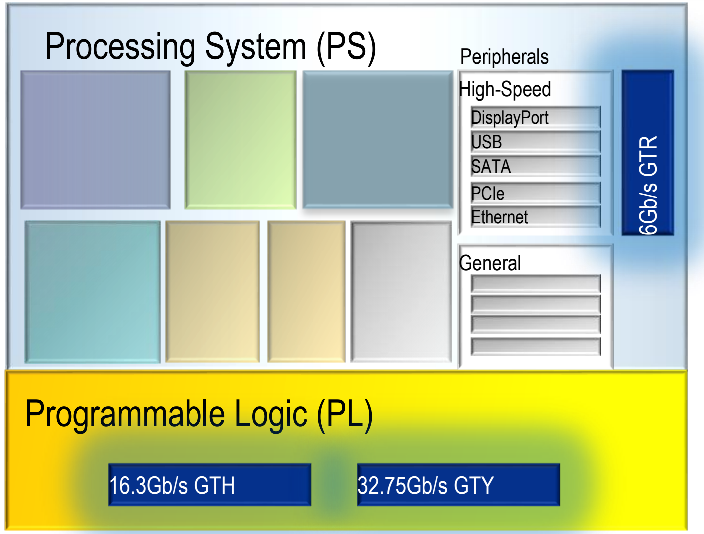
Unique feature of Xilinx FPGAs

- BRAM cascades can be used instead of CLB LUTs for MUX logic saving area and power.

Transceiver Portfolio in Zynq UltraScale+

Feature	Benefit
6G (GTR) Transceivers	• Integrated in Processing System for direct access to key processing elements • Full PHY/IP compliance for key protocols: USB, SATA, DisplayPort, PCIe, Ethernet
16G (GTH) Transceivers	• 16G backplane support, industry leading auto-adaptive equalization • Enables PCIe Gen4 (16G), JESD204B (12.5G), CPRI (16.3G), Serial Memory (HMC & MoSys) • Fractional PLL for multiple non-integer line rates and fabric clocks (eliminates clock components)
33G (GTY) Transceivers	• 28Gb/s (CEI-25G-LR) backplane support for Nx100G to 400G systems • Support for Interlaken, OTU4 over CFP4, 802.3bj (28G Ethernet backplane) • Equivalent fractional PLL functionality as GTH transceivers





Delivering Customer Value with UltraScale Architecture

Programmable System Integration	▪ Meeting Users' Demands on Logic Capacity and Performance ▪ Flexible, Efficient Implementation of Common Memory Functions ▪ Vast Quantity of Flexible, On-Chip Block Memory ▪ Built-In Memory Error Checking and Correction
Increased System Performance	▪ Dramatically Increase On-Chip Processing Bandwidth ▪ Exceed Next Generation Fabric Performance Demands ▪ Higher Performance and Capability Block Memory Where Required
BOM Cost Reduction	▪ Integration of High-Performance Block Memory
Total Power Reduction	▪ Enhanced Power Reduction Modes in UltraScale Architecture BRAM
Accelerated Design Productivity	▪ CLB Enhancements Greatly Increase Resource Utilization ▪ Memory Features & Complexity Optimized for Market Requirements

UltraScale+™ Portfolio Applications

KINTEX UltraSCALE+ | VIRTEX UltraSCALE+


1 Terabyte OTN Switching


800G MAC-Interlaken Bridge


800G Data Center Interconnect


Mobile Backhaul - 1 GHz eBand Modem & Packet Processing


Mobile Backhaul - 112 MHz PtP MWR Modem & Packet Processing


Test & Measurement Instrumentation


24-Channel Radar (Beamformer + Pulse Compressor + Doppler Filter)

ZYNQ UltraSCALE+


8x8 100 MHz LTE Remote Radio Head


Dual-Channel Battery-Powered Public Safety & Military Mobile Radios


Camera-Based Automotive Driver's Assist Systems (ADAS)


4K Broadcast Cameras


Solid State Drives (SSDs) for Data Center

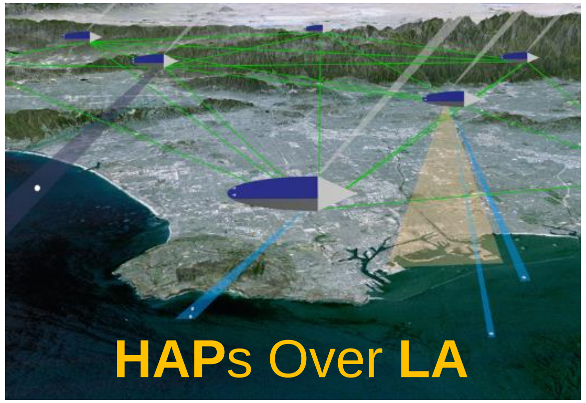

Video Conferencing


High-Performance Scalable Programmable Logic Controllers (PLCs)

Outline

- Introduction and Outline
- Business Drivers
- Network Architecture Evolution
- ➔ Practical Deployment Considerations
- Security Considerations
- IP & Design Considerations
- Q&A

INDUSTRY AGENDA – Practical Pre-5G Deployment



- **Practical Reality**:
  - Is **R&D** Money in the Bank?
  - lowest **Risk** & fastest path to a healthy **ROI**
  - What is **5G-Ready** and what does it mean?
  - Common Public Radio Interface does Ethernet; **eCPRI**
- **Transport** Evolution or ***Revolution***?
  - 5G Crosshaul for 4G LTE Advanced Pro?
  - eCPRI absorbs Midhaul; Small-cell & WLAN CoMP?
  - CPRI Legacy Requirements; cost of timing and optics
- What other ***surprises*** come with **5G?**
  - **M-CORD;** when, if, else, what? NVF and SDN **= Yes!**
  - **Gaps, Haps,** and 'how to do it right the first time *so you don't have to do again'!*

Discussions Continue on ***Brax.Me***

PREFACE: Reality Impact

#1 – **USA Ranks 55th in terms of LTE 4G download speeds**

- *Report from OpenSignal compared LTE speeds and coverage around the world!*

See

https://**opensignal.com**/reports/2016/11/state-of-lte#speed

Telecom R&D Spending?

Pretty close to China except US doesn't manufacture Telecom equipment

- *2005: Spends 8% of Revenue*
- *NA (US) < **$2B** for **11** years*
- *Europe (EU) > **$6B in 7 of 11** years*

See
http://www.strategyand.pwc.com/global/home/what-we-think/innovation1000/rd-intensity-vs-spend-2016

Into the Top 10 in 2018?

See
https://**opensignal.com**/reports/2016/11/state-of-lte#speed

The Three R's: R&D, Risk, and ROI, as in when?

ONE: US Telecom **R&D** spending increases 3-fold over 2015 level to $6B

- This brings us close to what the EU Spent. But is it enough?

TWO: Respect the **RISK** in mixing 5G Technology

- Biggest Risk = 5G's *Byzantine* complexity
- *Solution:* adopt new community-based methodologies

THREE: Maximize **ROI** *everywhere*

- 4.9G Revenue trumps 5G Tech!

5G Technology's expansive scope has reached Byzantine complexity levels Internationally!

GHB Intellect
Unparalleled Expertise | Unprecedented Service

Essential **e2e5G.Tech** *based on LTE Advanced PRO*

Dramatic Increase in R&D Funding Expands 5G Dev Opportunity

Increased availability of R&D funding expands US 5G Developer Opportunity

- **2017** will see a dramatic increase in US (Telecom) R&D spending
  - Telecom R&D spending traditionally *skewed to Europe and Japan*
  - **Softbank:** $50B Sprint Investment, **ARM** Holdings for $32B, etc.
  - Repatriated Tech Company Foreign Earnings: anyone's guess? ++
- US Government gets 5G Smart (How smart? TBD, *but we can help.*)
  - Established Programs Expand in 2017: NITRD (next), DARPA, ITIF, etc.
  - The US Congress' bill, the ***Developing Innovation and Growing the Internet of Things (DIGIT) Act*** aims to ensure appropriate spectrum planning and interagency coordination for the 5G Internet of Things (IoT).
  - Government can do more to help smaller companies

NITRD Likely Plays a Key Role with 5G Technology in 2017

Networking and Information Technology Research and Development (NITRD) Program

"NITRD is our Nation's primary source of federally funded work on advanced information technologies (IT) in computing, networking, and software. The multiagency NITRD Program seeks to provide the research and development (R&D) foundations for assuring continued U.S. technological leadership and meeting the needs of the Federal Government for advanced information technologies."

More... https://www.nitrd.gov/about/about_nitrd.aspx

The right time to get involved in now!

How? Possible to develop 5G Tech Community & encourage participation on ***Brax.Me***!
100% Secure and Anonymous Developer Communities on ***Brax.Me***

5G RISK Mitigation

What is the end-to-end 5G Technology **RISK** and resulting **ROI** challenge?

- Over-the-top byzantine (Extreme) complexity around the world!
  - Risk Mitigation: Focus on ROI by targeting LTE Advanced Pro or 4.7G
- Deeper analysis & Community Engagement is key to successful 5G development
  - Alternative practices and study uncovers telecom industry norms;
    - Reverse Engineering (RE) Can be most revealing
    - Brax.ME 5G Tech Community is key example of alternative practices & study
- RE accelerates R&D/product development analysis
  - Avoid costly mistakes! Better understanding of 5G Extreme (Byzantine) Complexity
  - **Alt Practices Minimize Risk** and **Maximize ROI success!**

5G Risk: Extreme Complexity

*Beyond **Byzantine** given 5G's Goals, Expectations, and Reality*

Massive Complexities
Architectures,
HW/SW/System Dev,
Unknown System/Subsystem
Test Validation Requirements

New Apps & Use Cases
New Markets
New Technology
New Radios/Spectrum
Unknown Gaps
Cost sensitive markets

Forced Failure Testing!
Test Coverage 99.999% (?)

5G Design Challenge: Cost-Related Risk and ROI

Brax.Me Communities can provide essential information on

What? **COST**
Who? **Consumer 1st**
When? **2024 to 2025?**
Where? **Balanced $/Benefit**

	4.7G / 4.8G / 4.9G	5G+4.9G / 5G-Only
What →	LTE Advanced Pro favors Incumbent OEMs	**High R&D Cost** carried by existing **4G customers**
Who →	MNOs cater to **cost-sensitive markets**	**Emerging markets** with **free-for-all** competition!
When →	**4.9G** by **2020** +7 year equipment service life	**5G New Radio (NR) Trials** by **2020** continuing to **2024**
Where →	Population dense areas given priority	Markets where **LTE/WiFi** doesn't meet BW Demands

- Existing Mobile/Network Infrastructure changes SLOWLY and…
- Wired-/Wireless-markets transformed by end-2-end 5G Technology
- New Vertical 4.9G/5G Markets untested and unproven at best!

Pre-5G Systems: *5G-Ready* Hardware Now Shipping

What allows existing HW to actually be **5G-Ready**? Use of RE might be only way to find out.

