附件 1

FMMC

Spectrum Futures 2017

5G from a Developed Market Perspective: What We Plan to Do

Monday, 18 September 2017

5G Global Trend

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5G in major countries

5G frequency bands
Global harmonization for 5G

■Candidate bands identified at WRC-15

WRC-15	EU(CEPT)	USA(FCC)
24.25-27.5 GHz	24.5-27.5 GHz ◎	△
—	—	27.5-28.35 GHz
31.8-33.4 GHz	31.8-33.4 GHz ○	△
37-40.5 GHz	—	37-38.6 GHz 38.6-40 GHz
40.5-42.5 GHz	40-5.43.5 GHz ○	△
42.5-43.5 GHz		—
45.5-47 GHz	45.5-48.9 GHz	—
47-47.2 GHz		
47.2-50.2 GHz		△
50.4-52.6 GHz	—	△
66-76 GHz	66-71 GHz	64-71 GHz
	71-76 GHz	△
81-86 GHz	81-86 GHz	△
—	—	△(95 GHz以上)

■Sharing studies in EU

5G bands	Bandwidth	Existing services
24.5-27.5 GHz	3 GHz	Data Relay Satellite("Copernicus"), Satellite uplink, Fixed link
31.8-33.4 GHz	1.6 GHz	High Density application in the Fixed Service(HDFS) band ruled by Radio navigation(RR 5.547)
40-5.43.5 GHz	3 GHz	Satellite, Radio astronomy
45.5-48.9 GHz	3.4 GHz	Satellite
66-71 GHz	5 GHz	Satellite
71-76 GHz	5 GHz	Fixed, Satellite

■New service rules for 5G adopted by FCC

Category	Bands	Block sizes	Proposed rules
Licensed use (3.85GHz bandwidth)	28GHz (27.5-28.35GHz)	425MHz	County-sized geographic area Licenses(more than 3,000 areas)
	37GHz (37-38.6GHz)	200MHz	To allow for continuity of commercial operations To protect a limited number of Federal military sites across the full 37 GHz band To maintain the existing Federal fixed and mobile allocations
	Low band (37-37.6GHz)	200MHz	To create a space for coordinated co-primary shared access between Federal and non-Federal users
	High band (37.6-38.6GHz)	200MHz	PEA(Partial Economic Areas) licenses(416 areas)
	39GHz (38.6-40GHz)	200MHz	PEA license To maintain the co-primary Federal FSS and MSS allocations in the 39.5-40 GHz band, limited to military systems
Unlicensed use (7GHz bandwidth)	64-71GHz	—	To operate in the 64-71 GHz band under Part 15* based on the rules FCC recently adopted for the adjacent 57-64 GHz band

Note: First priority is ◎ and second one is ○ in UE. △ means bands that FCC proposes to allocate as additional bands for 5G. Italic means additional allocation bands for mobile services as primary base.

* § 15.255 Operation within the band 57-64 GHz

Sources: Various materials

USA
Upper Microwave Flexible Use Service

- FCC: "Spectrum Frontiers Proposal" (Jun 23, 2016)
  "Spectrum Frontiers R&O and **FNPRM**" (July 14, 2016)
- The Obama administration: Investment of a $400 million Advanced Wireless Research Initiative led by the National Science Foundation (NSF), and deployment of four city-scale testing platforms for Advanced Wireless Research(PAWR) using 5G bands over the next decade (July 15, 2016)

- Additional 5G fixed and mobile bands for UMFUS (Upper Microwave Flexible Use Service)
  - 24GHz band: 24.25-24.45/24.75-25.25 GHz
  - 32 GHz band: 31.8-33GHz
  - 42 GHz band: 42-42.5 GHz
  - 47 GHz band: 47.2-50.2 GHz
  - 50 GHz band: 50.4-52.6 GHz
  - 70/80 GHz band: 71-76 GHz/81-86 GHz
  - Above 95GHz
- Sharing policies
  - Sharing framework both among non-Federal operators and with the Federal government in the 37-37.6GHz band
  - Sharing framework that federal government users can gain coordinated access to spectrum in the 37.6-38.6 GHz band (in addition to the protected sites) in the future

Sources: https://www.fcc.gov/document/fact-sheet-spectrum-frontiers-item, https://apps.fcc.gov/edocs_public/attachmatch/FCC-16-89A1.pdf, https://obamawhitehouse.archives.gov/the-press-office/2016/07/15/fact-sheet-administration-announces-advanced-wireless-research, https://www.nsf.gov/cise/advancedwireless/

USA
Mid-Band Spectrum Between 3.7 and 24 GHz

- Specific bands for consideration
  - 3.7-4.2GHz
    - More intensive fixed use or mobile broadband use in the 3.7-4.2GHz
  - 5.925-6.425GHz
    - Expansion of unlicensed use within the 5.925-6.425 GHz band
  - 6.425-7.125GHz
    - Potential for more intensive fixed or flexible use of the 6.425-7.125 GHz band
- Google studying 3.7-4.2 GHz band
  - The 3.7-4.2 GHz band is substantially underused by the satellite industry.
  - According to the FCC database, 29% of ground-based fixed satellite service (FSS) sites didn' t exist.
  - One of the first steps to examining the use of 3.7 to 4.2 GHz would be a clean up of the database, in order to get an accurate picture of the satellite sites that exist and that really require protection.
  - As for protecting the satellite dishes, it would be possible to adopt Spectrum Access System (SAS) and Environmental Sensing Capabilities (ESC) which already deal with the military incumbents in the CBRS(Citizens Broadband Radio Service band) band, 3.5GHz.

Source: NOTICE OF INQUIRY, Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz
https://www.fcc.gov/document/fcc-opens-inquiry-new-opportunities-mid-band-spectrum

USA
Field test license applications by stakeholders

- Raytheon Missile Systems
  - Bands: 71-76GHz, 81-86GHz and 92-94GHz (January 2016)
  - Use case: Next generation broadband communications for both of DOD and commercial customers (e.g. between aircrafts, ground to air etc.)
- Google
  - Bands: 71-76GHz, 81-86GHz (Nationwide coverage) (March 3, 2017-April 1, 2018)
  - Use case: Communications between aircrafts, ground to air etc.
- Boeing
  - Bands: 47.2-50.2 GHz (↑)、50.4-52.4 GHz (↑) (June 22, 2016)
  - Use case: Satellite broadband internet service, NGSO (non-geostationary satellite orbit constellations) low-earth orbit satellite system to compete with SpaceX and OneWeb
  - Total number of satellites: 2956 stations
- Facebook
  - Bands: 73GHz (Transmission distance: 13km, transmission speed: 20GHz) (November 2016)
- SpaceX
  - Bands: 10.7-12.7 GHz, 13.85-14.5 GHz, 17.8-18.6 GHz, 18.8-19.3 GHz, 27.5-29.1 GHz, 29.5-30.0 GHz (November 2016)
  - Total number of satellites: 4425 stations (Latency: 25-35 millisecond, Attitude: 1100-1325km) (May 2017)
- OneWeb with Airbus
  - Bands: 10.7-12.7 GHz, 14-14.5 GHz, 17.8-18.6 GHz, 18.8-19.3 GHz, 27.5-29.1 GHz, 29.5-30 GHz (NGSO FSS license applications) (June 2017)
  - Total number of satellites: 2000 stations until 2027
- Apple with Boeing
  - Bands: 28GHz, 39GHz (experimental term: 12 month) (May 2017)
    - Apple invests the satellite broadband project of Boeing.
    - Apple headhunts an executive belonging satellite department from Google. (April 2017)

Sources: Various materials

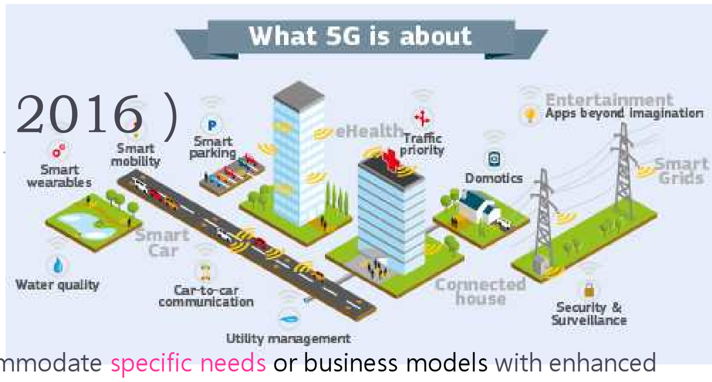
USA
5G strategies of mobile operators

- Verizon and AT&T are planning to introduce 5G fixed wireless service using 28GHz and 39GHz in consumer broadband market in order to compete with major CATV operators.

Operator	Band	Summary
Verizon	28GHz 39GHz	➢ Establishment of 5G Technology Forum (5GTF) in second half of 2015 ➢ Launch of 5G fixed wireless pilot service in 11 markets in 2017（Ann Arbor, Michigan; Atlanta; Bernardsville, New Jersey; Brockton, Massachusetts; Dallas; Denver; Houston; Miami; Sacramento; Seattle; and Washington, D.C.) ➢ Supplier: Ericsson Samsung, Technical partner:: Intel and Qualcomm ➢ Demonstration of vehicle-mounted 5G system and VR at Indianapolis 500 (May 2017) ➢ Acquisition of 28GHz and 39GHz licenses from XO communications and StraightPath
AT&T	28GHz 39GHz	➢ Field test license applications of 3.7-4.2 GHz, 27.5-2.835 GHz, 3.7-3.86 GHz, 64-71 GHz, 71-76 GHz (License term: 2 years) (March 2017) ➢ Launch of video streaming test of "DirecTV Now" based on fixed 5G (May 2017) ➢ Planning to start fixed BB service using 28 GHz band for premise and SME customers in 2017 ➢ Partnership with Qualcomm and Ericsson to test 5G for both mobile and fixed in 2017 ➢ Planning to conduct a test based on 5G New Radio specification of 3GPP
T-Mobile	600MHz 28GHz 38GHz	➢ Deployment of 5G nationwide network until 2019 using 600 MHz band ➢ Field trial license applications of 28GHz and 38GHz (March 2017)
Sprint	2.5GHz	➢ Agreement of 5G technical development using band 41 (2.5GHz) based on 3GPP New Radio with Softbank and Qualcomm (May 2017) ➢ Collaboration with New York University Wireless for mobile 5G

Sources: Various materials

EU
5G Manifesto (July 2016)



- 5G deployment
  - European operators will target launching 5G in at least one city in each of the 28 European Member States by 2020
- 5G use-cases (Vertical industries)
  - 5G network virtualisation (slicing) to accommodate specific needs or business models with enhanced levels of service assurance and guarantees
  - Connected automotive scenarios, including ultra-broadband infotainment, safety applications and automated / autonomous driving across motorways in Europe
  - Connected eHealth scenarios that can spark Healthcare innovation and business transformation across the continuum of care, keeping Healthcare affordable to citizens and government (and tax payers).
  - Reliable, high capacity broadband connectivity in connected planes, railway and high-speed transportation across Europe, and transport and logistic networks with multimodal cargo (truck, rail, shortsea, barge, plane/drone)
  - Public Safety use-cases providing security, reliability and real-time broadband connectivity for key events involving large audience
  - Smart grids: ensuring networks stability and coordinating energy distribution from diverse sources (e.g. wind, solar, power-plant) and different regions
  - Smart City use-cases including connected bus shelters, real-time traffic monitoring and analytics, crowd management, smart homes, ageing population, augmented reality for tourism and advertising
  - Media and entertainment use-cases, including the integration of satellite and terrestrial network services, demonstrating the power of multicast and caching for delivering a cost-effective and scalable user experience anywhere in Europe, as well as immersive video scenarios showcasing the benefits of 5G capacity enhancements

Sources: 5G Manifesto for timely deployment of 5G in Europe, Brussels, July 7th 2016
https://ec.europa.eu/digital-single-market/en/news/commissioner-oettinger-welcomes-5g-manifesto

EU
5G Action Plan (September 2016)

Items	Actions
Frequency	➢ Identifying by the end of 2016 a provisional list of pioneer spectrum bands for the initial launch of 5G services ➢ Agreement by end of 2017 on the full set of spectrum bands (below and above 6 GHz) to be harmonised for the initial deployment of commercial 5G networks in Europe, based on a planned RSPG opinion on 5G spectrum
Coverage	➢ Encouraging Member States to develop, by end 2017, national 5G deployment roadmaps as part of the national broadband plans ➢ Ensuring that every Member State will identify at least one major city to be "5G-enabled" by the end of 2020 and that all urban areas and major terrestrial transport paths have uninterrupted 5G coverage by 2025. ➢ 5 cities (Berlin, Amsterdam, Stockholm, Tallinn in Estonia, Matera in Italy) (as of December 2016)
Early adopter	➢ Ensuring that hardware, terminals* and devices based on 5G connectivity are available in due time before 2020 to encourage uptake and demand ➢ Migrating public safety and security services from existing proprietary communications platforms to commercial 5G platforms which will be even more secure, resilient and reliable
Financing	➢ Setting up a specific 5G venture financing facility, to support innovative European start-ups aiming to develop 5G technologies and related new application across industrial sectors

* Not only smart phones but also a full range of Internet of Things and connected devices (cars, drones, urban furniture, etc).

Sources: 5G for Europe: An Action Plan (Brussels, 14.9.2016, COM(2016) 588 final)
https://ec.europa.eu/digital-single-market/en/news/communication-5g-europe-action-plan-and-accompanying-staff-working-document

EU
5G strategic roadmap (November 2016)

Opinion on spectrum related aspects for 5G (Radio Spectrum Policy Group)

- 3400-3800 MHz band to be the primary band suitable for the introduction of 5G -based services in Europe even before 2020
- Using of 700 MHz band in order to enable nationwide and indoor 5G coverage
- Ensuring that technical and regulatory conditions for all bands already harmonised for mobile networks are fit for 5G use
- Realising harmonization of 24.25-27.5 GHz (26 GHz band) as a pioneer band for 5G above 24 GHz before 2020
- Considering 31.8-33.4 GHz（33 GHz band）and 40-5.43.5 GHz（42 GHz band）as next priority 5G bands
- Taking also into account the work of the RSPG working groups on IoT and ITS as well as existing licences in the pioneer bands.

出所：STRATEGIC ROADMAP TOWARDS 5G FOR EUROPE, Brussels, 09 November 2016, RSPG16-032 FINAL
http://rspg-spectrum.eu/wp-content/uploads/2013/05/RSPG16-032-Opinion_5G.pdf

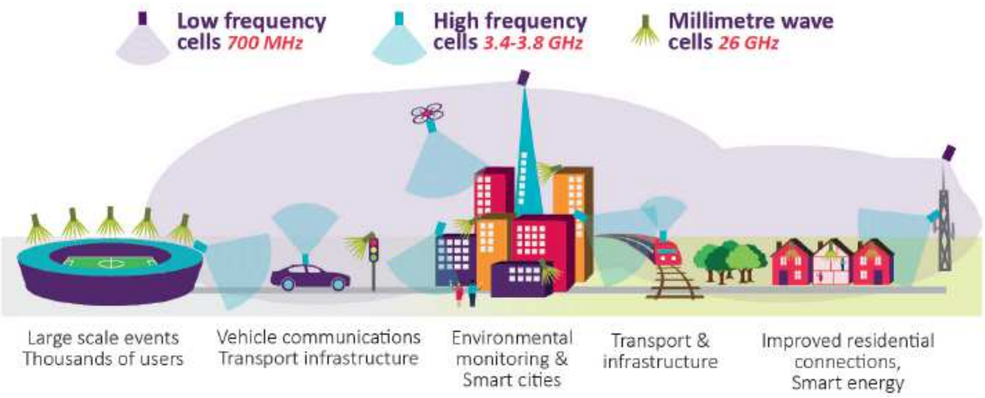
UK
Government policies for 5G deployment

- HM Treasury: "Autumn Statement 2016" (23 November 2016)
  - The government will invest over £1 billion by 2020-21, including £740 million through the NPIF(National Productivity Investment Fund), targeted at supporting fibre and 5G.
- National Infrastructure Commission(NIC): "Connected Future" (December 2016)
  - Deployment of 5G infrastructure across major centres and transport networks
    - Major roads: Our motorways must have roadside networks fit for the future. The infrastructure should be in place by 2025.
    - Key rail routes: The railway network must rapidly improve connectivity. This will be best delivered in future by a trackside network. Government should provide a plan by 2017, and the infrastructure should be in place on main rail routes by 2025.
    - Towns and cities: Local Authorities and LEPs should work with network providers to develop approaches that enable the deployment of the tens of thousands of small wireless cells we expect to need in our urban centres.
- Department for Digital, Culture, Media & Sport(DCMS)
  - "UK strategy and plan for 5G & Digitisation - driving economic growth and productivity" (January 2017)
  - "Next Generation Mobile Technologies: A 5G Strategy for the UK" (March 2017)
    - The Government will ask Ofcom to review and report back to DCMS by the end of 2017, the scope for the spectrum licensing regime to facilitate better 4G and 5G deployment at national, regional and local scales, including in-building usage.
    - The Government will work with Ofcom to assess the feasibility of accessing the 3.8-4.2 GHz range on a shared basis as an extension to adjacent 3.4-3.8 GHz spectrum and promote this in Europe and agree a timescale and clear milestones for further work.

Source: https://www.gov.uk/government/publications/autumn-statement-2016-documents/autumn-statement-2016
https://www.gov.uk/government/publications/connected-future
https://www.gov.uk/government/publications/interim-report-of-future-communications-challenge-group-uk-strategy-and-plan-for-5g-digitisation

UK
5G spectrum in UK (February 2017)

- 700 MHz
  - Conducting auction in 2018/19 and ensuring that the band is available nationally for mobile data by Q2 2020
- 3.4 - 3.8 GHz
  - 3410-3480 MHz and 3500-3580 MHz: 150 MHz of spectrum in this range (3410-3480 MHz and 3500-3580 MHz) has been cleared and released by the public sector and is due to be auctioned later this year, 2017.
  - 3605 - 3689 MHz: Conducting public consultation on sharing study between existing users (satellite earth stations, fixed links and UK Broadband' s licence for the 3605 to 3689 MHz band) and mobile services in 2017
- 26 GHz (24.25-27.5GHz)
  - Announcement of Call for Input on spectrum assignment plan of 26 GHz band (July 2017-)



Sources: Update on 5G spectrum in the UK, Statement, 8 February 2017
https://www.ofcom.org.uk/__data/assets/pdf_file/0021/97023/5G-update-08022017.pdf,
Call for inputs on 5G spectrum access at 26 GHZ and update on bands above 30 GHz
https://www.ofcom.org.uk/consultations-and-statements/category-2/5g-access-at-26-ghz

(Reference)
5G field trial using 28GHz by Arqiva

- The trial is set to take place in the second half of 2017 in central London and will involve the deployment of an end-to-end 5G FWA network, operating in the 28GHz band. Arqiva owns the national license in the UK for this spectrum, which is also the standard band being used for 5G trials in the USA, Japan and South Korea.
- Samsung's 5G Access Units (the base stations) will use high-frequency mmWave (millimeter wave) spectrum and advanced technologies such as beam-forming, to provide high-density coverage and ultra-high-bandwidth connectivity to CPEs (or Customer Premise Equipment) installed in nearby locations.
- These can be self-installed, therefore limiting costs, and can bring a subscriber online in a matter of minutes. This gives 5G FWA considerable advantages over comparable FTTH or FTTB (Fibre-to-the-Home/Building) deployments in terms of service rollout times and the costs to both the service provider and the subscriber.
- The CPEs will be based at locations in London including Arqiva's offices at Percy Street, London W1 and will provide ultra-high speed connectivity to multiple devices. The locations will be selected because of the wide range of customer groupings in business and residential premises.

Source: https://www.arqiva.com/news/press-releases/arqiva-and-samsung-to-undertake-first-5g-fixed-wireless-access-trial-in-the-uk/

Major countries
Considerations of 5G spectrum allocations

Country	M/Y	Summary
Finland	5/2017	Announcement by Minister of Transport and Communications Assignment of 3,400–3,800MHz in 2018 and launch of use in 2019
Sweden	3/2017	Spectrum allocation plan for 5G test (Announcement by PTS) Allocation of 100-200MHz bandwidth within 3.4-3.6GHzband and 1000MHz bandwidth within 26 GHz band; Assignment for commercial use in 2020
France	3/2017	5G: ISSUES & CHALLENGES (Accouchement by ARCEP) 26 GHz band: Planning to conduct sharing study between fixed link for 4G by mobile operators, fixed satellite, earth station of space and to transfer existing services to other millimeter band 3.4 - 3.8 GHz: 3400 – 3600MHz is primary band for ARCEP(Non primary for Interior Ministry and Defense Department). 3600 - 3800 MHz is exclusive band for ARCEP and is necessary to conduct sharing study between wireless local loop and satellite.
France	1/2017	Proposal of spectrum allocation for 5G etc. (ARCEP public consultation) 40MHz bandwidth within 2.6GHz band for PMR; 40MHz bandwidth within 3.5GHz band for fixed wireless broadband in rural area; remained band within 3.5GHz band for 5G
South Korea	1/2017	The first economic ministers 'meeting 2017: "K-ICT spectrum plan" New allocations of 1000MHz bandwidth within 28GHz band and 1300MHz bandwidth within 3.5GHz band until 2018
China	12/2016	Announcement by Ministry of Industry and Information Technology(MIIT) Allocation of 3.3GHz-3.4GHz, 4.4GHz-4.5GHz and 4.8GHz-4.99GHz for 5G; launch of spectrum use above 6GHz after 2019
China	1/2016	The 13th five-year plan(2016-2020) New allocation of more than 500MHz bandwidth for 5G; Permission of assignment of 200MHz bandwidth within 3.5GHz band for 5G test
Germany	12/2016	Proposal of spectrum allocation for 5G (Announcement by BNetzA) Allocation of 700 MHz(center gap), 2 GHz, 3.4 – 3.8 GHz, 26 GHz, 28 GHz(27,8285 – 28,4445GHz, 28,9485 – 29,4525 GHz) for 5G
Australia	10/2016	Spectrum relocation for 5G (Announcement by ACMA New allocation of 1.5GHz band and 3.6GHz band for 5G (Existing users of 3.6GHz: satellite and fixed broadband, Existing users of 1.5GHz: defense, fixed service in rural area etc.)

Sources: Various materials

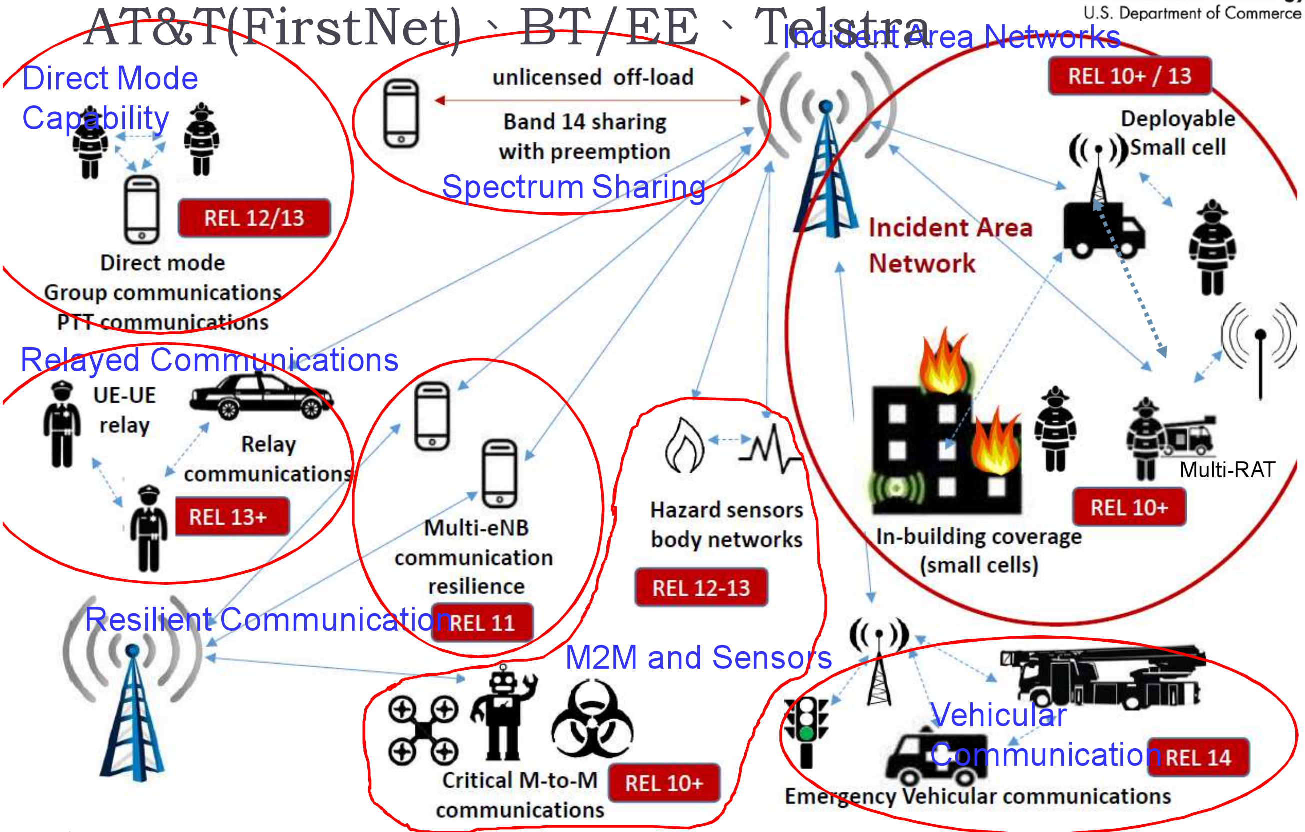
Germany "5G-ConnectedMobility" 5G trial in transportation system (2016/11)

- Founding members
  - Ericsson, BMW Group, Deutsche Bahn, Deutsche Telekom, Telefónica Deutschland, Vodafone, the TU Dresden 5G Lab Germany, the Federal Highway Research Institute (BASt) and the Federal Regulatory Agency (BNetzA)
- Governmental supporters
  - Federal Ministry of Transport & Digital Infrastructure and Bavarian Road Construction Administration
- Trial network
  - Dedicated 5G test network in the 700-MHz band along the A9 motorway and the high speed rail track between Nuremberg and Greding

Sources: https://www.ericsson.com/news/161117-ericsson-initiates-5g-motorway-project-with-cross-industry-consortium-in-germany_244039853_c

5G use case for public safety AT&T(FirstNet)、BT/EE、Telstra

NIST
National Institute of Standards and Technology
U.S. Department of Commerce



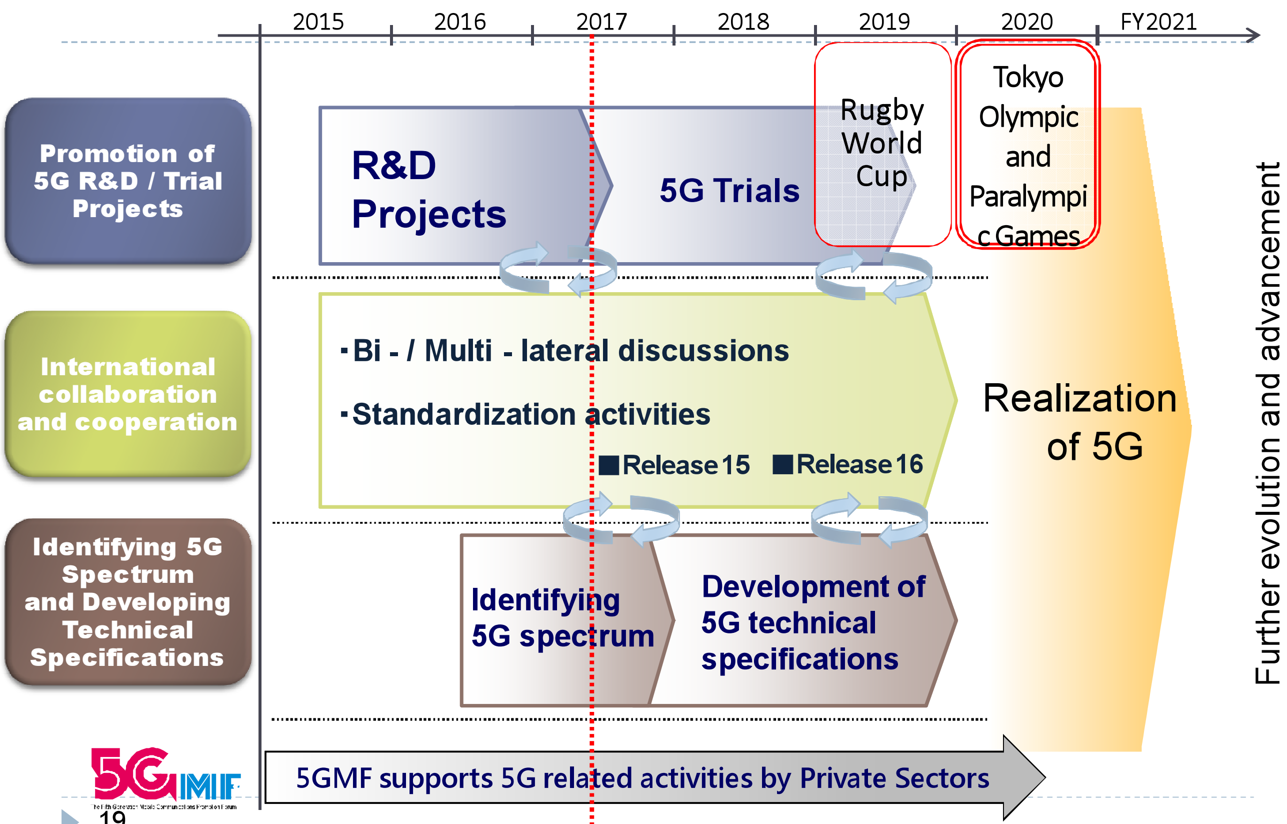
Source: https://www.atis.org/5GSymposium/presentations/5G_PublicSafety_TMcElvaney.pdf

Input from 5G activities in major countries

- Demand stimulation of millimeter band by 5G spectrum considerations
  - Three-sided battle in technical and service development (i.e. competition between Communications, IT and Space-defense companies)
  - Necessary of study on spectrum needs of existing licensees including fixed and satellite
  - Expansion of spectrum sharing between existing users(especially governmental users) and new 5G user
- Consideration of spectrum sharing framework
  - Spectrum and operational coordination procedure between users
  - Development of dynamic spectrum access technology to protect existing licensees
  - Use-or-share approach for spectrum efficient use
- 5G use case and areas (commercial and private uses)
  - Area of high population density, big event sites etc. (possibility of unlicensed use as an alternative)
  - Alternatives to optical fixed broadband as a last one mile to compete with CATV (especially USA)
  - Backhaul network between base stations (especially in rural areas)
  - Linkage between important points in transportation including road, rail, canal, aviation etc.
  - Operational areas for public safety entities and critical infrastructure owners
- Adoption of priority access service
  - Promotion of shared use of single network with priority access control technology by different users or applications depending on emergency and ordinary situations or service level agreements
- Effective use of licensed and unlicensed bands (for mobile)
  - Separate use depending on the situations: Whereas licensed bands are used for mission critical applications, unlicensed bands are for consumers mobile data.

5G in Japan

5G Development Roadmap toward 2020 in Japan



Source: Ministry of Internal Affairs and Communications (MIC)

Inquiry on 5G Technical Specifications

- Information and Communications Council started its study [October 12, 2016]

(Study Items)

- Key Concepts
- Network Architecture
- Use Cases and Models
- Requirements
- Migration Scenario (4G to 5G)

⇒

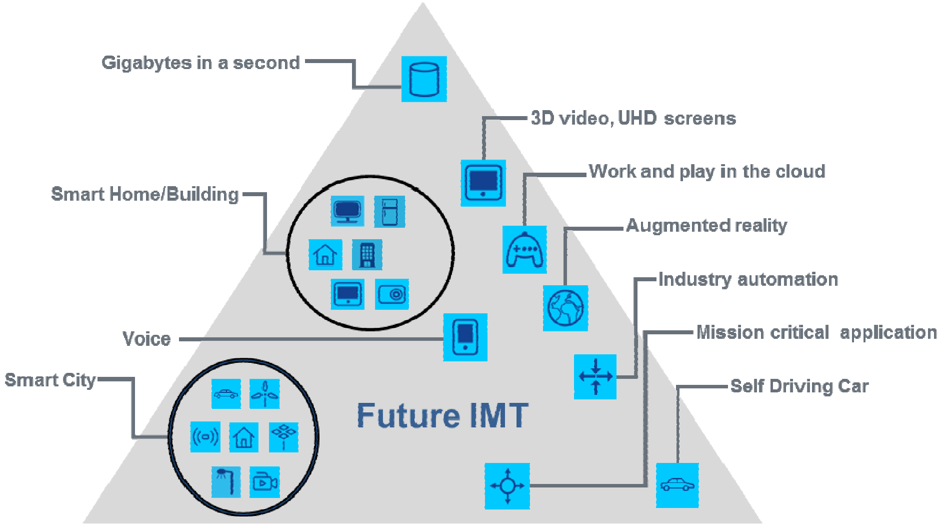
- Identification of 5G Spectrum
- Development of Technical Specifications

- The first report of the Council will be available <u>around Summer 2017</u>. The study will go forward.

