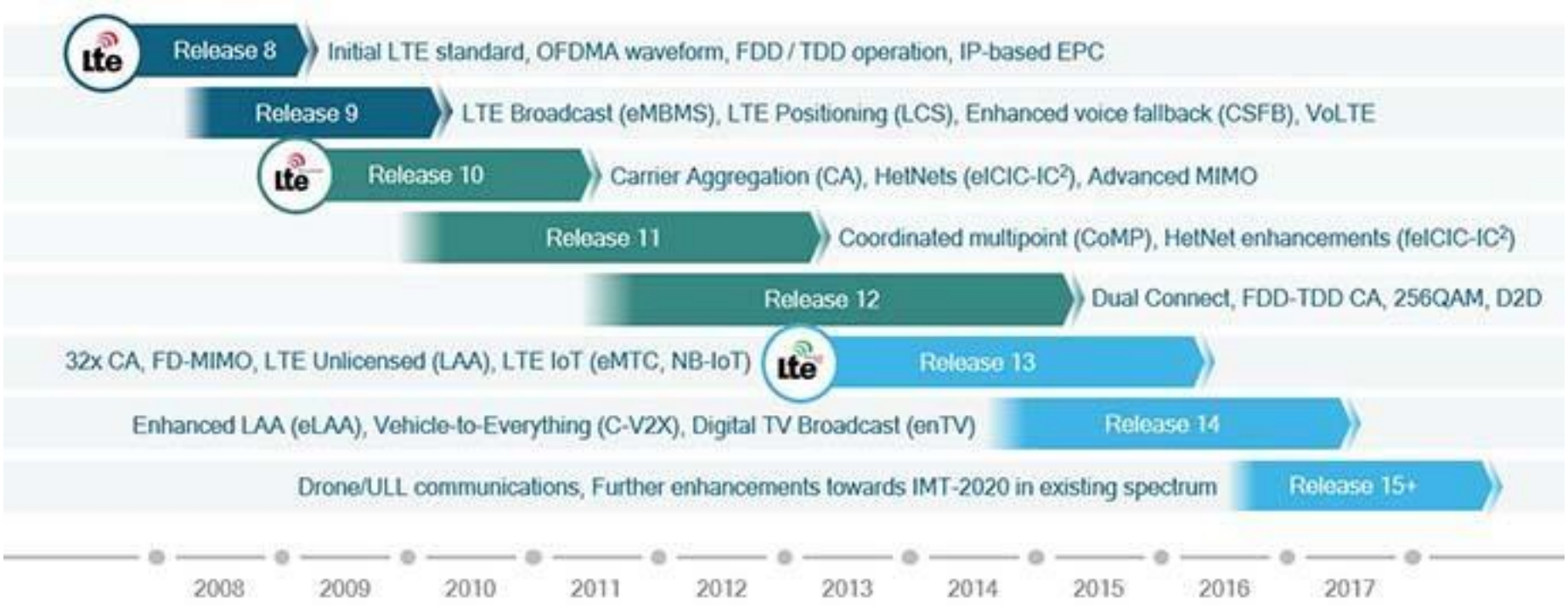
LONG TERM SPECTRUM STRATEGY ON ENABLING FREQUENCY BANDS FOR IMT

Mindaugas Žilinskas
Communications Regulatory Authority of the Republic of Lithuania
Tbilisi, 14 May 2019, EaPeReg

TOPICS

- Standardisation
- Spectrum („Leftovers“?; „6G“?)
  - UHF band
  - Bands above 3 GHz
  - Terahertz gap