❶ **Radio System Architectures (RSA)**

❷ **eNB** Detailed Architectural Overview

❸ **eNB** Powered Operation w/Software

❹ **ASIC, Module, and Sub-Module Detail**
Voltage Scaling, Clock Distro, Performance Scalability

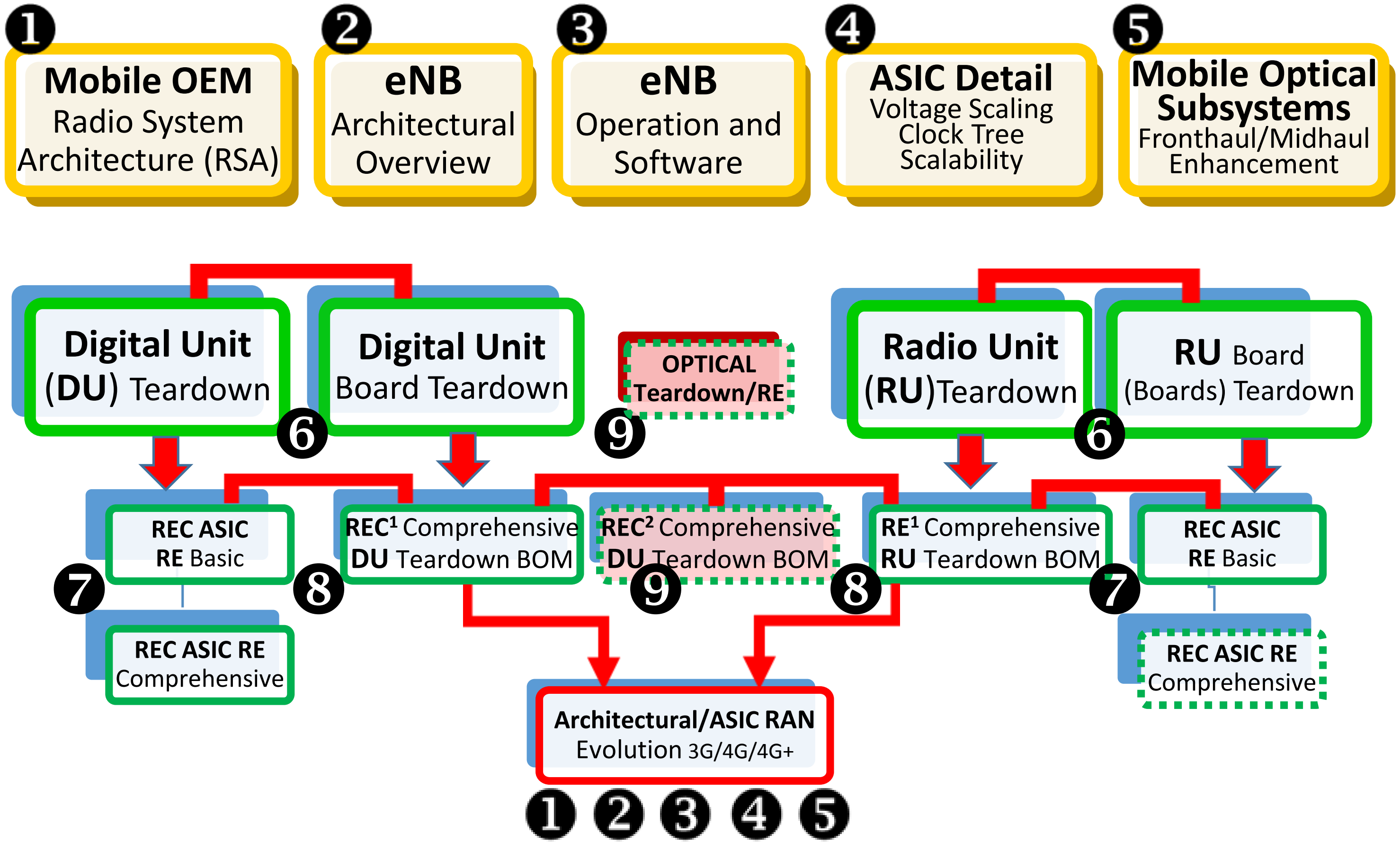
❺ **Mobile Optical Subsystems**
Fronthaul/Midhaul Enhancement

❻ **Unit, Board, and Module Teardowns**

❼ **Chip, ASIC, and Package**
Reverse Engineering (RE) Discovery: protocols & IP

❽ **Digital Unit (DU) / Radio Unit (RU)**
Radio Equipment Controller (REC) &
Radio Equipment (RE) Analysis

❾ **Optical Fronthaul/Midhaul Analysis**



Pre-5G Systems: *5G-Ready* Hardware Now Shipping

❶ **Radio System Architectures (RSA)**

❷ **eNB** Radio Equipment Controller (REC)
to Radio Equipment (RE)

❸ ➔ **REC**[1] = eNB Core

❹ ➔ **REC**[2] = Fronthaul Network Controller

❺ ➔ **RE**[1] = LTE Advanced Pro Radios

❻ ➔ **RE**[2] = New WLAN/Small Cell Radios

❼ **eNB OEMs**

Pre-5G Systems: *5G-Ready* Hardware Now Shipping

❶ **Radio System Architectures (RSA)**

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❺ ➔ **RE[1]** = LTE Advanced Pro Radios

❻ ➔ **RE[2]** = New WLAN/Small Cell Radios

❼ **eNB OEMs**

- Nokia (ALU)
- Huawei
- Ericsson
- Samsung, ZTW, and others

Continuing Evolution of LTE Advanced Pro

What does ***5G Ready*** mean?

✓New Radio Architectures

✓Control/User Plane Separation (**CUPS**)

✓New Radio (**NR**) frequencies

- 28 GHz + +

✓Ethernet Common Public Radio Interface (eCPRI) already supported

- ? HW already supports 5G Crosshaul Multi-layer Switch? Packet Muxing?
- Multistandard, Multiband, Multilayer

✓WLAN interworking supports split-bearer architecture for Dual Connectivity

Continuing Evolution of LTE Advanced Pro

Design Target 2020 = LTE Advanced Pro

Main ***ROI***
Source until
2024

Pre-5G Radios / RANs

Pseudo-5G NR

- Technically a “Pre-5G” New Radio due to future 5G >6 GHz targets
- WiGig Spec; IEEE 802.11ad & IEEE 802.15.3c
- AP Coordination w/4G LTE RAN

4G/5G Prototype RAN

- Spectrum based on anticipated 5G Phase 1 Release 15 requirements
- May include ‘5G Light’ aka WiGig or 802.11ad APs.

Central Office Re-architected as a Datacenter (**CORD**) Slower Migration to Mobile (**M-CORD**)

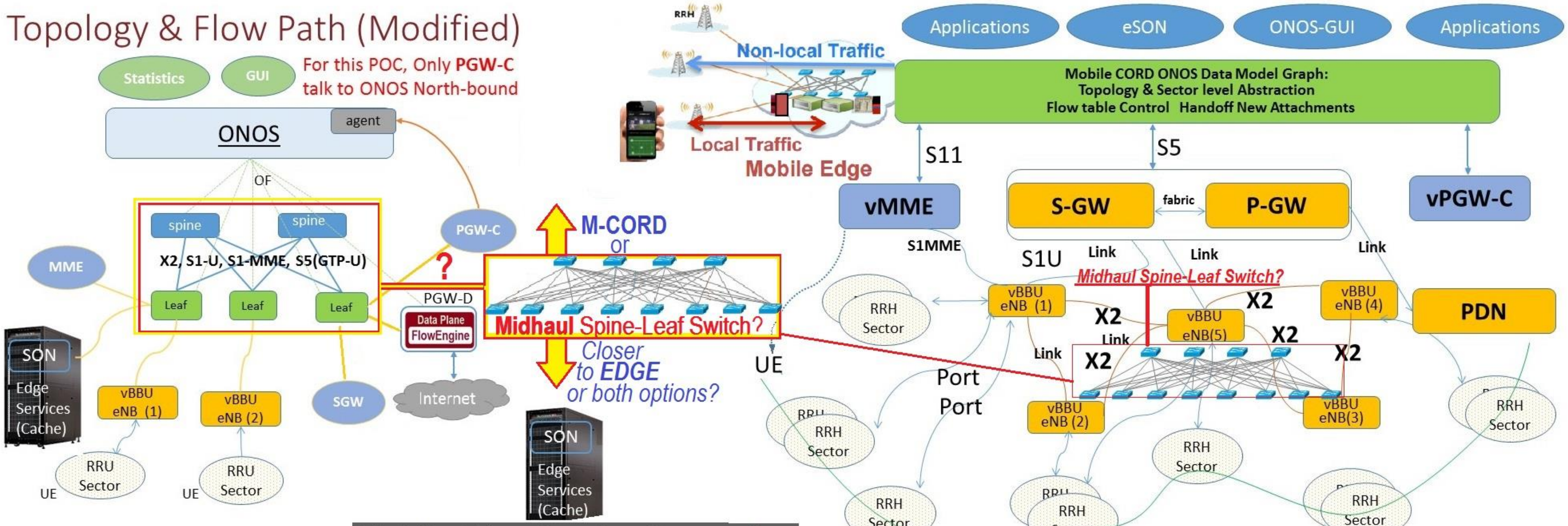
Mobile Infrastructure Equipment

- Black Box Traditional ← Incumbent OEMs
  - **Proprietary** Software
  - **Proprietary** Hardware (>ASIC Cost)
  - **Long** Equipment Life-Cycle
    - Trial Qualification - >2 years
    - CAPEX / OPEX Revenue Driven +ROI
- Grey Box Traditional
  - **Proprietary** Source Software
  - Bare Metal Hardware
  - Longer State-of-Art Life-Cycle
- White Box Traditional
  - **OPEN** Source Software
  - Bare Metal Hardware
  - Short State-of-Art Life-Cycle