Source: Ministry of Internal Affairs and Communications (MIC)

ITU-R IMT Vision Report (M.2083) (Sept, 2015)

(eMBB : Enhanced mobile broadband)



(mMTC : Massive Machine Type Communication)

(URLLC : Ultra reliable and low latency communication)

Source: Ministry of Internal Affairs and Communications(MIC)

5G with Ultra Flexibility

～4G : Best effort

○Broadband

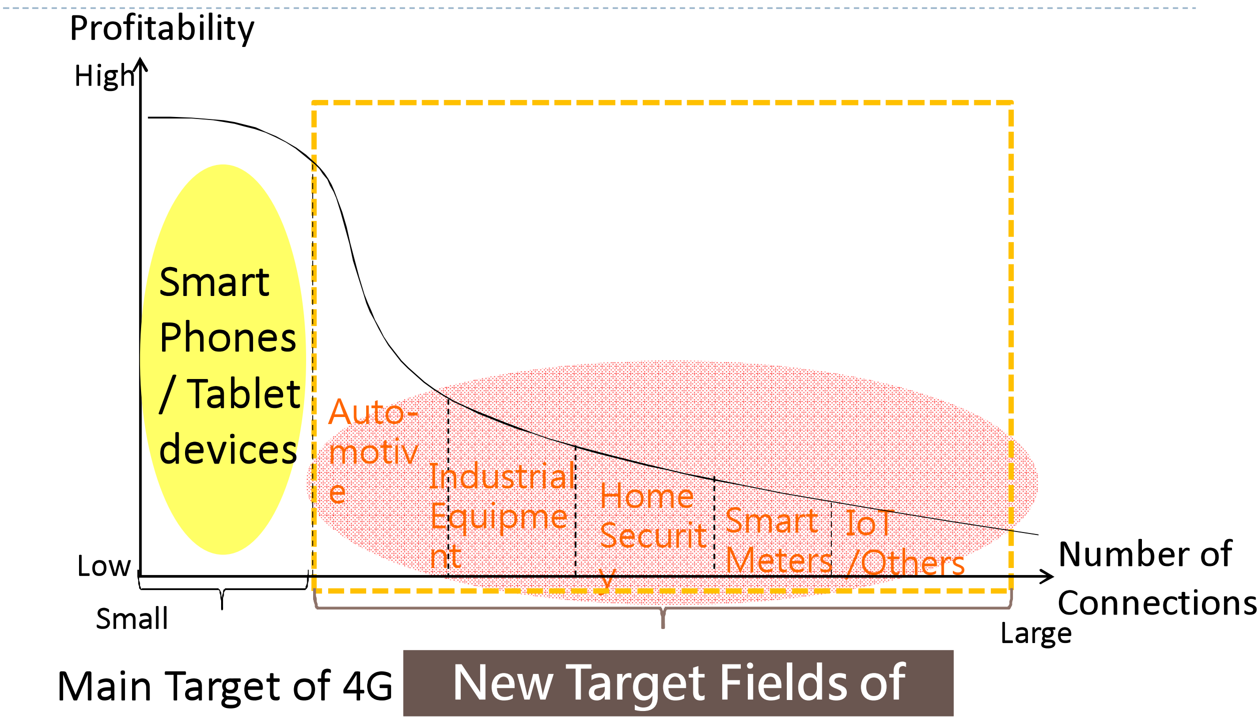
- Difficulty to cover every use case

～5G : Ultra flexibility

○Providing required quality

Source: Ministry of Internal Affairs and Communications(MIC)

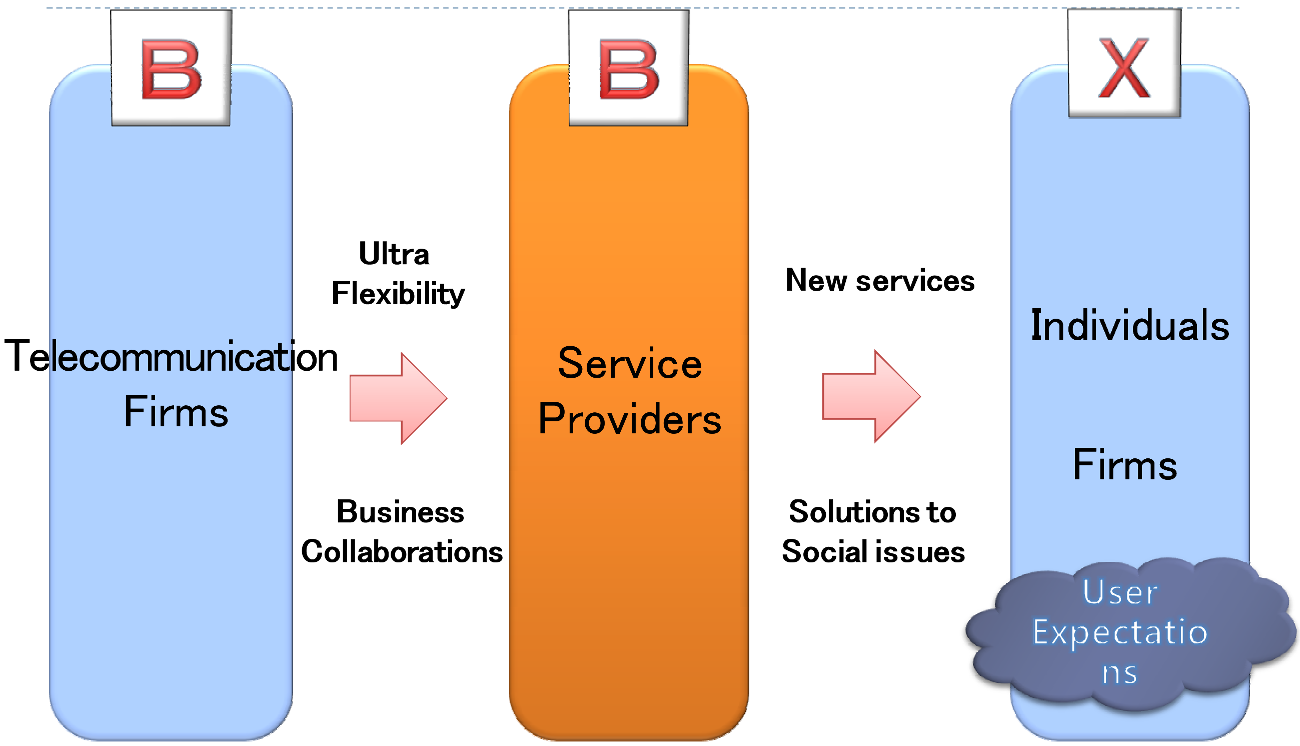
Expansion of business fields



Source: Nikkei Communications April 2015

Source: Ministry of Internal Affairs and Communications(MIC)

5G B2B2X Model



Source: Ministry of Internal Affairs and Communications(MIC)

5G Field Trials in Japan (1)

[Period]

FY 2017 – FY 2019（3 years）

[Places]

Tokyo + Local areas

[Places]

Tokyo + Local areas

[Radio Spectrum]

below 6 GHz, 28 GHz

[Test Environments]

- Urban micro-cell or Urban macro-cell
- Suburban macro-cell or Rural macro-cell
- Indoor hotspot

[Key Capabilities]

- eMBB（10Gbps peak data rate）
- mMTC （1 million connected devices/km^2 ）
- URLLC（1ms over-the-air latency）

Source: Ministry of Internal Affairs and Communications(MIC)

5G Field Trials in Japan (2)

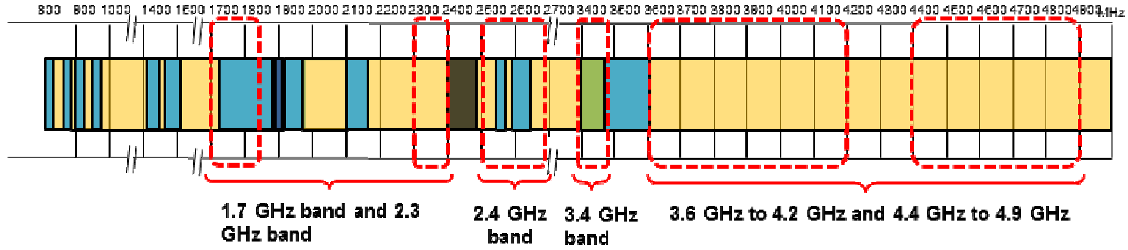
	Responsible Organization	Main Partners	Trial Overview	Main Trial Locations	Technology
Ⅰ	NTT DOCOMO	･TOBU TOWER SKYTREE ･ALSOK ･Wakayama Pref.	･Sightseeing ･Smart Cities ･Medical Services	･Tokyo ･Wakayama	eMBB
Ⅱ	NTT Communications	･Tobu Railways ･Infocity	･Transport	･Tochigi ･Shizuoka	eMBB
Ⅲ	KDDI	･Obayashi Corp. ･NEC	･Construction	･Saitama	URLLC
IV	ATR	･Naha City ･Keikyu Railways	･Entertainment	･Okinawa ･Tokyo/HND	eMBB
V	Softbank	･Advanced Smart Mobility Co., Ltd. ･SB Drive Corp.	･Transport	･Yamaguchi	URLLC
VI	NICT	(TBD)	･Logistics	･Hokkaido	mMTC

＊ Based on current plans, which are subject to change.

Source: Ministry of Internal Affairs and Communications(MIC)

Candidate Frequencies for 5G

Below 6GHz



Assigned (mobile phone)

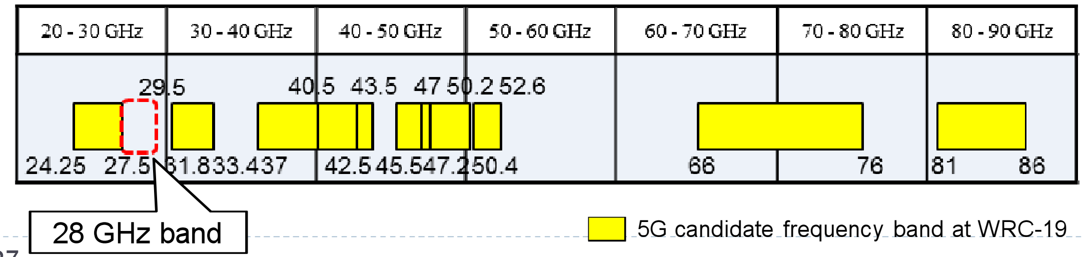
Bandwidth during the transition of the frequency band of existing radio

Assigned (wireless LAN (indoors only))

Band used by other radio stations (satellites, broadcasting, etc.)

Studying new allocation to mobile communications

Above 24GHz



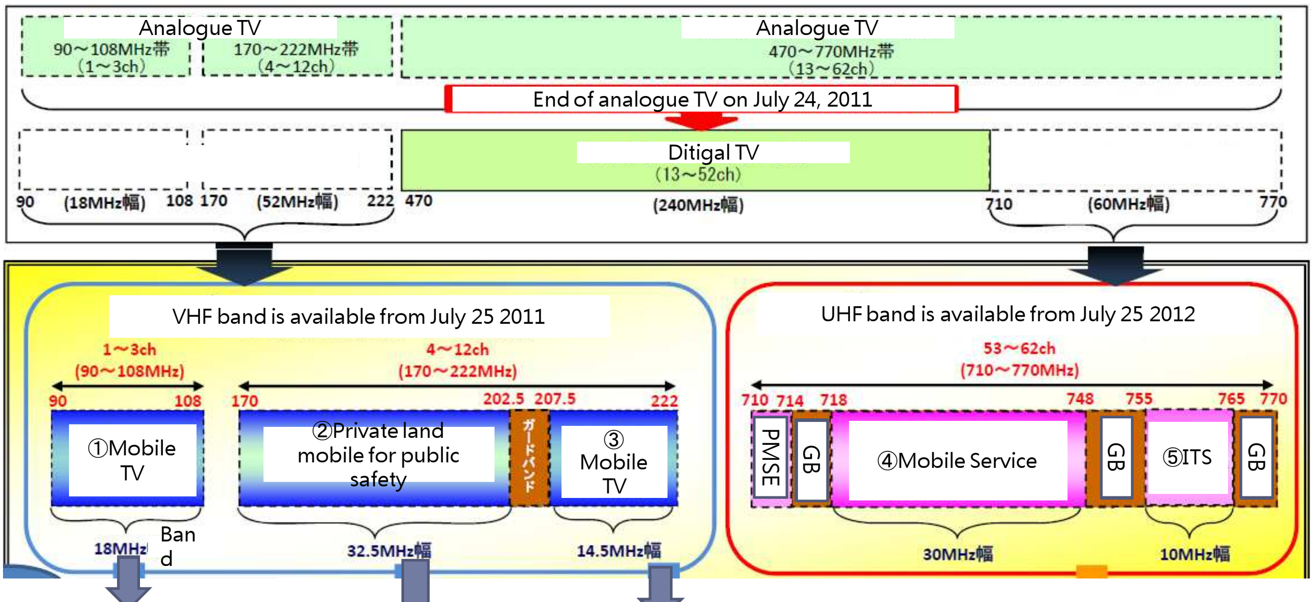
5G candidate frequency band at WRC-19

Source: Ministry of Internal Affairs and Communications (MIC)

References

Applications like 5G in Japan

Spectrum refarming after digital switchover



V-Low: Local services based on 7 blocks

O" i-dio" by Tokyo FM etc. wad lunched on March 2016

V-High: Nationwide service

O" NOTTV" by NTT Docomo was finished on June 2016.

Mobild broadband for public safety services etc.

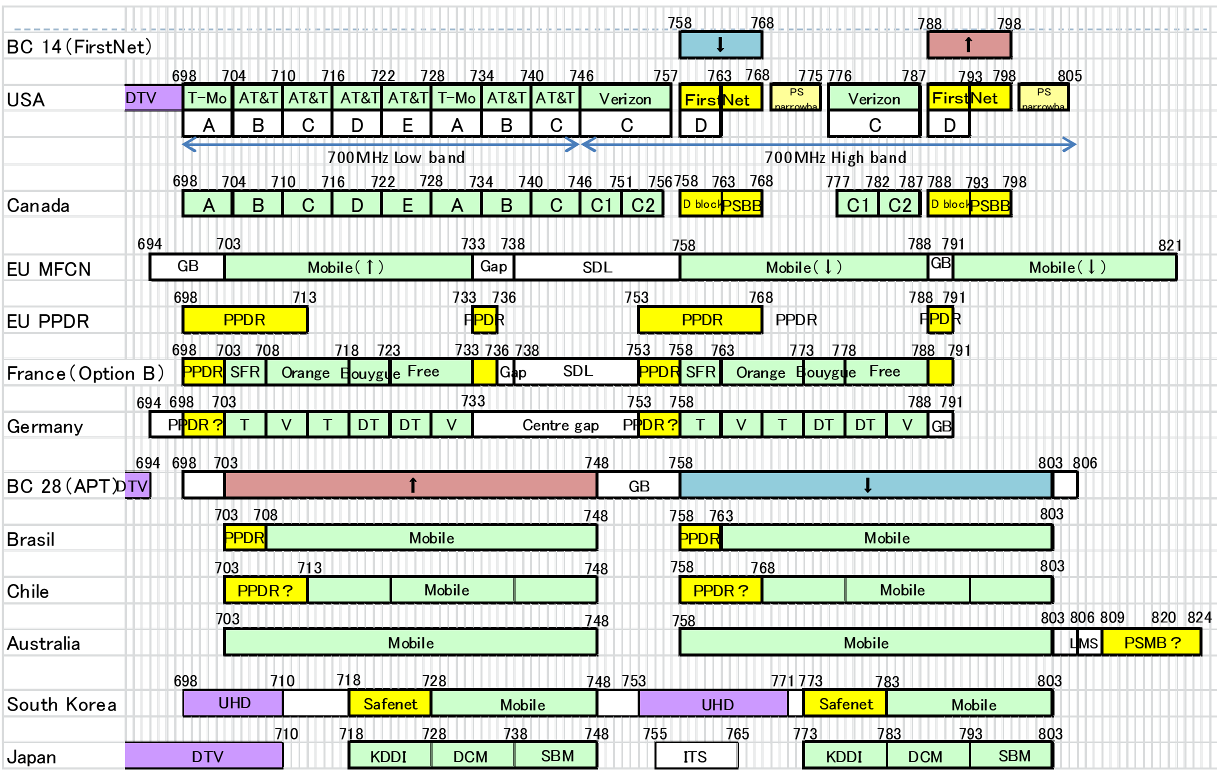
・Video transmission at disaster sites

・Sharing videos between fire, police and emergency officers and staffs on site

Note: "帯" is band and "幅" is bandwidth.

Source: http://www.arib.or.jp/osirase/seminar/no100konwakai.pdf

700MHz band plans after digital switchover

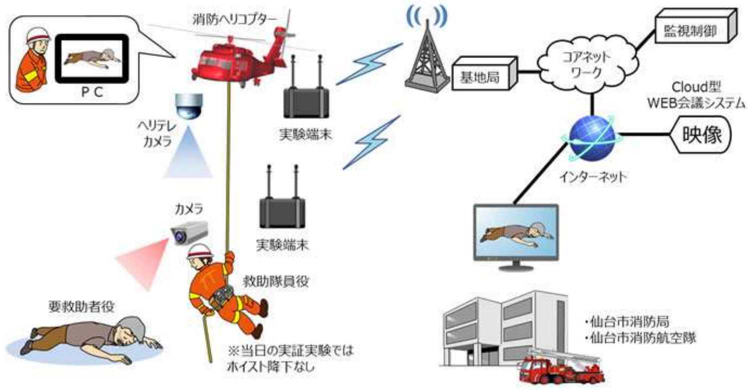


Sources: Various materials

Public Safety TD-LTE using 190MHz band

Field trial by NTT Docomo (June 2017)

Field test on area cover of base station with TD-LTE using VHF band
- Maximum radius: 50km
- Maximum transmission speed of trial device: 50Mbps（↓）／13Mbps（↑）



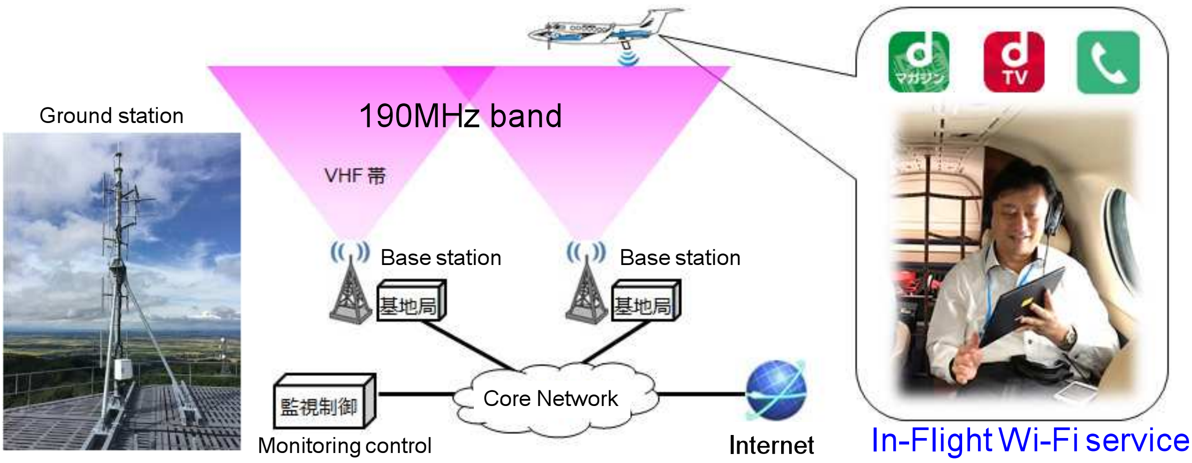
Field test of video transmission
- Broadband communications between helicopter to field staff
- Real-time transmission to multiple facilities

Source: https://www.nttdocomo.co.jp/info/notice/tohoku/page/2017/170613_01.html

Ground-to-air TD-LTE using 190MHz band

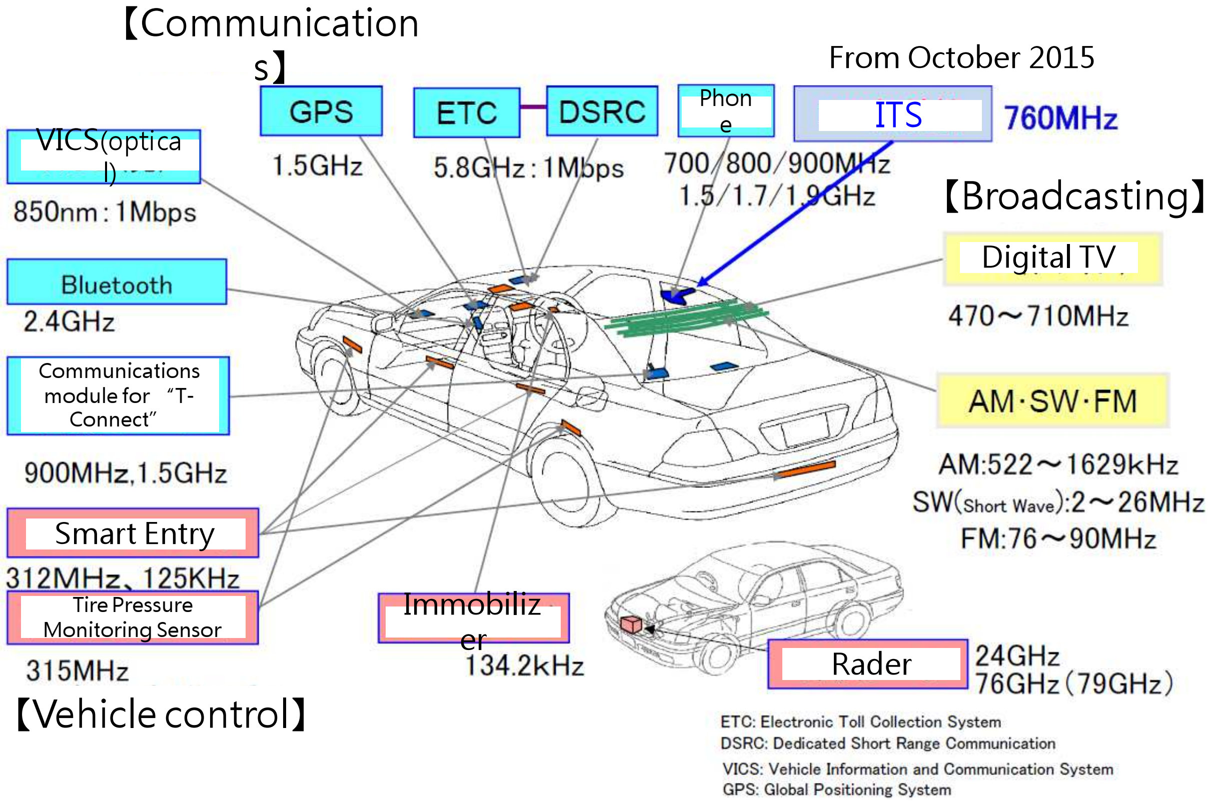
Experimental result
- Altitude：28,500feet（8,700m）
- Radius: 93km
- Cruising speed: 230knot（430km/h）
- Maximum speed: 27Mbps

Partners
- NTT DOCOMO, ELECTRONIC NAVIGATION RESEARCH INSTITUTE(ENRI), All Nippon Airways(ANA), Panasonic, JAMCO Corporation



Source: https://www.nttdocomo.co.jp/info/news_release/2017/08/08_01.html

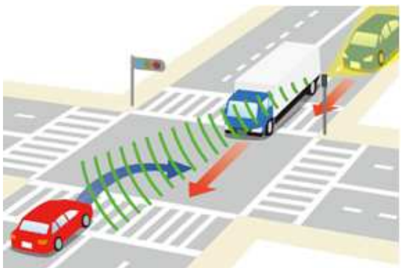
Wireless technologies for Vehicle



Source: http://www.chubu.meti.go.jp/b34jyoho/shiryo/20151020yugoseminar/20151020toyota.pdf

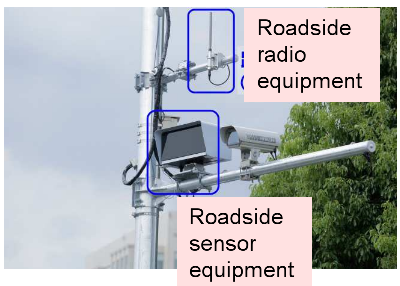
ITS using 760MHz band
Applications of ITS Connect by Toyota

Driving Assistance Service via Use of V2I Communication

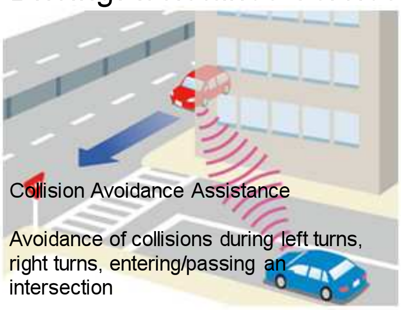


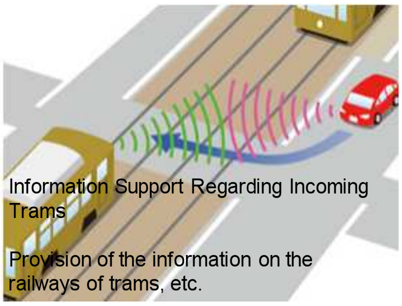
Collision Avoidance Assistance during Right Turns

Assistance in Avoiding the Overlooking of Pedestrian Crossings



Driving Assistance Service via Use of V2V Communication





Source: http://toyota.jp/technology/safety/itsconnect/, https://www.itsconnect-pc.org/en/

THANK YOU FOR YOUR KIND ATTENTION

ご清聴ありがとうございました

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一般財団法人
マルチメディア振興センター
FMMC Foundation for MultiMedia Communications

http://www.fmmc.or.jp/

附件 2

Experience. Outcomes.

4G to 5G: How Will It Happen?

Spectrum Futures 2017

Remus Tan
Senior Advisor, Mobility Networks and Architectures (CTO Office – Asia Pacific)
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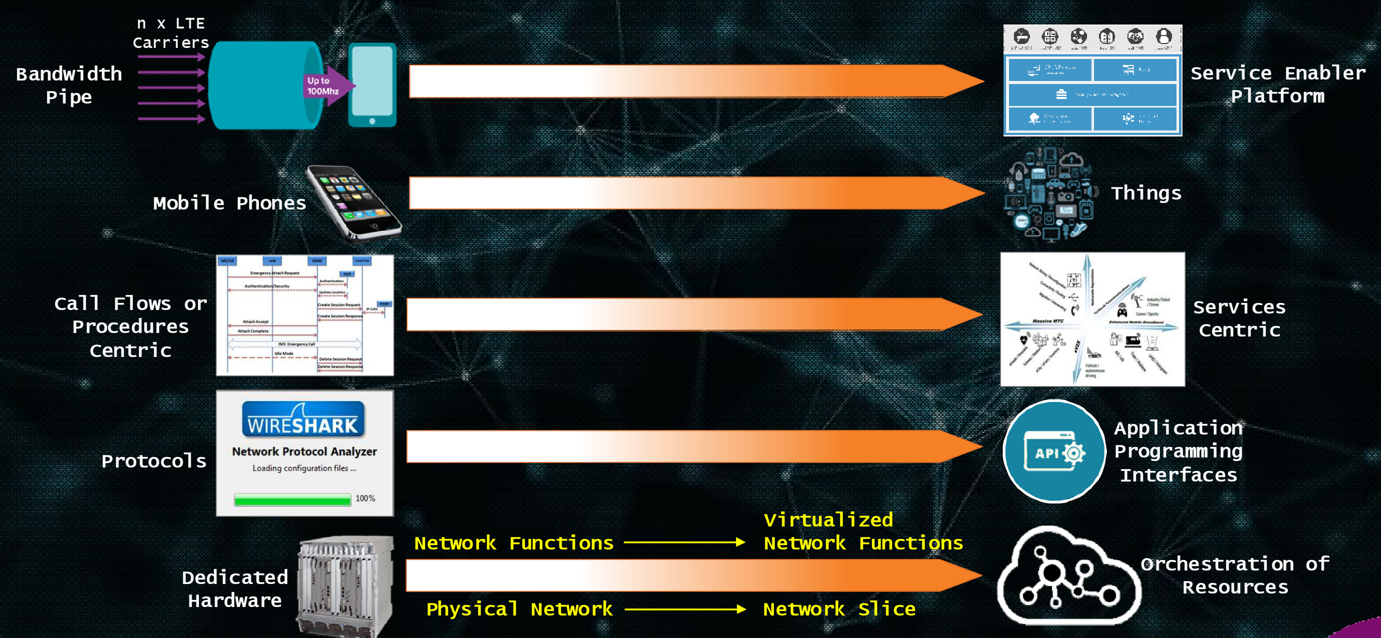
m1: +65 9639.7989 | m2: +886 970.265.322

18th September 2017

Version 1.5

4G to 5G: Significant Network Evolution is Expected in 5G Networks

Transformation Towards a Software & Service Centric Architecture



4G to 5G: Schedule and Key Aspects

3GPP Standardization Status Overview and the Key Aspects of 5G Networks

	09.16 TSG#73	12.16 TSG#74	03.17 TSG#75	06.17 TSG#76	09.17 TSG#77	12.17 TSG#78	03.18 TSG#79	06.18 TSG#80	09.18 TSG#81	12.18 TSG#82	03.19 TSG#83	06.19 TSG#84	09.19 TSG#85	12.19 TSG#86	03.20 TSG#87
Rel-14	Stage 2		Stage 3	ASN.1											
Rel-15			Stage 1			Stage 2		Stage 3	ASN.1	5G Phase 1					
Rel-16		5G Phase 2								Stage 1		Stage 2		Stage 3	ASN.1

- Rel-14 freezing (completion of ALL items) at TSG#76
  - Some aspects continue (e.g. testing, legal intercept) but expected to conclude by 12.17
- Rel-15
  - Stage 1 freeze at TSG#76
  - Underway: Stage 2 5G Work on architecture, security, charging, management in SA, studies on 5G aspects of protocols, end-to-end aspects in CT, studies on RAN aspects

5G Spectrum & Use Cases | RAN Centralization & RAN Virtualization | Control/User Plane Split in RAN & Core | Deterministic Networking in 5G | Network Virtualization | End-to-End Network Slicing

4G to 5G: Standards vs Open Sources (Part One)

Key Standards Development Organizations and Forums Chartering the Path for 5G and Future Networks