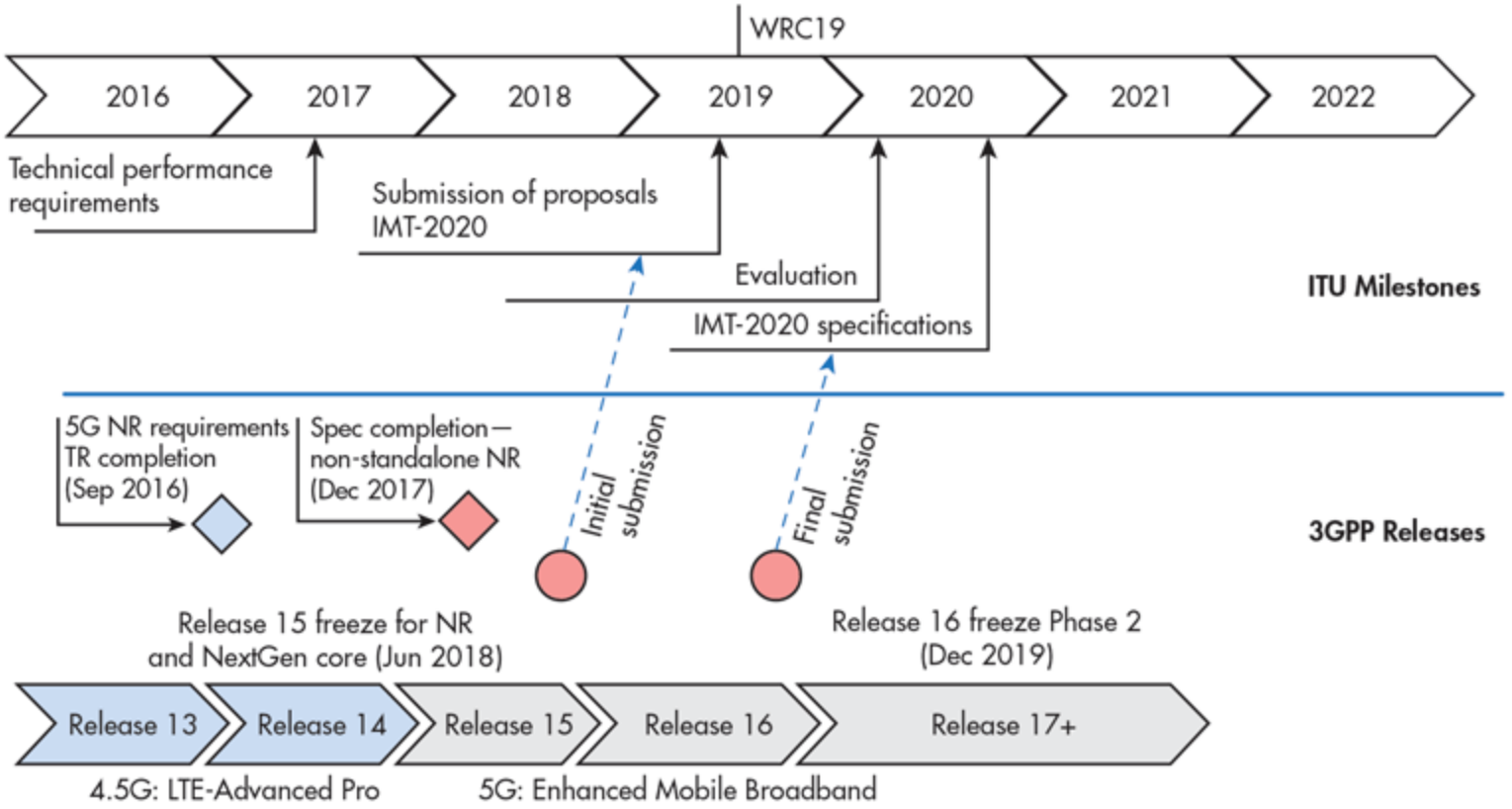
TECHNOLOGICAL EVOLUTION



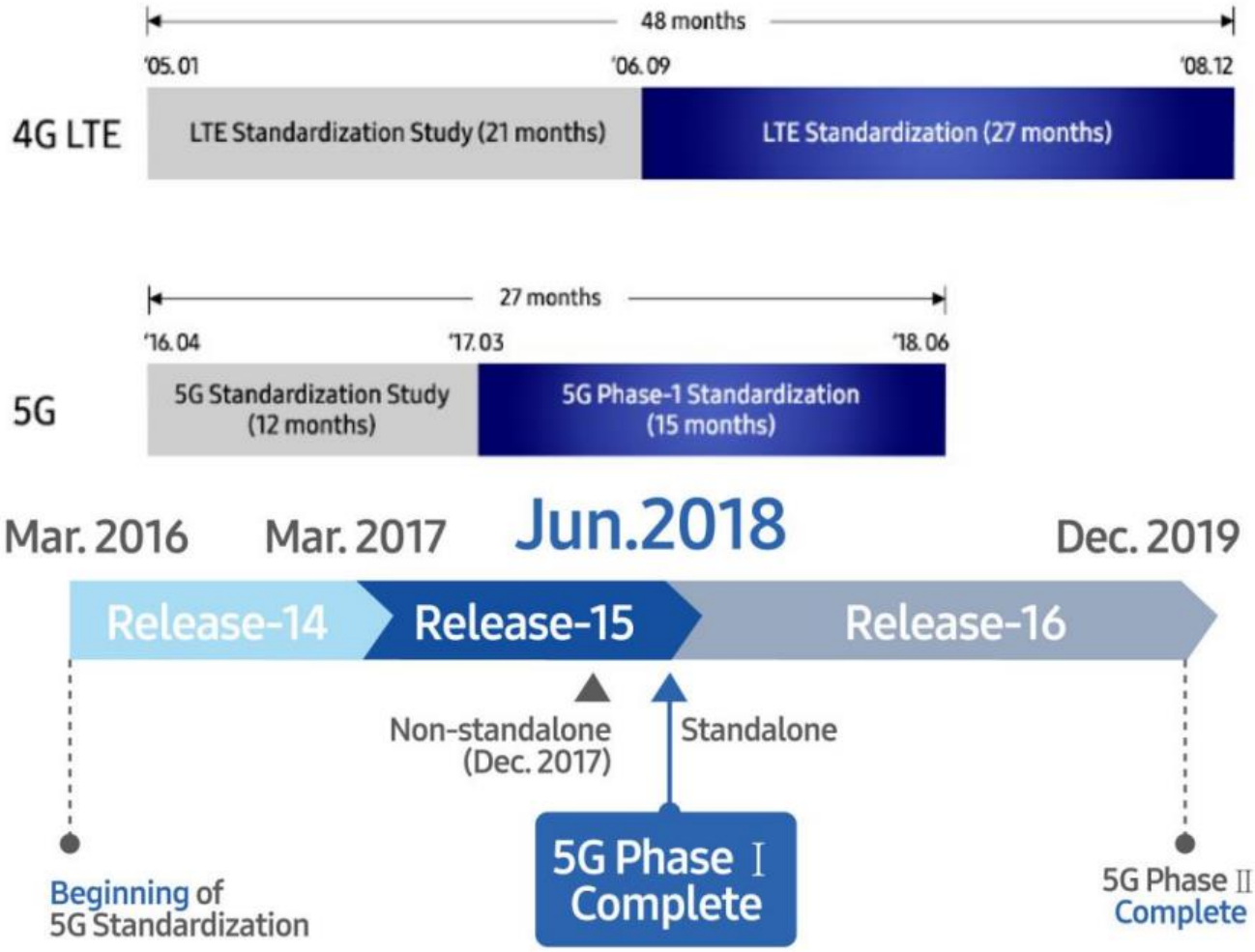
Qualcomm

Samsung Galaxy S8 – can maintain 32 different frequency bands, LTE-A 5-CA, Cat16
Samsung Galaxy S10 – can maintain 32 different frequency bands, LTE-A 7-CA, Cat20

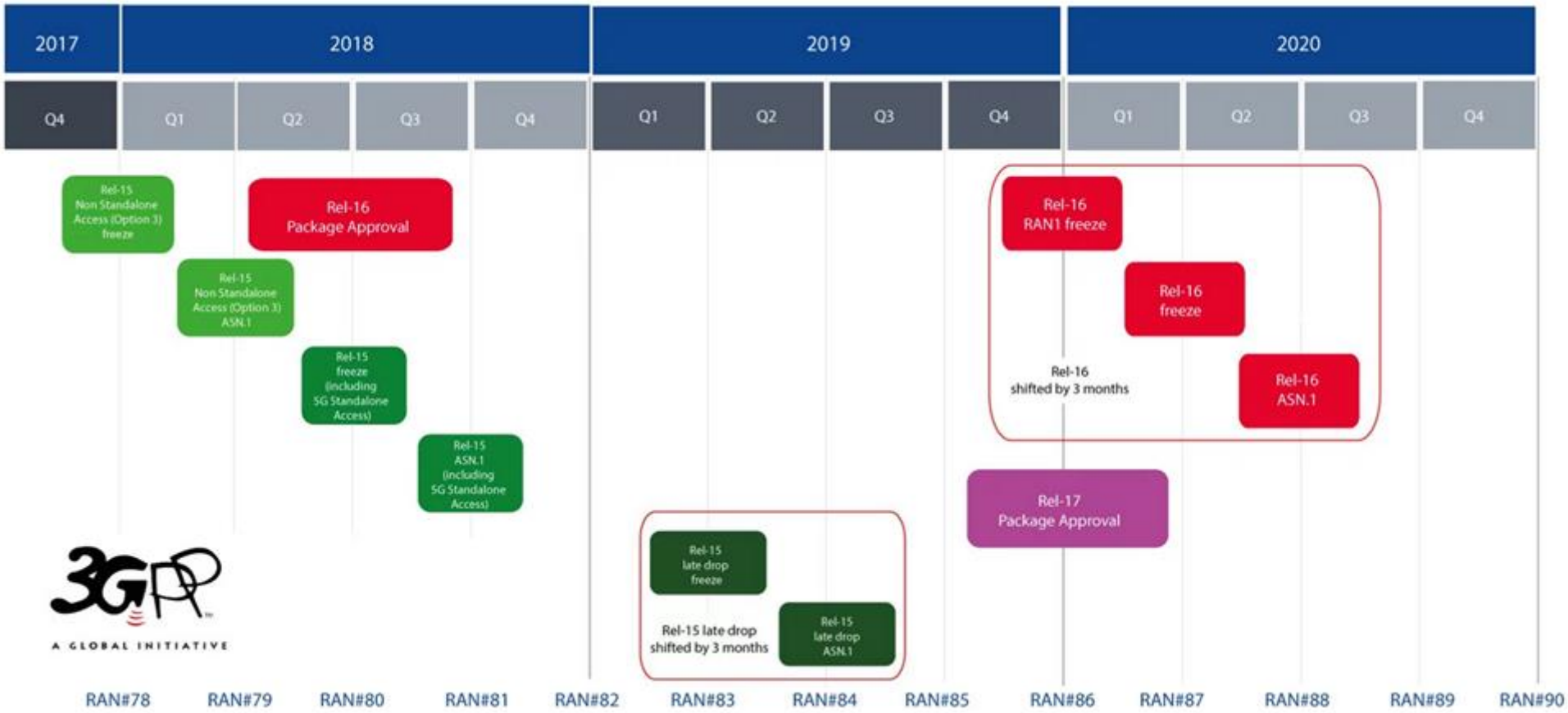
WHAT'S NEXT?