CORD Going Mobile (**M-CORD**) < Cost / > Revenue

The Start/Stop in Re-Architecting Mobile Infrastructure Equipment

- White Box **Wish** 🡐 Grey Box in the **middle** 🡒 Black Box **Reality**



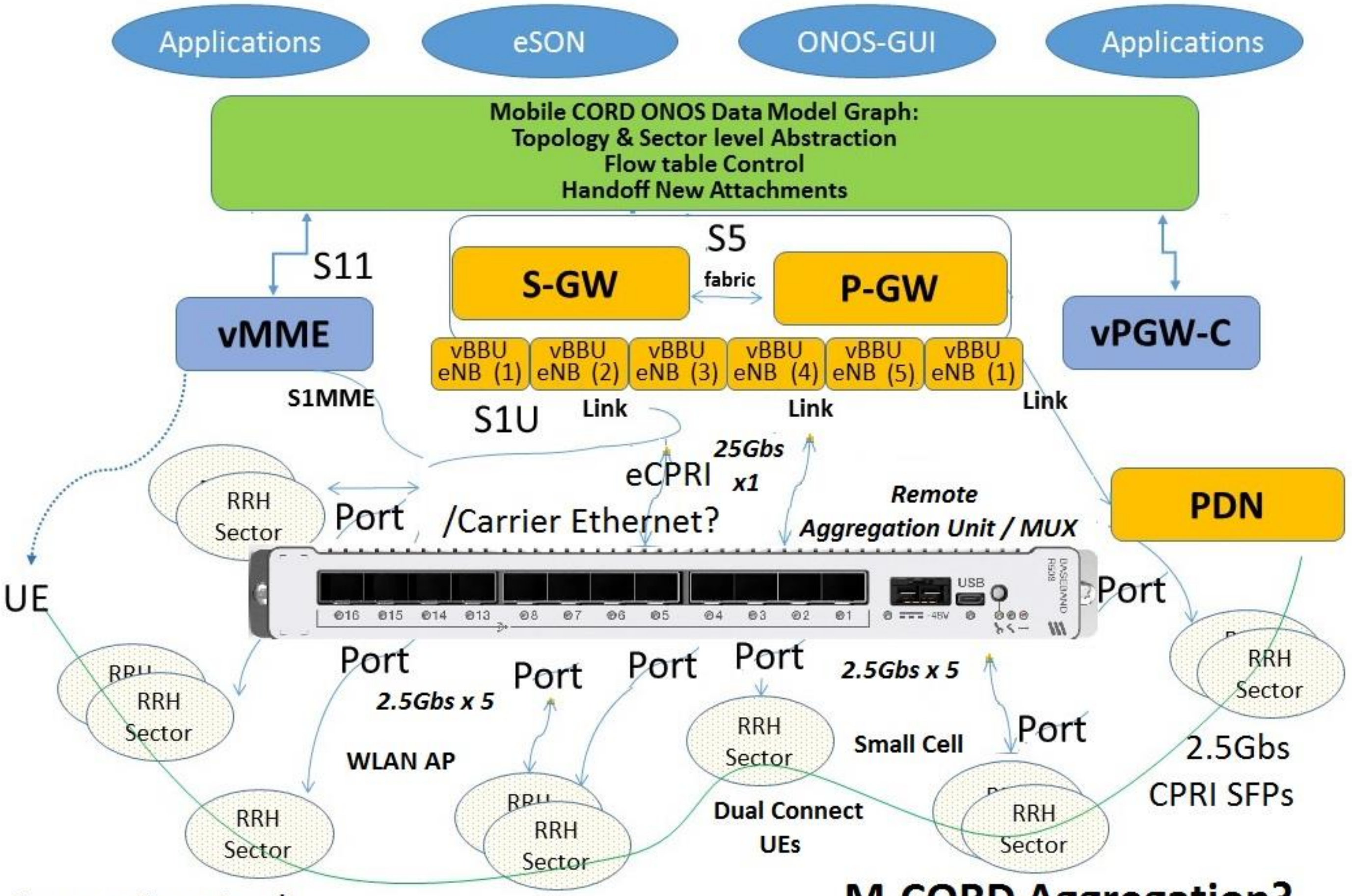
Source: http://opencord.org/

Mobile Edge Service Processing

CORD Going Mobile (M-CORD) < Cost / > Revenue

Hybrid eCPRI-Enabled Mobile Equipment Infrastructure Configurations?

- Traditional Black Box Approach
- Based on already shipping 5G Ready Hardware
- eCPRI enabled Ethernet?
  - Extended Temp Range SFPs
  - 25 Gbps eCPRI Data rates w/
  - eCPRI L1 Functional Splits



Source: OpenCord

M-CORD Aggregation?

Virtualized Baseband Unit Comparisons

M-CORD vBBU RAN Configurations

- 24-core Intel x86, 48 core ARM
- Commodity Servers vBBU
  - Viable with new eCPRI split option**?**
  - Unproven Technology
  - Considerable Cost:
    - Fork-lift Upgrade, New Racks
  - Capacity/Subscriber PoC limitation:
    - 16 UEs per RRH=338 connected users

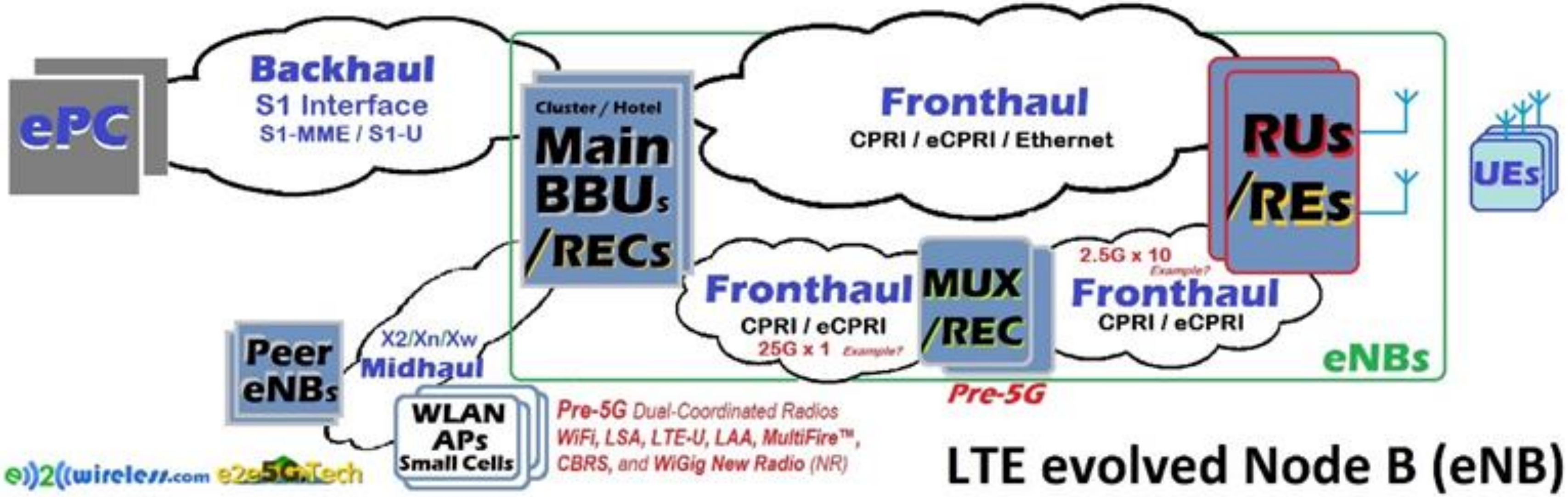
Source: https://Opencord.org

Typical 4G LTE Advanced Pro BBU RAN

- 16 Cortex R8 ARM + Quad CPU
  - Remote Radio Unit, a 2x5MW microcell and a new 256 core baseband unit that can control up to 24 macro radios, with
  - 960MHz antenna bandwidth."
- Custom ASIC-based Architecture
  - Proven 3G and 4G LTE Technology
  - Incremental Upgrade(s)
  - Baseband 5216:
    - **80,000** Subscribers per BBU
    - **8K** connected users 330 UEs per Cell

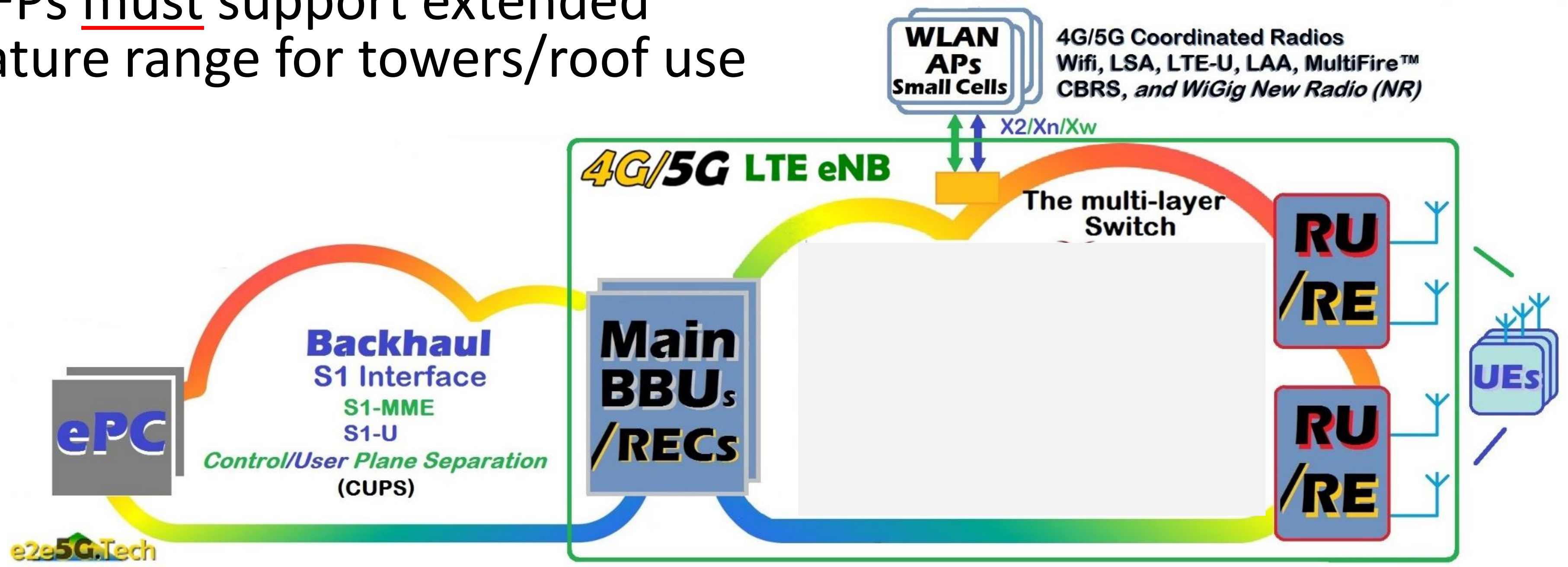
Incremental Fronthaul/Midhaul Transport Upgrade

- **4G** Backhaul = 10GbE | **5G** = 100-400GbE, recommend **<5ms Latency.**
- **CPRI** Fronthaul = 2.5G to 10G with <150ms Latency
- **eCPRI** Fronthaul = 2.5G to 25G+ Ethernet with <25ms Latency
- The fact current shipping hardware is "**5G Ready**" says a lot!



~~Incremental~~ Fronthaul/Midhaul *5G Crosshaul based*?