3GPP A GLOBAL INITIATIVE

ITU

ETSI World Class Standards

IEEE

ngmn the engine of broadband wireless innovation

SMALL CELL FORUM Solving the HetNet puzzle

CPRI Common Public Radio Interface

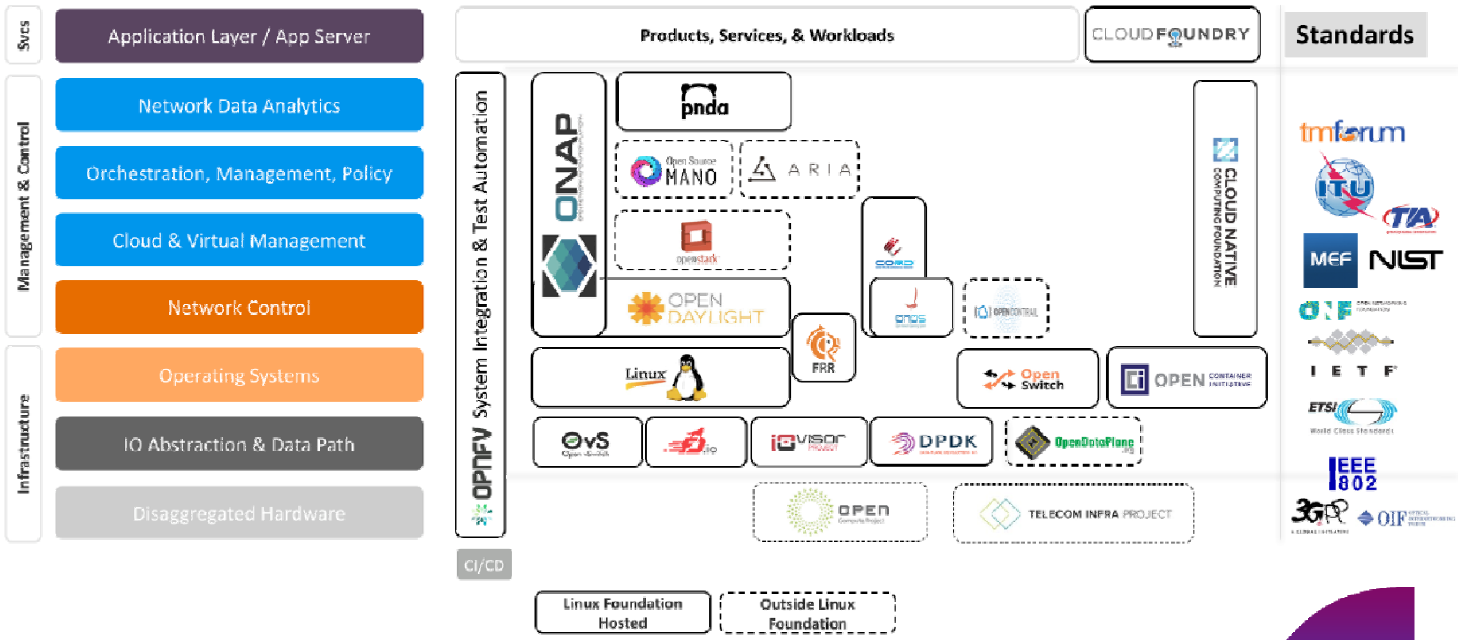
IETF

OIF OPTICAL INTERNETWORKING FORUM

MEF METRO ETHERNET FORUM

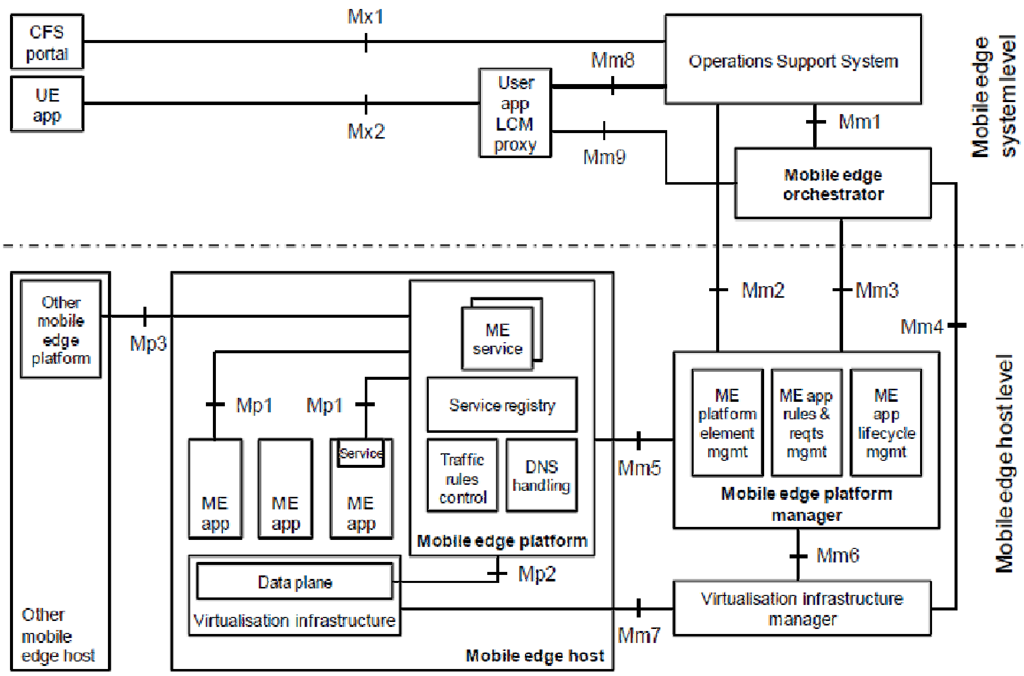
4G to 5G: Standards vs Open Sources (Part Two)

Linux Foundation Unified Open Networking & Orchestration Architecture



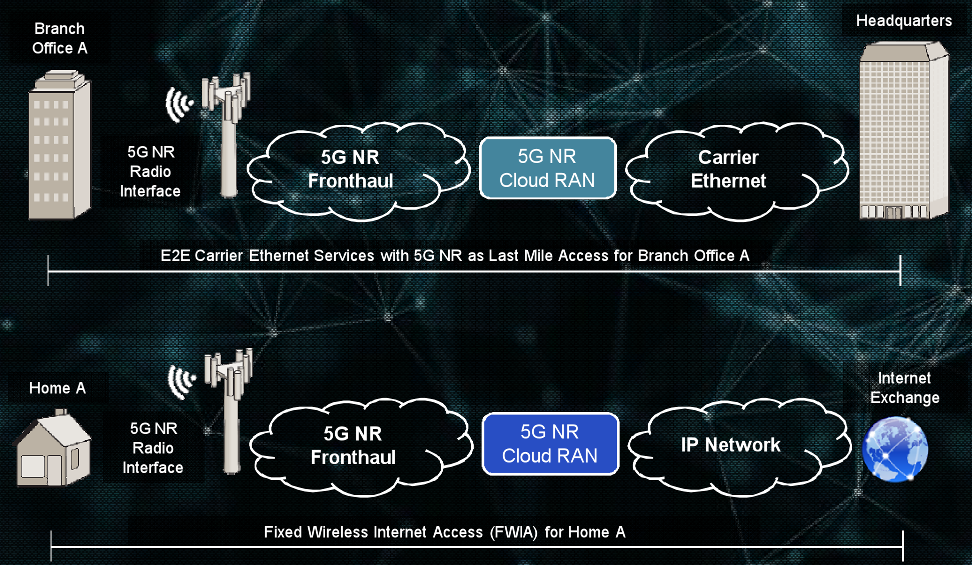
4G to 5G: Realization of ETSI Multi-Access Edge Compute (MEC) Architecture

Real Time Payloads Processing • Network Data Analytics & Continuous Control



4G to 5G: Fixed 5G Services (Pre-5G) with mmWave Spectrum

Fixed Wireless Internet Access (FWIA) & Wireless Carrier Ethernet Services (W-CES) Made Possible with 5G NR (Standardization-in-Progress)



For Both Scenarios:

- 5G NR Cloud RAN **does not connect back** to a 5G Next-Gen Core User Plane Function (UPF). They connect directly into a Fixed Line Services Network
- Such Fixed Line Equivalent Services are made possible due to a **high amount of available spectrum** in the Above 6GHz spectrum
- Leverages 5G NR **PDU** capabilities (e.g. **Ethernet**, IPv4/IPv6 and Non-IP)
- Service Data Flow QoS is now fully accessible in the RAN due to the **new SDAP sublayer** introduced in the 5G NR RAN Stack

4G to 5G: Mobile 5G Services with Sub-6GHz Spectrum

Significant Focus on Low Latency and High Reliability Communications Network to Deliver Mission Critical 5G Services

Smart Cities
(Massive Machine-Type Communications)
Both IP-based & Non-IP based

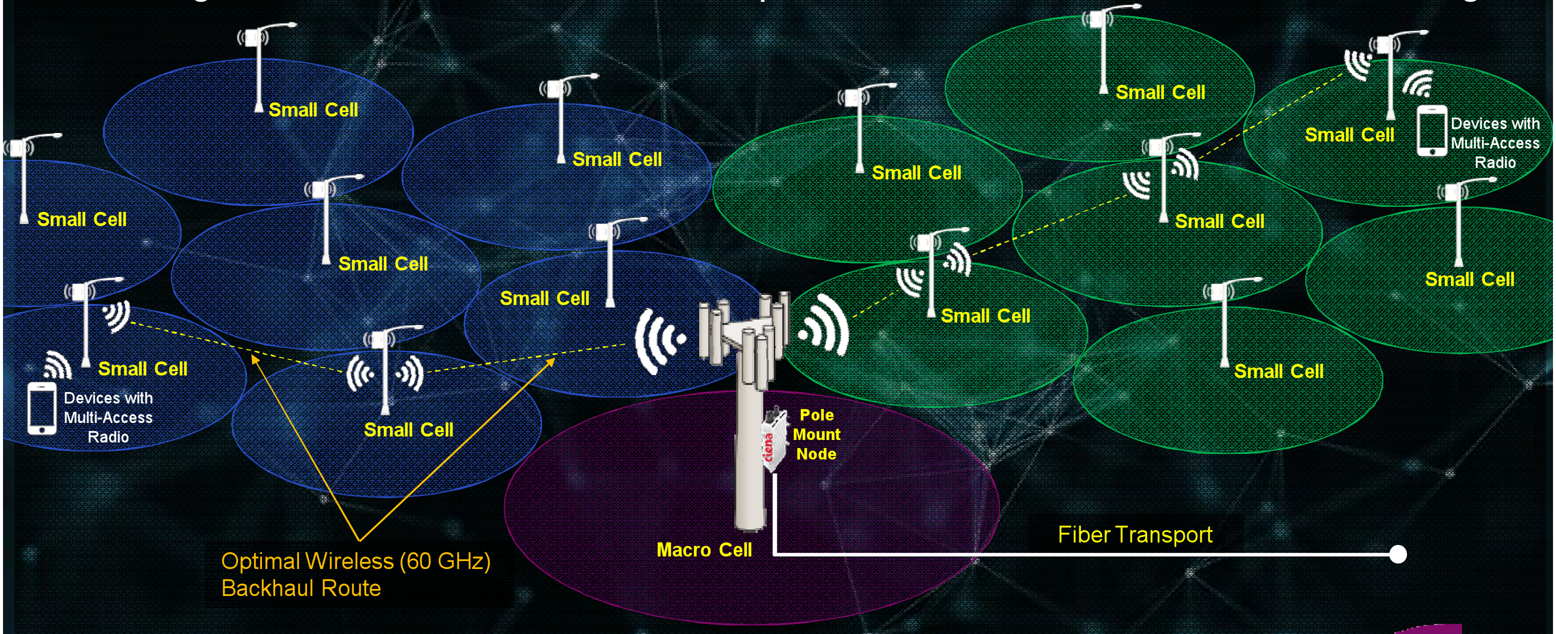
Mobile Broadband
(Enhanced MBB)

Drone Operations
(Ultra-Reliable Low Latency Communications)

Cellular V2X
(Ultra-Reliable Low Latency Communications)

4G to 5G: Mobile 5G Services with Sub-6GHz Spectrum

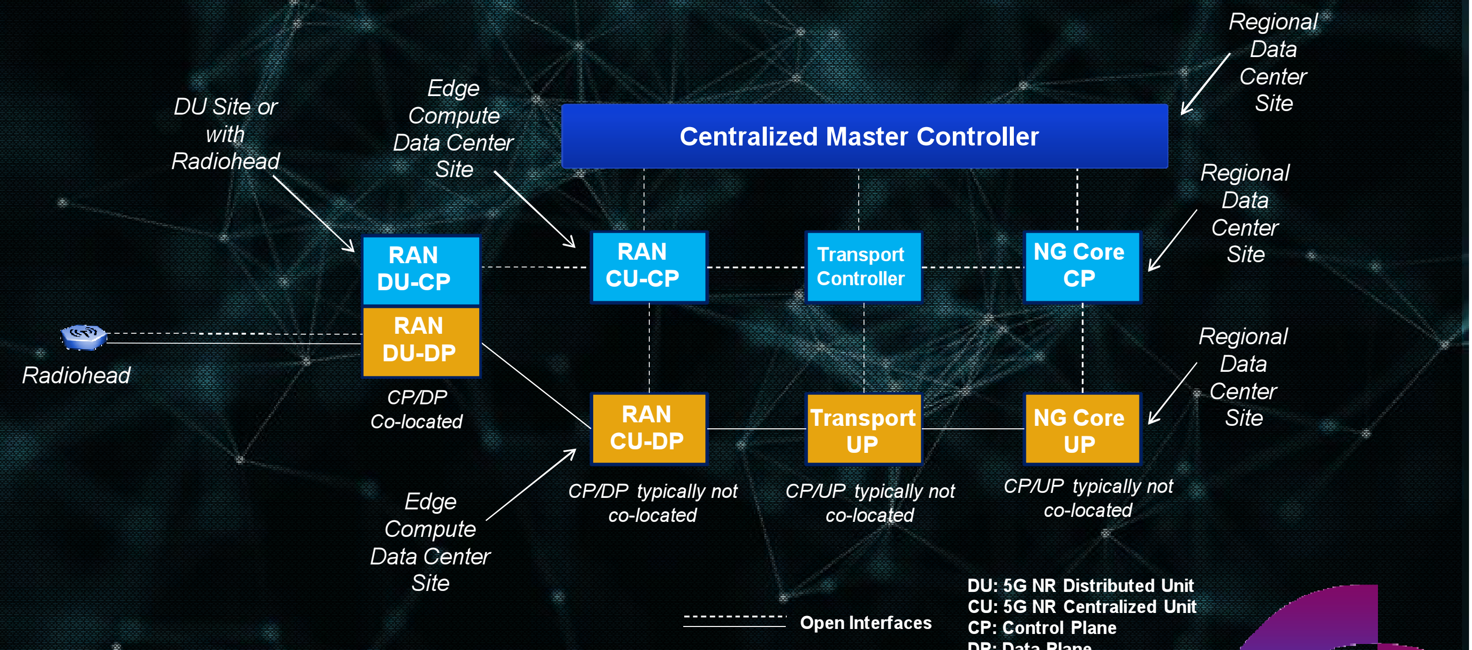
Achieving Cell Densification with Multi-Hop Wireless Mesh Self-Backhaul Technologies



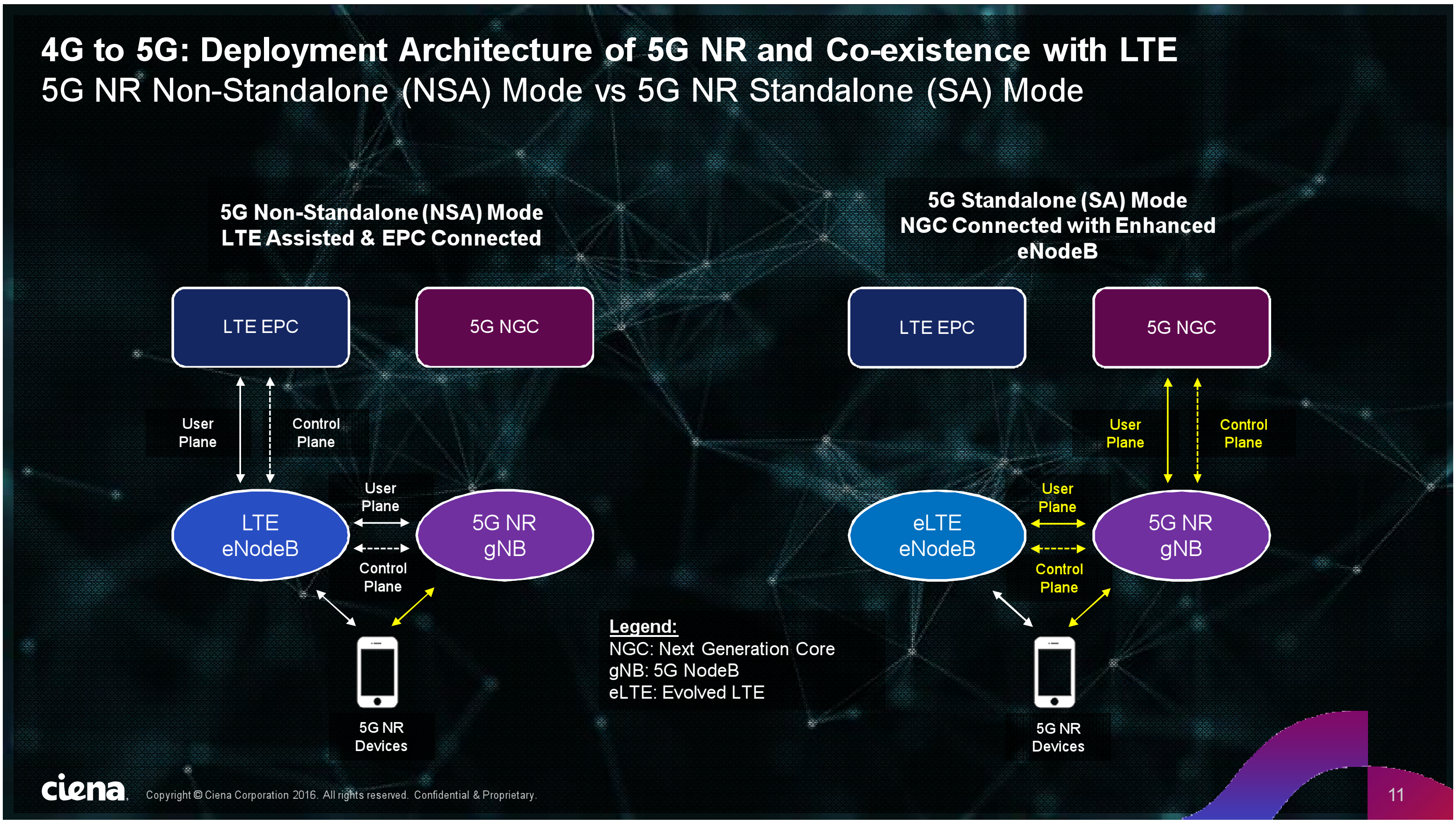
60 GHz Multi-Hop Wireless Mesh Self-Backhaul Concept

4G to 5G: Control/User Plane Split in RAN & Core

Future State Architecture for 5G NR RAN, 5G Next Gen Core and 5G Transport



DU: 5G NR Distributed Unit
CU: 5G NR Centralized Unit
CP: Control Plane
DP: Data Plane
UP: User Plane


4G to 5G: Deployment Architecture of 5G NR and Co-existence with LTE
5G NR Non-Standalone (NSA) Mode vs 5G NR Standalone (SA) Mode
5G Non-Standalone (NSA) Mode
LTE Assisted & EPC Connected
LTE EPC
5G NGC
User Plane
Control Plane
LTE eNodeB
User Plane
Control Plane
5G NR gNB
5G NR Devices
5G Standalone (SA) Mode
NGC Connected with Enhanced eNodeB
LTE EPC
5G NGC
User Plane
Control Plane
eLTE eNodeB
User Plane
Control Plane
5G NR gNB
5G NR Devices
Legend:
NGC: Next Generation Core
gNB: 5G NodeB
eLTE: Evolved LTE
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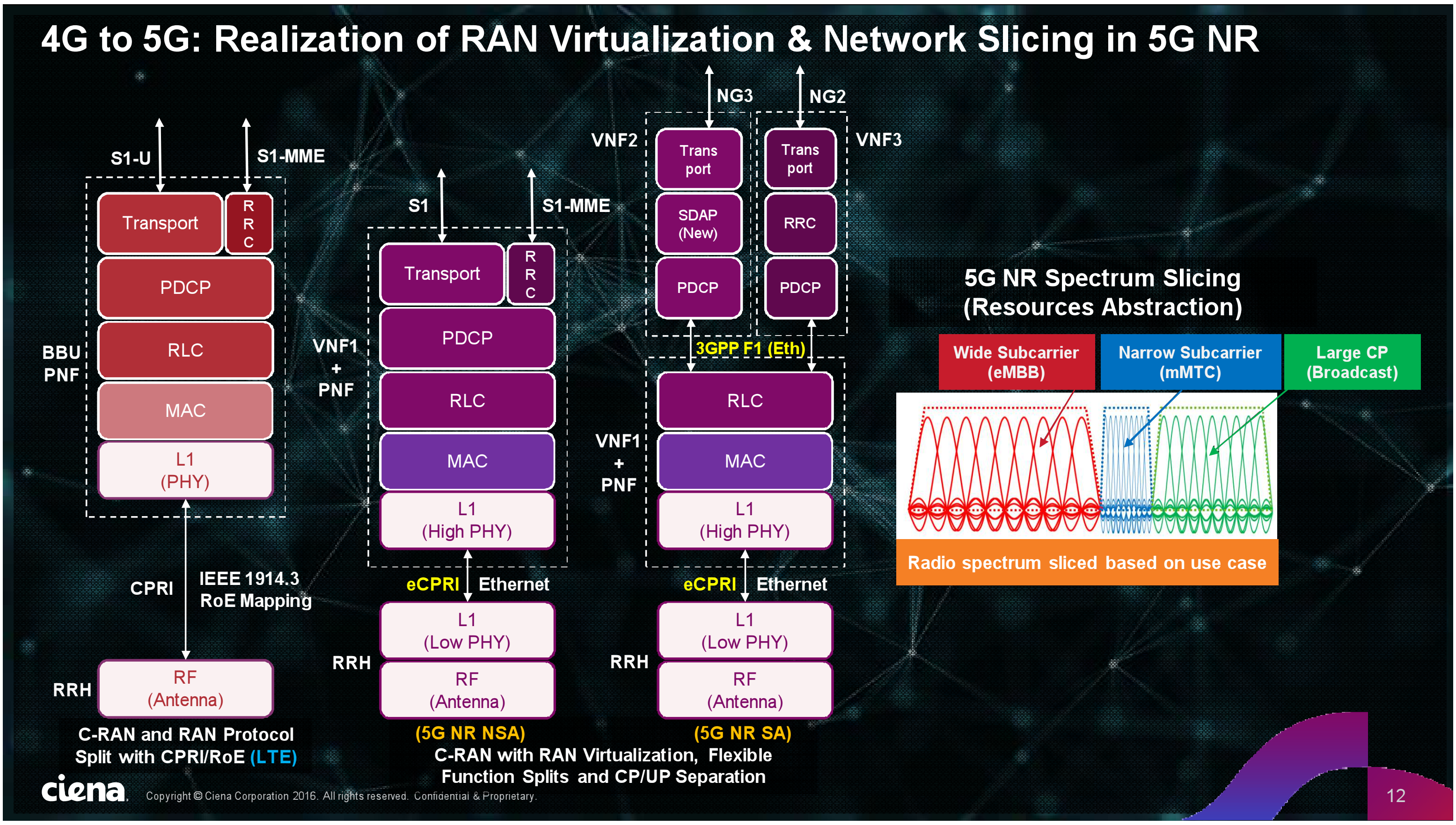
4G to 5G: Realization of RAN Virtualization & Network Slicing in 5G NR
S1-U
S1-MME
Transport
RRC
PDCP
RLC
MAC
L1 (PHY)
BBU PNF
CPRI
IEEE 1914.3 RoE Mapping
RRH
RF (Antenna)
C-RAN and RAN Protocol Split with CPRI/RoE (LTE)
S1
S1-MME
Transport
RRC
PDCP
RLC
MAC
L1 (High PHY)
VNF1 + PNF
eCPRI
Ethernet
L1 (Low PHY)
RRH
RF (Antenna)
(5G NR NSA)
NG3
NG2
VNF2
VNF3
Trans port
SDAP (New)
PDCP
Trans port
RRC
PDCP
3GPP F1 (Eth)
RLC
MAC
L1 (High PHY)
VNF1 + PNF
eCPRI
Ethernet
L1 (Low PHY)
RRH
RF (Antenna)
(5G NR SA)
C-RAN with RAN Virtualization, Flexible Function Splits and CP/UP Separation
5G NR Spectrum Slicing (Resources Abstraction)
Wide Subcarrier (eMBB)
Narrow Subcarrier (mMTC)
Large CP (Broadcast)
Radio spectrum sliced based on use case
ciena
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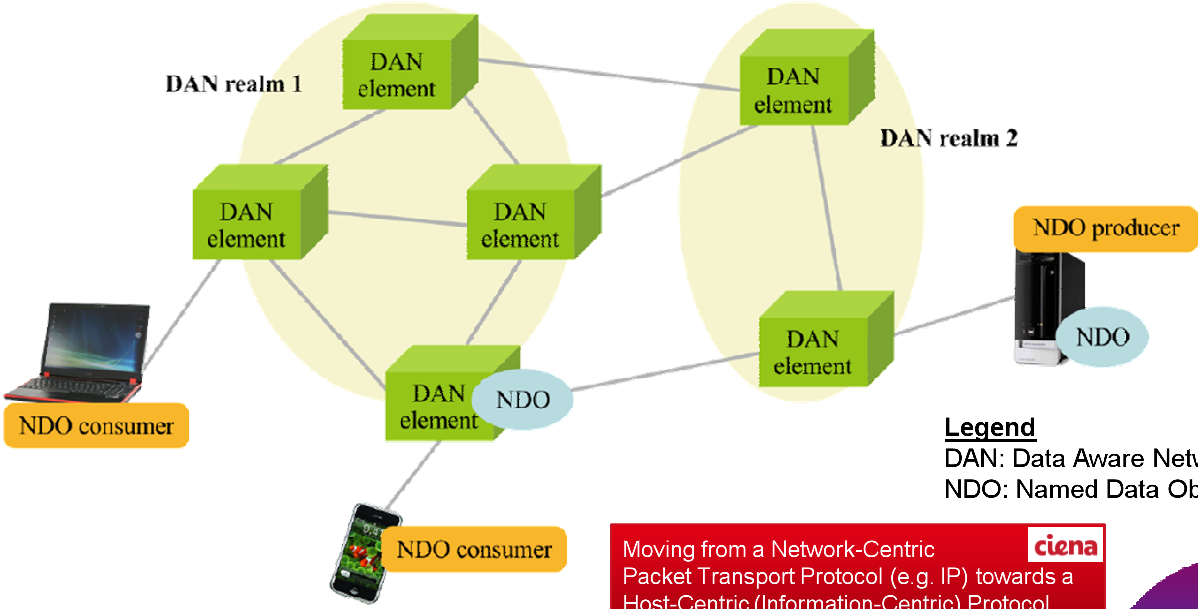
12

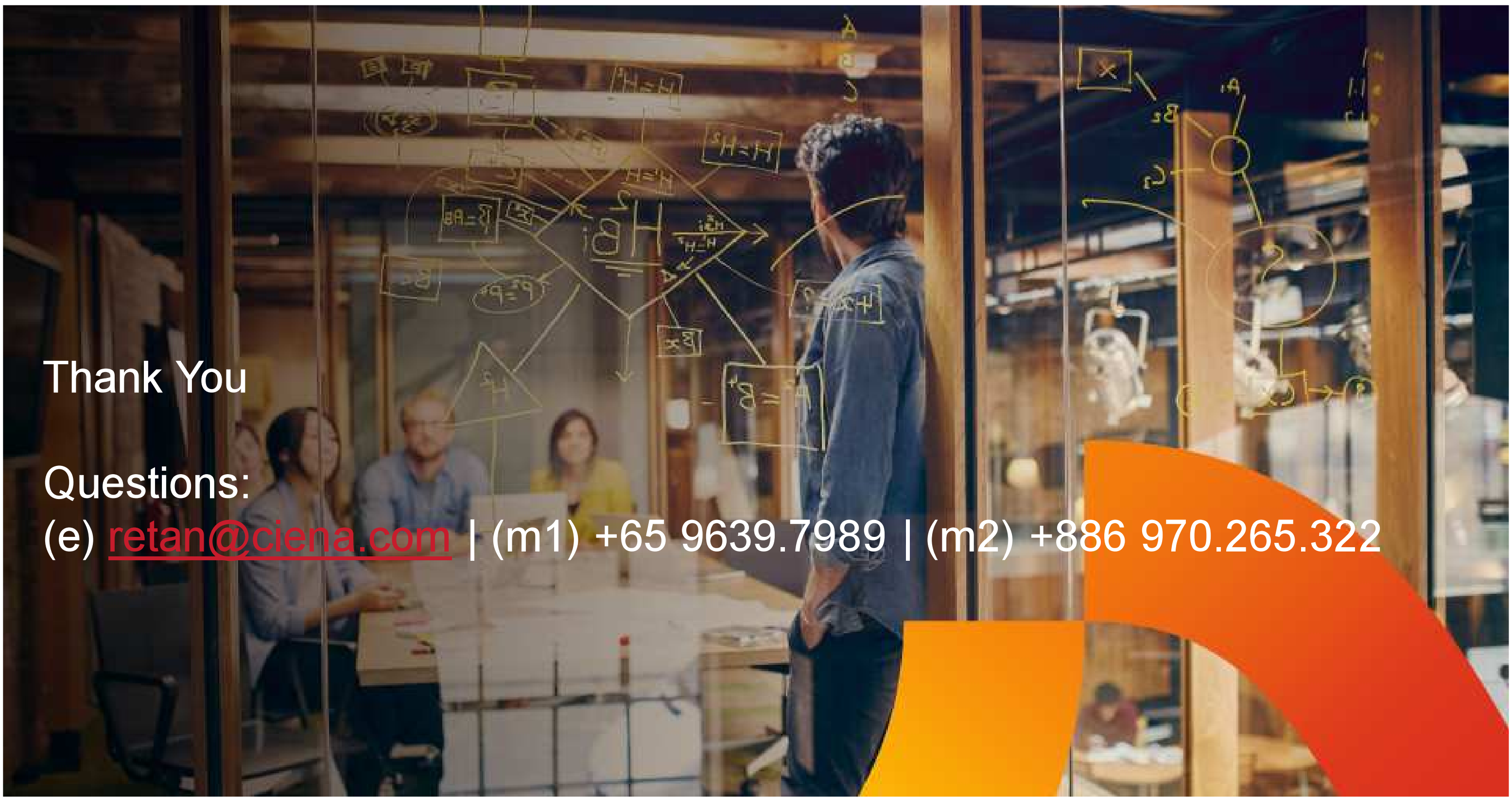
4G to 5G: What Next Generation Networks Really Means

Next Generation Protocol Recommendations for Future Networks: ITU-T SG-13 Y.3071 Data Aware Networking (Information Centric Networking)



Legend
DAN: Data Aware Networking
NDO: Named Data Objects

Moving from a Network-Centric Packet Transport Protocol (e.g. IP) towards a Host-Centric (Information-Centric) Protocol



Thank You

Questions:
(e) retan@ciena.com | (m1) +65 9639.7989 | (m2) +886 970.265.322

Future X Network

Sanjay Kamat
Managing Partner, Bell Labs Consulting

NOKIA Bell Labs

Future X → New network architecture for the 5G era (and beyond)

WHY NEW ARCHITECTURE?

A. One Huge Expectation on Creating New Value
- **Enable the Next Technological Revolution**

B. Three Fundamental Limits
- **Physics, Mathematics, Economics**

C. Seven Dominant Forces Shaping the Architecture

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Humanity's Needs | Human Needs

Technological Revolution

=

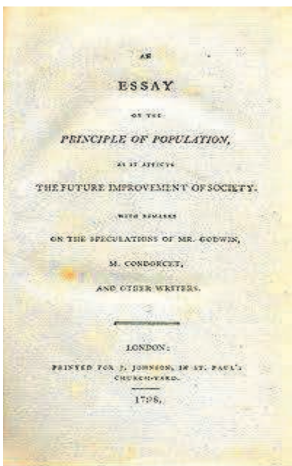
Interconnection and interdependence of new systems and technologies

\+

The capacity to profoundly transform the economy and eventually society

New Value Creation – How?

Remember Malthus and his dismal prophecy?

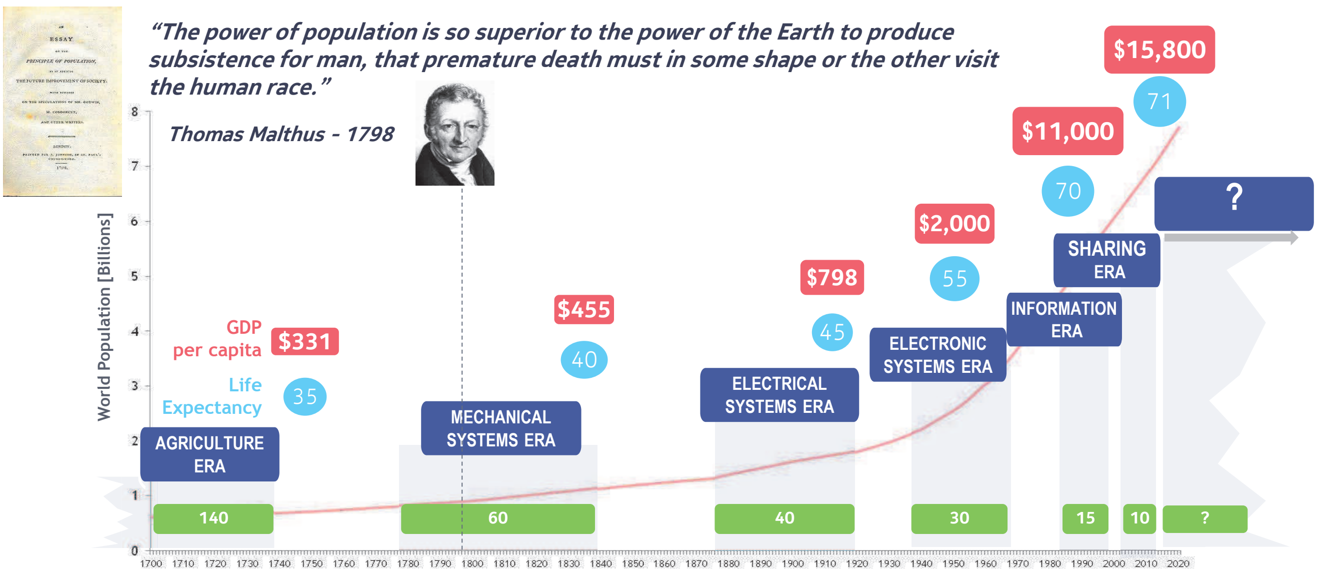

AN
ESSAY
ON THE
PRINCIPLE OF POPULATION,
AS IT AFFECTS
THE FUTURE IMPROVEMENT OF SOCIETY.
WITH REMARKS
ON THE SPECULATIONS OF MR. GODWIN,
M. CONDORCET,
AND OTHER WRITERS.
LONDON:
PRINTED FOR J. JOHNSON, IN ST. PAUL'S
CHURCH-YARD.
1798.