WRC19
2016
2017
2018
2019
2020
2021
2022
Technical performance requirements
Submission of proposals IMT-2020
Evaluation
IMT-2020 specifications
ITU Milestones
5G NR requirements TR completion (Sep 2016)
Spec completion— non-standalone NR (Dec 2017)
Initial submission
Final submission
3GPP Releases
Release 15 freeze for NR and NextGen core (Jun 2018)
Release 16 freeze Phase 2 (Dec 2019)
Release 13
Release 14
Release 15
Release 16
Release 17+
4.5G: LTE-Advanced Pro
5G: Enhanced Mobile Broadband

4G & 5G STANDARDIZATION TIMESCALE



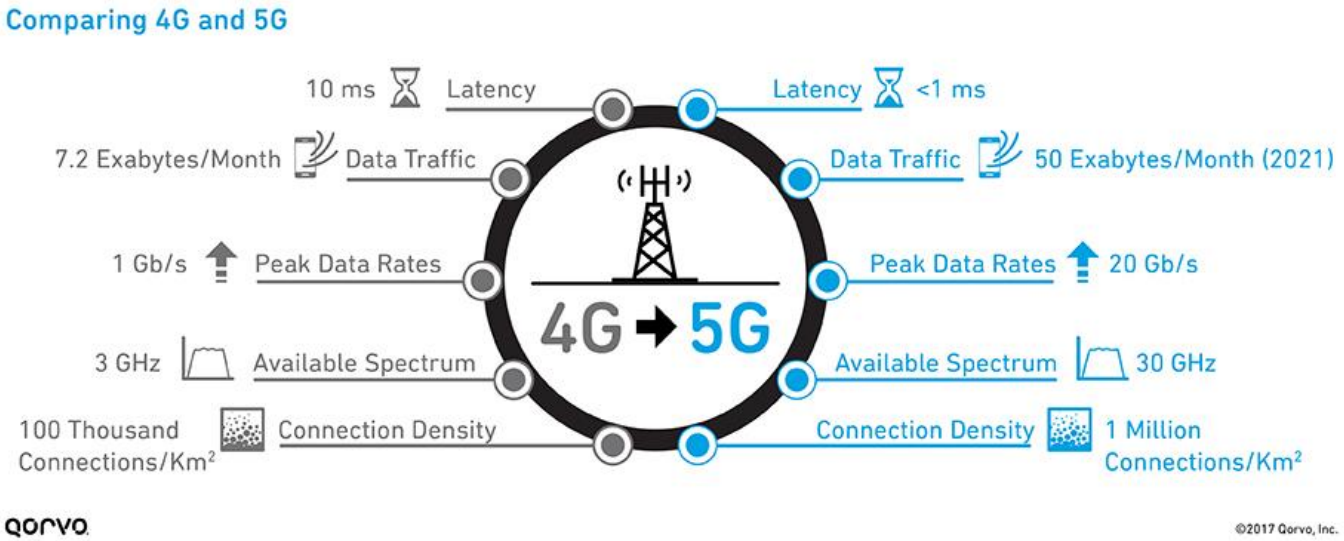
TIMING OF TECHNOLOGY



A three-month delay in finalising 3GPP's Rel 15 standard (phase 1 of 5G) has resulted in a knock-on delay to Rel 16 (phase 2 of 5G).

By the third quarter of 2018, both Ericsson and Huawei said they'd deployed more than 10,000 base stations on that Rel 15.

COMPARING 4G AND 5G



KEY PARAMETERS

	LTE	LTE-A	LTE-A Pro
QAM	64 QAM	256 QAM	256 QAM
MIMO	up to 4Tx	up to 8Tx	upto 16 Tx, 3D-MIMO
CA	-	up to 5 carriers, up to 100 MHz of BW	up to 32 carriers, up to 640 MHz of BW
	-	-	LAA, LWA

LAA: Licensed Assisted Access
LWA: LTE-WLAN Aggregation

256 QAM – Data transmission efficiency increased by 33% compared to 64 QAM

Future LTE Designed by SK Telecom: (1) 4.5G Evolution Roadmap - 5-CA Commercialization and 4x4 MIMO Deployment
June 13, 2017 | By Dr. Michelle M. Do @ Netmanias

BANDS UNDER CURRENT STUDY

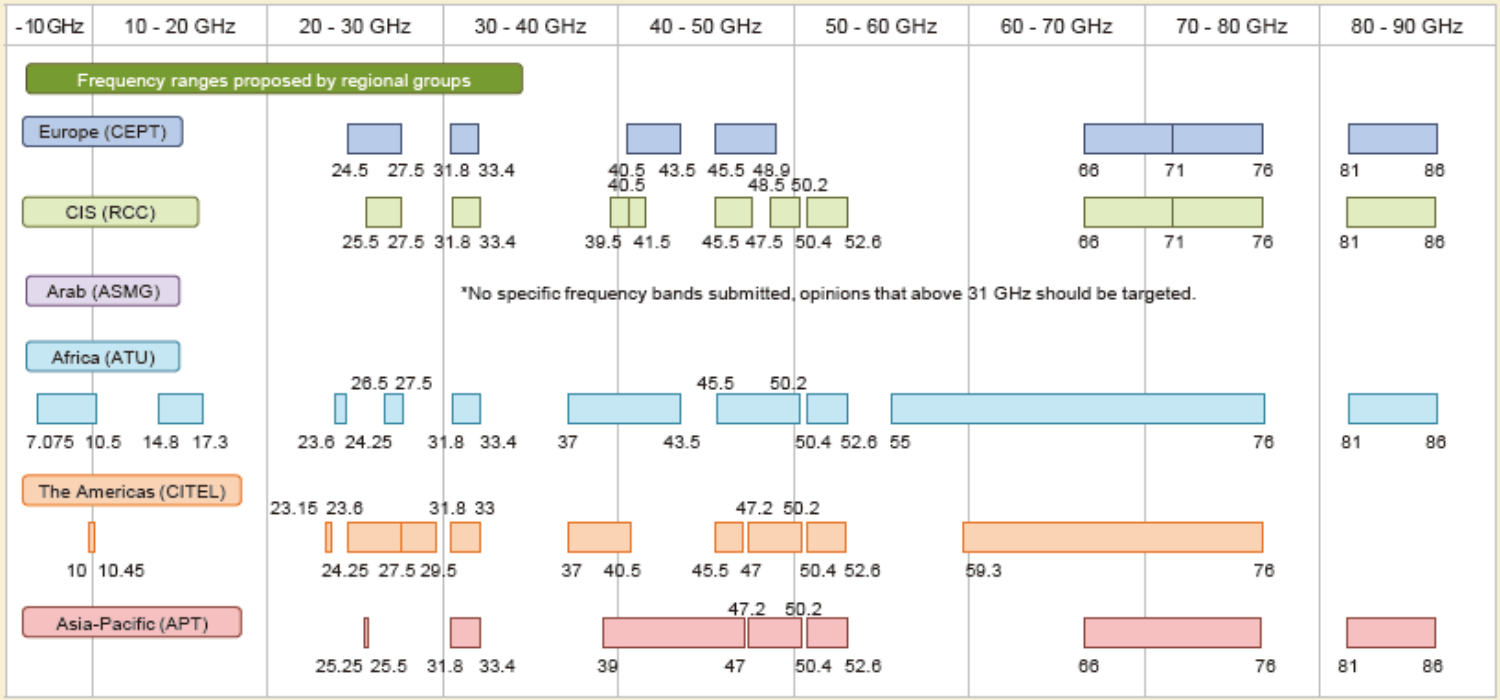


Figure 2 Frequency ranges to study for IMT identification in WRC-19

SPECTRUM FOR 5G NR

Bands for 5G New Radio (NR)

Frequency range designation	Corresponding frequency range
FR1	450 – 6000 MHz
FR2	24250 – 52600 MHz

The frequency ranges in 3GPP Release 15 for 5G NR designed for the frequency ranges FR1 and FR2

NR operating band	Uplink (UL) and Downlink (DL)	Duplex Mode
n257	26500 MHz – 29500 MHz	TDD
n258	24250 MHz – 27500 MHz	TDD
n260	37000 MHz – 40000 MHz	TDD