- **5G** Backhaul = 100-400GbE, recommend **<5ms Latency.**
- **eCPRI** Fronthaul + Midhaul (<5ms recommended) 2.5G to 25G+ Ethernet with <25ms Latency (Ericsson Baseband 5216 /R503 likely supports Xhaul?)
- **eCPRI** SFPs must support extended temperature range for towers/roof use

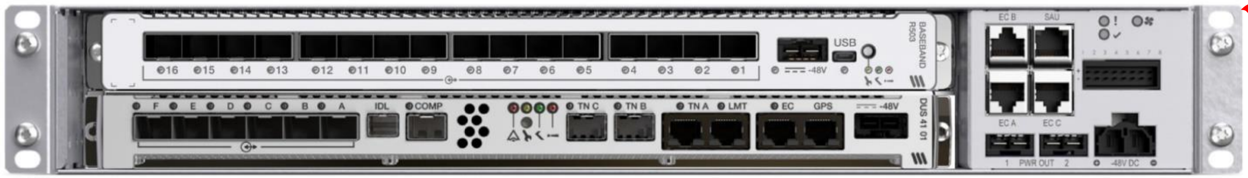


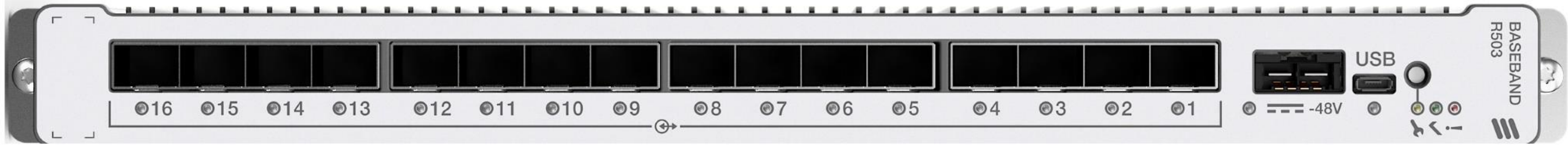
Easier eCPRI Fronthaul Optical Networks

Ericsson Baseband REC & RE Products

Baseband 5212/5216

Baseband R503 and T503





BASEBAND 5216

- **LTE (FDD & TDD supported)**
  - 8000 connected users
  - 1.2 Gbps Downlink & 600 Mbps Uplink
  - Up to 24 cells & 960 MHz antenna bandwidth
- **WCDMA**
  - 1152 CE Downlink & 1920 CE Uplink
  - 336 Mbps Downlink & 168 Mbps Uplink
  - Up to 24 cell carriers
- **GSM**
  - Up to 24 TRX in a mixed mode configuration

Supports 80,000 Subscribers

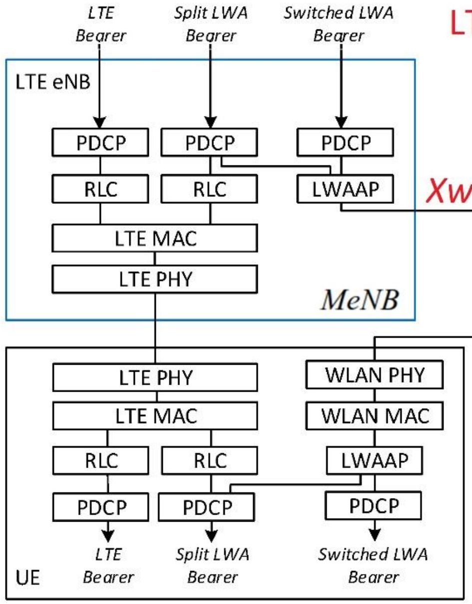
✓ Supports Multi-level Fronthaul Switching

✓ eCPRI Capable*

*eCPRI capability determination based on a number of technical factors and 5G ready hardware disclosures.

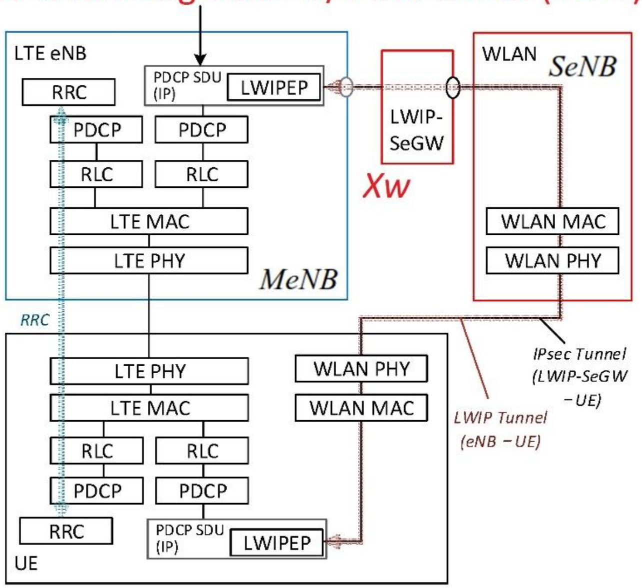
Midhaul/Fronthaul Coordination Testing 2017

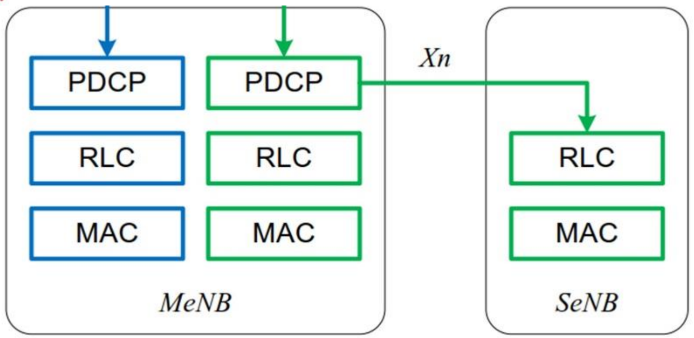
- **Midhaul** w/Xn = 10GbE
  - Testing X2, Xn, and Xw
- **Fronthaul**
  - Tight or *Very Tight Coordination?*
- **Ethernet Fronthaul + Midhaul** ≈ 5G Crosshaul?



LTE-WLAN aggregation (LWA)

LTE-WLAN radio level integration w/IPsec tunnel (LWIP)





Dual connectivity split-bearer architecture.

Two Perspectives on Mobile Fronthaul Networks

Mobile Network Operators (MNOs)
Multi-Vendor Mobile Net (MvNOs)

- Lowest CAPEX/OPEX Rant
  - Software Defined Radio (SDR) separation increases competition
  - Open Ethernet Can Retire CPRI
- CPRI over Ethernet can work
  - Yes. It takes time and lots of change
  - NGFI (Next Gen Fronthaul Interface) Subservient to CPRI
  - CPRI key to IEEE P1914 & 802.1CM

Top 5 OEMs set Trends & Direction with
Common Public Radio Interface (CPRI)

- Committed To Proven Technology
  - Proprietary Digital Control to RF Linkage is the essential QoS KPI
  - CPRI v7.0 25G Surprise (2015)
- CPRI.org Cooperative drives reality
  - eCPRI could be Proven Technology✓
  - Likely defines 5G L1 processing splits
  - Already meets phase, sync & latency timing requirements +necessary QoS

OPEN STANDARDS: Historical Weakness

Open Radio Interface

✓ **Specification Contributor List**

Organisation Name	URL
Alcatel-Lucent	www.alcatel-lucent.fr
AT&T Global Network Services Belgium SPRL	www.att.com
Bell Mobility	www.bell.ca
CATR	www.catr.cn
Deutsche Telekom AG	www.telekom.de
Docomo Communications Laboratories Europe GmbH	www.docomolab-euro.com
E-Blink s.a	www.e-blink.com
ETRI	www.etri.re.kr
France Telecom	www.francetelecom.fr
Freescale Semiconductor SA	www.freescale.com
Fujitsu Laboratories of Europe	www.fujitsu.com/emea
Huawei Technologies Co. Ltd	www.huawei.com
Kathrein-Werke KG	www.kathrein.de
Motorola Ltd	www.motorola.com
Orange	www.orange.com
Rohde Schwarz GmbH	www.rohde-schwarz.com
Samsung Electronics Research Institute	www.samsung.com
Sprint Nextel	www.sprint.com
Telecom Italia S.p.A	www.telecomitalia.it
Vodafone Group Plc	www.vodafone.com
ZTE Corporation	www.zte.com.cn

ORI: Layered requirements extension to Common Public Radio Interface (CPRI)

ETSI, “ETSI ORI (Open Radio Interface)” [Online]

✓ Weak Participation

✓ Missing Keyplayer OEMs

LIST OF PARTICIPANTS

Amphenol Fiber Optics Products	www.amphenol.com
ASOCS Ltd	www.asoctech.com
China Mobile Research Institute	www.chinamobileltd.com
Comcores AsP	www.comcores.com
Integrated Device Technology Canada, Inc (IDT)	www.idt.com
KDDI R&D Laboratories Inc	www.kddilabs.jp
NGMN Ltd	www.ngmn.org
NTT Docomo Japan	www.nttdocomo.co.jp
PMC-Sierra Inc.	www.pmc-sierra.com
Radiocomp ApS	www.radiocomp.com
Reverb Networks Inc.	www.reverbnetworks.com
SK telecom	www.sktelecom.com
Xilinx, Inc.	www.xilinx.com

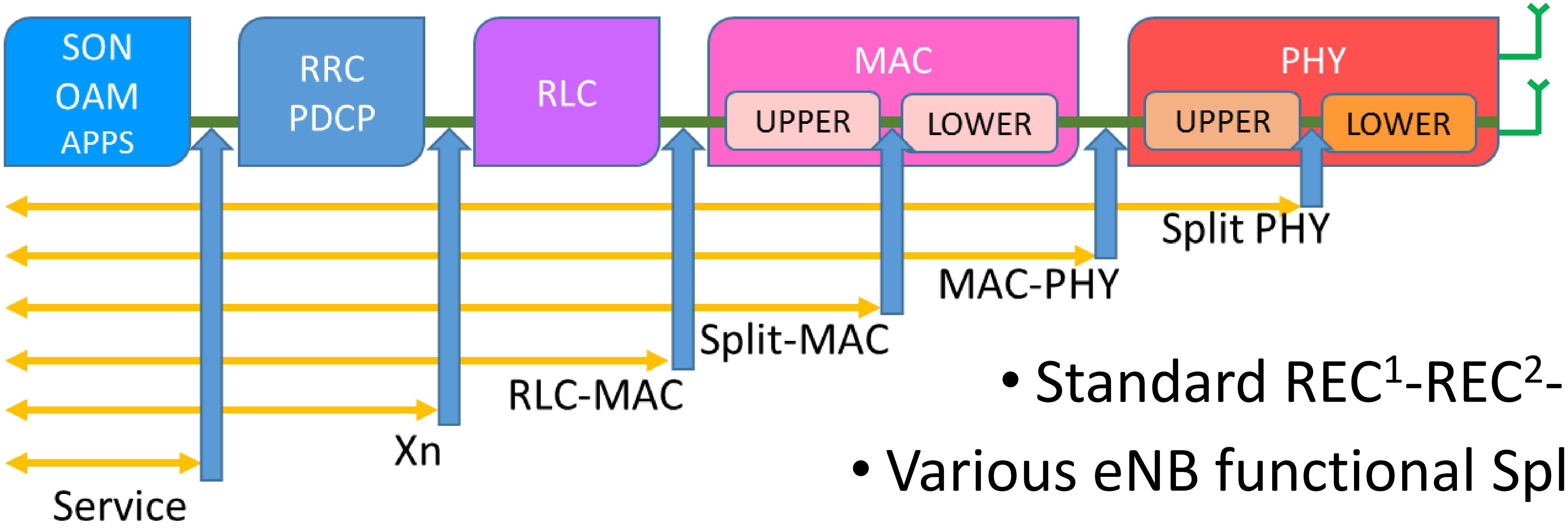
CPRI.Info will release **eCPRI Spec** by **August 2017**

CPRI.Info Publishers: NEC, Nokia (ALU), Ericsson, and Huawei

- The eCPRI specification will be based on new functional partitioning of the cellular base station functions, positioning the split point inside the Physical Layer.
- The target of the eCPRI Specification is to offer several advantages to the base station design:
  - The new split point enables ten-fold reduction of the required bandwidth
  - Required bandwidth can scale flexibly according to the user plane traffic
  - Use of main stream transport technologies like Ethernet will be enabled
  - The new interface is a real time traffic interface enabling use of sophisticated coordination algorithms guaranteeing best possible radio performance
  - The interface is future proof allowing new feature introductions by SW updates in the radio network