"The power of population is so superior to the power of the Earth to produce subsistence for man, that premature death that must in some shape or the other visit the human race."

Thomas Malthus - 1798

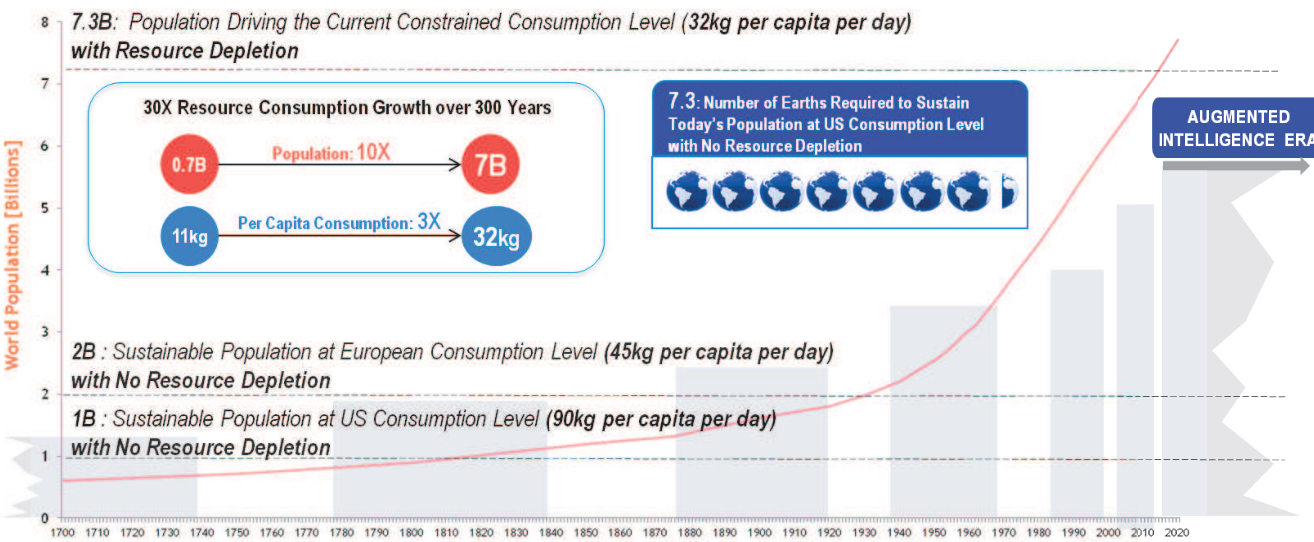
How did we prove him wrong?

Technological Revolutions – Creation of new value



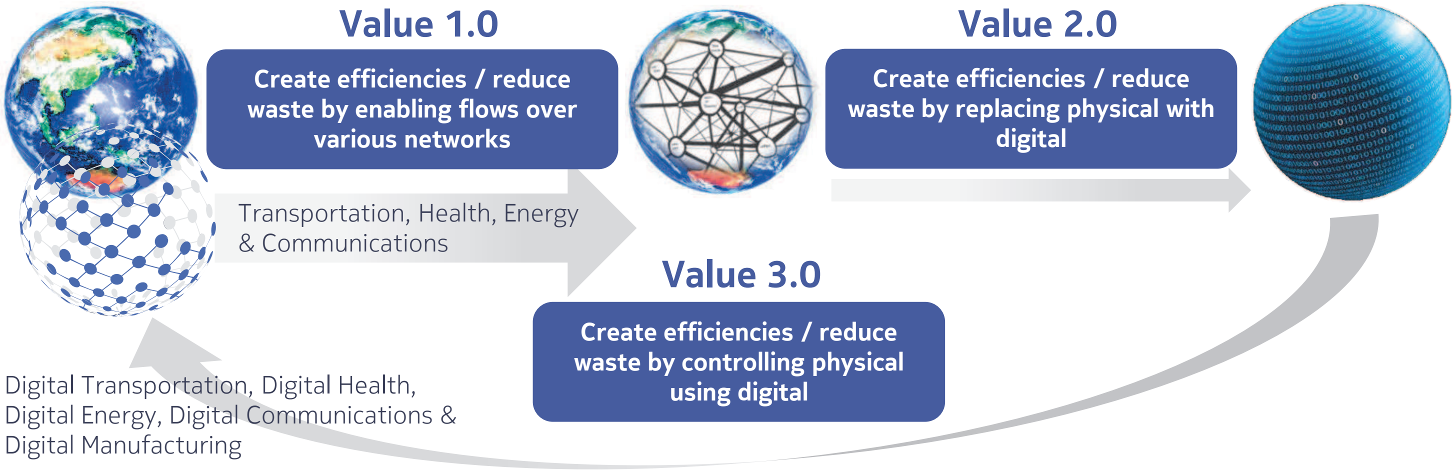
Our industry has helped create the "sharing era" – what is next?

Creating New Value – for "Augmented Intelligence Era"



Can our industry help crack the problem of enabling sustainable growth?

Our Thesis - Digitization as enabler of "Networked Augmented Intelligence"

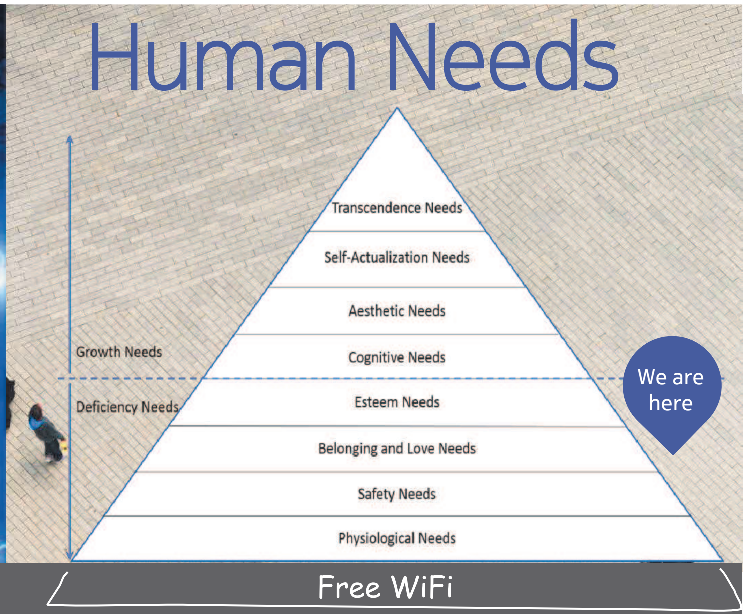


Automation, Optimization & Control of everything that matters

New Value
– Remove waste

How?
– Sense, Analyze, Control X
where X = …

New Value Creation – How?



New Value Creation – How?

New Value
– Create / Save time

How?
– Automate X

where X = …

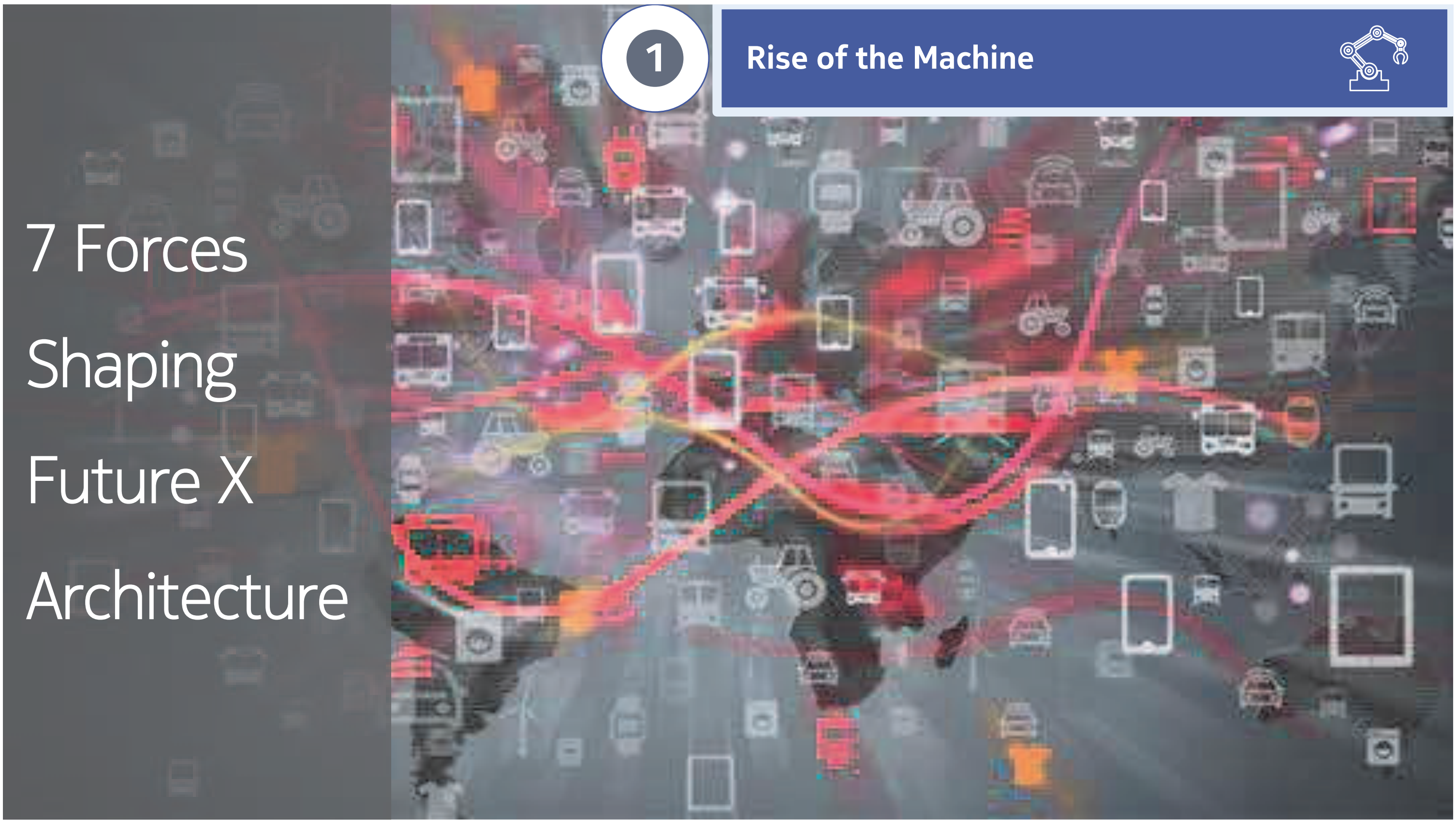
– While building and keeping

New Value
– Create new eXperiences

How?
– Connect Digital and Physical X
where X = ...

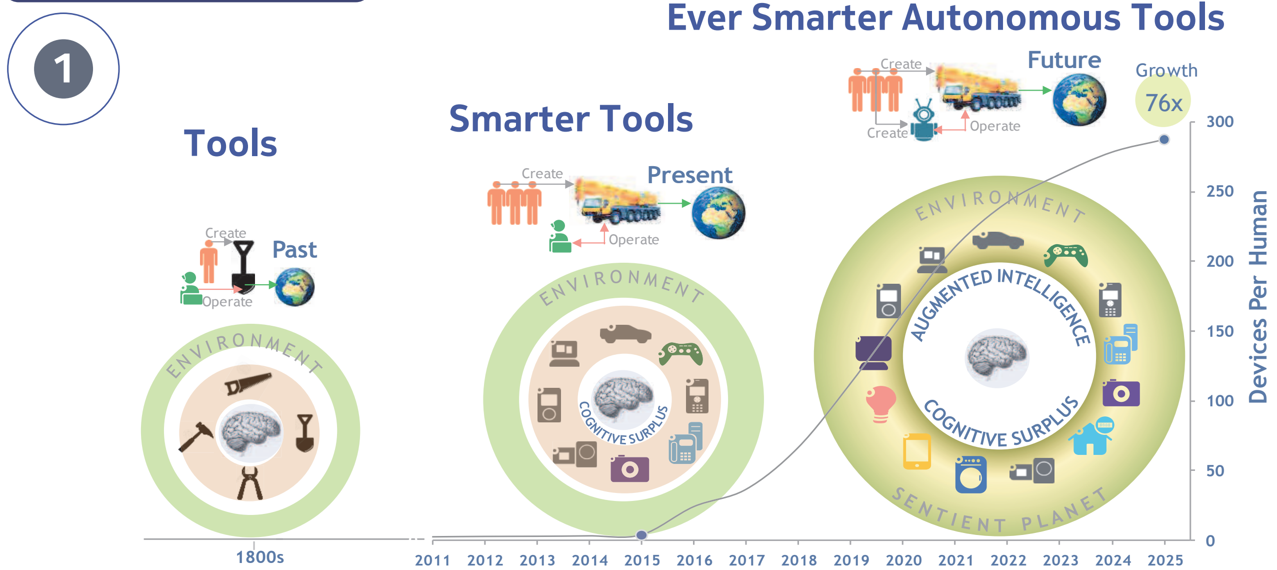
New Value
– Create new knowledge

How?
– *Augmented* Intelligence to better understand X
where X = ...



Rise of the Machine = Create time, experience, knowledge → remove waste

Ever Smarter Autonomous Tools



From Mechanical Advantage to Cognitive Advantage – with new network

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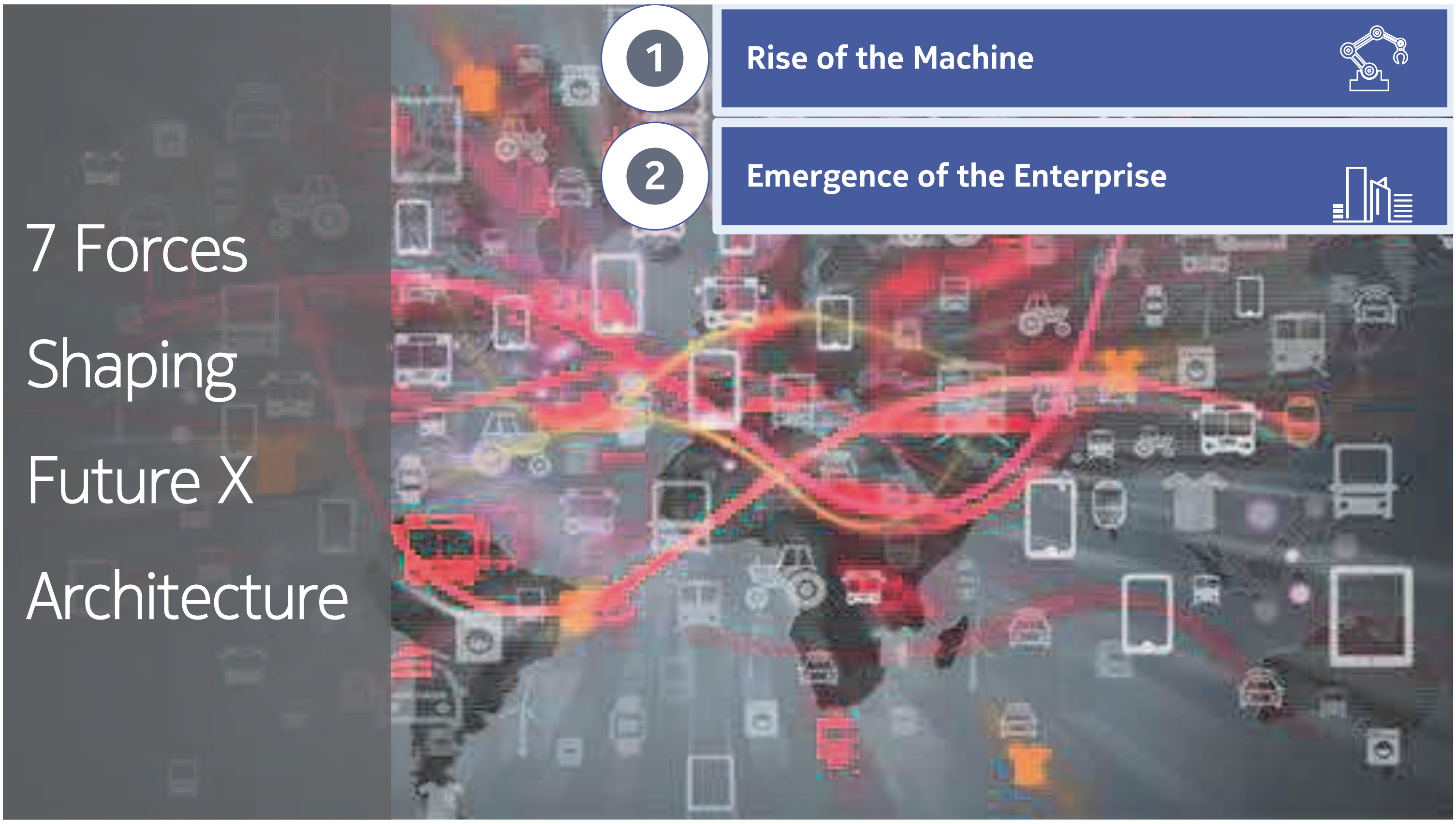


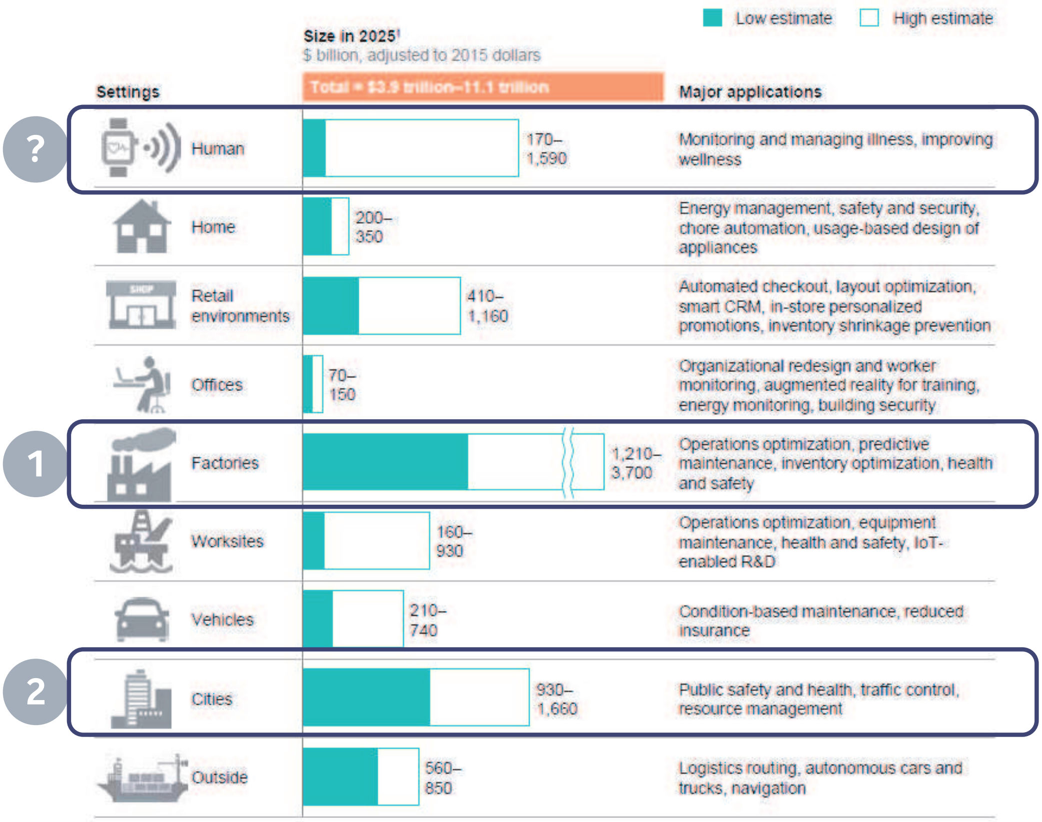
Economic Value

$3.8T-$11T economic impact in 2025

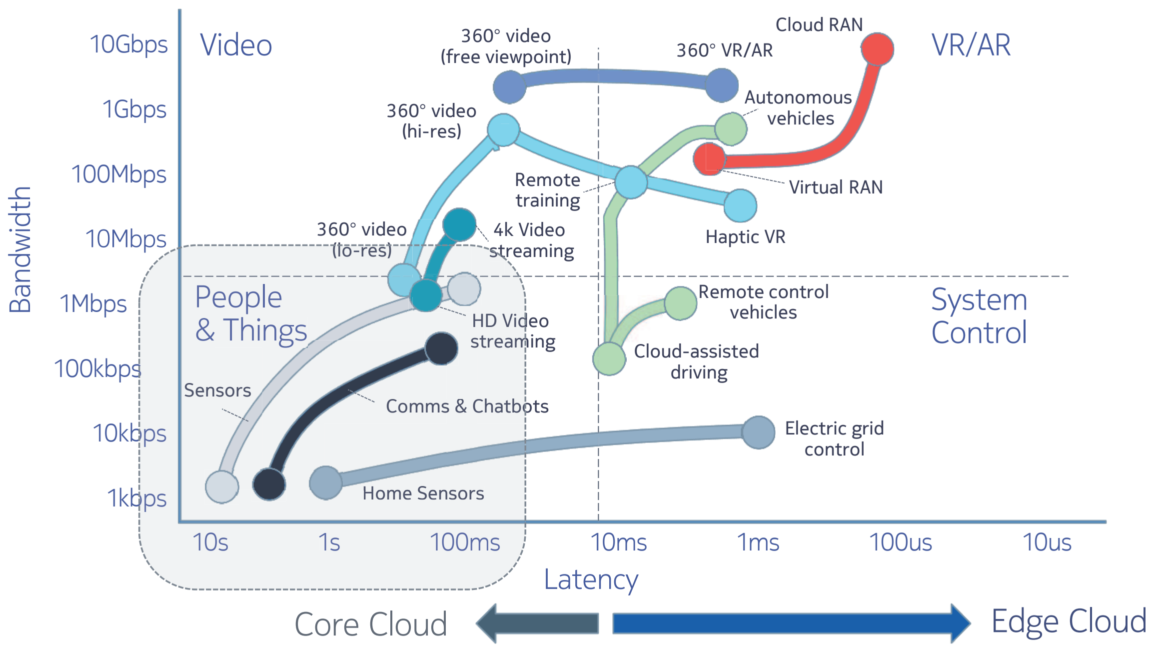
Source: McKinsey Global Institute, The Internet of Things: Mapping the Value Beyond the Hype, June 2015

Emergence of the Enterprise

2



Latency & bandwidth matter … for new digital experiences + saving time



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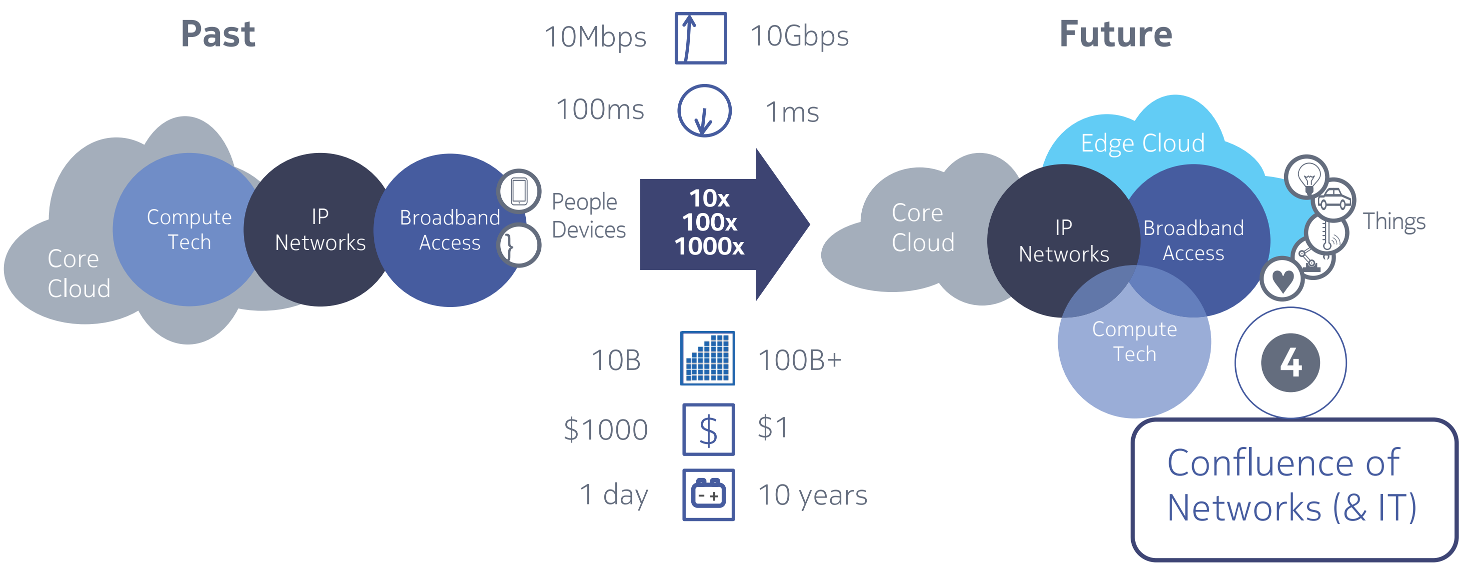
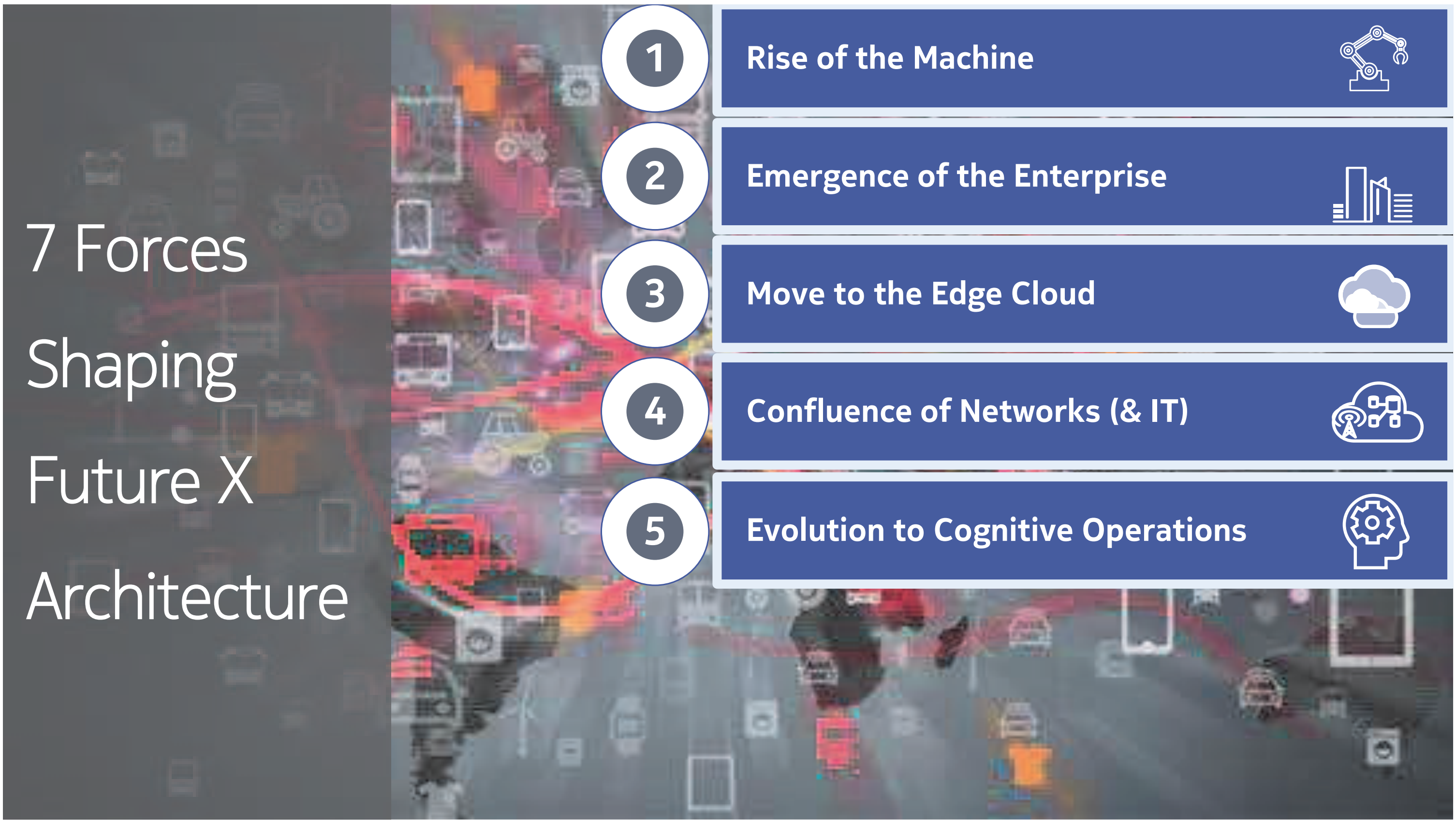
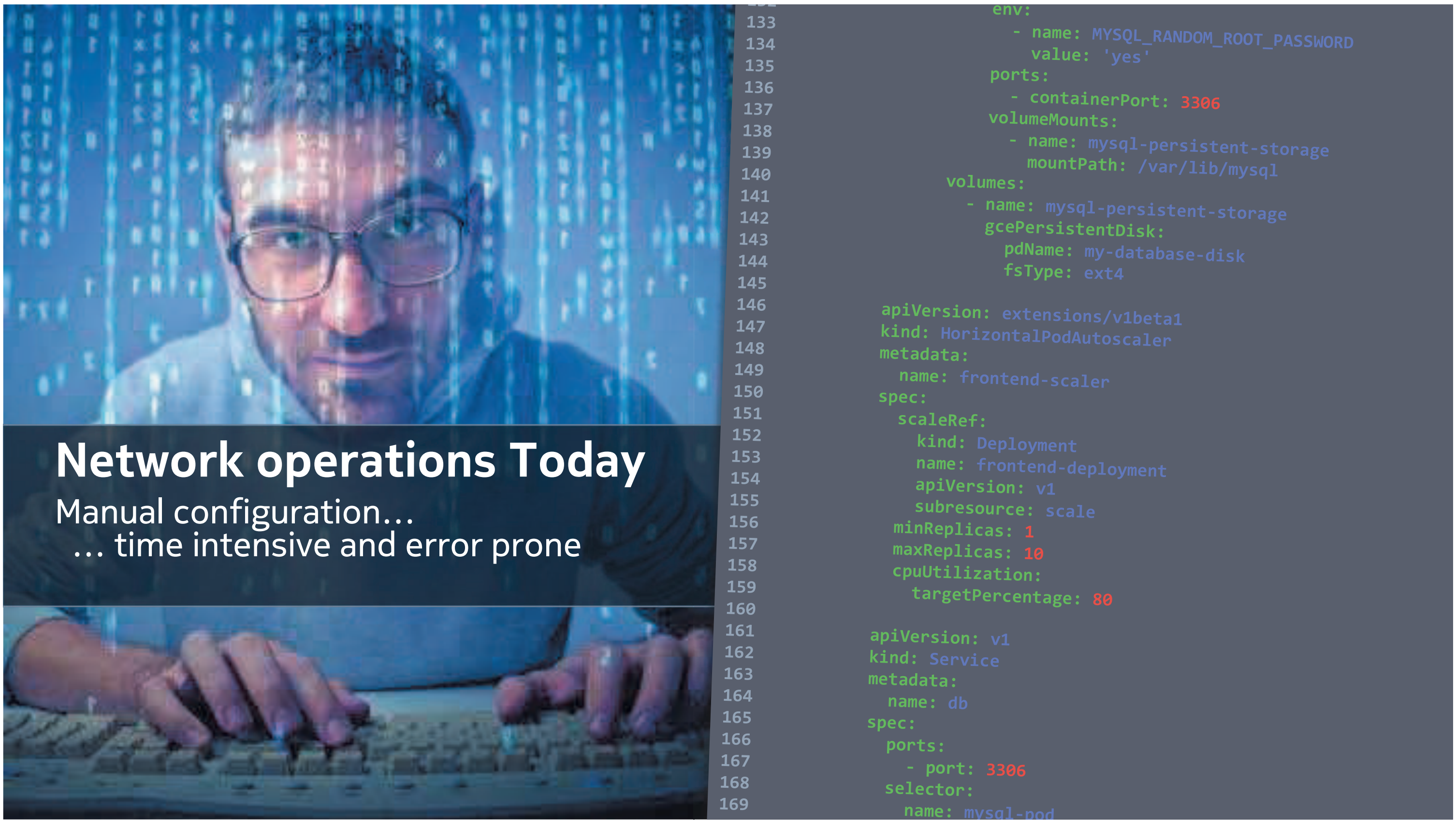
Architecture – old silos vs. new convergence (& joint optimization)