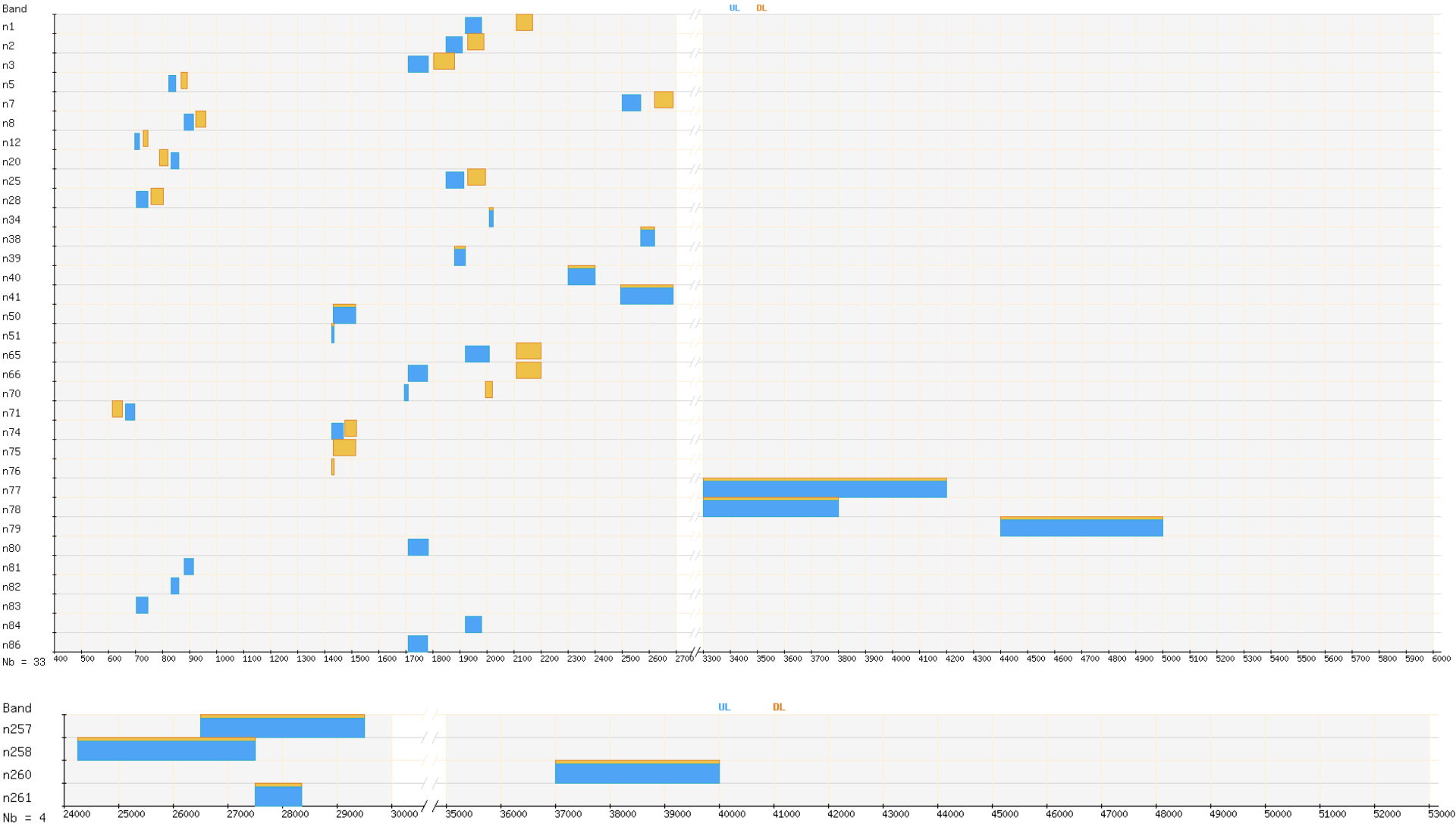
5G NR bands in FR2

All the European harmonized bands for MFCN are specified as 5G NR bands by 3GPP

NR operating band	Uplink (UL) operating band	Downlink (DL) operating band	Duplex Mode
n1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
n2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
n3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD
n5	824 MHz – 849 MHz	869 MHz – 894 MHz	FDD
n7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz	FDD
n8	880 MHz – 915 MHz	925 MHz – 960 MHz	FDD
n20	832 MHz – 862 MHz	791 MHz – 821 MHz	FDD
n28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
n38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz	TDD
n41	2496 MHz – 2690 MHz	2496 MHz – 2690 MHz	TDD
n50	1432 MHz – 1517 MHz	1432 MHz – 1517 MHz	TDD
n51	1427 MHz – 1432 MHz	1427 MHz – 1432 MHz	TDD
n66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz	FDD
n70	1695 MHz – 1710 MHz	1995 MHz – 2020 MHz	FDD
n71	663 MHz – 698 MHz	617 MHz – 652 MHz	FDD
n74	1427 MHz – 1470 MHz	1475 MHz – 1518 MHz	FDD
n75	N/A	1432 MHz – 1517 MHz	SDL
n76	N/A	1427 MHz – 1432 MHz	SDL
n77	3300 MHz – 4200 MHz	3300 MHz – 4200 MHz	TDD
n78	3300 MHz – 3800 MHz	3300 MHz – 3800 MHz	TDD
n79	4400 MHz – 5000 MHz	4400 MHz – 5000 MHz	TDD
n80	1710 MHz – 1785 MHz	N/A	SUL
n81	880 MHz – 915 MHz	N/A	SUL
n82	832 MHz – 862 MHz	N/A	SUL
n83	703 MHz – 748 MHz	N/A	SUL
n84	1920 MHz – 1980 MHz	N/A	SUL