P1914 Fronthaul demo by CMRC (China Mobile) used eCPRI not P1914.3 ✓

Common Public Radio Interface (eCPRI) Splits



- Standard REC[1]-REC[2]-RE
- Various eNB functional Splits
- Various Fronthaul/Midhaul Latencies

5G Experimentation: 2017 to 2022

Licensed Spectrum:

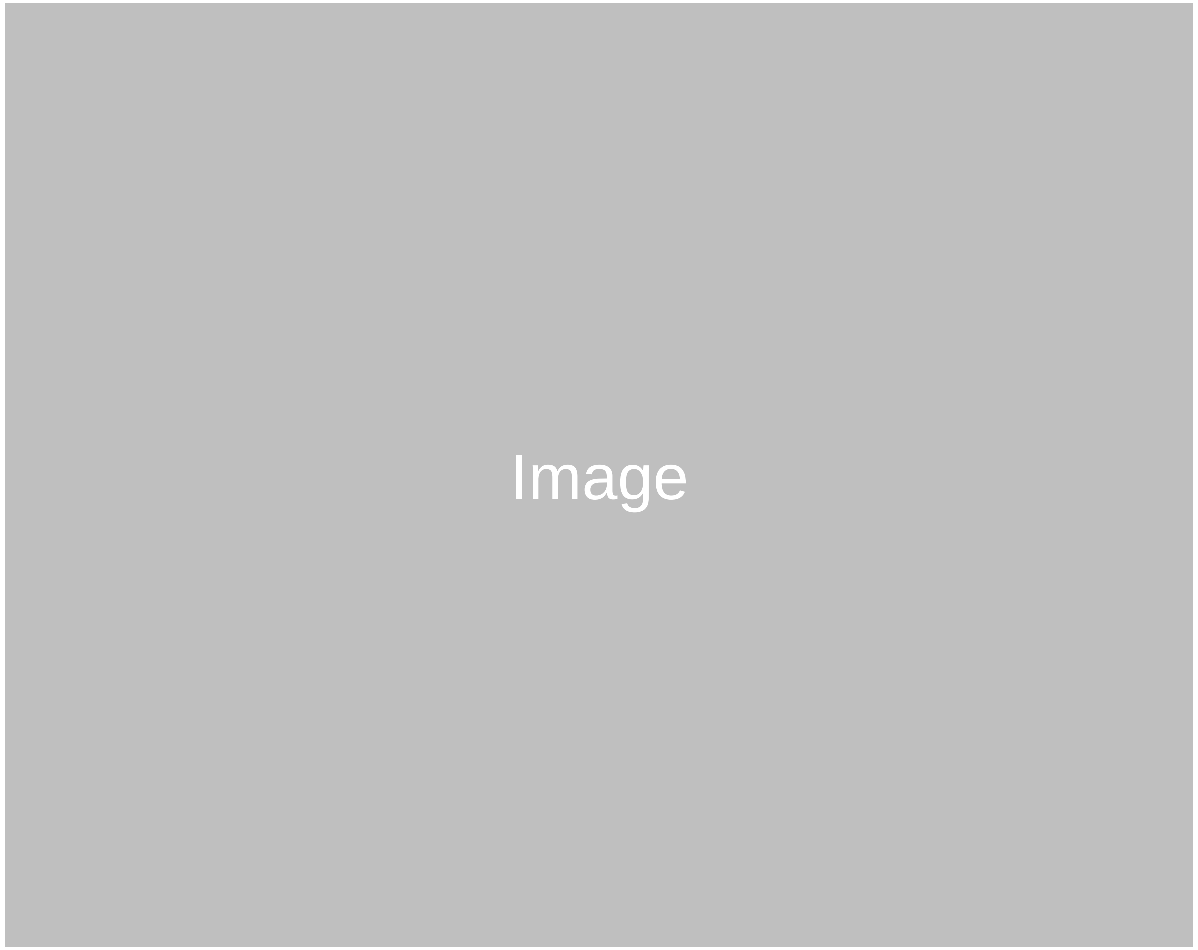
- New Frequencies awaiting World Radio Congress (WRC) 2019
- Global Regulatory Harmonization

Shared Spectrum:

- Shared Spectrum in the LTE, WLAN and other bands.

New Unlicensed Spectrum Use:

- Tightly Coupled and coordinated
- LTE-WLAN radio control.



Evolution of LTE Advance Pro Sets Design Schedule

Commercialized 5G Technology:

- 100% dependent upon LTE Advanced Pro
- Successful deployment of 4.7G, 4.8G, & 4.9G provides essential foundation for 5G!
- Production / Deployment ramps on a fixed schedule.

Pre-5G: Baseband + Radio Units = BBU+RU

- Baseline Requirements
  - Continued Evolution of Stable Radio System Architectures
    - System and Primary Infrastructure Equipment Hardware Typically Fixed
    - Copious Amounts of Software!
      - Continuous Transition on 6 Month Release Schedule
      - ALL SW Undergoes extensive field trials before Release, then Going Live!
  - Continuous Evolution of **LTE Advanced Pro** Software Implementation

3GPP Release Features UE
Lag ~18 months to ∞

5G New Radio (NR) R&D Test: 2017 to 2026

VS.

Nokia AirScale

Ericsson AIR 6468

5G NR R&D efforts start in 2017

Both Nokia and Ericsson's development goal is to apply NR to its Antenna Integrated Radio products (AirScale and AIR).

5G is mainly evolution

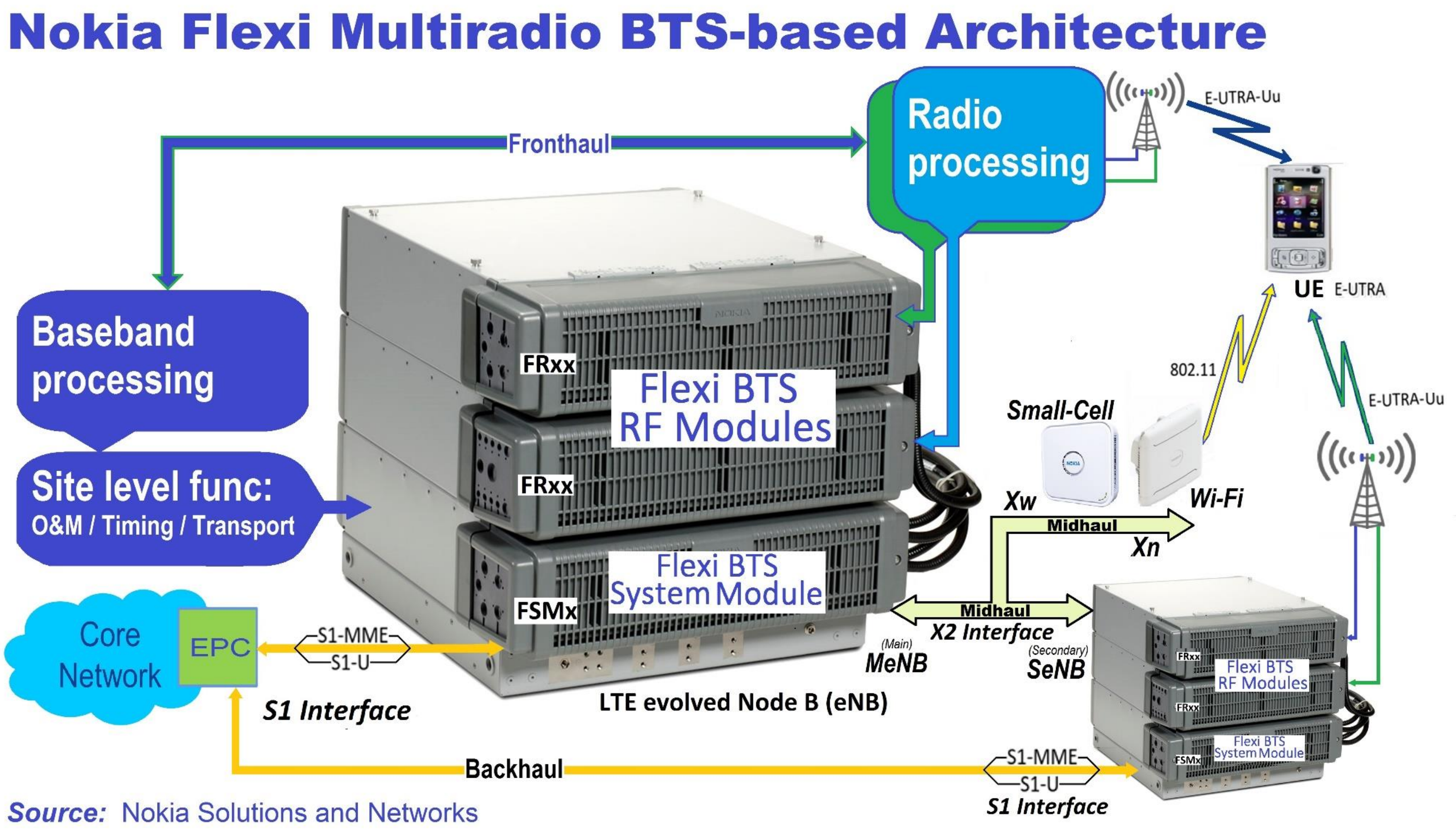
App space Net Society explosion

New architectures

SDR, CR, SDN, NFC

Cognitive Radio (self-aware)

New 4.9G Optical Networks; Fronthaul & Midhaul



Optical Network Technology is essential to the further evolution of LTE Advanced Pro

Antenna Integrated Radio Tech AIR (Ericsson) and AirScale (Nokia)/

M-CORD, GAPS, and HAPS

- M-CORD Support by incumbent RAN OEMs is weak
  - Existing OEMs have an advantage with Antenna Integrated Radio (AIR) technology
  - X86-based servers win if they can deliver the full 5G feature set at a substantially lower cost. We predict this is possible by 2024.
- GAPS

  - Cost: Virtualized Baseband Units (vBBU) w/5G Crosshaul may price them out
  - Complexity: Sophisticated system and package integration complexity requires new 5G radio and subsystem architectures.
  - Security: enhanced threat and/or optically network intrusion detection subsystem capabilities will likely stretch
- Disruptive 5G Technology?

  - High Altitude Platform Station (HAPS)
  - Persistent Aerial Station Technology
  - Highest download capacity to the most customers at the lowest cost; TBD?