Radically new distributed network architecture to support confluence of technologies


7 Forces
Shaping
Future X
Architecture
1
Rise of the Machine
2
Emergence of the Enterprise
3
Move to the Edge Cloud
4
Confluence of Networks (& IT)
5
Evolution to Cognitive Operations


Network operations Today
Manual configuration…
… time intensive and error prone
env:
- name: MYSQL_RANDOM_ROOT_PASSWORD
value: 'yes'
ports:
- containerPort: 3306
volumeMounts:
- name: mysql-persistent-storage
mountPath: /var/lib/mysql
volumes:
- name: mysql-persistent-storage
gcePersistentDisk:
pdName: my-database-disk
fsType: ext4
apiVersion: extensions/v1beta1
kind: HorizontalPodAutoscaler
metadata:
name: frontend-scaler
spec:
scaleRef:
kind: Deployment
name: frontend-deployment
apiVersion: v1
subresource: scale
minReplicas: 1
maxReplicas: 10
cpuUtilization:
targetPercentage: 80
apiVersion: v1
kind: Service
metadata:
name: db
spec:
ports:
- port: 3306
selector:

Network Operations Future

Fully automated…

… self-orchestrating – Network OS

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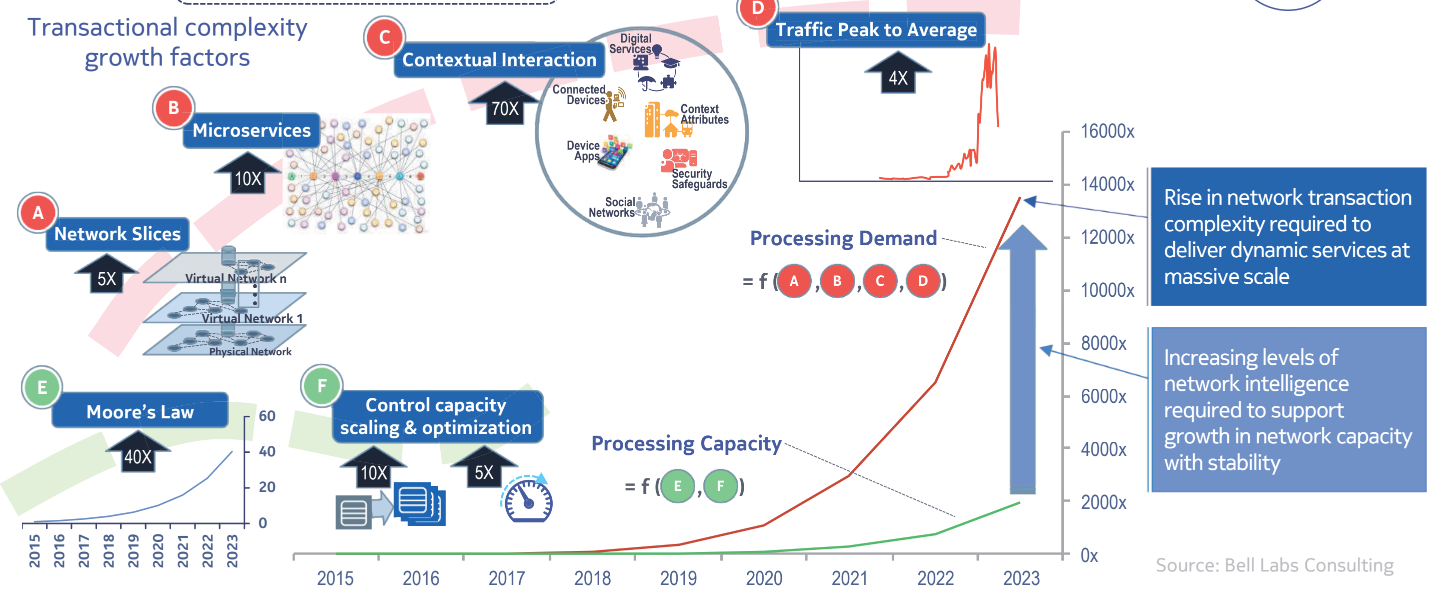
Need for Cognitive Operations – the only way to manage complexity

5



Future X Network → Cognitive = Predictive and Proactive Operations

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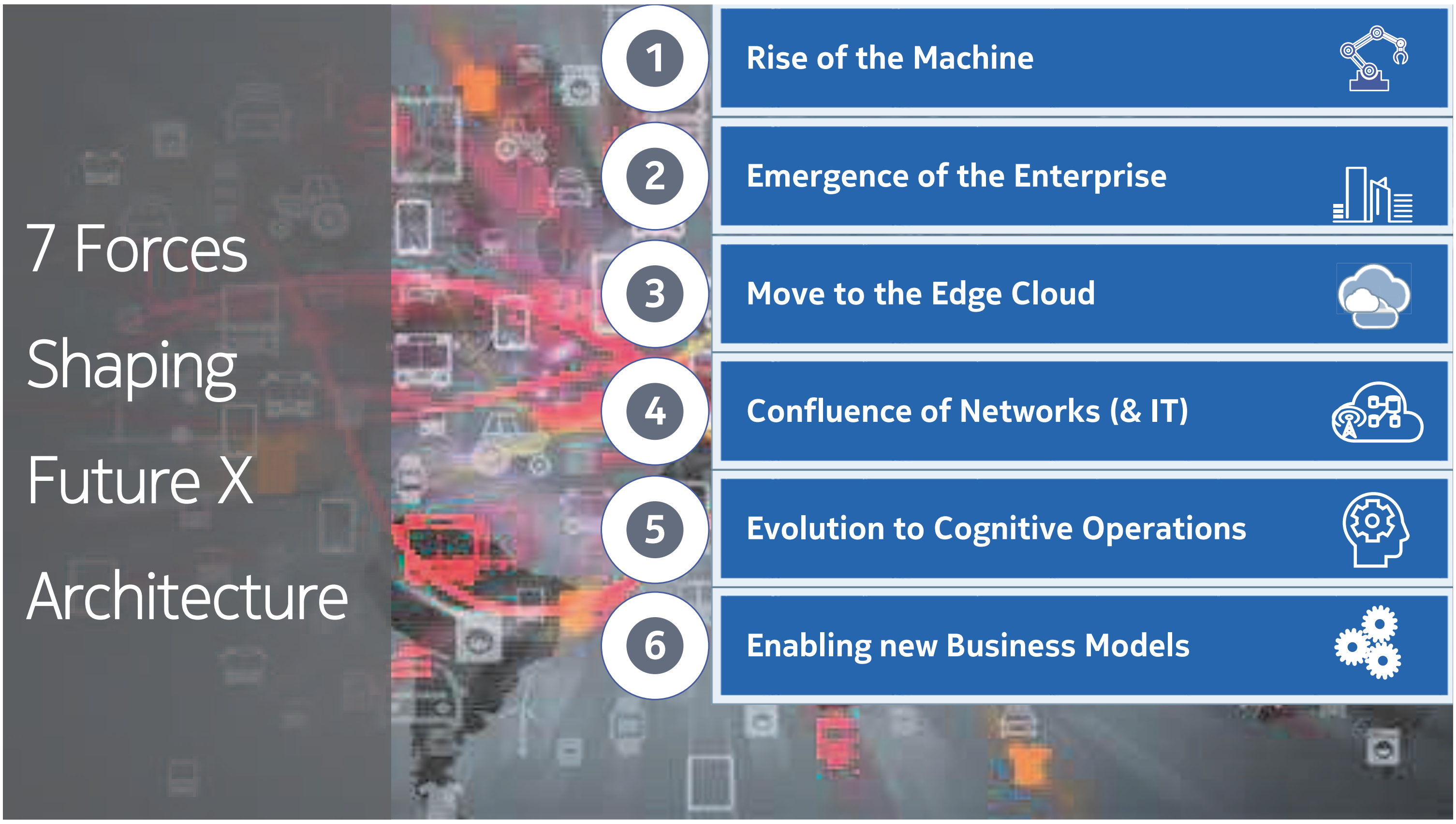

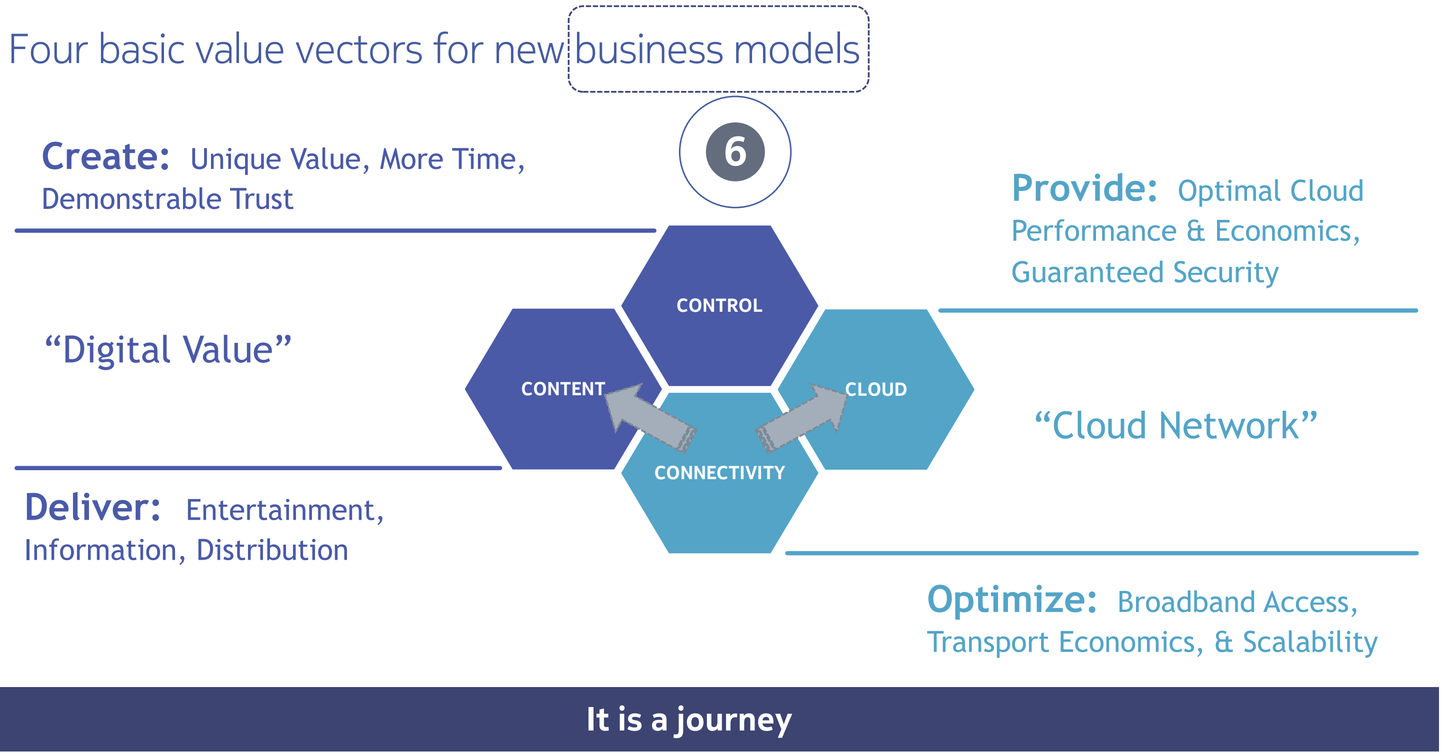

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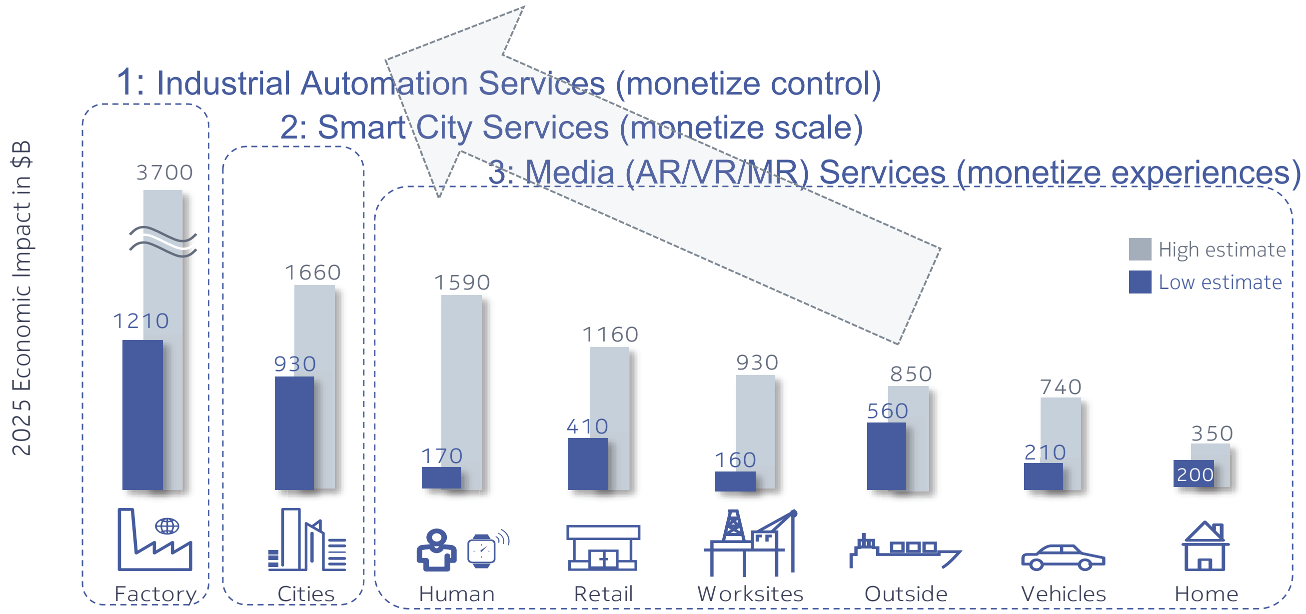
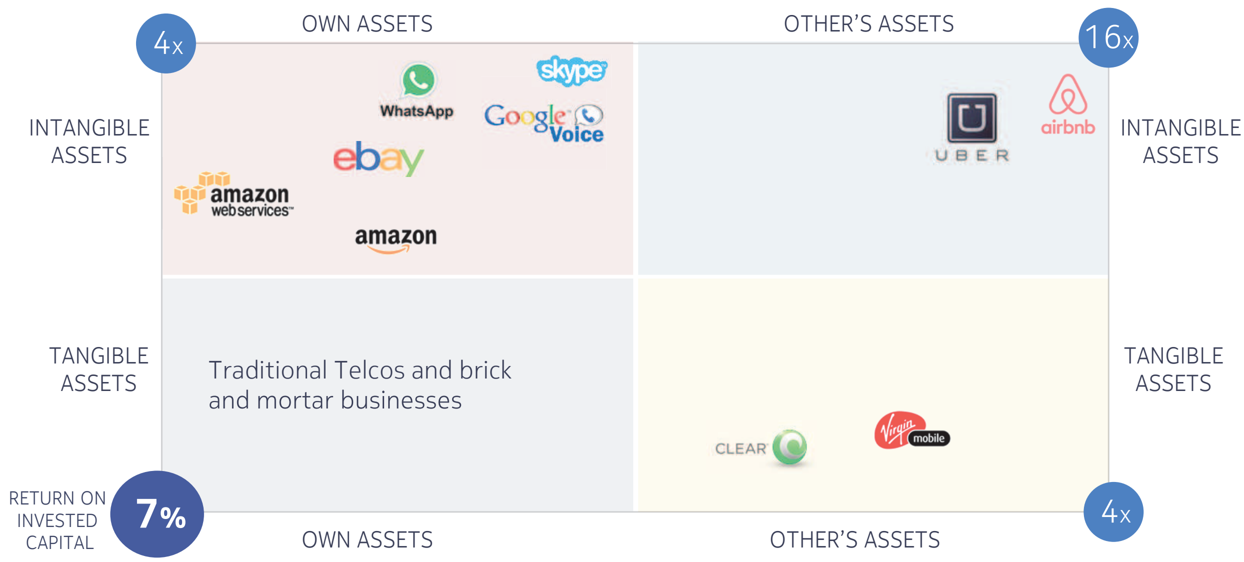
What to monetize – the big picture



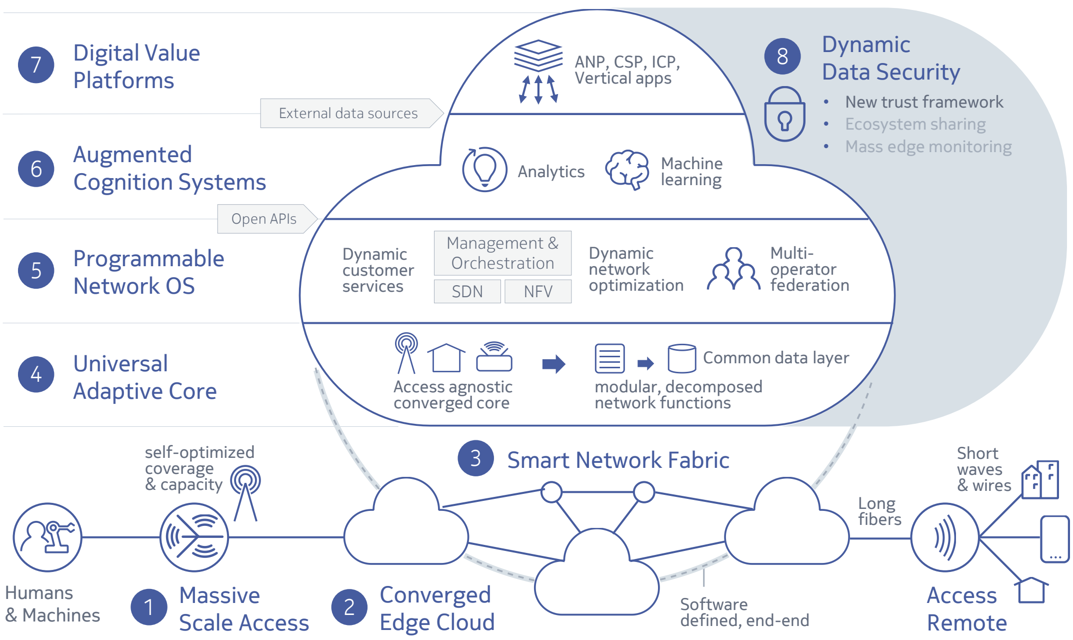
Source: McKinsey Global Institute, The internet of things: Mapping the value beyond the hype, June 2015

Fundamental role of assets



Digital Value Platforms to create "appreciating assets" + Smart sharing

Future X – A New Architecture for New Value in the 5G era



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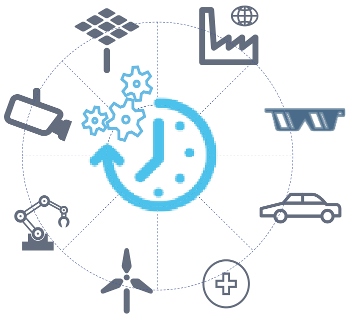
Networked Augmented Intelligence – the next technological revolution



Pervasive digital-physical systems drive life and business automation

Automation of everything transforms economy and society and creates time

Fundamental digital needs demand radically new network architecture

NOKIA Bell Labs

NOKIA

Spectrum for 4G and 5G

Qualcomm Technologies, Inc.
July, 2017

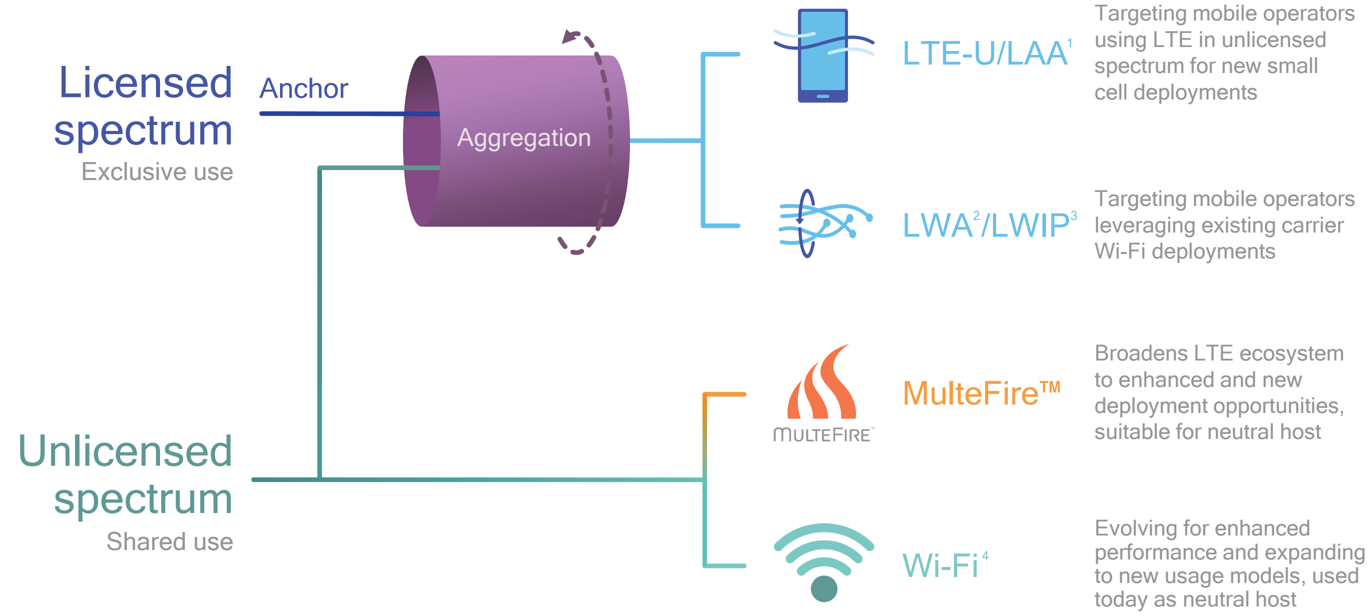
Using all available spectrum types and spectrum bands

Licensed spectrum
Exclusive use
Over 40 bands globally for LTE

Shared spectrum
New shared spectrum paradigms
Example: 2.3 GHz Europe / 3.5 GHz USA

Unlicensed spectrum
Shared use
Example: 2.4 GHz / 5 GHz / 60 GHz global

Making best use of shared/unlicensed spectrum

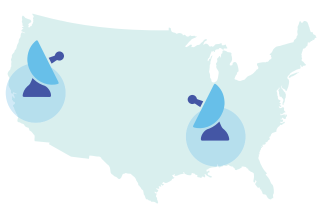


1. Licensed-Assisted Access (LAA), also includes enhanced LAA (eLAA); 2. LTE WLAN Link Aggregation (LWA); 3. LTE WLAN radio level integration with IPsec tunnel (LWIP); 4. 802.11ac / .11ad / .11ax / .11ay

New opportunities with shared/unlicensed spectrum

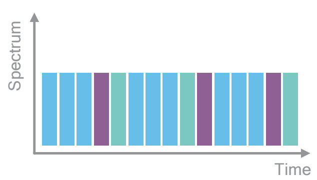
Unlocking more spectrum

Shared spectrum can unlock spectrum that is lightly used by incumbents



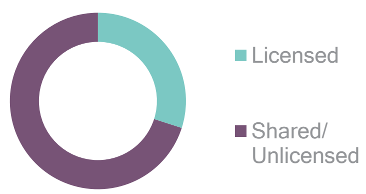
New spectrum sharing innovations

Spectrum sharing has the potential to increase spectrum utilization



A lot of spectrum may be shared/unlicensed

FCC 2016 decision on high-band spectrum included a significant portion of shared/unlicensed[1]



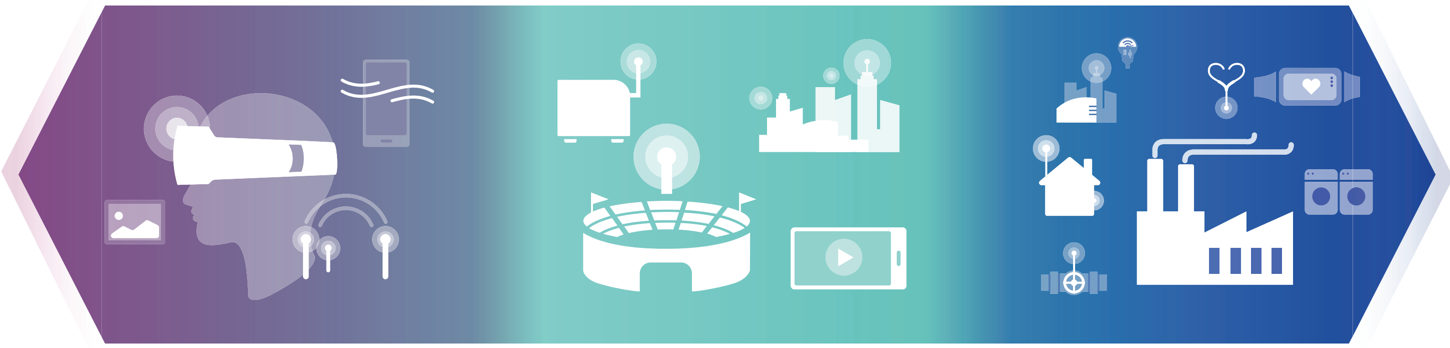
1 FCC ruling FCC 16-89 on 7/14/2016 allocated 3.25 GHz of licensed spectrum and 7.6 GHz of shared/unlicensed spectrum.

Spectrum sharing valuable for wide range of deployments

More spectrum to aggregate
Extreme bandwidths and more capacity

Enhanced local broadband
Neutral host, neighborhood network…

Private networks
Enterprise, Industrial IoT…

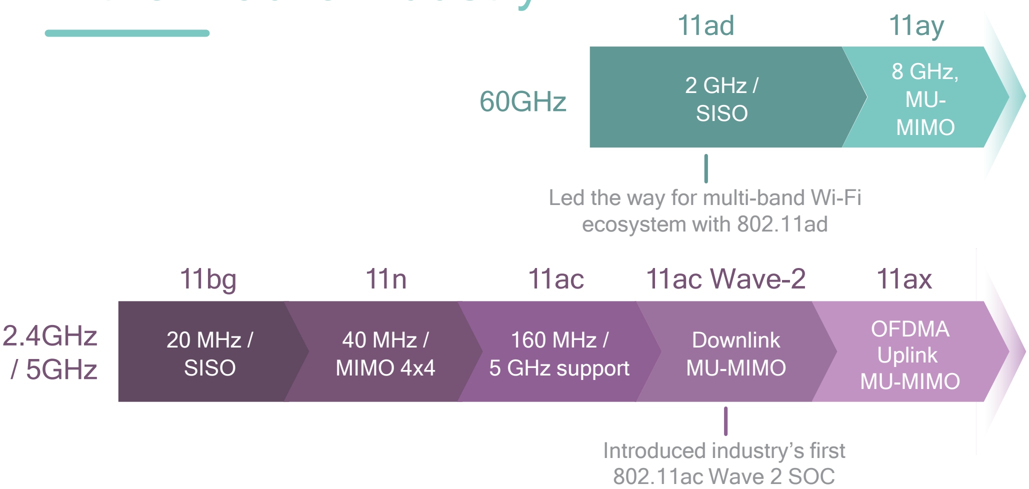


Enhancing existing deployments, e.g., LAA[1]

New types of deployments, e.g., MulteFire™ or LTE-based tech. in CBRS[2]

1) Licensed-Assisted Access (LAA); 2) Citizen Broadband Radio Service (CBRS)–a 3-tier shared spectrum where multiple LTE-based technologies are supported: LTE-TDD, MulteFire and LAA

Qualcomm Technologies leading the way with Wi-Fi in the mobile industry



Qualcomm Wi-Fi chipsets are products of Qualcomm Technologies, Inc.

Pioneering shared spectrum technologies in LTE

LSA[1]	LTE-U	LAA[2]	MulteFire	CBRS Alliance
Technically extensive pilot in France with Ericsson and Red in Jan 2016	We designed the original technology which was then commercialized by the LTE-U Forum, and is now being deployed by T-Mobile US	First over-the-air trials, LAA with DT Nov. 2015 and eLAA with SKT Sep. 2016	A founder of the MulteFire Alliance, first OTA connection Oct. 2016 & Release 1.0 specification Jan. 2017	A founder of the CBRS[3] Alliance and a key contributor to coexistence

1) Licensed Shared Access (LSA); 2) Licensed-Assisted Access (LAA), enhanced LAA (eLAA), Deutsche Telekom (DT), SK Telecom (SKT); 3) Citizen Broadband Radio Service (CBRS)

LTE-U and LAA are ready for commercial deployment

Specifications ready, FCC authorized, LBT globally, and available in products

Specifications finalized and published
LTE-U Forum published the LTE-U specs in Q1 2014, 3GPP published Rel. 13 standard with LAA in Q1 2016

FCC authorized devices for US deployments
FCC has granted equipment authorization for both LTE-U[1] and LAA[2]

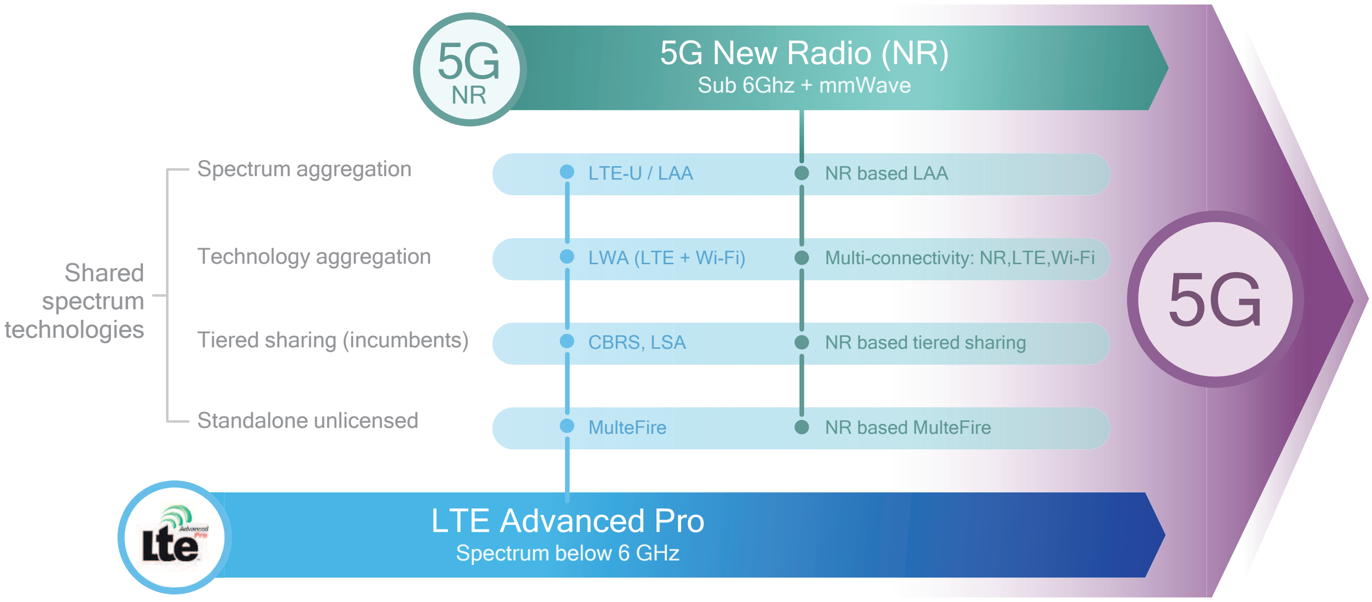
LAA for global deployments
Listen-before-talk (LBT) is used by both LAA and Wi-Fi globally in the 5 GHz unlicensed band

Supported by Qualcomm® Snapdragon™ LTE modems
LTE-U starting with X12 LTE modem; LAA starting with X16 LTE modem in Snapdragon 835 mobile platform

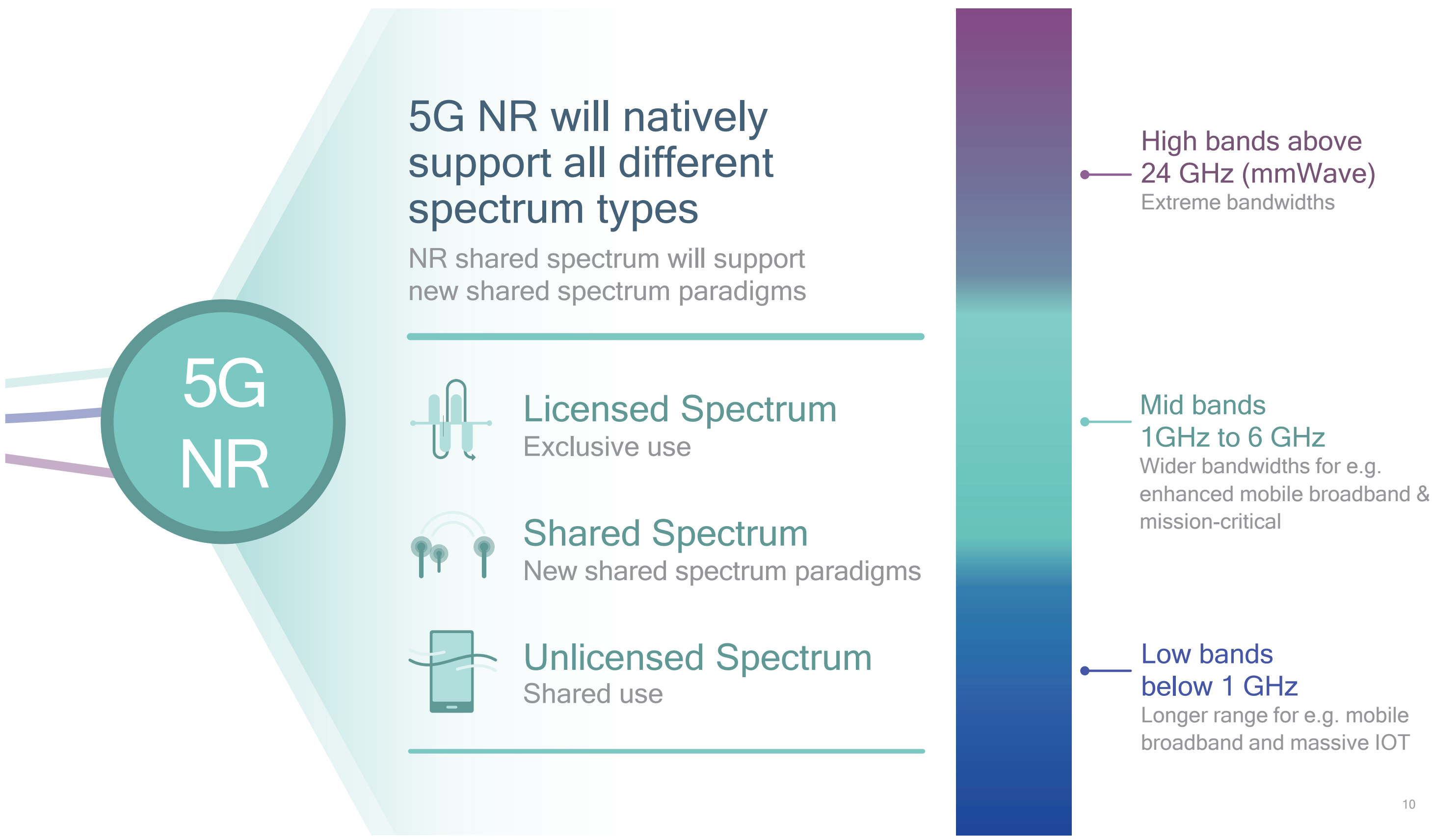
Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc.
1 FCC blog https://www.fcc.gov/news-events/blog/2017/02/22/oet-authorizes-first-lte-u-devices; 2 FCC blog https://www.fcc.gov/news-events/blog/2016/09/23/industry-makes-progress-unlicensed-lte-coexistence

Ushering in new spectrum sharing paradigms with 5G

Pioneering spectrum sharing technologies with LTE today

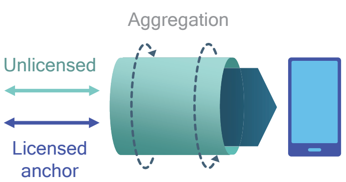


Learn more at: http://www.qualcomm.com/spectrum-sharing



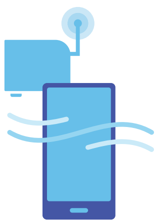
3GPP study on 5G NR operation in unlicensed spectrum

First time 3GPP studies cellular technology operating stand-alone in unlicensed[1]



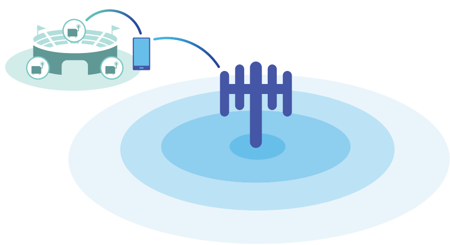
NR-based LAA

NR in unlicensed aggregated with LTE (dual-connectivity) or NR (carrier-aggregation) in licensed spectrum



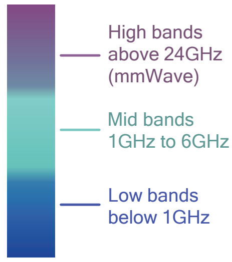
Stand-alone unlicensed

NR operating standalone in unlicensed spectrum. This will become the MulteFire™ evolution path to 5G.