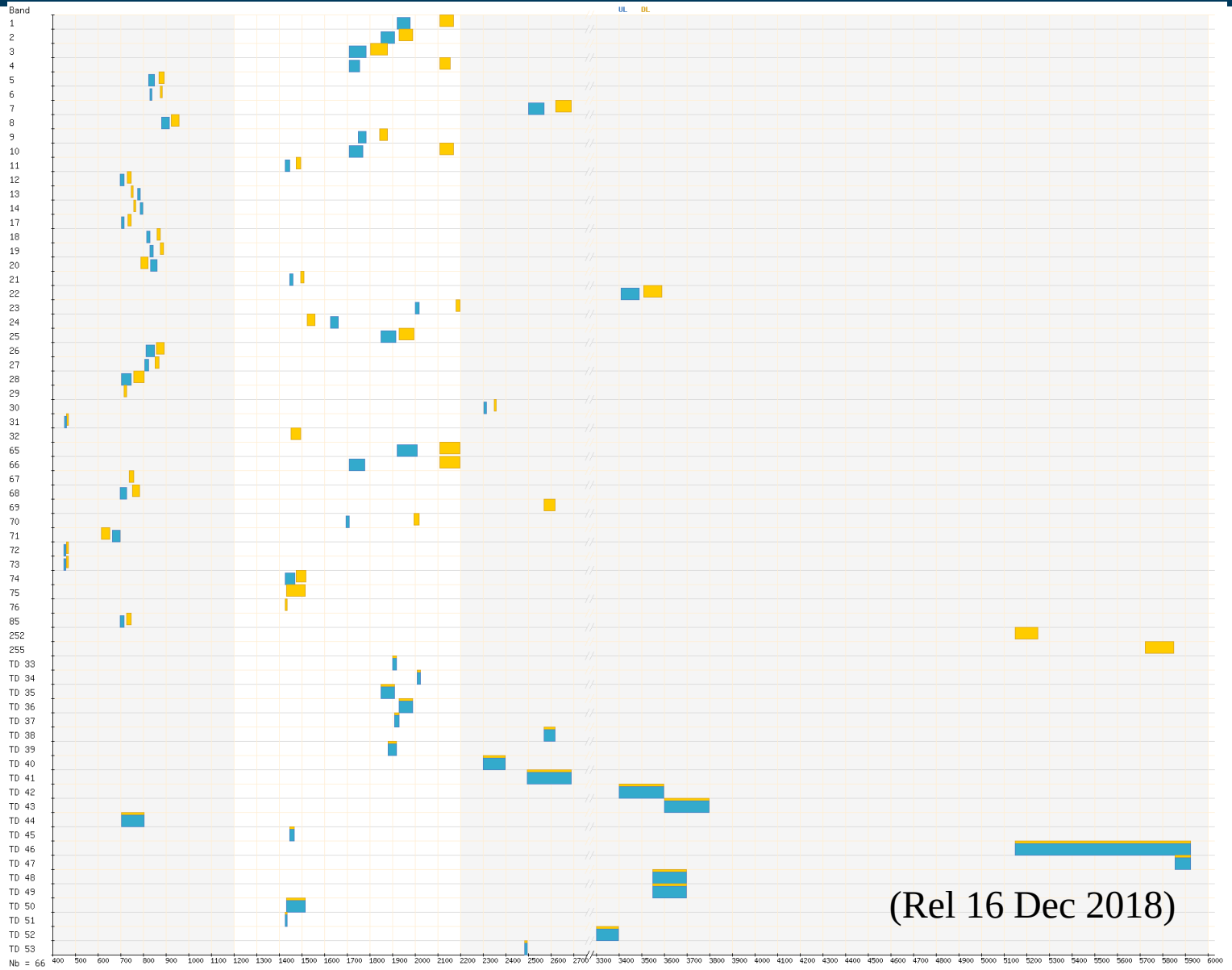
5G NR bands in FR1

NR FR1 & FR2



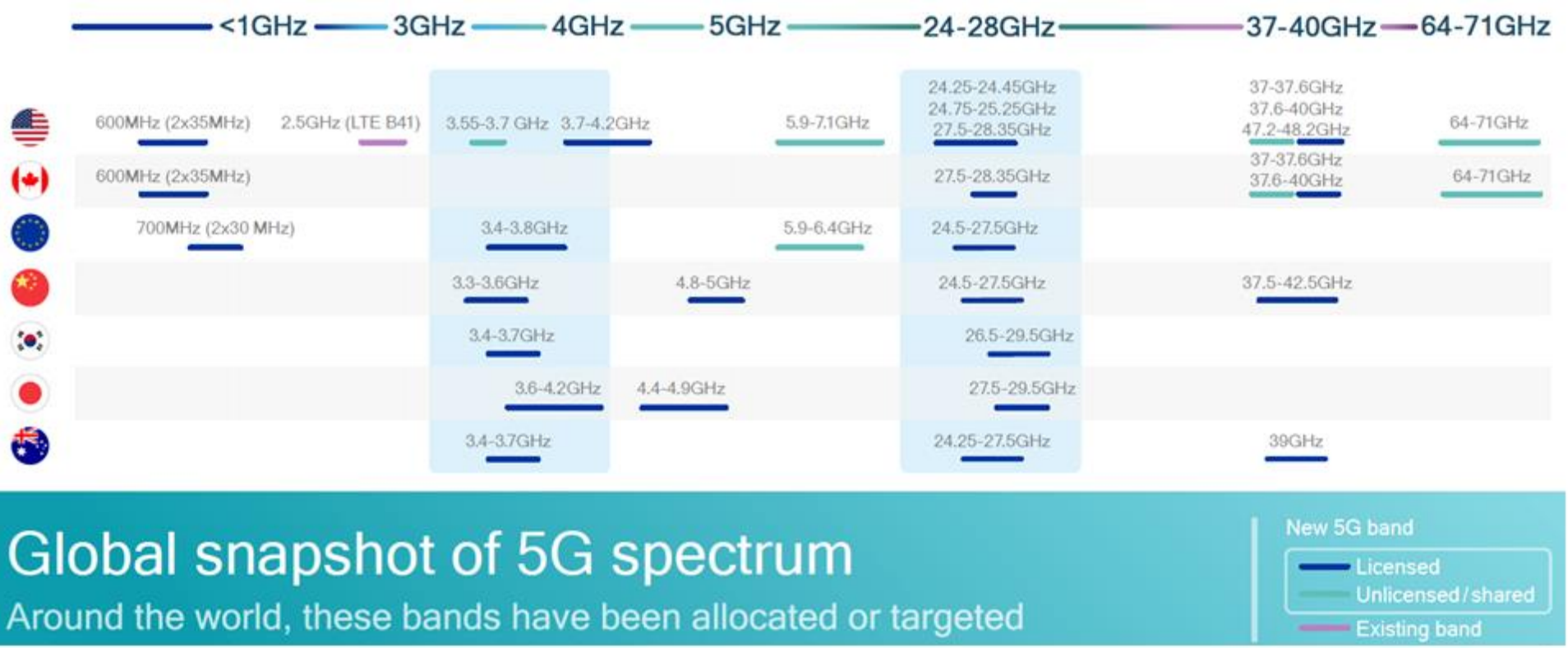
http://niviuk.free.fr/lte_band.php (Rel 15 Mar 2019)

LTE FREQUENCY BANDS



(Rel 16 Dec 2018)

SNAPSHOT OF 5G SPECTRUM



Qualcomm

USE OF THE 6 GHZ BAND

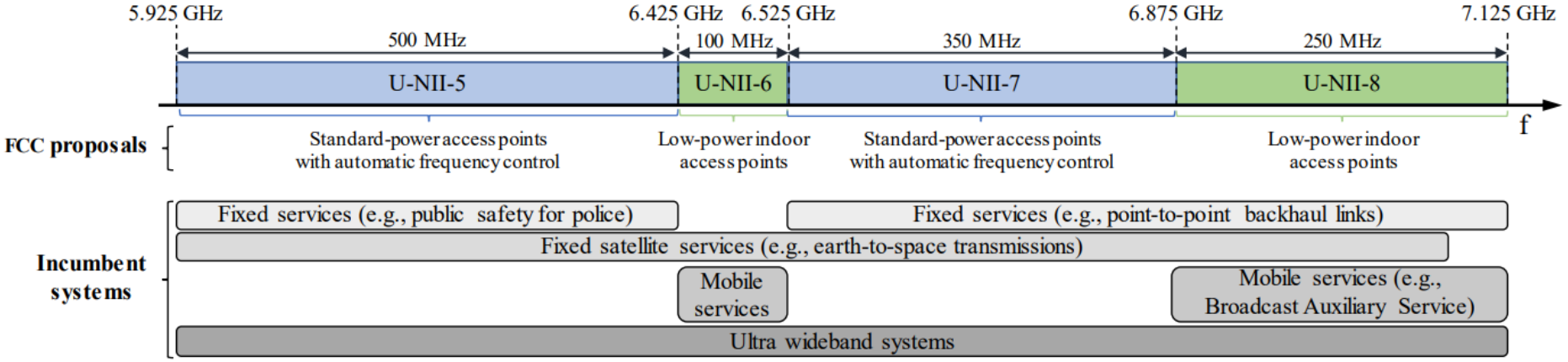
February 22, 2017

MCP (Belarus, Estonia, Liechtenstein, Lithuania, Russian Federation, Slovenia, Switzerland) submitted proposal to 44th ECC meeting for studies on Wireless Access Systems including Radio Local Area networks in 6 GHz band (ECC(17)012)

USE OF THE 6 GHZ BAND IN USA

Oct. 24, 2018

- FCC propose to expand unlicensed use in both the 5.925-7.125 GHz band (Notice of Proposed Rulemaking, FCC 18-147, ET Docket No. 18-295 (“NPRM”)).
- propose dividing the 6 GHz band into four sub-bands, each based on the prevalence and characteristics of the incumbent services that operate in that spectrum:



Standart power – 4W;
Low power -1W.

https://docs.fcc.gov/public/attachments/FCC-18-147A1.pdf
https://arxiv.org/pdf/1902.04320.pdf

USE OF THE 6 GHZ BAND IN EU

- Draft ECC Report 302
- *„Sharing and compatibility studies related to Wireless Access Systems including Radio Local Area Networks (WAS/RLAN) in the frequency band 5925-6425 MHz“* -provisionally approved for public consultation during WGSE meeting- 2019 January.
- **Brussels, 6 December 2017**
- **DG CONNECT/B4**
- **RSCOM17-53rev1**
  Mandate to CEPT to study feasibility and identify harmonised technical conditions for Wireless Access Systems including Radio Local Area Networks in the **5925-6425 MHz** band for the provision of wireless broadband services.
- Final Report from CEPT to the Commission - 2020 July.