What is Near-Space? Antenna Capabilities

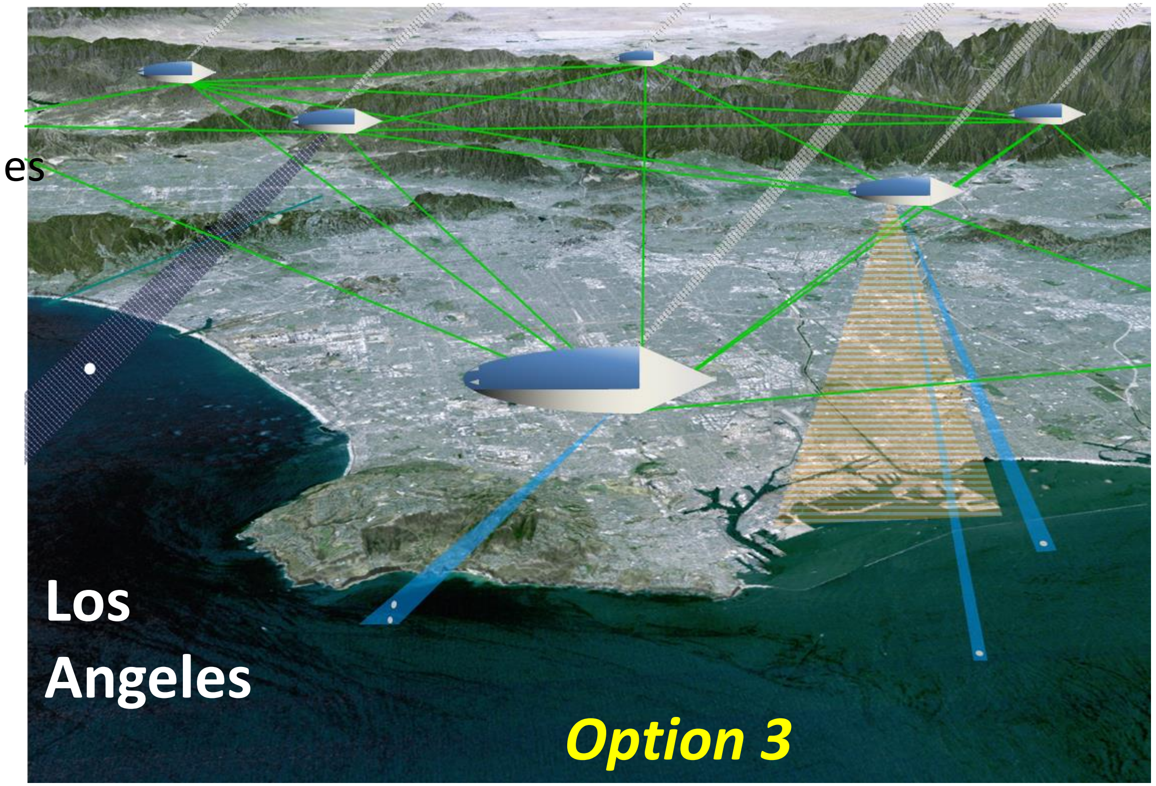
San Jose to Santa Barbara ***Option 1***

Los Angeles to Santa Cruz ***Option 2***

472 km= 293 miles

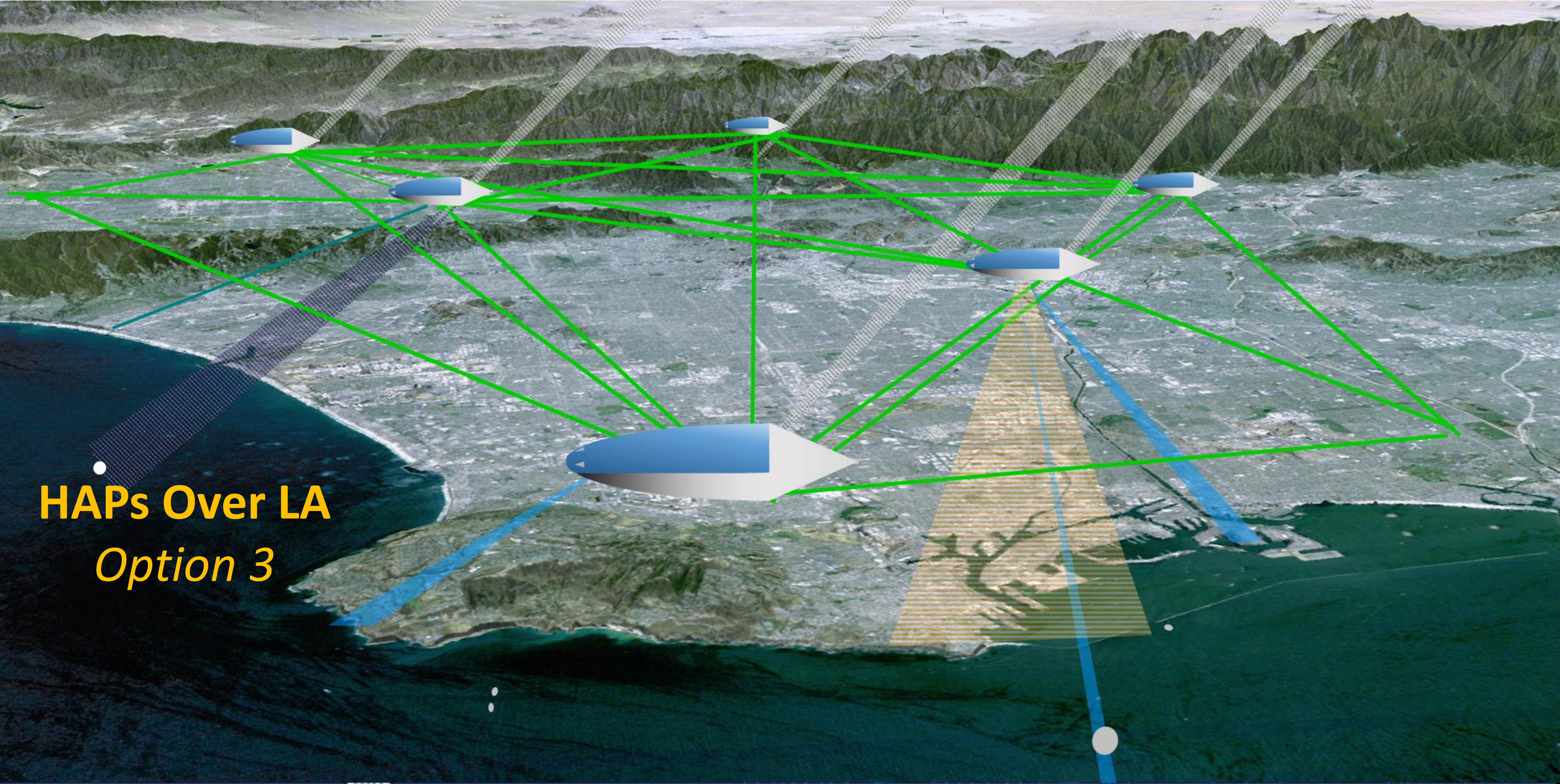
HAPS over Los Angels (What does it mean to me?) ***Option 3***

Find out more in the **5G Tech Community** on ***Brax.Me!***



HAPs Over LA

Option 3



Solar Airships Better:

- Large Payloads
- Low Density Payloads
- Dispersed Payloads
- Optical Payloads
- Energy Collection
- Energy Storage
- High Payload Energy Demand
- Station Keeping

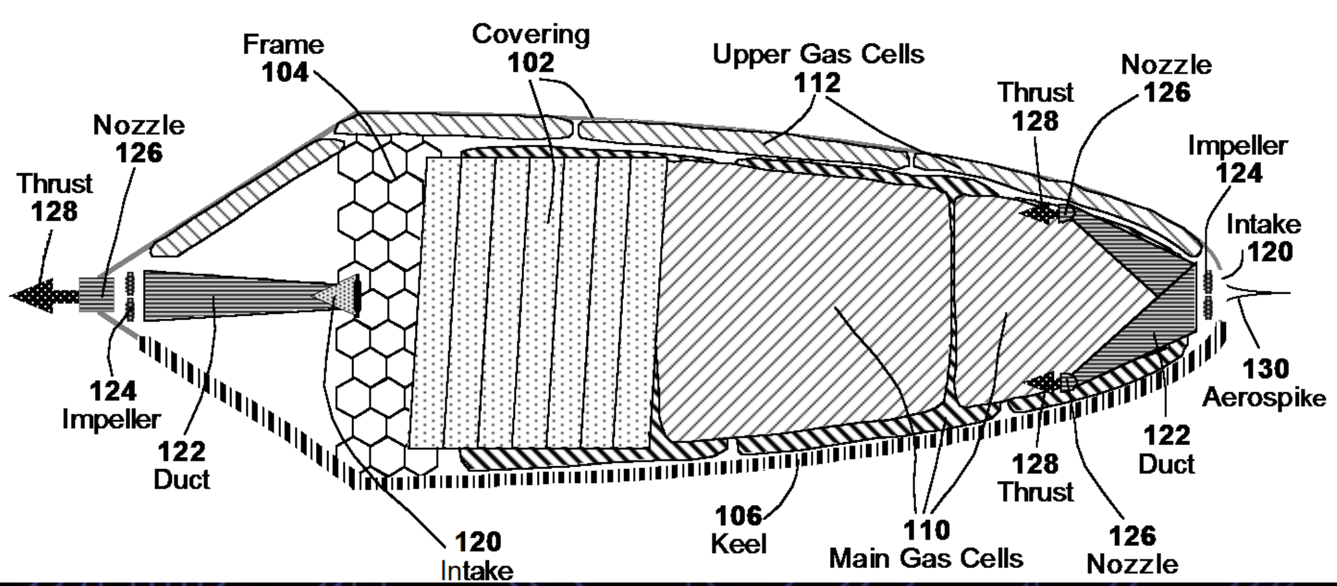
Solar Aircraft Better:

- Small Payloads
- High Density Payloads
- Low Payload Energy Demand
- Speed
- Rapid Altitude Change
- Rapid Deployment
- Return to Ground

Fig. 1

Large, Rigid Airship (patent pending).