Service continuity

When moving between licensed and unlicensed bands



Across spectrum bands

Both below and above 6 GHz, e.g., 5GHz, 37GHz, 60GHz*

(*assuming no change to waveform)

Designing with fair co-existence in any unlicensed spectrum: NR / NR, NR / LTE, NR / Wi-Fi

[1] Study item in Rel. 15 (RP-170828), which could be followed by a work item that is completed in Rel. 16.

Global 4G & 5G spectrum update

Opening more spectrum for 5G is a global effort

5G spectrum status in key Asian markets and Australia

China
- Currently focusing on sub-6 GHz; approved trials at 3.4-3.6 GHz & 4.8-5 GHz, probably approve frequency planning in 3.3-3.4 GHz (indoor only)
- mmWave in longer term. Chinese gov't solicited public opinion for candidate bands of 24.75-27.5 GHz & 37-42.5 GHz non-exclusively in Jun'17
- Chinese government approved small scale trial frequencies usage in 24.75-27.5 GHz & 37-42.5 GHz mmWave ranges in Jul'17

Korea
- Phase 1 (2018+): 27.5-28.5 GHz & 3.4-3.7 GHz, also 26.5-29.5 GHz if 3GPP assigns it to 5G, auction expected in 2018
- Phase 2 (2018-2021): 2 GHz BW in 26.5-27.5 GHz, 28.5-29.5 GHz, or WRC-19 bands
- Phase 3 (2021-2026): Looking at another 1 GHz allocation

Japan
- Trials have started at 4.4-4.9 GHz & also looking at 3.6-4.2 GHz; mmWave: 27.5-29.5 GHz
- Official 5G bands: 3.7 GHz, 4.5 GHz (max 500 MHz in sub-6 GHz), and 28 GHz (max 2 GHz)
- Actual band(s) allocation and technical rules are expected in 2018

Singapore
- Regulator issued a public consultation on 5G spectrum, including bands below 1 GHz, between 1 and 6 GHz, and above 6 GHz.

Hong Kong
- Regulator announced plan to allocate low-band, mid-band (3.4-3.7 GHz) and mmWave (24.25-28.35 GHz) spectrum

Indonesia
- With recent 5G demonstration, the Indonesia minister hopes to allocate 2 GHz at 28 GHz
- Government would like to have a 5G demo/showcase for its hosting of the Asian Games in August 2018

Australia
- Planning for 3.4 to 3.7 GHz and also investigating mmWave bands
- Telstra has already announced trials in 2018 at the Commonwealth Games, using 28 and 39 GHz
- Many other governments in the region initiating 5G stakeholder consultations this year

Asia Pacific Telecommunity also driving 4G & 5G spectrum

Working on regional spectrum allocation, harmonization, and innovation

- Established in 1979, headquartered in Bangkok, Thailand
- Founded on joint initiative of the UNESCAP[1] and ITU
- 38 member countries and 130+ associate/affiliate members

- We are working within APG[2] with our ecosystem partners and regulators on planning for the next World Radio Conference (WRC-19) to develop regional proposals.
- Also actively working within AWG[3] to help drive regional spectrum harmonization, spectrum sharing studies, and to encourage innovation.

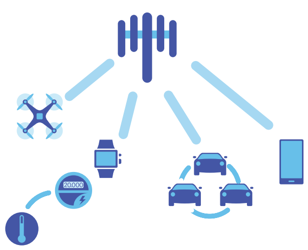
1 United Nations Economic and Social Commission for Asia and the Pacific; 2 APT Conference Preparatory Group; 3 APT Wireless Group

Why Wait™

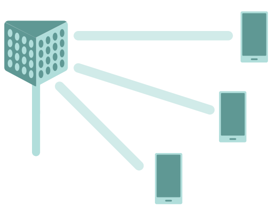
Anyone can talk about 5G. We are creating it.

Qualcomm Research 5G NR end-to-end prototype systems

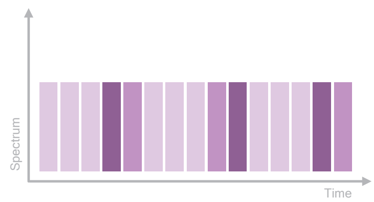
Sub-6 GHz
Ubiquitous coverage and capacity for a wide-range of 5G use cases



Mobilizing mmWave
Large bandwidths for extreme throughput and capacity



Spectrum sharing
More efficient utilization of, and access to, scarce resources



Accelerating 5G NR commercialization

Test, demonstrate and verify our 5G designs | Drive and track 3GPP 5G NR standardization | Achieve impactful trials with network operators | Drive timely commercialization

Thank you

Follow us on:

For more information, visit us at:
www.qualcomm.com & www.qualcomm.com/blog

附件 5

Disruptive Analysis

Don't Assume

Spectrum-Sharing & CBRS Business Models

Dean Bubley, Disruptive Analysis

Spectrum Futures, September 2017

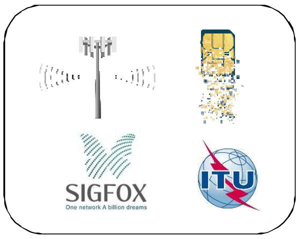
dean.bubley@disruptive-analysis.com @disruptivedean

Disruptive Analysis

Don't Assume

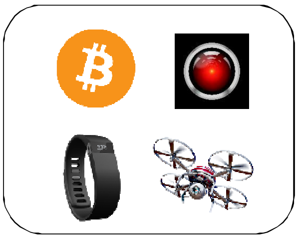
Dean Bubley & Disruptive Analysis

- Tech/telecom analyst & strategic consulting since 1991
- Futurism, Forecasting, Anti-Forecasting, Policy
- Cross-silo, contrarian, independent
- *Often provocative. Sometimes obscure. Occasionally wrong.*



Network Tech, Policy & Business Models

Communications Apps & Services



Telecom-Futurism

Disruptive Analysis

Don't Assume

Dedicated spectrum enables limited business models

- **National MNO licences**
  - B2C Prepay & Post-Paid Subscriptions
  - IoT Embedded
  - Wholesale, eg MVNO
- **Non-MNO licences**
  - Government eg Public Safety
  - Few corps, eg utilities, rail

Disruptive Analysis

Don't Assume

Demand for mobile access by many user types

Onsite Employees & collaboration

Onsite Mobile IoT

Sensors & controls (non-mobile)

Guests & visitors

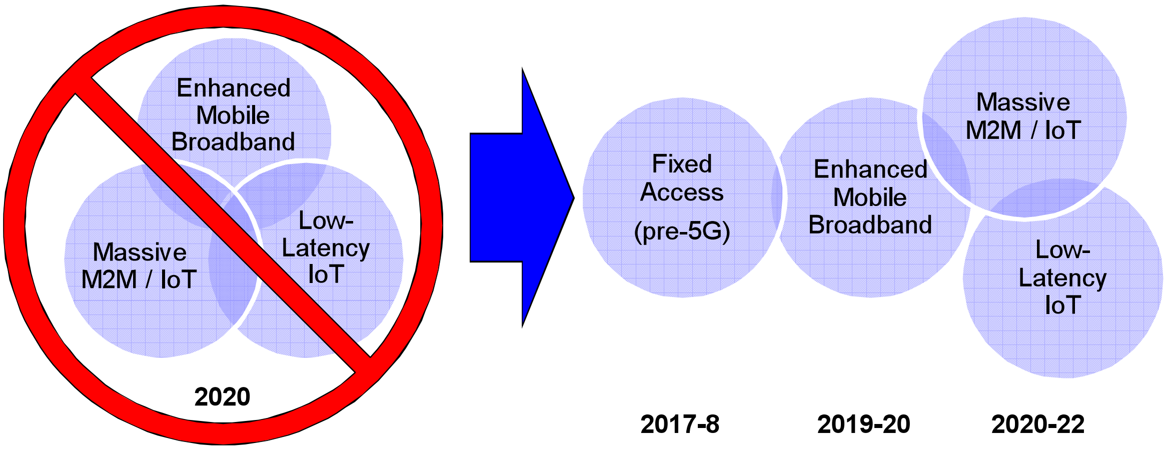
Safety & Security

Tenants & Contractors

Disruptive Analysis
Don't Assume

Rethinking the 5G roadmap….

5G Use-Cases & Probable Timeline

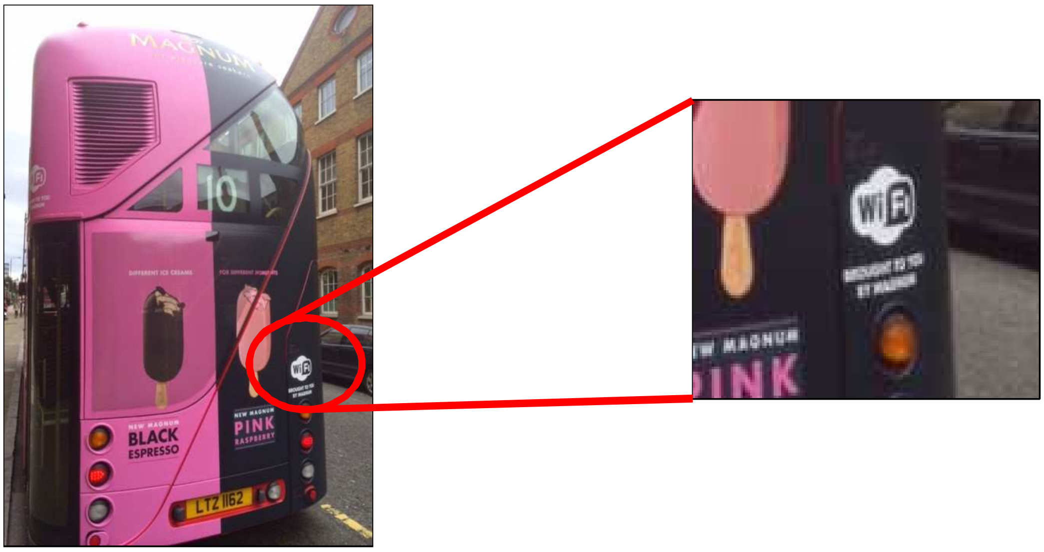


Disruptive Analysis
Don't Assume

MNOs cannot cover the needs of every vertical

Disruptive Analysis
Don't Assume

WiFi & unlicensed bands: lessons in new business models



Disruptive Analysis
Don't Assume

Many possible stakeholders / models with shared spectrum

Government (Telecom Ministry)
Spectrum License Fees + Coverage goals

Government (Business / Economy)
GDP & Tax uplift from Industry 4.0

Existing MNOs
Cheaper capacity + vertical oppos

Venue Owners
Higher rent / happy visitors & Neutral Host $$

Industrial companies
Owned & controlled IoT connections (cost/risk calculation)

Niche MNO entrants
Geo-specific license for new service / rev types

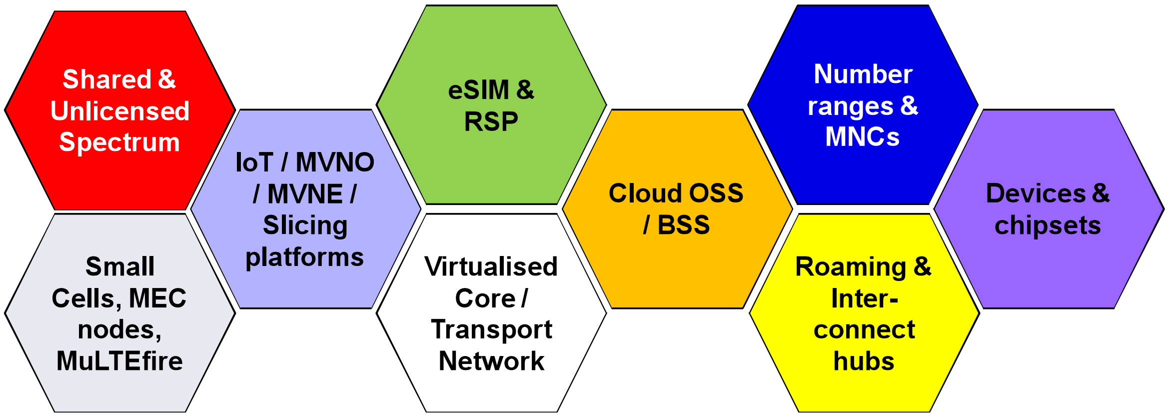
IoT solution integrator
Embedded WAN ability in similar fashion to WiFi / LoRa

Community / decentralised
Improve off-grid locations, offer neutral-host or mesh / micropayment

Disruptive Analysis

Don't Assume

Key ingredients for "4G / 5G private MNOs" emerging



& Facebook TIP, IoT connectivity specialists, blockchains, AI….

Disruptive Analysis

Don't Assume

Many possible SP / MNO / VNO types

MNO in Enterprise	Macro spectrum	Local spectrum	Local RAN / DAS	Transport & Core	SIM / eSIM	IoT / app platform	BSS / OSS	Device mgmt
IoT-type MVNO	Macro spectrum	Local spectrum	Local RAN / DAS	Transport & Core	SIM / eSIM	IoT / app platform	BSS / OSS	Device mgmt
Industrial MNO	Macro spectrum	Local spectrum	Local RAN / DAS	Transport & Core	SIM / eSIM	IoT / app platform	BSS / OSS	Device mgmt
Fully private MNO	Macro spectrum	Local spectrum	Local RAN / DAS	Transport & Core	SIM / eSIM	IoT / app platform	BSS / OSS	Device mgmt
Neutral host	Macro spectrum	Local spectrum	Local RAN / DAS	Transport & Core	SIM / eSIM	IoT / app platform	BSS / OSS	Device mgmt
WAN / FAN NO	Macro spectrum	Local spectrum	Local RAN / DAS	Transport & Core	SIM / eSIM	IoT / app platform	BSS / OSS	Device mgmt

Traditional MNO | New PNO | Enterprise | 3rd-party eg vendor cloud

Disruptive Analysis
Don't Assume

CBRS-type spectrum sharing model could be beneficial

- Many different business models
- IIoT & Industry 4.0 pitch
- Neutral hosts / Communities
- Opportunities for MNOs / MVNOs
- Various options for inhouse / outsourced
- WiFi experience suggests innovation unbounded

Disruptive Analysis
Don't Assume

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附件 6

CBRS

Why, How, Where, When?

Dave Wright

Director, Regulatory Affairs & Network Standards, Ruckus

Secretary, CBRS Alliance

@wifidave

Goals for this Session

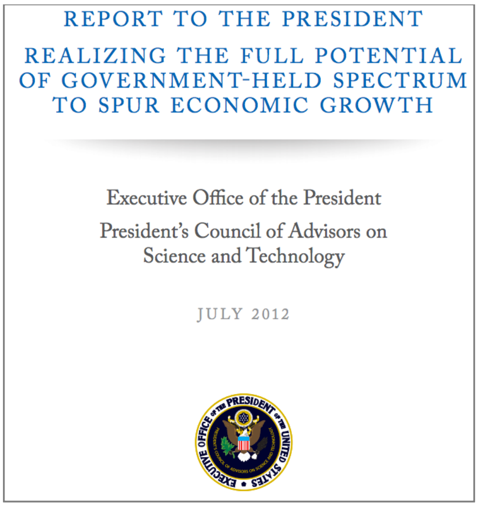
- **Why?** The Need for and Origins of CBRS
- **How?** An Overview of CBRS
- **Where?** The Roles of WInnForum and the CBRS Alliance
- **When?** Status of Commercial Operation

- Application to other Geographies
- Additional Resources

CBRS

Citizens Broadband Radio Service

CBRS – The Backstory


REPORT TO THE PRESIDENT
REALIZING THE FULL POTENTIAL OF GOVERNMENT-HELD SPECTRUM TO SPUR ECONOMIC GROWTH

Executive Office of the President
President's Council of Advisors on Science and Technology

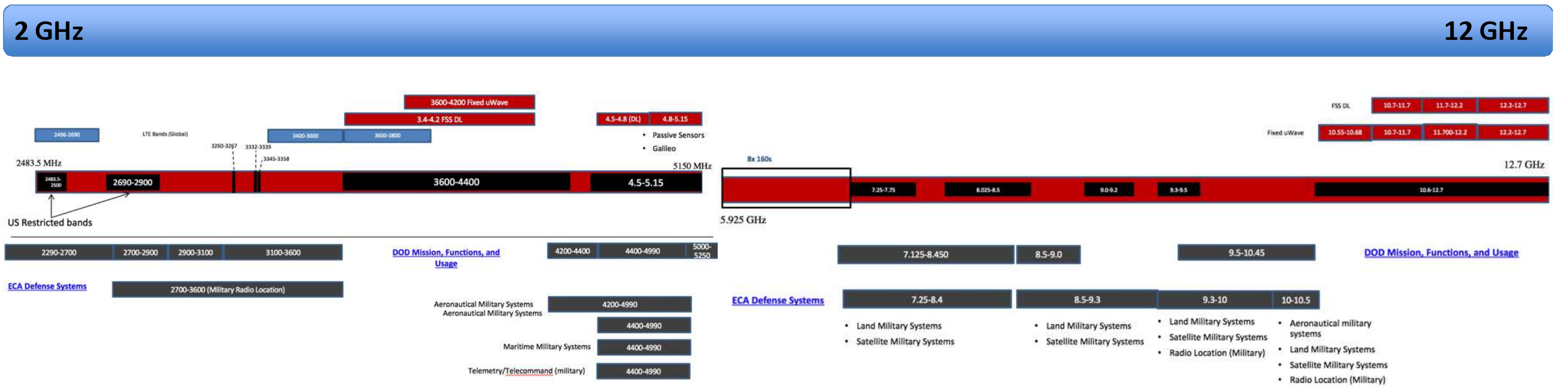
JULY 2012

Many notable participants, including:

- Tom Wheeler (prior to becoming FCC Chairman)
- Yochai Benkler (Harvard economist)
- Preston Marshall (Google / Access Technologies)
- John Leibovitz (FCC WTB Liaison)

PCAST Report: https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf
Open Wireless vs. Licensed Spectrum: Evidence from Market Adoption (Benkler):
https://cyber.harvard.edu/publications/2012/unlicensed_wireless_v_licensed_spectrum

Spectrum Sharing Critical to < 10 GHz Access



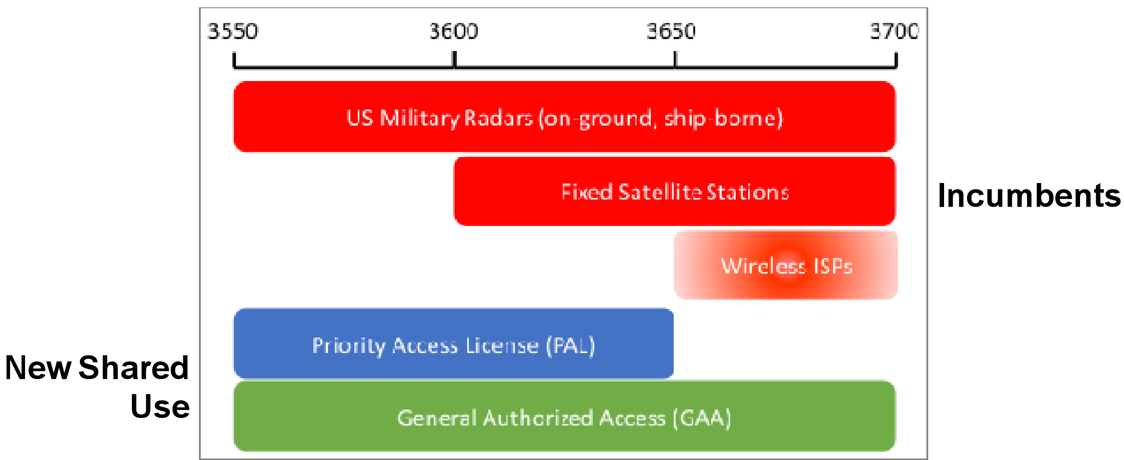
- Virtually no available spectrum (full of government and commercial incumbents)
- “Clear and Repurpose” takes too long and is politically challenging
- Look for spectrum where incumbent use is “light” – in terms of geography, time, or frequency

SPECTRUM FUTURES WILL CHANGE EVERYTHING

Ruckus Simply Better Wireless.

CBRS

Provides for new commercial use on a shared access basis in the 3550-3700 MHz band, while protecting incumbent federal and commercial operations.



Source: Mobile Experts, LLC

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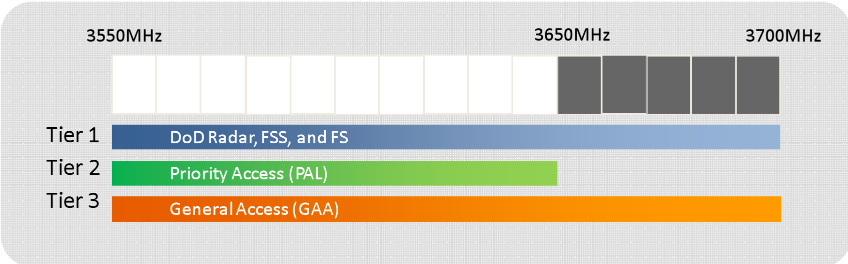
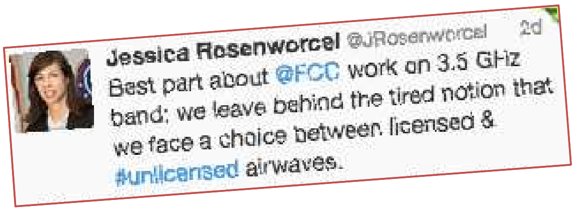
3 Tier Spectrum Sharing – Blurring the Lines





Tier 1 – Navy Radars protected (including active sensing and preemption), FSS (satellite) protected, FS (WISPs) protected short term then transition to CBRS (Part 96) operation

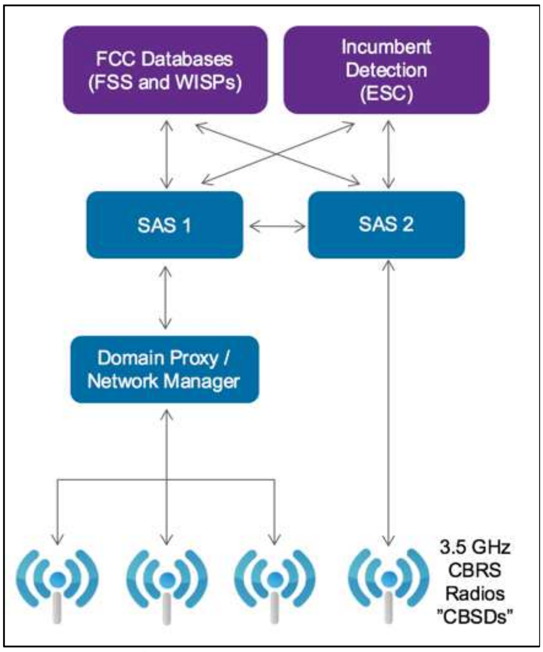
Tier 2 – Priority Access Licenses (PAL) – available in 3550-3650 MHz

- Licensed at the census tract level (~74K nationally)
- 3 Year Term
- 10 MHz Channels, no more than 70 MHz can be allocated for PAL, a single entity may only purchase 40 MHz of PAL in a tract, must be 2 bidding entities in a tract for PALs to be issued
- PALs give a right to an amount of spectrum (10 MHz channel), but not to a specific frequency assignment

Tier 3 – General Authorized Access (GAA) – available in 3550-3700 MHz

- Opportunistic/Permissive use of the band where and when it is not used by Tier 1 or Tier 2

CBRS Conceptual Framework



•Spectrum Access System (SAS)

– Centrally coordinates access to the shared spectrum, enforcing priorities and modeling the RF environment

•Environmental Sensing Capability (ESC)

– Detects incumbent activity and informs SAS so that channels can be cleared of lower priority use

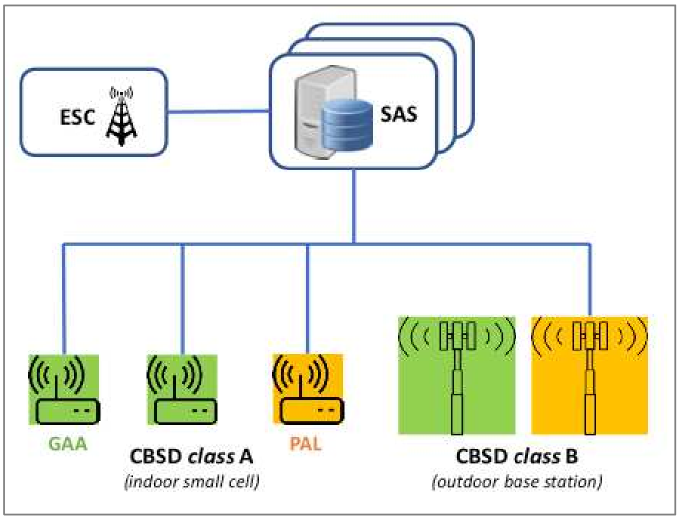
•Domain Proxy

– CBSD aggregation and proxy function for large networks, can be integrated with an EMS / NMS or be standalone

•CBRS Device (CBSD)

– Radio nodes operating in the CBRS band, must be centrally coordinated by a SAS in order to transmit

CBSD Types



Source: Mobile Experts, LLC

Device	Maximum EIRP (dBm/10 megahertz)	Maximum PSD (dBm/MHz)
End User Device	23	n/a
Category A CBSD	30	20
Category B CBSD*	47	37

* Category B CBSDs will only be authorized for use after an ESC is approved and commercially deployed consistent with [Ref-2, 96.15 and96.67].

- "CBSDs must [shall] support transmit power control capability and the capability to limit their maximum EIRP and the maximum EIRP of associated End User Devices in response to instructions from an SAS.
- End User Devices shall include transmit power control capability and the capability to limit their maximum EIRP in response to instructions from their associated CBSDs."