TOPICS (CONT.)

- Spectrum („Leftovers“?)
  - Future of UHF
  - harmonisation of bands >3 GHz

A MORE EFFICIENT USE OF THE UHF BAND

aetha

[White paper on behalf of Digital UK](#) (November 2017)

LS telcom

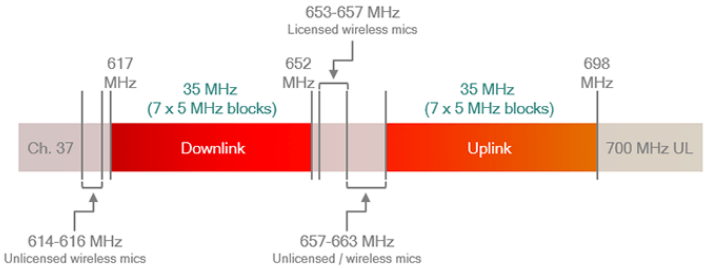
[Report for the UK Spectrum Policy Forum](#) (July 2018)

600 MHZ BAND

- WRC-15: footnotes making the band 470-698 MHz or parts of it for use by IMT in some R2, R3 countries
- WRC-15: agreed Resolution 235; to review the use and needs in 470-960 MHz (Region 1)
- Decision (EU) 2017/899 of the European Parliament and of the Council of 17 May 2017 (Article 4)

- Proposed ITU-R Report M.[IMT.EXPERIENCES] – National experiences on the use of certain frequency bands for IMT systems (e.g. 600 MHz, 700 MHz, 800 MHz, 1800 MHz, 3500 MHz)

- 3GPP Band 71 (uplink 663-698 MHz / downlink 617-652 MHz)
  - US concluded incentive auction (March 2017)
  - Mexico released 600 MHz band from DTT (October 2018)



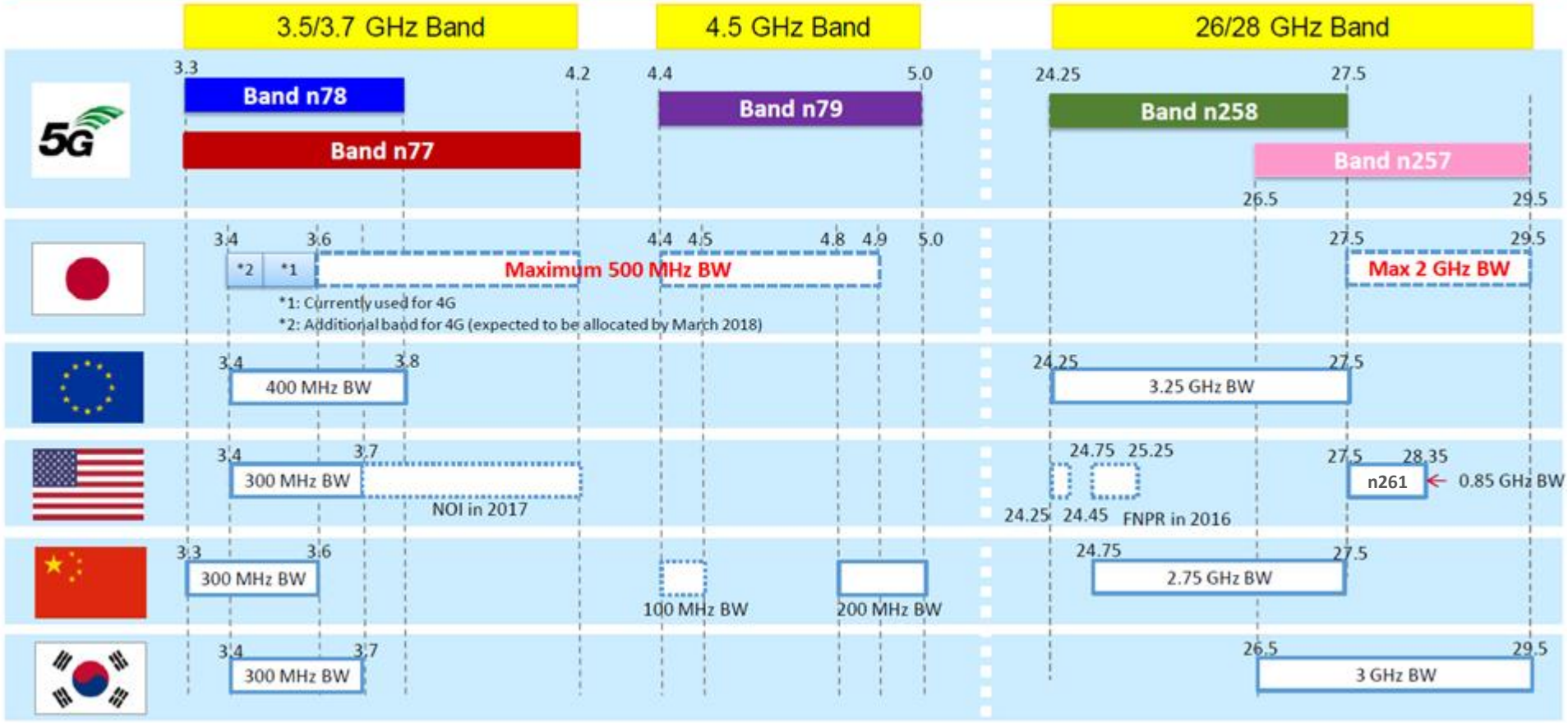
TOPICS (CONT.)

- Spectrum („Leftovers“?)
  - Future of UHF
  - harmonisation of bands >3 GHz

CURRENT 5G NR BANDS ABOVE 3 GHZ

5.441B In Cambodia, Lao P.D.R. and Viet Nam, the frequency band **4 800-4 990 MHz**, or portions thereof, is identified for use by administrations wishing to implement International Mobile Telecommunications (IMT)… The use of this frequency band for the implementation of IMT is subject to agreement obtained under No. **9.21** with concerned administrations… In addition, before an administration brings into use an **IMT station** in the mobile service, it shall ensure that the power flux-density produced by this station **does not exceed −155 dB(W/(m^2 · 1 MHz))** produced **up to 19 km above sea level** at 20 km from the coast, defined as the low-water mark, as officially recognized by the coastal State. This criterion is subject to review at WRC-19. See Resolution **223 (Rev.WRC-15)**. This identification shall be effective after WRC-19. (WRC-15)