Direction of Flight

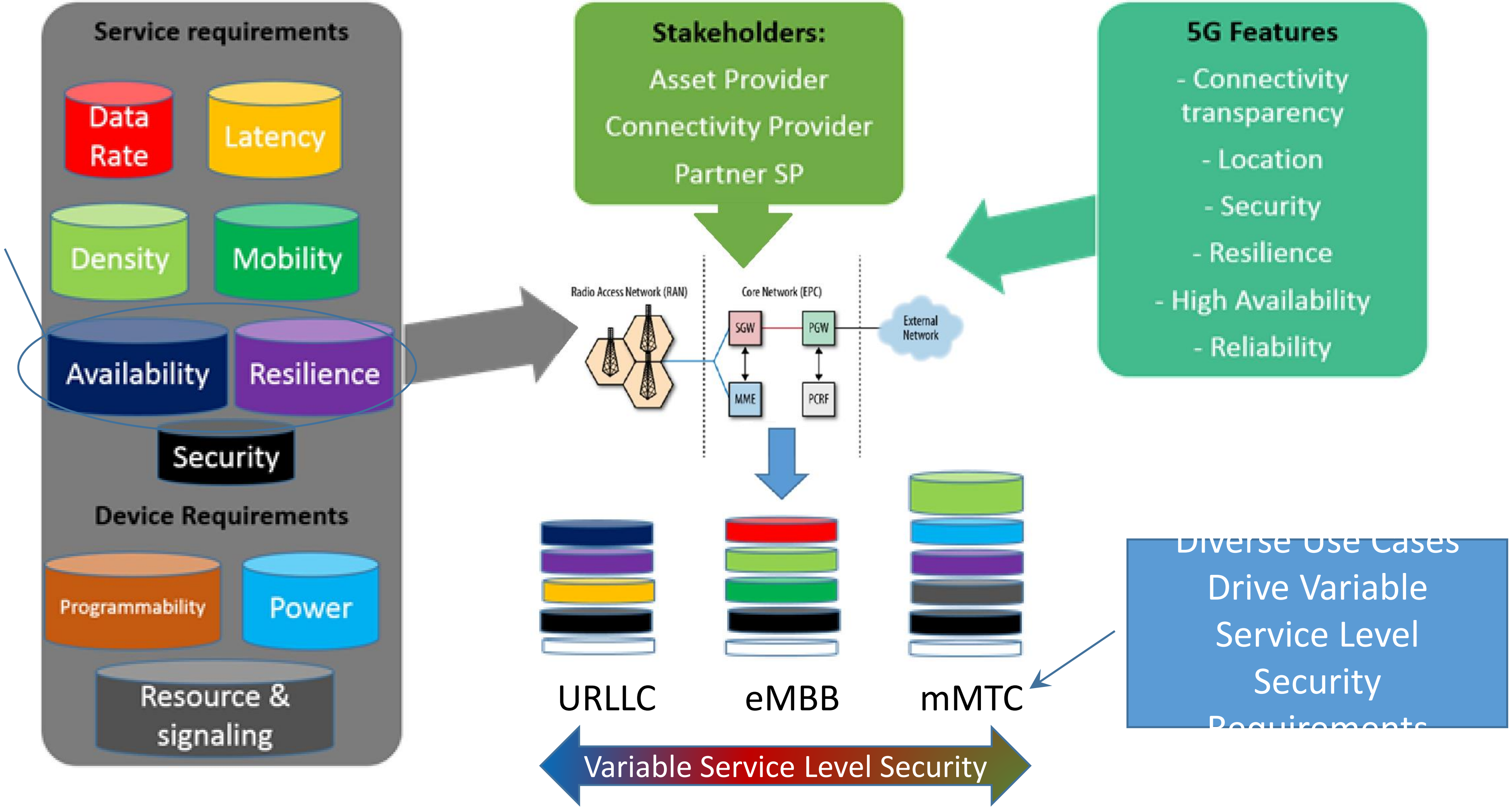


Topics

- Introduction and Outline
- Business Drivers
- Network Architecture Evolution
- Practical Deployment Considerations
- ➔ Security Considerations
- IP & Design Considerations
- Q&A

5G: Diversity of Services

New Requirements for 5G

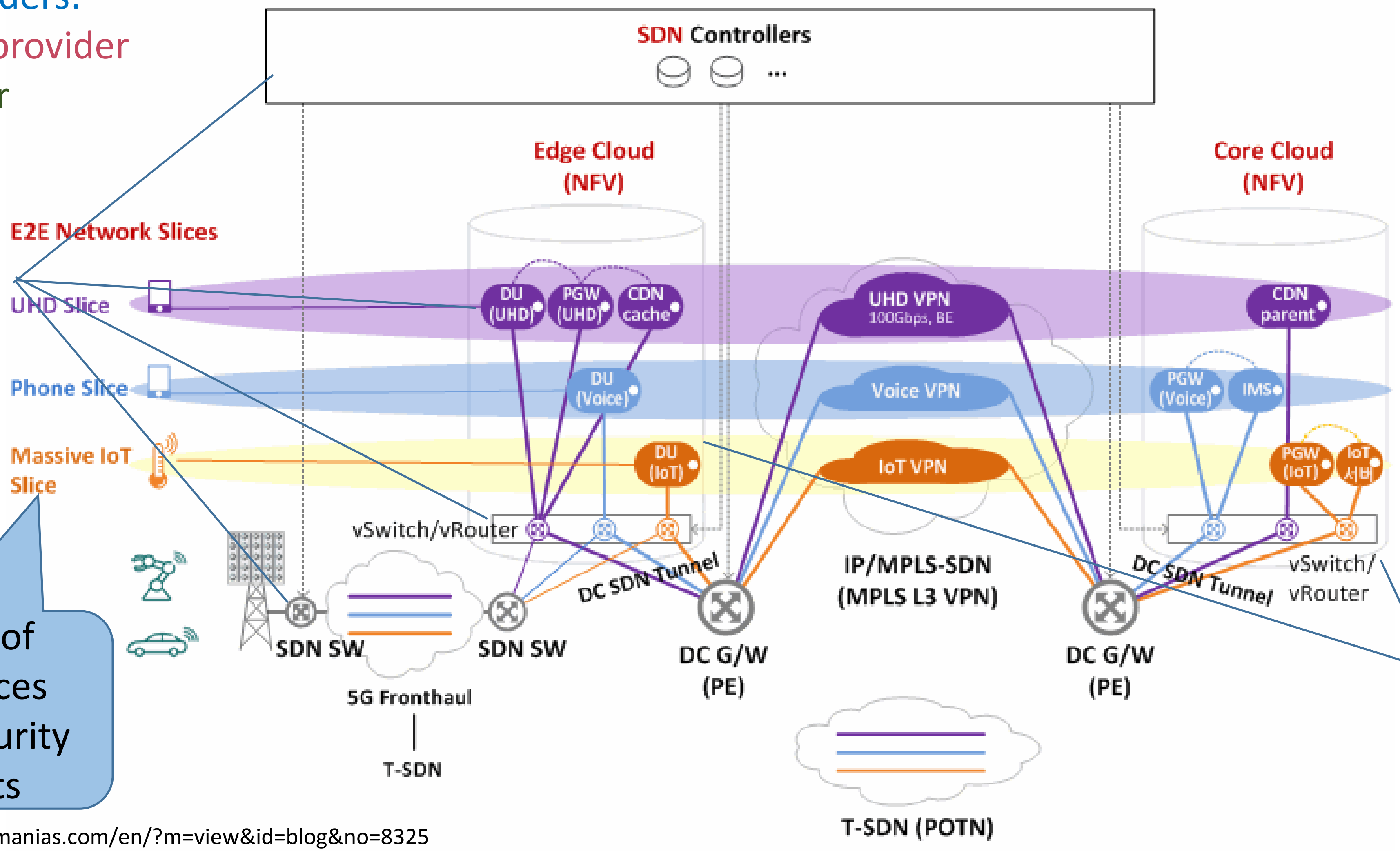


5G: Security for Service Integrity and Isolation

Multiple Stakeholders:

- Connectivity provider
- Asset provider
- Partner SP

Programmability and Agility



Convergence of Multiple Services of Differing Security Requirements

From Dedicated Boxes to COTS platforms

Source: http://www.netmanias.com/en/?m=view&id=blog&no=8325

Security Challenges & Design Assumptions

- 5G network communications systems
  - With the pressure on reduction of cost and introduction of new services, critical network functionality is being moved to the cloud
  - Evolution from centralized well protected systems to highly distributed and physically less defined/protected systems with virtual network topology
  - Traditional separation of trusted vs untrusted part of a system separated by a Demilitarized Zone (DMZ) is no longer a valid security model as a result of the virtual network topology
- Three out of four drivers for 5G security involve new requirements
  - New service delivery models
  - Evolved threat landscape
  - Increased focus on privacy
- The fourth driver requires an analytical approach to identifying the requirements
  - New trust models

5G Security - Core Areas of Focus

Flexible and Scalable Security Architecture

- Virtualization and dynamic configuration for 5G promotes new dynamic and flexible security architecture
- Security for RAN signaling could be located close to the access (e.g., virtualization) with a higher degree of independence to the user plane security, allowing more robust security (key distribution, key isolation, etc.)

5G Radio Network Security

- Attack resistance of radio networks to threats such as Denial of Service from potentially misbehaving devices
- Adding mitigation measures to radio protocol design
- Utilize available trusted computing technologies

Virtualization Security

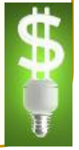
- Network virtualization with high assurance of VNF isolation to simplify the handling of diverse security requirements in common infrastructure
- Use existing trusted computing tools (TCG) and concepts for Virtualized Platform Integrity
- Cloud-friendly data encryption (homomorphic encryption, allowing operations on encrypted data)

Identity Management Architecture

- Billions of heterogeneous end-devices, sensors, network nodes with variable security capabilities, device attributes, and policies
- Allow enterprises with an existing IDM solution to reuse it for 5G access.
- New ways to handle device/subscriber ID with network slicing, enabling different IDM solutions per slice

Energy-efficient Security

- Most constrained, and battery-dependent devices with a long life time might be separated in specialized energy-efficient lightweight network slice
- Need to compare energy cost of encrypting one bit vs. transmitting one bit and consider hardware acceleration benefits



Security Assurance

- Deployment of heterogeneous hardware and software components creates greater need for security certification
- System state attestation needs to be communicated between entities to provide assurance in platform integrity
- Multi-layer security certification scheme is needed to efficiently create and traverse certification records

Class of Security Services

- Authentication
  - Ensures that the nodes that are communicating are correctly identified
- Authorization
  - Ensures that the access to a resource (data or service) is according to security policy
- Accounting
  - Ensures accurate accounting of transactions and attributable to the rightful party
- **Availability ***
  - Ensures that a legitimate party is not denied access to resources (e.g. communication link, network resources, etc.)
- Confidentiality
  - Ensures that data is only read by authorized parties
- **Privacy ***
  - Disclosing party's ability to control data that is revealed to a receiving party and how it is handled by that party through the lifecycle of the data
- Integrity
  - Ensures that data is not modified by any party other than authorized entities
- **Non-repudiation ***
  - Ensures that a party that sent/received data cannot deny having done so. Data can be traced and audited