Source: WInnForum, CBRS Operational and Functional Requirements

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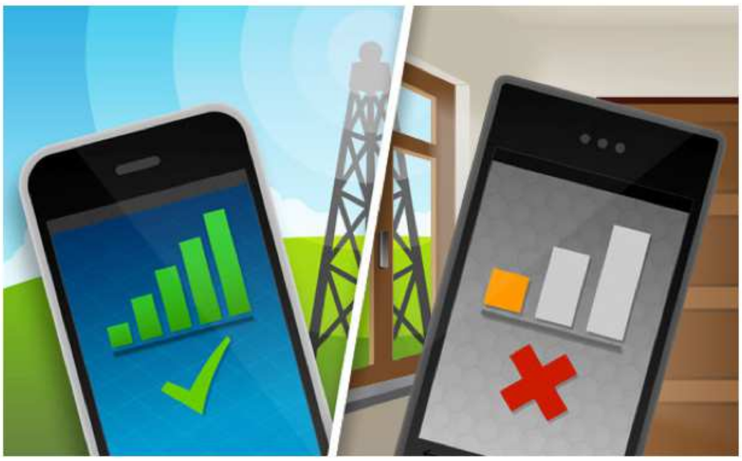
Indoor Cellular Coverage
Current Options – Falling Short



DAS: Focused on the high-end

- Focused on venues > 200K sq ft
- Expensive
- Complex to deploy

Small Cell: Flawed deployment model

- Complex to deploy
- No clear neutral host solution
- Dependency on spectrum allocation, RF planning, mobile operator direct support

SPECTRUM FUTURES
WILL CHANGE EVERYTHING

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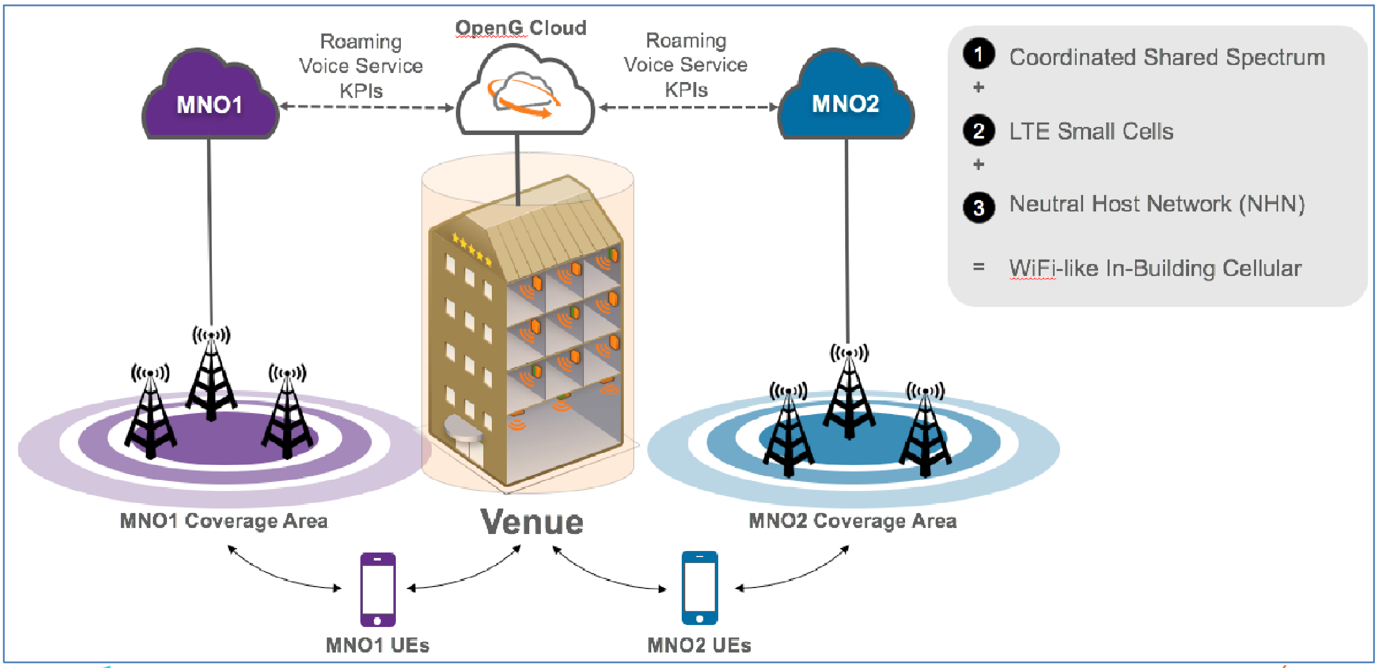
Putting the Pieces Together



Wireless Innovation Forum (WInnForum)
Spectrum Sharing Committee (SSC)

- Fleshing out the FCC's CBRS Framework
  - WG1: Operational and Functional Requirements
  - WG2: Security
  - WG3: Protocols
  - WG4: Test and Certification
  - WG5: Operations
- Air Interface Independent
- Communicating regularly with the FCC

82 members

http://www.wirelessinnovation.org/

CBRS Alliance

Mission & Purpose

Support the development, commercialization, and adoption of LTE solutions for the US 3.5 GHz Citizens Broadband Radio Service (CBRS)

- Evangelize CBRS technology and applications
- Drive necessary technology requirements (Coexistence, Radio, E2E Services)
- Establish certifications to ensure vendor interoperability

...72 members total

http://www.cbrsalliance.org/

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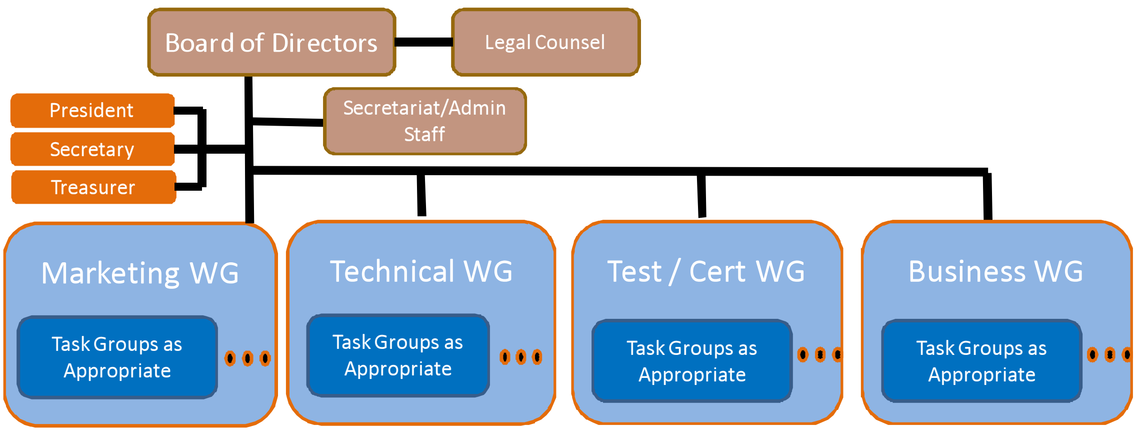
CBRS Alliance Structure



TWG Task Groups
- Coexistence
- Radio
- Network Services

BWG Initial Areas
- IoT
- Buildings (Enterprise, Retail, MDU)
- Public Spaces (Venues, Stadiums, Public Lands)

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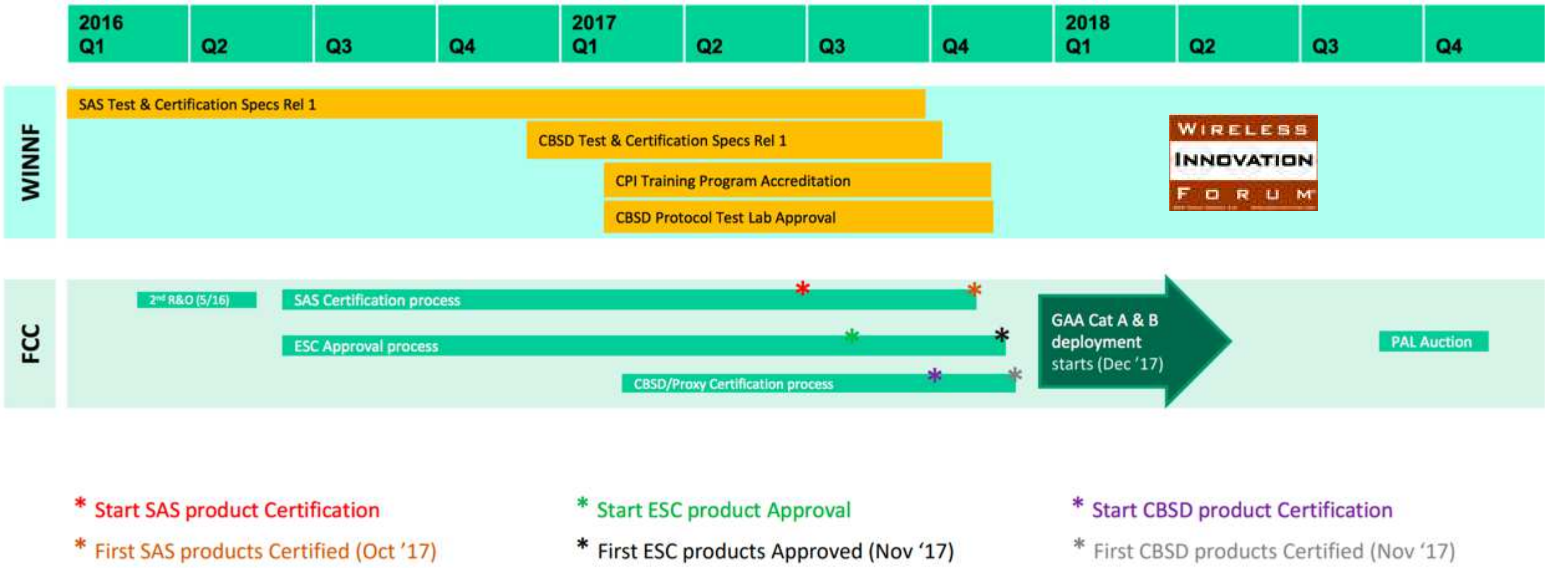
CBRS Timeline (WInnForum)



Analyst Monica Paolini on CBRS

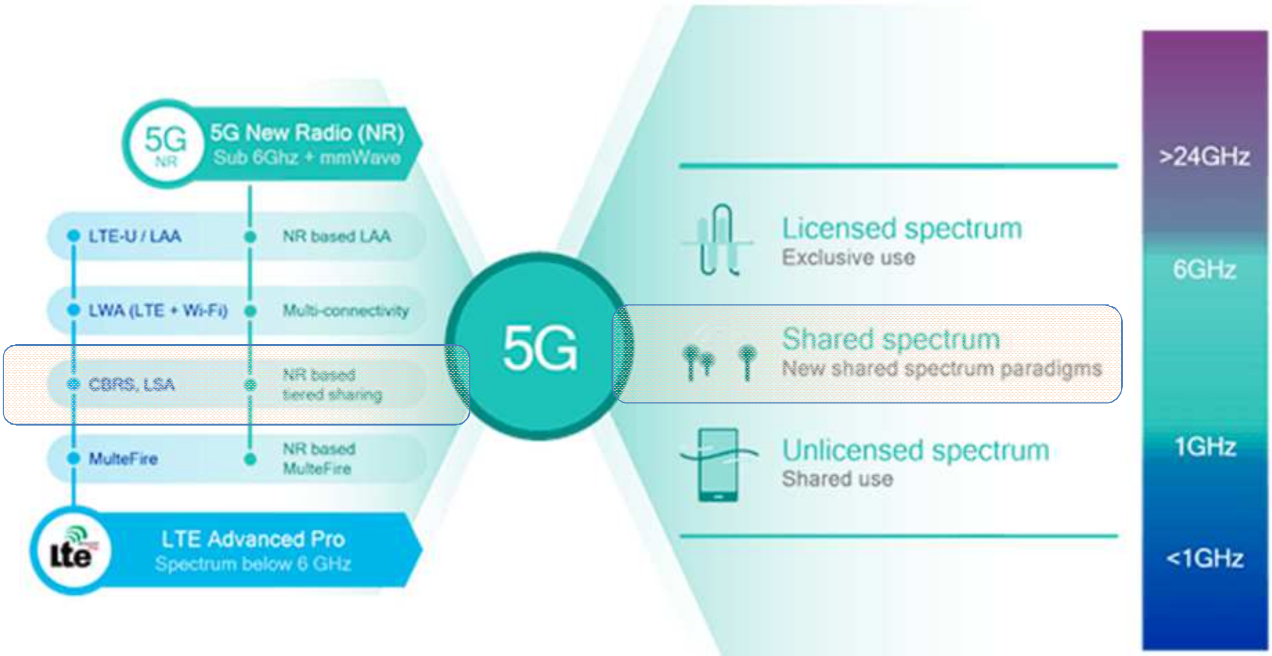
FierceWireless April 7th: "It's somewhat remarkable how far the 3.5 GHz sector has come in one year." –

"If this works out, it's going to have a huge impact, not just in the U.S. but other parts of the world as well."

SPECTRUM FUTURES
WILL CHANGE EVERYTHING

Ruckus
Simply Better Wireless

Spectrum Sharing and 5G



Source: Qualcomm, *3GPP starts study on 5G NR spectrum sharing*, https://www.qualcomm.com/news/onq/2017/04/26/3gpp-starts-study-5g-nr-spectrum-sharing

What about the Rest of the World?

Other countries are deploying or evaluating Spectrum Sharing:

- Australia: ACMA 1.5 and 3.6 GHz Consultation
- Singapore: IMDA 5G Consultation
- Hong Kong: OFCA Consultation on 3.4-3.7 GHz
- Netherlands: Company Specific Licenses in 3.5 GHz
- UK: National Infrastructure Commission Report

  https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/577906/CONNECTED_FUTURE_ACCESSIBLE.pdf
- UK: Ofcom 3.8-4.2 GHz Consultation
- France: ARCEP 2.6 and 3.5 GHz Consultation
- Germany: Key Elements Paper – 2 and 3.6 GHz
- Italy: 5G Enquiry (enabling vertical industries)
- Switzerland: 5G Enquiry (enabling vertical industries)

Where to Learn More

- FCC
  - 2nd R&O https://www.fcc.gov/document/35-ghz-order-recon-and-2nd-ro
  - SAS / ESC Administrator Approval Proceeding https://www.fcc.gov/ecfs/ (Proceeding 15-319)
- WInnForum
  - Version 1.0 Specs http://www.wirelessinnovation.org/specifications
  - Webinar on SAS-SAS and SAS-CBSD Protocol Specs https://www.youtube.com/watch?v=vJJFFHmjI8E&feature=youtu.be
- CBRS Alliance
  - Whitepapers on Shared Spectrum LTE, IoT, and Private LTE Business Models https://www.cbrsalliance.org/copy-of-in-the-news
- MulteFire Alliance (NHN Access Mode – multi-operator support)
  - Version 1.0 Specs http://www.multefire.org/specification/

SPECTRUM FUTURES
WILL CHANGE EVERYTHING

Ruckus
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BROCADE Ruckus

THANK YOU!

5G Spectrum Tutorial

Reza Arefi

Director, Spectrum Strategy

Next Generation Standards

Intel Corporation

Part 1

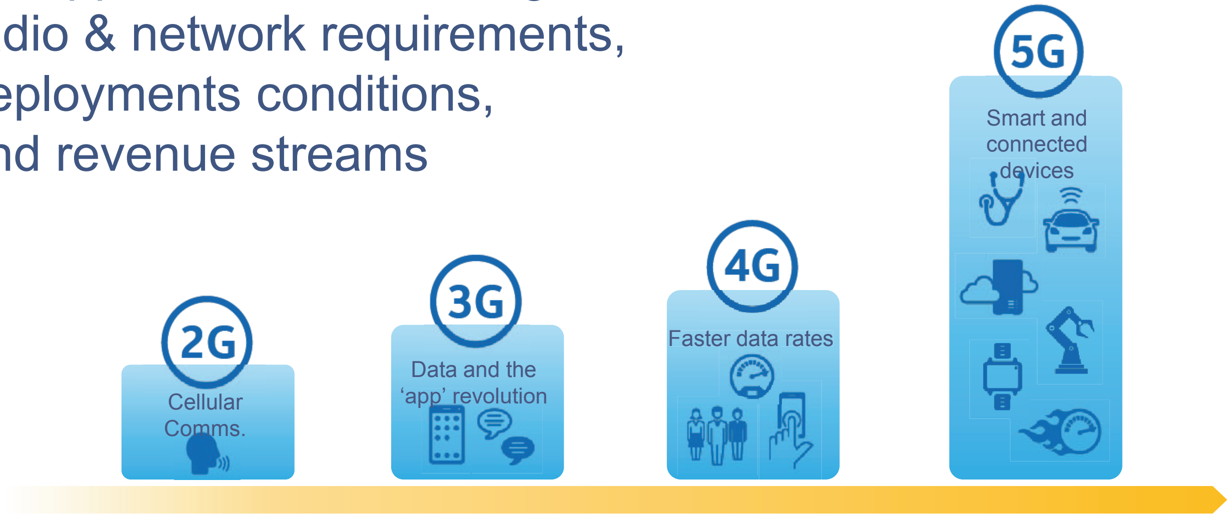
TECHNICAL & OPERATIONAL REQUIREMENTS AND REGULATORY CONSIDERATIONS

Part 1 Outline

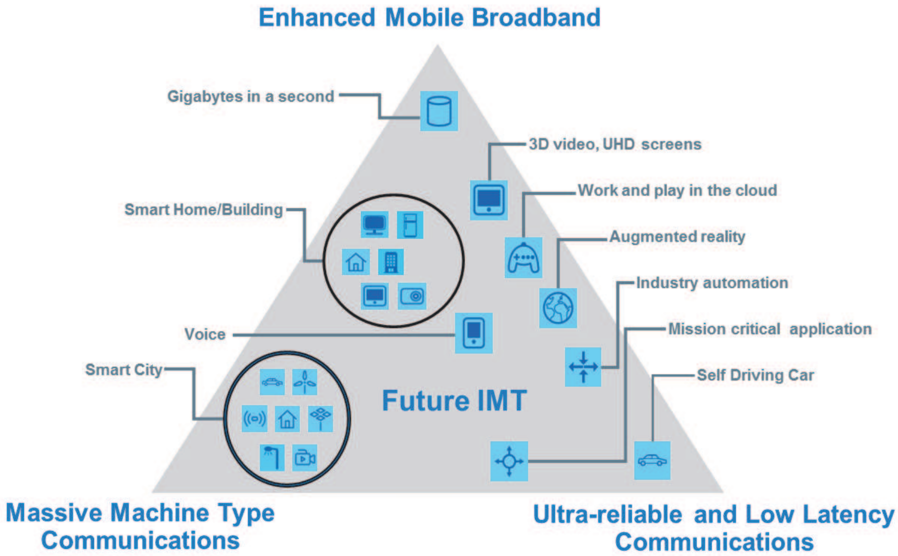
- Technical Requirements
  - Performance-related
  - Application-related
- Operational Requirements
  - Coverage & Capacity
  - Deployment Environment Considerations
- Regulatory Considerations
  - Licensing schemes
  - National priorities and leadership

5G: Evolution to a Smart and Connected World

5G applications drive usages, radio & network requirements, deployments conditions, and revenue streams



Usage Scenarios of IMT for 2020 and Beyond



Source: Recommendation ITU-R M.2083, "IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond"

Three Major Usage Scenarios of 5G

Enhanced Mobile Broadband

- Improved performance over existing Mobile Broadband applications for an increasingly seamless user experience.
  - Covers both wide-area coverage and hotspots, which have different requirements.
  - Hotspots – areas with high user density, very high traffic capacity, low mobility, user data rate is higher than that of wide area coverage.
  - Wide area coverage – seamless coverage and medium to high mobility, much improved user data rate compared to existing data rates.

Ultra-reliable and low latency communications

- Stringent requirements for capabilities such as throughput, latency and availability.
  - Examples include industrial manufacturing, remote medical surgery, distribution automation in a smart grid, transportation safety, etc.

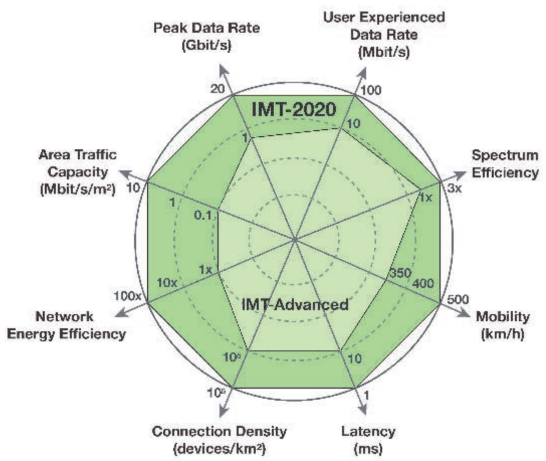
Massive machine type communications

- Characterized by a very large number of connected devices typically transmitting a relatively low volume of non-delay-sensitive data.
  - Low cost devices, very long battery life.

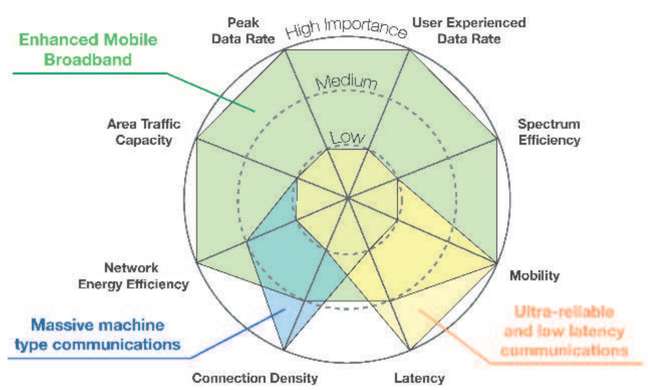
Key Performance Indicators (KPIs) from ITU-R

- **The peak data rate** for enhanced Mobile Broadband is expected to reach 10 Gbit/s, and under certain scenarios would support up to 20 Gbit/s.
- **User experienced data rates** covering a variety of environments.
  - For wide area coverage cases, 100 Mbit/s is expected.
  - In hotspot cases, expected to reach higher values (e.g. 1 Gbit/s).
- **The spectrum efficiency** is expected to be 3 times higher than IMT-Advanced for enhanced Mobile Broadband.
  - Will vary between scenarios and could be higher in some scenarios (e.g. 5 times, subject to further research).
  - Expected to support 10 Mbit/s/m2 area traffic capacity (e.g. in hot spots).
- **The energy consumption** for the radio access network of IMT-2020 not to be greater than IMT networks deployed today.
- **Latency** of 1 ms over-the-air.
- To enable **high mobility** up to 500 km/h with acceptable QoS.
- **Connection density** of up to 10^6 /km^2, for example in massive machine type communication scenarios.

Enhancement of KPIs



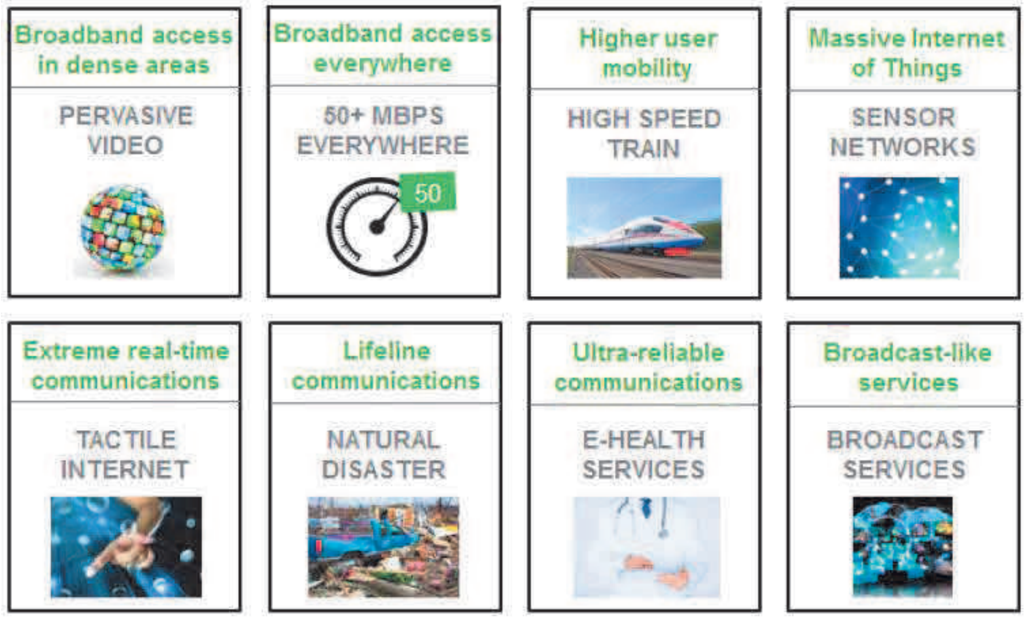
KPIs in various usage scenarios



M.[IMT-2020.TECH PERF REQ] and M.[IMT-2020.EVAL] include details and conditions/scenarios to meet various KPIs

Source: From M.2083: "The values in the figure above are targets for research and investigation for IMT-2020 and may be further developed in other ITU-R Recommendations, and may be revised in the light of future studies."

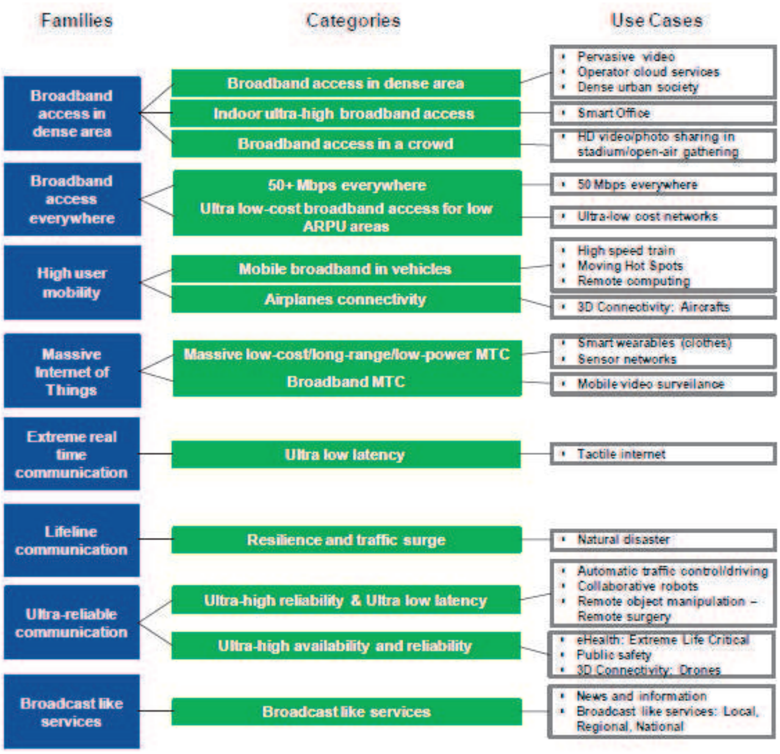
5G Use Case Families and Examples



Source: NGMN 5G white paper

Use Case Categories

- Various categories are envisaged, each with specific requirements imposing conditions on radio interface design.
- Some have spectrum implications that should be considered in order to optimize performance.



Source: NGMN 5G white paper

A Changing Face

From 2G to 4G and beyond, technology has moved from providing **user connectivity** to a means for creating **connected societies**.

Recommendation ITU-R M.2084

"It is expected that the socio-technical trends and the evolution of mobile communications systems will remain tightly coupled together and will form a foundation for society in 2020 and beyond."

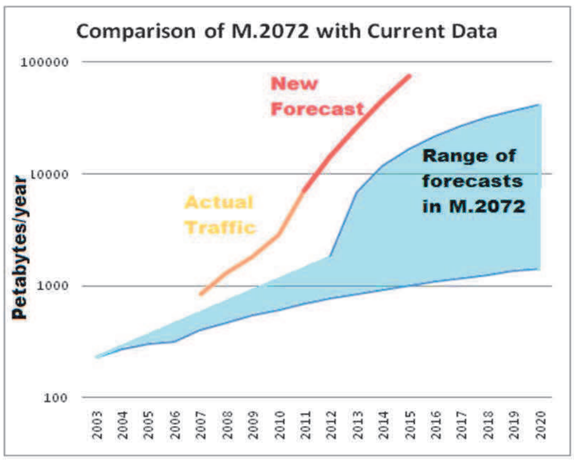
The trend is evident in emergence of new applications and use cases such as those discussed earlier:

- There are already several devices/subscription per user
- Machines and sensors are becoming increasingly an important part of our daily lives

Paradigm Shift

- Over the past decades, exponential increase in data consumption has dominated the overall demand for mobile broadband services.
- The global data consumption of networks seems to undergo contiguous explosive growth.
- Increasing data consumption of **individuals** (browsing, downloading, streaming, etc.), however, is complemented by new and emerging **applications** requiring various types and amounts of connectivity/data/resources dictating radio interface capabilities.
- New application centric methodologies are needed to model this growth.

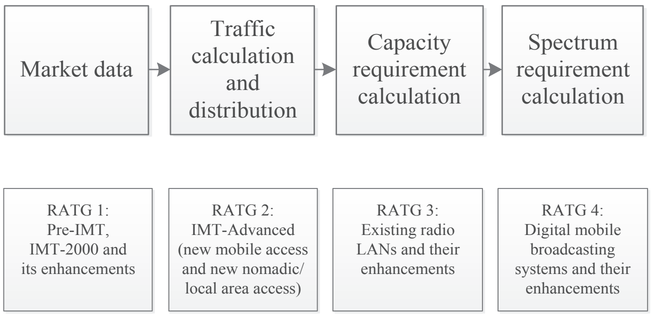
ITU traffic estimates done at year 2005 (Report ITU-R M.2072)

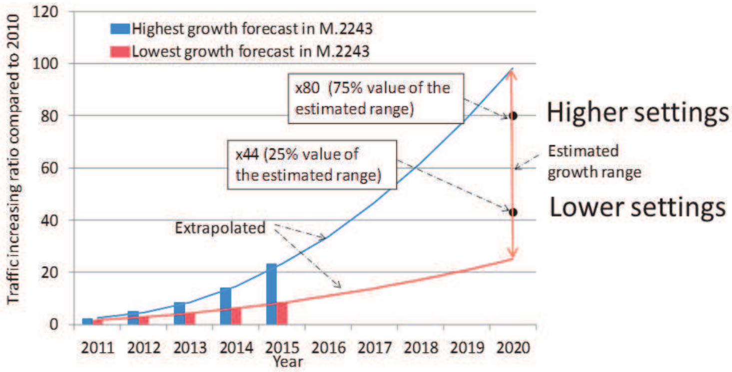


Source: Report ITU-R M.2243, "Assessment of the global mobile broadband deployments and forecasts for IMT", 2011.

IMT-Advanced (4G) Spectrum Requirements

General flow of spectrum requirement calculation





Total spectrum requirements for both RATG 1 and RATG 2 in the year 2020

	Total spectrum requirements for RATG 1	Total spectrum requirements for RATG 2	Total spectrum requirements RATGs 1 and 2
Lower user density settings	440 MHz	900 MHz	1 340 MHz
Higher user density settings	540 MHz	1 420 MHz	1 960 MHz

Source: Report ITU-R M.2290, "future spectrum requirements estimate for terrestrial IMT."

5G User Experience

- User experience associated with use case categories could have spectrum implications in order to optimize overall performance

Use case category	User Experienced Data Rate	E2E Latency	Mobility
Broadband access in dense areas	DL: 300 Mbps UL: 50 Mbps	10 ms	On demand, 0-100 km/h
Indoor ultra-high broadband access	DL: 1 Gbps, UL: 500 Mbps	10 ms	Pedestrian
Broadband access in a crowd	DL: 25 Mbps UL: 50 Mbps	10 ms	Pedestrian
50+ Mbps everywhere	DL: 50 Mbps UL: 25 Mbps	10 ms	0-120 km/h
Ultra-low cost broadband access for low ARPU areas	DL: 10 Mbps UL: 10 Mbps	50 ms	on demand: 0-50 km/h
Mobile broadband in vehicles (cars, trains)	DL: 50 Mbps UL: 25 Mbps	10 ms	On demand, up to 500 km/h
Airplanes connectivity	DL: 15 Mbps per user UL: 7.5 Mbps per user	10 ms	Up to 1000 km/h
Massive low-cost/long-range/low-power MTC	Low (typically 1-100 kbps)	Seconds to hours	on demand: 0-500 km/h
Broadband MTC	See the requirements for the Broadband access in dense areas and 50+Mbps everywhere categories		
Ultra-low latency	DL: 50 Mbps UL: 25 Mbps	<1 ms	Pedestrian
Resilience and traffic surge	DL: 0.1-1 Mbps UL: 0.1-1 Mbps	Regular communication: not critical	0-120 km/h
Ultra-high reliability & Ultra-low latency	DL: From 50 kbps to 10 Mbps; UL: From a few bps to 10 Mbps	1 ms	on demand: 0-500 km/h
Ultra-high availability & reliability	DL: 10 Mbps UL: 10 Mbps	10 ms	On demand, 0-500 km/h
Broadcast like services	DL: Up to 200 Mbps UL: Modest (e.g. 500 kbps)	<100 ms	on demand: 0-500 km/h

Source: NGMN 5G white paper, 2015

5G System Performance

- System performance KPIs associated with use case categories could also have spectrum implications in order to optimize over all performance

Use case category	Connection Density	Traffic Density
Broadband access in dense areas	200-2500 /km^2	DL: 750 Gbps / km2 UL: 125 Gbps / km2
Indoor ultra-high broadband access	75,000 / km^2 (75/1000 m^2 office)	DL: 15 Tbps/ km2 (15 Gbps / 1000 m2) UL: 2 Tbps / km2 (2 Gbps / 1000 m2)
Broadband access in a crowd	150,000 / km^2 (30.000 / stadium)	DL: 3.75 Tbps / km2 (DL: 0.75 Tbps / stadium) UL: 7.5 Tbps / km2 (1.5 Tbps / stadium)
50+ Mbps everywhere	400 / km^2 in suburban 100 / km^2 in rural	DL: 20 Gbps / km2 in suburban UL: 10 Gbps / km2 in suburban DL: 5 Gbps / km2 in rural UL: 2.5 Gbps / km2 in rural
Ultra-low cost broadband access for low ARPU areas	16 / km^2	16 Mbps / km^2
Mobile broadband in vehicles (cars, trains)	2000 / km^2 (500 active users per train x 4 trains, or 1 active user per car x 2000 cars)	DL: 100 Gbps / km^2 (25 Gbps per train, 50 Mbps per car) UL: 50 Gbps / km^2 (12.5 Gbps per train, 25 Mbps per car)
Airplanes connectivity	80 per plane 60 airplanes per 18,000 km^2	DL: 1.2 Gbps / plane UL: 600 Mbps / plane
Massive low-cost/long-range/low-power MTC	Up to 200,000 / km^2	Non critical
Broadband MTC	See the requirements for the Broadband access in dense areas and 50+Mbps everywhere categories	
Ultra-low latency	Not critical	Potentially high
Resilience and traffic surge	10,000 / km^2	Potentially high
Ultra-high reliability & Ultra-low latency* (*) the reliability requirement for this category is described in Section 4.4.5	Not critical	Potentially high
Ultra-high availability & reliability* (*) the reliability requirement for this category is described in Section 4.4.5	Not critical	Potentially high
Broadcast like services	Not relevant	Not relevant

Source: NGMN 5G white paper, 2015

5G Applications and Spectrum Implications

To be enabled, technical requirements of 5G applications need to be addressed.

- Adequate design of the 5G radio interface.
- Access to appropriate frequency ranges.

While some applications, e.g. 4k/8k video, would require ultra-high speed connections, others might need very robust performance and long range.

Applications already supported by 4G and its evolution are expected to have additional capabilities.