Overview of “5G” spectrum



3-6 GHZ SPECTRUM AVAILABILITY

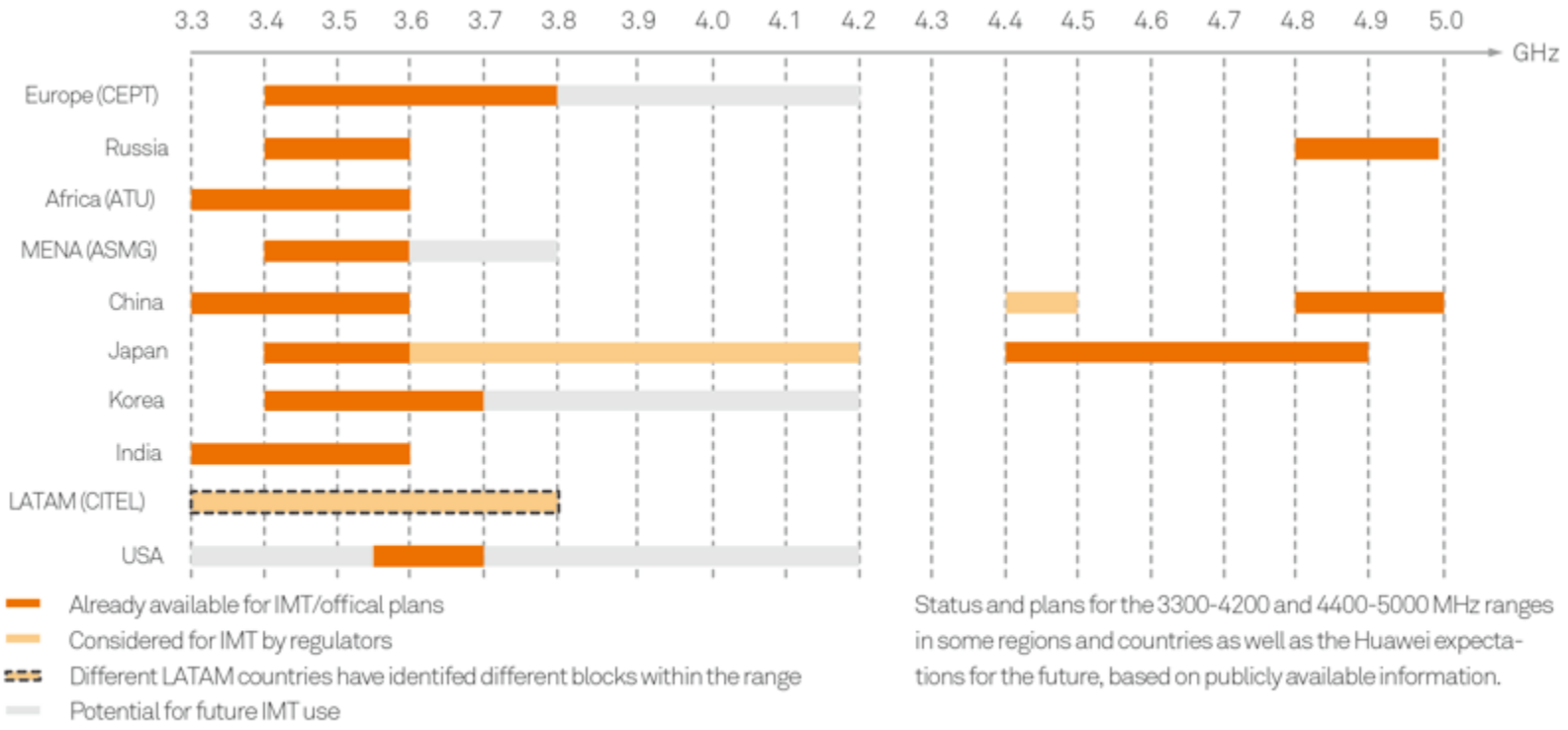


Figure: Global availability and planning of the 3300-4200 MHz and 4400-5000 MHz frequency ranges

Source: Huawei

AI 10, PROPOSALS UNDER CPG PTA

- to consider additional spectrum allocations to the mobile service on a primary basis when required and identification of additional spectrum within the frequency bands 3.8-4.2 GHz, 6425-8500 MHz and 14.3-15.35 GHz for International Mobile Telecommunications (IMT), to secure future development of terrestrial mobile broadband applications

Contribution	Proposal for new agenda item for WRC-23 to study additional spectrum for IMT
035 (ETNO)	3800-4200 MHz, 6425-8500 MHz, 14.3-15.35 GHz
036 (GSMA)	3300-3400 MHz, 3800-4200 MHz, 7125-8500 MHz, 10.7-11.7 GHz, 14.5-15.35 GHz
062 (Ericsson, Huawei)	6425-7125 MHz
INFO01 (RUS)	Above 6525 MHz, in particular 6525-7100 MHz

Check latest documents of ECP and draft Brief in CPG meeting documents

USE OF THE 6 GHZ BAND

November 13, 2015

MCP (Estonia, Lithuania, Slovenia, Ukraine) submitted proposal for IMT identification in the frequency band 5 925-6 425 MHz (Contribution 283)

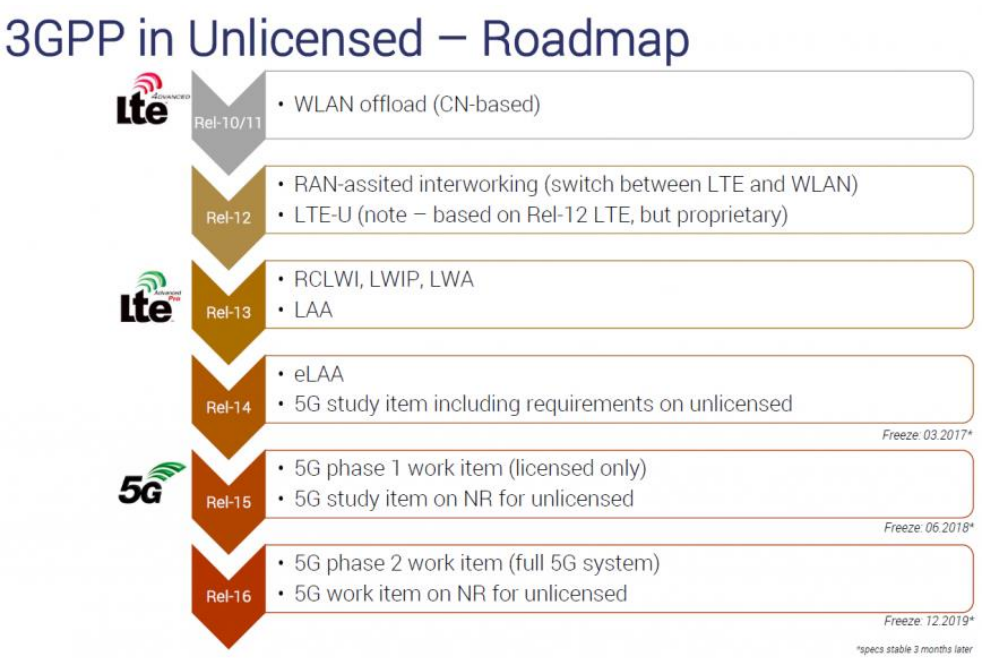
Apr 01, 2019

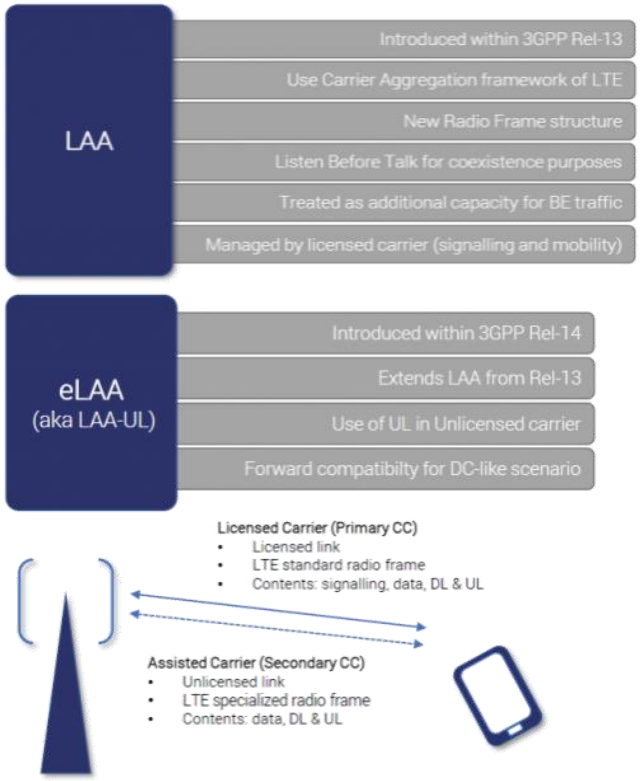
PolicyTracker
Spectrum news, research and training

China is considering raising the idea that 5925-6425 MHz and 6425-7125 MHz could be used for mobile by industry verticals, suggesting it at WRC-19 as a possible agenda item for WRC-23