*** Features requiring more emphasis than was the case for earlier generations of 3GPP standards**

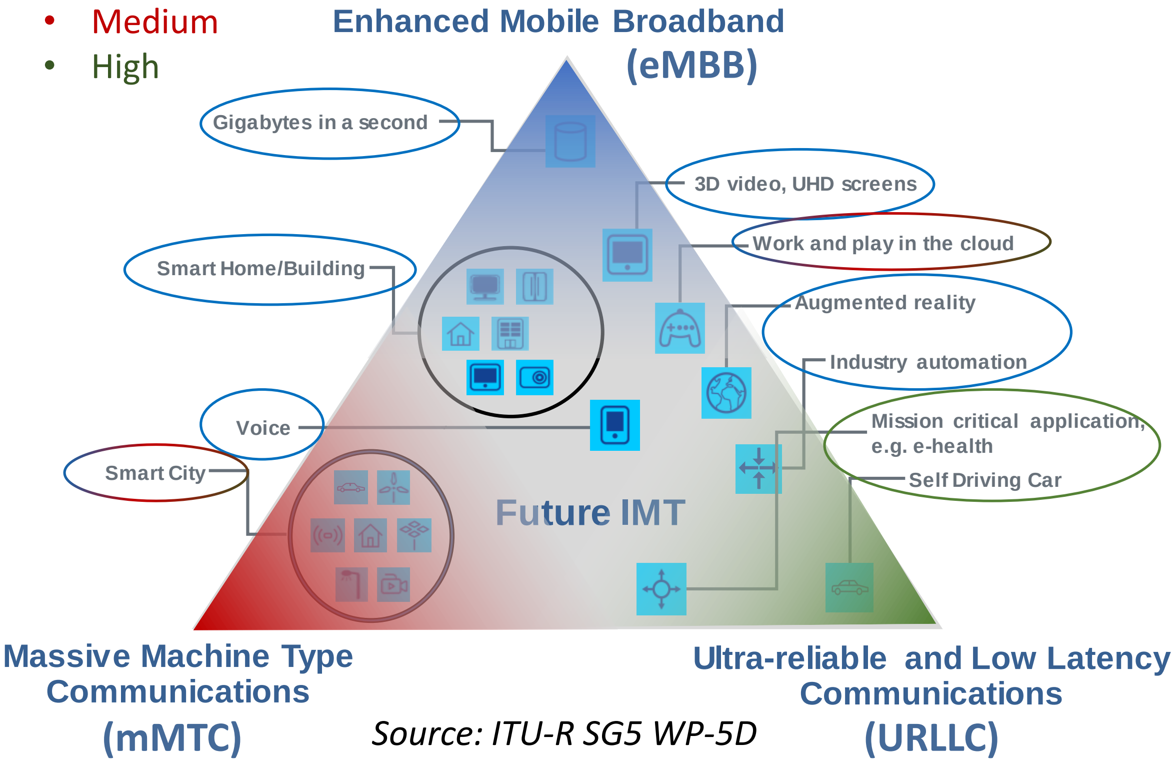
5G Security Requirements

- Network trust model
  - Traditional trust model based on inherent operator owned equipment, dedicated communications lines and physical protections
  - New flexible trust model is required to capture the highly evolved, distributed and shared infrastructure architecture model of 5G (e.g., establish trust in Endpoints, Cloud, and Fog)
- Communications link security
  - Existing communications link security is either on or off and with one level of security
  - Need for more flexible, on-demand and scalable security assigned on a per flow/service basis
- Unified authentication and authorization
  - HSS/HLR has traditionally been a repository of identities and attributes: will not scale to expected number of identities in 5G
  - Need for Identity Management capabilities extended to 3rd party application services
  - Need for flexible and dynamic authentication and authorization mechanisms

5G: Diverse Service Security Requirements

Key Challenge for 5G Networks: Support for Divergent Service Requirements

Security level
- Low
- Medium
- High



Source: ITU-R SG5 WP-5D

eMBB
- Peak Data Rate of 20 Gbps
- 1 ms Latency (air interface)
- 10 $Tbps$ per $km2$ Area Traffic
- Indoor/hotspot and enhanced wide-area coverage

mMTC
- Low data rate (1 to 100 kbps)
- High device density (up to 200,000/km2)
- Latency: seconds to hours
- Low power: up to 15 years battery life

URLLC
- Low to medium data rates (50 kbps to 10 Mbps)
- < 1 ms air interface latency
- 99.999% reliability and availability
- High mobility

Variable Service Level Security

5G: Security for Service Integrity and Isolation

Multiple Stakeholders:

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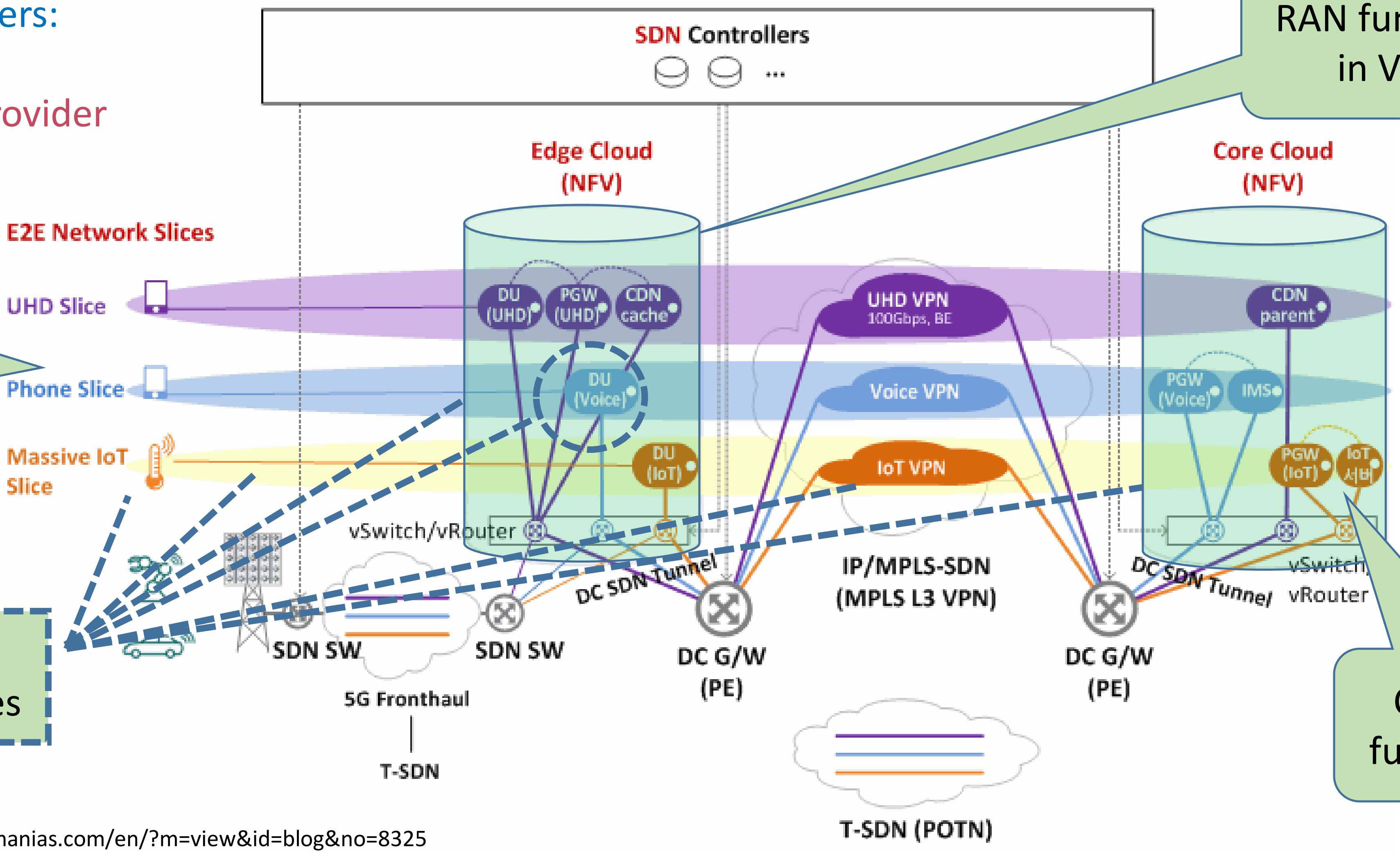
- Connectivity provider
- Partner SP



RAN functions in VMs

Convergence of Multiple Services

Security vulnerabilities

Core Network functions in VMs

Source: http://www.netmanias.com/en/?m=view&id=blog&no=8325

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Intellectual Property & Technology Development

- Technology development and IP go hand in hand
- Design/development of new or improved systems/networks takes
  - Expertise
  - Resources
  - Industry alliances
  - Standards collaborations
- Reaping benefits from the designs/developments takes
  - Competitive IP portfolio development
    - Innovation Protection
    - IP Acquisition
  - IP portfolio management
    - Competitive Analysis & Landscaping
    - Risk Analysis and Mitigation
    - Patent evaluation and maintenance
  - IP infringement vigilance
    - IP licensing/sale/ligitaiton

IP Race in 4G

- Mobile Technology Wars of 2010-2015
  - Apple, Samsung, Google, Qualcomm, Microsoft/Nokia, …
- Patent Purchases as Defensive Measures
  - The new big players to the mobile industry bought/licensed boatloads of patents
    - Apple & Microsoft boughtNortel's patents for $4.5B
    - Google bought Motorola mostly for its patents
      - 17,000 patents
      - 10,000 related to mobile communication
    - Microsoft bought Nokia Mobile Phones for $7B
      - Included a 10-yr licensing of Nokia patents to Microsoft

Standard Essential Patents (SEP)

- ETSI's definition:

  "**ESSENTIAL**" as applied to IPR **means that it is not possible** on technical (but not commercial) grounds, taking into account normal technical practice and the state of the art generally available at the time of standardization, **to make, sell, lease, otherwise dispose of, repair, use or operate EQUIPMENT or METHODS which comply with a STANDARD without infringing that IPR**.

  http://www.etsi.org/images/files/IPR/etsi-ipr-policy.pdf

- Qualcomm generated licensing revenue of $7.8 Billion from SEPs in 2014
- Qualcomm declared the most # of SEPs to ETSI
- Ericsson arguably had the most 4G contributions to 3GPP
  - Based on approved contributions to various working groups during 2007-2008

Standard Essential Patents (SEP), cont.

- FRAND licensing practices
  - Fair, Reasonable and Non-Discriminatory
  - Not easy to ascertain fairness and reasonableness
- SEP determination
  - ETSI database
    - self-proclaimed essentiality by 3GPP member companies
    - Not reliable
    - Not complete
  - Keyword Search
    - Unreliable
  - Licensing Deals & Court Decisions
    - Best source

Standard Essential Patents (SEP), cont.

- IEEE made dramatic changes to its patent policies
  - Royalties calculated based on the **smallest salable patent-practicing unit** (SSPPU)
    - No longer based on a percentage of the finished product
  - Patent holders obliged to offer licenses to all applicants; discouraged from taking licensees to court over royalty levels
  - In favor:
    - Intel, Cisco, Dell, HP, …
  - Against:
    - Qualcomm, Nokia, Ericsson, …

IP Race in 5G

- 5G Applications
  - Enhanced Mobile Broadband (eMB)
    - high data rate internet access
    - augmented Reality
    - cloud Storage
  - Internet of Things (IoT)
    - sensor networks
    - smart homes/buildings
    - remote health monitoring
    - logistics tracking
  - Ultra-Reliable and Low Latency Communications (URLLC)
    - industrial automation
    - driverless cars
    - remote surgery
    - smart grids

IP Race in 5G, cont.

- Biggest 3GPP Contributors for 5G
  - Huawei
  - Samsung
  - Nokia,
  - Ercisson
  - Qualcomm
  - NTT Docomo
  - Intel
  - ZTE
  - China Mobile
  - LG

Patent & Portfolio Analysis is a Must

- Both essential (SEP) and non-essential patents are highly valuable and sought after
- Companies must take stock of
  - Their own IP strength
  - Their competitors' IP strength
  - Take defensive/offensive measures as necessary
- Evaluation of patents is critical
  - Standard-Essential Patents
    - Essentiality determination requires command of both technology and standard
  - Implementation (non-essential) patents
    - Infringement analysis usually performed on suspected products
    - Valuation analysis is performed to determine the grounds for licensing terms

What to Look for When Outsourcing

- Subject Matter Experts
  - First and Foremost
- Engineering Resources
  - Technicians/Tools/Labs
  - For when engineering or reverse engineering is needed
- Management
  - For complicated projects
- Reputation/Referrals
  - For when time and quality is of essence
- Comprehensive Services
  - Capability to address all aspects of the project(s)

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