- Consideration of required spectrum for 5G includes applications foreseen for future networks.

Application Requirements

- Examples of various 5G applications for the three main usage scenarios and their requirements impacting radio link design (not an exhaustive list)

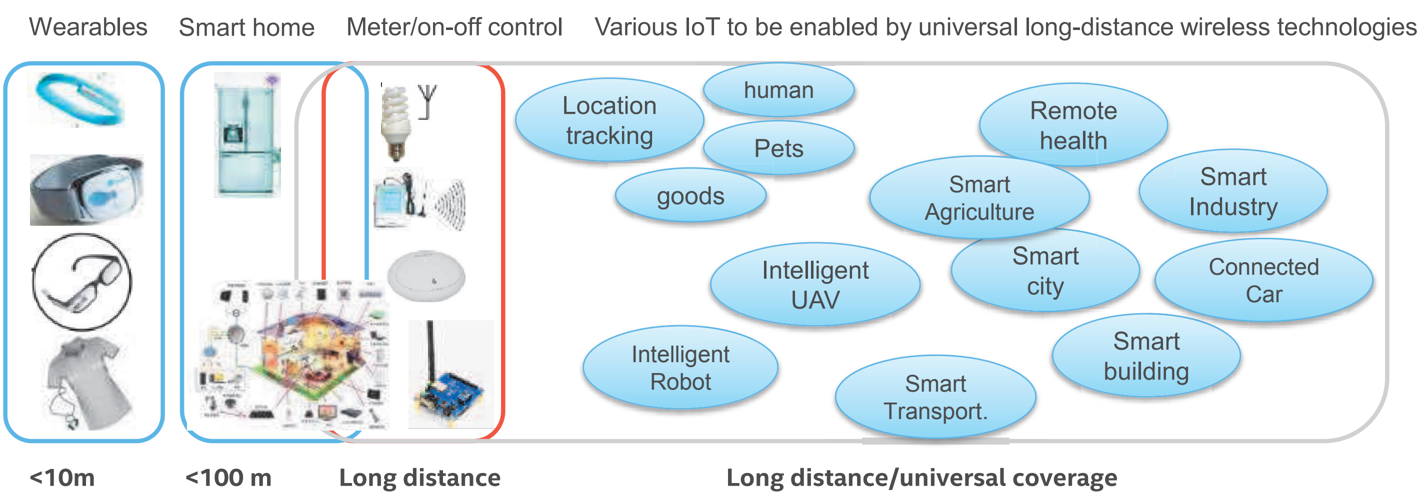
Usage Scenario	Application	High-level Requirement
Massive Machine-Type Communications	Smart home	Operation in cluttered environment Obstacle penetration
	Smart office	Operation in cluttered environment Obstacle penetration High reliability radio links
	Smart city	Short to long range Operation in cluttered environment Operation near fast moving obstacles High reliability radio links Ground/obstacle penetration
	Sensor networks (industrial, commercial, etc.)	Short to long range Operation in cluttered environment Operation near fast moving obstacles Ground/obstacle penetration Mesh networking

Usage Scenario	Application	High-level Requirement
Enhanced Mobile Broadband	UHD video (4k, 8k), 3D video (including broadcast services)	Ultra-high speed radio links Low latency (real-time video)
	Virtual Reality	Ultra-high speed radio links Ultra-low latency
	Augmented Reality	Ultra-high speed radio links Low latency
	Tactile Internet	Ultra-low latency
	Cloud gaming	Ultra-high speed radio links Low latency
	Broadband kiosks	Ultra-high speed radio links Short range
	Vehicular (cars, buses, trains, aerial stations, etc.)	Ultra-high speed radio links Short to long range Support for low to high-Doppler environments

Source: 5G Spectrum Recommendation, 5G Americas, 2015

Usage Scenario	Application	High-level Requirement
Ultra-reliable Communications	Industrial automation	Ultra-high reliability radio links High speed radio links Low to ultra-low latency Short to long range Operation in cluttered environments
	Mission-critical applications e.g. e-health, hazardous environments, rescue missions, etc.	Ultra-high reliability radio links High speed radio links Low to ultra-low latency Short to long range Operation in cluttered environments Ground/obstacle penetration
	Self-driving vehicles	Ultra-high reliability radio links High speed radio links Low to ultra-low latency Short to long range Operation in cluttered environments Operation near fast moving obstacles

Example: mMTC Range Requirements



Spectrum Implications

- Examples of spectrum-related implications of high-level requirements for various 5G applications in the three main usage scenarios (not an exhaustive list)

Usage Scenario	High-level Requirement	Potential Spectrum-Related Implications
Enhanced Mobile Broadband (eMBB)	Ultra-high speed radio links	Ultra-wide carrier bandwidths, e.g. 500 MHz Multi-gigabit front haul/backhaul, indoor
	High speed radio links	Wide carrier bandwidths, e.g. 100 MHz Gigabit fronthaul/backhaul
	Support for low to high-Doppler environment	Depends on the throughput requirement
	Ultra-low latency	Short range implications
	Low latency	Mid-short range implications
	Ultra-high reliability radio links	Severe impact of rain and other atmospheric effects on link availability in higher frequencies, e.g. mm-wave, for outdoor operations
	High reliability radio links	Impact of rain and other atmospheric effects on link availability in higher frequencies, e.g. mm-wave, for outdoor operations
Ultra-reliable Low-Latency Communications (URLLC)	Short range	Higher frequencies, e.g. mm-wave
	Medium-Long range	Lower frequencies, e.g. sub-6 GHz
	Ground/obstacle penetration	Lower frequencies, e.g. sub-1 GHz
Massive Machine-Type Communications (mMTC)	Operation in cluttered environment	Diffraction dominated environment in lower frequencies Reflection dominated environment in higher frequencies
	Operation near fast moving obstacles	Frequency-selective fading channels
	Mesh networking	High-speed distributed wireless backhauls operating in-band or out-of-band

Source: 5G Spectrum Recommendation, 5G Americas, 2015

Spectrum Range Considerations

Certain applications require highly robust performance over long distances.

- A characteristic of lower frequencies.

Other applications need very high throughput over shorter distances.

- A characteristic of higher frequencies.

These aspects could be optimally achieved through access to a variety of bands to deliver full 5G service.

- Needs for sufficient amount of spectrum in a variety of bands – e.g. <1 GHz, < 6 GHz, > 6 GHz
  - < 1 GHz – wider reach; examples include: macro cells, robust obstacle penetration, sensor networks, automotive, etc.
  - < 6 GHz – coverage/capacity trade-off; examples include: small cells, capacity boost, etc.
  - > 6 GHz – higher throughput; examples include: hot spots, UHD video streaming, VR, AR, etc.

Mapping of Usage to Spectrum Ranges

Usage Scenario	High-level Requirement	Potential Spectrum-Related Implications	Spectrum Ranges Considered Suitable
Enhanced Mobile Broadband	Ultra-high speed radio links	Ultra-wide carrier bandwidths, e.g. 500 MHz Multi-gigabit front haul/backhaul, indoor	> 24 GHz
	High speed radio links	Wide carrier bandwidths, e.g. 100 MHz Gigabit fronthaul/backhaul	3-6 GHz
	Support for low to high-Doppler environment	Depends on the throughput requirement	All ranges
	Ultra-low latency	Short range implications	3-6 GHz, > 24 GHz
	Low latency	Mid-short range implications	3-6 GHz
	Ultra-high reliability radio links	Severe impact of rain and other atmospheric effects on link availability in higher frequencies, e.g. mm-wave, for outdoor operations	< 6 GHz
	High reliability radio links	Impact of rain and other atmospheric effects on link availability in higher frequencies, e.g. mm-wave, for outdoor operations	< 6 GHz
Ultra-reliable Communications	Short range	Higher frequencies, e.g. mm-wave	> 24 GHz
	Medium-Long range	Lower frequencies, e.g. sub-6 GHz	< 6 GHz
	Ground/obstacle penetration	Lower frequencies, e.g. sub-1 GHz	< 1.5 GHz
Massive Machine-Type Communications	Operation in cluttered environment	Diffraction dominated environment in lower frequencies Reflection dominated environment in higher frequencies	All ranges
	Operation near fast moving obstacles	Frequency-selective fading channels	All ranges, especially below 6 GHz
	Mesh networking	High-speed distributed wireless backhauls operating in-band or out-of-band	> 24 GHz

Source: 5G Spectrum Recommendation, 5G Americas, 2017

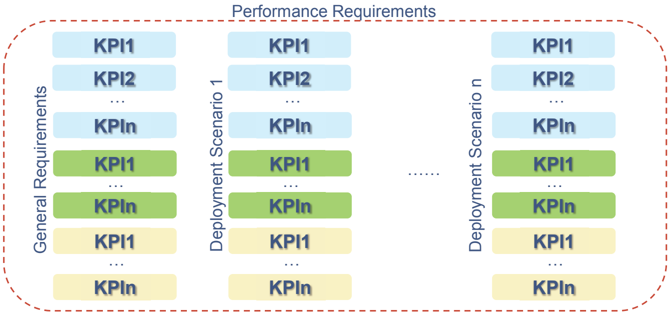
Performance Requirements

High-level methodology based on application performance requirements developed in industry (e.g. NGMN), followed by ITU-R

Source: NGMN input to 3GPP RAN workshop on 5G, September 2015

General Approach

- For a given deployment scenario, requirements of all user applications with potential concurrent operation could be derived.
- Number of users/devices/elements per site, number of sites, inter-site distance, cell area leads to cell capacity.
- Given spectral efficiency targeted for the deployment scenario, spectrum supporting the concurrent applications in a given deployment scenario could be obtained.



The detailed process depends on assumptions on several factors decided through the ITU-R process

Performance Requirements of Verticals - Examples

- Smart Sustainable City (SSC) requirements according to ITU-T[1]:
  - Smart grid: up to ~1.5 Mbytes reliably delivered in in 8 ms
  - Emergency services:
    - Throughput: 100 Mbit/s in high mobility
    - Latency: Down to 1 ms in high mobility
- Automotive
  - A self-driving car is expected to process 1 GB of data every second[2]
  - Low latency (1 ms), high mobility (400 km/h), high reliability (~100%), high UL throughput (10s of Mbit/s), high positioning accuracy (0.1 m), high density (>1000), etc.

1) http://www.itu.int/en/ITU-T/focusgroups/ssc/Documents/Approved_Deliverables/TR-Overview-SSC.docx
2) smartdatacollective.com/bigdatastartups/135291/self-driving-cars-will-create-2-petabytes-data-what-are-big-data-opportunitie

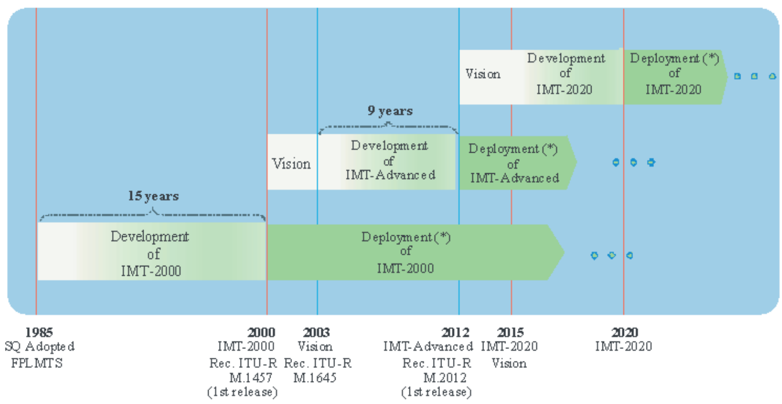
ITU-R Work on Technical Requirements & Spectrum Needs of IMT-2020

IMT Development in ITU-R

- Radio Interface Specifications of IMT Generations are included in ITU-R Recommendations M.1457 (3G), M.2012 (4G), and future M.[IMT-2020]
- Acceleration of the process over generations

FIGURE 1

Overview of timeline for IMT development and deployment



(*) Deployment timing may vary across countries.

M.2083-01

Source: Recommendation ITU-R M.2083, “IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond”

Technical Performance-Related Needs of 5G

ITU-R Minimum Technical Performance Requirements

- Many of these requirements have spectrum-related implications*
  - **Type of spectrum** (low/mid/high)
    - Bandwidth requirement
  - **Amount of spectrum**
    - Spectral efficiency values, latency, data rate values, connection density, etc.
- ITU-R used these to come up with spectrum needs

IMT-2020		
Technical Performance Requirements (TPR)	**DL**	**UL**
Peak Data Rate (Gbit/s)	20	10
Peak Spectral Efficiency (bit/s/Hz)	30	15
User-Experienced Data Rate (Mbit/s)	100	50
5-th %ile User Specral Efficiency (bit/s/Hz)		
Indoor Hotspot – eMBB	0.3	0.21
Dense Urban – eMBB (macro)	0.225	0.15
Rural – eMBB	0.12	0.045
Average Spectral Efficiency (bit/s/Hz)		
Indoor Hotspot – eMBB	9	6.75
Dense Urban – eMBB (macro)	7.8	5.4
Rural – eMBB	3.3	1.6
User Plane Latency (ms)		
eMBB	4	
URLLC	1	
Bandwidth (MHz)		
minimum	100	
up to (e.g. in higher bands)	1000	
Area Traffic Capacity - eMBB (Mbit/s/m^2)	10	
Connection Density - mMTC (devices/km^2)	1000000	
Mobility - Normalized Traffic Ch. Data Rate (bit/s/Hz)		
Indoor Hotspot – eMBB (10 km/hr)		1.5
Dense Urban – eMBB (30 km/hr)		1.12
Rural – eMBB (120 km/hr)		0.8
Rural – eMBB (500 km/hr)		0.45

* For a sample analysis, see 5GAmericas white paper "5G Spectrum Recommendations", 2017

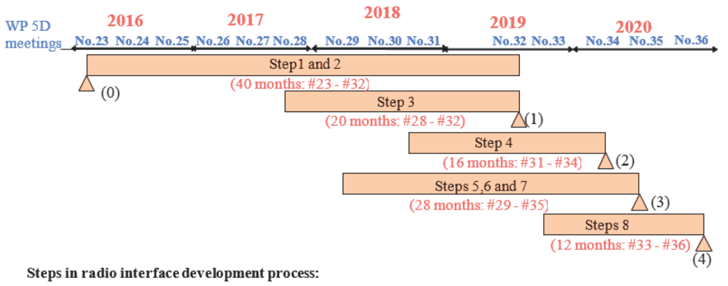
Evaluation Test Environments and Criteria

Mapping of test environments and usage scenarios

Usage scenarios	eMBB			mMTC	URLLC
Test environments	Indoor Hotspot - eMBB	Dense Urban – eMBB	Rural – eMBB	Urban Macro – mMTC	Urban Macro – URLLC

- Step 2: An RIT needs to fulfil the minimum requirements for at least **three** test environments; two test environments under eMBB and one test environment under mMTC or URLLC.
- Step 8: An RIT or SRIT6 will be accepted for inclusion in the standardization phase described in Step 8 if, as the result of deliberation by ITU-R, it is determined that the RIT or SRIT meets the requirements of Resolution ITU-R 65, *resolves* 6 *e)* and *f)* for the **five** test environments comprising the three usage scenarios.

Schedule for the development of IMT-2020 radio interface Recommendations



Steps in radio interface development process:

Step 1: Issuance of the circular letter
Step 2: Development of candidate RITs and SRITs
Step 3: Submission/Reception of the RIT and SRIT proposals and acknowledgement of receipt
Step 4: Evaluation of candidate RITs and SRITs by Independent Evaluation Groups
Step 5: Review and coordination of outside evaluation activities
Step 6: Review to assess compliance with minimum requirements
Step 7: Consideration of evaluation results, consensus building and decision
Step 8: Development of radio interface Recommendation(s)

Critical milestones in radio interface development process:

(0): Issue an invitation to propose RITs — March 2016
(1): ITU proposed cut off for submission of candidate RIT and SRIT proposals — July 2019
(2): Cut off for evaluation report to ITU — February 2020
(3): WP 5D decides framework and key characteristics of IMT-2020 RIT and SRIT — June 2020
(4): WP 5D completes development of radio interface specification Recommendations — October 2020

IMT-2020 2-01

5G Spectrum Needs

$B = (D \times N)/S$

D: Maximum data rate supported by a user/device (bit/s)
N: Number of simultaneously supported users/devices in a cell
S: Spectral efficiency (bits/s/Hz)

IMT-2020 Spectrum needs for bands **above 24 GHz**

- Two approaches
  - Spectrum needs as dictated by certain TPRs
  - Spectrum needs as dictated by requirements of envisaged applications

Estimated spectrum needs based on cell edge and latency targets

Examples	Spectrum needs
#1 – Based on cell-edge user throughput and spectral efficiency targets in Recommendation ITU-R M.2083 with *N* simultaneously served users/devices at the cell-edge	User experienced data rate of 1 Gbit/s: 3.33 GHz (*N*=1), 6.67 GHz (*N*=2), 13.33 GHz (*N*=4), e.g., Indoor User experienced data rate of 100 Mbits/s: 0.67 GHz (*N*=1), 1.32 GHz (*N*=2), 2.64 GHz (*N*=4), for wide area coverage
#2 – Based on cell-edge user spectral efficiency (obtained from 3GPP technical specifications) and data rate targets (from Recommendation ITU-R M.2083) in two given test environments	0.83-4.17 GHz (for eMBB Dense Urban) 3-15 GHz (for eMBB Indoor Hotspot)
#3 – Impact of latency and spectral efficiency targets and a typical user throughput value on spectrum needs	With a file transfer of 10 Mbits by a single user at cell-edge in 1 msec: 33.33 GHz (one direction) With a file transfer of 1 Mbit by a single user at cell-edge in 1 msec: 3.33 GHz (one direction) With a file transfer of 0.1 Mbits by a single user at cell-edge in 1 msec: 333 MHz (one direction)

5G Spectrum Needs Summary

- Differences in values due to different starting point assumptions in each example
- In both approaches, the bottleneck points to several GHz of spectrum in order to meet the most demanding targets

Estimated spectrum needs based on the application-based approach

Example	Teledensities	24.25-33.4 GHz	37-52.6 GHz	66-86 GHz	Total
Example 1	Overcrowded, dense urban and urban areas	3.3 GHz	6.1 GHz	9.3 GHz	18.7 GHz
	Dense urban and urban areas	2.0 GHz	3.7 GHz	5.7 GHz	11.4 GHz
Example 2	Highly crowded area	666 MHz	1.2 GHz	1.9 GHz	3.7 GHz
	Crowded area	333 MHz	608 MHz	933 MHz	1.8 GHz

Spectrum needs based on the information from some countries

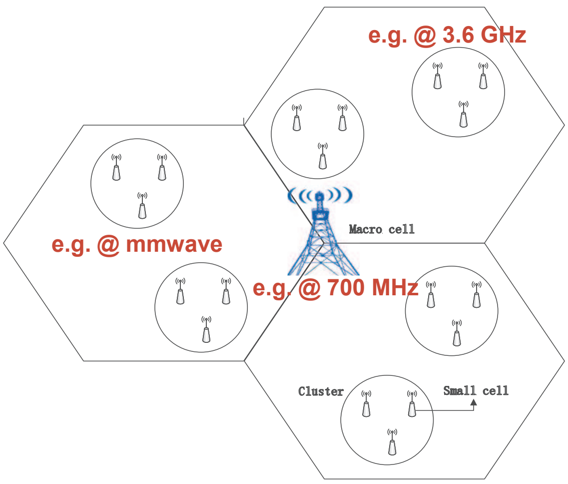
Frequency ranges	24.25-43.5 GHz	43.5-86 GHz
Spectrum needs	2-6 GHz	5-10 GHz

Adding Operational Context

HetNet for Coverage/Capacity Trade-off

A.k.a. “anchor-booster” configuration includes

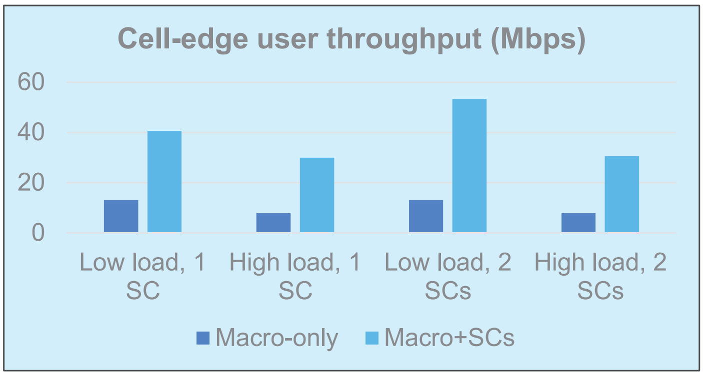
- a macro-cell coverage layer, typically operated at low-range frequencies such as 700 MHz or 2 GHz, and
- a small cell layer that operates at higher frequencies such as mid-range spectrum around 4 GHz or even higher bands near or in the mm-wave spectrum
- users data plane switches between macro layer and small cell layer, optimizing network performance in line with user’s QoS requirements, control plane on macro layer at all times

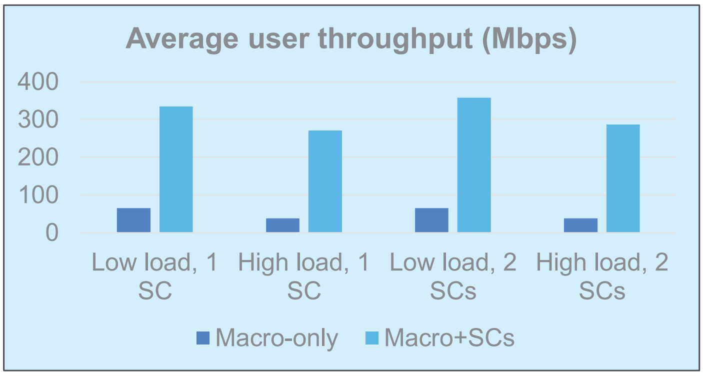


Example Comparison

Macro at 2 GHz (20 MHz), small cell at 4 GHz (100 MHz, 4x4 MIMO)

- Across all scenarios analyzed, introduction of C-band small cells:
  - the cell-edge user throughput is enhanced by as much as 3.7 times
  - the average user throughput is enhanced by as much as 6.3 times

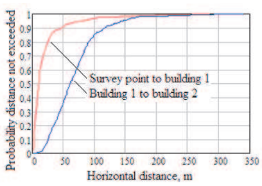


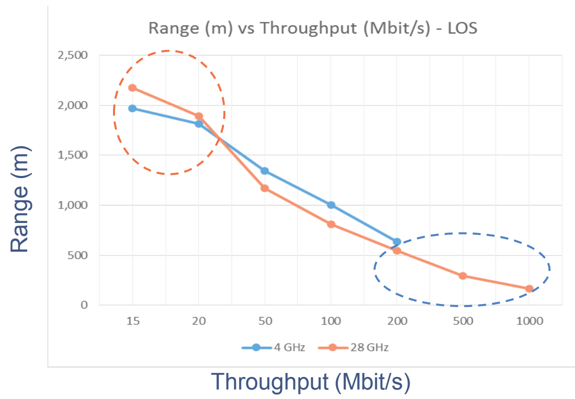


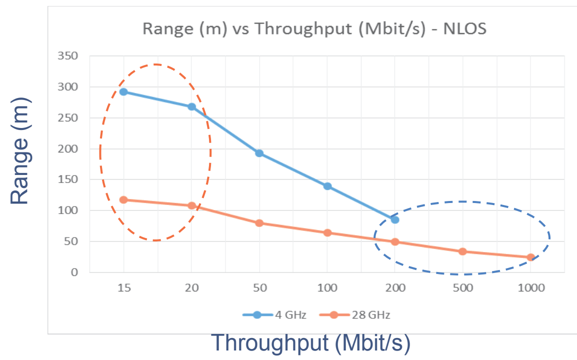
Adding Higher Bands

Adding a 28 GHz layer (1 GHz bandwidth, 8x16/4x4)

- While 4 GHz range is generally superior to that of 28 GHz, higher throughput values are only possible with the conditions achievable at higher frequencies:
  - Higher channel bandwidth
  - Higher EIRP through large antenna array size
- Environment (statistics of LOS/NLOS) plays a role







Other Spectrum-related Considerations

Multiple-operator deployments

- Needs for sufficient amount of spectrum to build multiple networks
- Wireless backhaul/fronthaul requirements

Interference impacts of adjacent systems

- Consideration of proper separation (e.g. guardband) of adjacent networks/bands, including the unsynchronized TDD scenario

Frequency reuse

- Need for additional carriers even though reuse 1 is dominant scheme

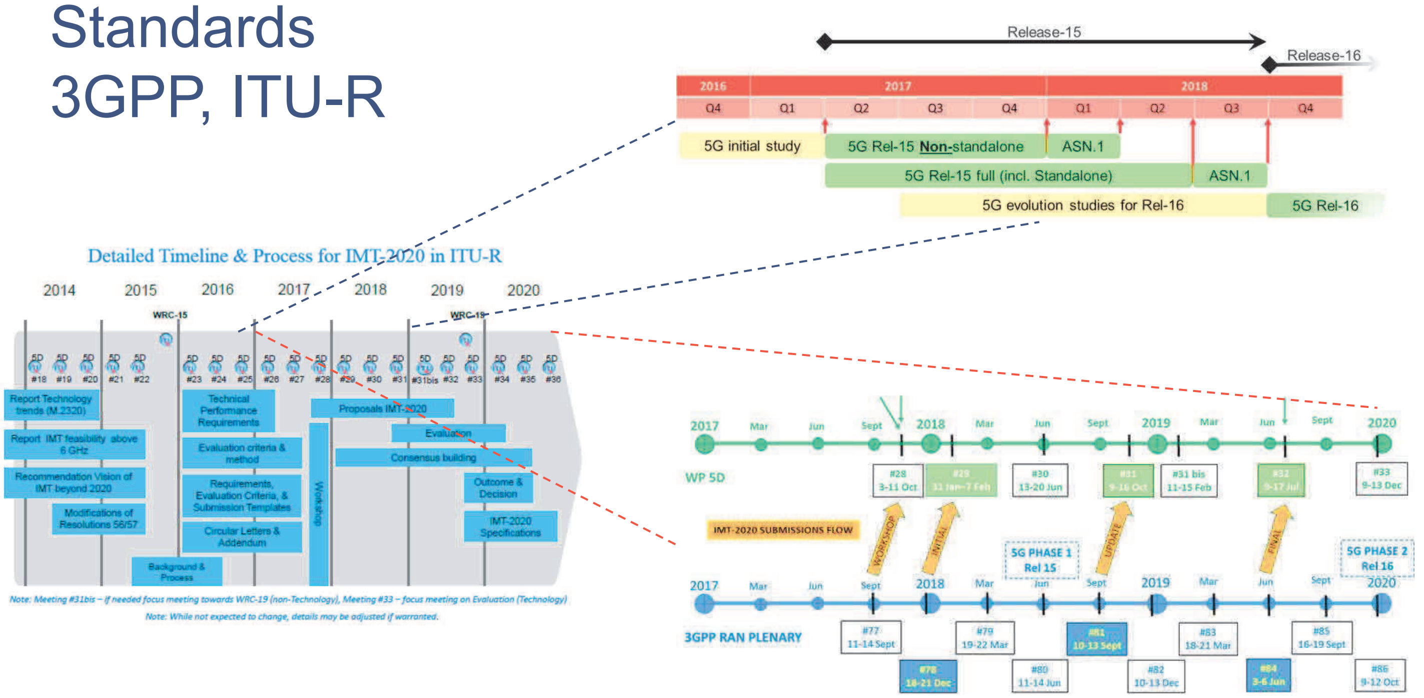
Technical features

- Multiple antennas, beamforming, novel multiple access and coding schemes, and other factors impacting spectral efficiency of 5G

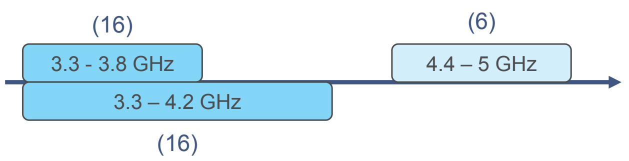
Source: 5G Spectrum Recommendations, 5G Americas, 2015

Standardization of 5G

Standards
3GPP, ITU-R

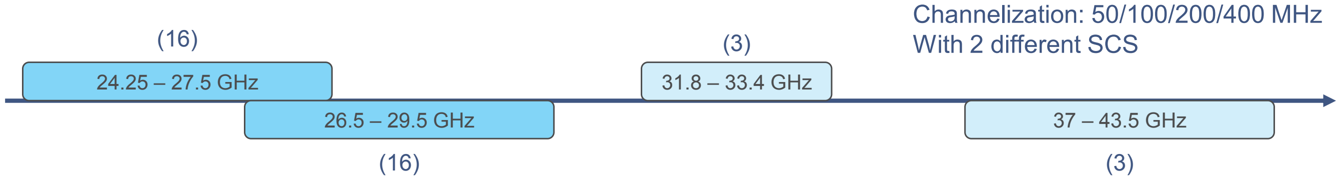


3GPP New NR Bands (August 2017)



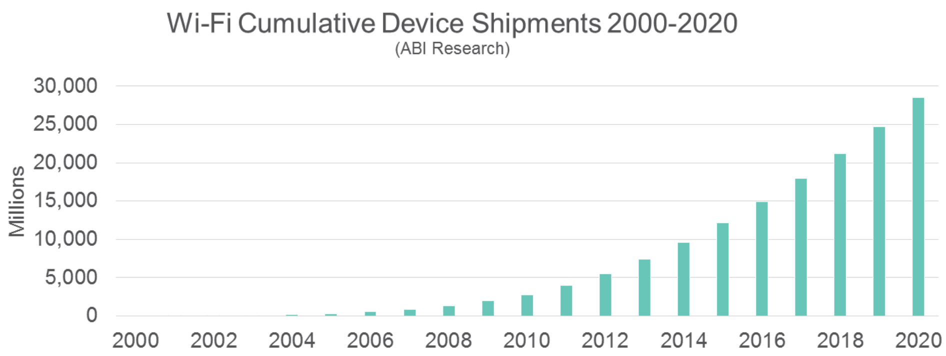
Sub 6 GHz Channelization: 10 MHz to 100 MHz
With 3 different SCS

Channelization: 50/100/200/400 MHz
With 2 different SCS



(# of operators supporting the WI)

Unlicensed Spectrum Needs



- In 2015, 802.11ac was 59.5% of home-routers shipped
- By 2020, 96.6% of home routers will be equipped with 802.11ac (i.e., 5 GHz) (CISCO VNI, 2016)
- Growing offload from cellular networks on to Wi-Fi (in 2015 over 50% of cellular traffic offloaded to Wi-Fi, see Cisco VNI 2016)
- Wi-Fi Alliance estimate (https://www.wi-fi.org/discover-wi-fi/unlicensed-spectrum)
  - Spectrum needs in addition to existing (2.4 and 5 GHz) by 2025:
    - Lower bound: 500 MHz to 1 GHz
    - Upper bound: 1.3 – 1.8 GHz
  - Need contiguous spectrum to accommodate 160 MHz channels of 802.11ac

Part 2

SPECTRUM OPPORTUNITIES FOR 5G AND BEYOND

Part 2 Outline

- Towards Connected Societies
  - Multiple levels of connectivity and implications on spectrum
  - What to connect?
- Optimization of Spectral Resources
  - Application-based
  - Network-based
- New Paradigms
  - Moving away from regulatory silos

Connected

- Current regulatory frameworks allow terrestrial connectivity at two levels
  - Local-area, e.g. short range, indoor
  - Wide-area, e.g. cellular
- These regulatory frameworks reflect existing types of connectivity/devices
  - BT, Wi-Fi, WiGig
  - 2G, 3G, 4G, and now on to 5G
- Connected "things" are growing in number
  - in diverse and unusual set of places
  - Connected device, home, campus, community, city, and larger

Additional Levels of Connectivity

- With addition of home, campus, community, city levels of connectivity supporting millions of devices
  - What are the optimum regulatory frameworks for enabling coexistence?
  - What are the optimum spectral resources to maximize performance and minimize interference?

Optimization of Spectral Resources

- What needs to be changed in identification, allocation, and use of spectrum to accommodate new use cases
  - We will have many low-, mid-, and high-range spectrum but not all spectrum is equal; congestion in one place, underutilization in another
- Mapping spectrum assets to best use to create solutions, deployment models, and business opportunities, for example in areas such as:
  - Future ITS
  - Tactile/Haptic
  - Deep learning/AI
  - AR/VR

New Regulatory Paradigms

New paradigms are needed to facilitate better use of spectrum and increase spectral efficiency beyond traditional methods of sharing

- Existing classification of Radiocommunication Services (Mobile, Fixed, FSS, etc.) is based on silos
  - Services are designed and operated independently
  - Therefore, regulations need to step in to prevent from interference
- Is it possible to move from regulatory silos to a regulatory safety net?
  - Same entities could design/deploy/operate more than one service as long as there are financial incentives
  - Regulations could lead to optimized spectrum use as long as technical solutions exist

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