USE OF UNLICENSED SPECTRUM (3GPP)

- **Licensed Assisted Access (LAA)** was introduced in the 3GPP release 13 as part of LTE-Advanced Pro. Enhanced LAA (eLAA) was introduced in Release 14.
- LAA is a concept of Carrier Aggregation between the licensed LTE carrier (Primary Component Carrier, PCC) and one or more (up to 4) unlicensed LTE carriers (Secondary Component Carrier(s), SCC) at 5GHz band [3GPP TS 36.300]

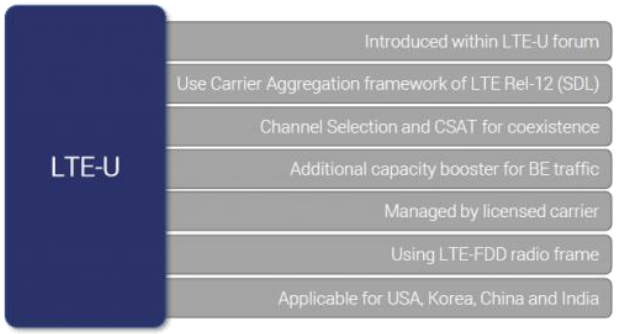


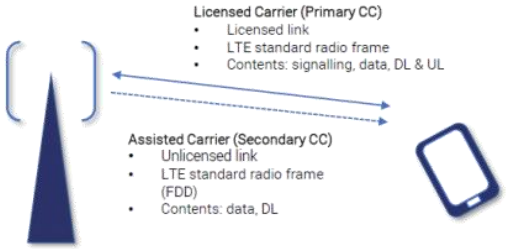


https://www.grandmetric.com/blog/2019/01/07/lte-unlicensed-spectrum/

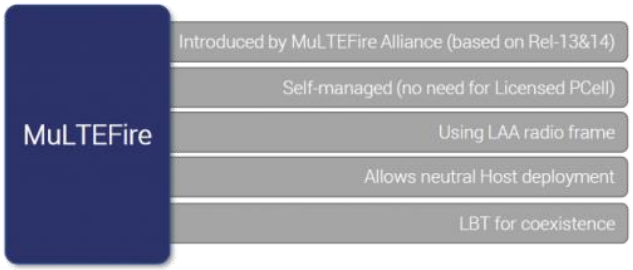
USE OF UNLICENSED SPECTRUM (NON-3GPP)

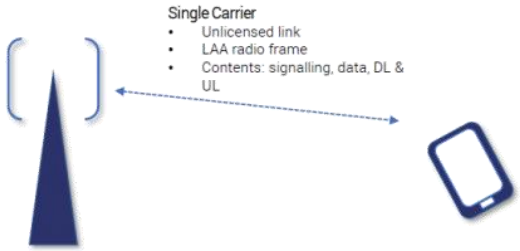
- LTE-Unlicensed is specified by LTE-U Forum as a proprietary technology.





- MuLTEFire system is being specified by MulteFire alliance, where the basic approach is to support LTE in unlicensed spectrum as a standalone operation (not anchored to licensed LTE counterpart).





https://www.grandmetric.com/blog/2019/01/07/lte-unlicensed-spectrum/

USE OF UNLICENSED SPECTRUM (SUMMARY)

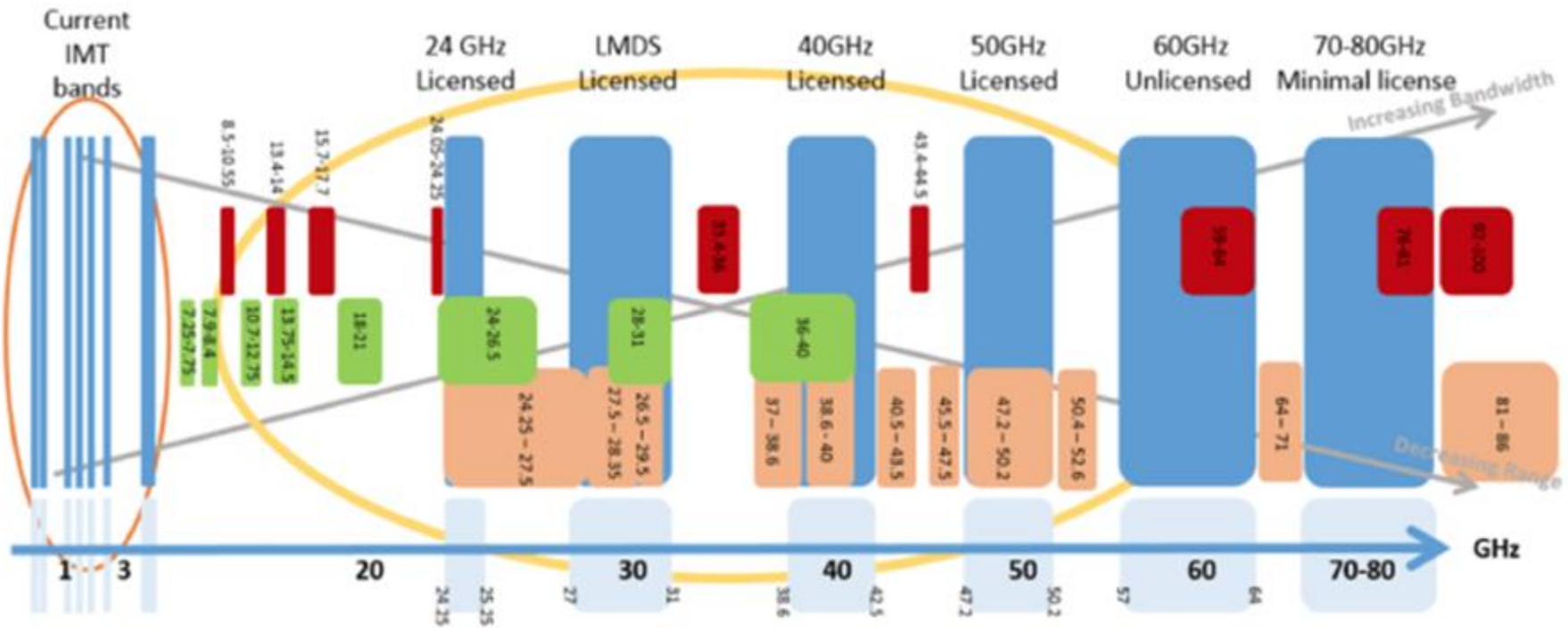
- Comparison of three technologies for the LTE in unlicensed spectrum operation [M. Rahnema, M. Dryjanski, "From LTE to LTE-Advanced Pro and 5G", Artech House, 2017]

System	LAA/eLAA	LTE-U	MuLTEfire
Specification	3GPP	LTE-U Forum	MuLTEfire alliance
Operating spectrum	5GHz	5GHz	5GHz, 3.5GHz (GAA for USA)
Operation	Aggregation: - CA SCell (SDL) (Rel-13) - CA DL/UL SCell (Rel-14 eLAA)	Aggregation - CA SCell (SDL)	Standalone (based on LAA and eLAA)
Coexistence mechanism	LBT	CSAT	LBT
Deployment possibility	Worldwide (compliant with regulations of most countries)	China, Korea, India, USA	Worldwide (supports LBT)
Transmission direction	DL only (Rel-13) DL and UL (Rel-14 eLAA)	DL only	DL (LAA based) and UL (eLAA based)
Licensed anchor cells	Yes, FDD or TDD	Yes, FDD	No (standalone)
Unlicensed Frame structure	Frame type 3 (LAA)	Frame type 1 (FDD)	Frame type 3 (LAA) with enhancements
Changes to licensed LTE	High (LAA PHY)	Low (fast to deploy, regular LTE PHY)	High (standalone RAN, LAA PHY)
Support for neutral host	No (bound to specific MNO due to licensed anchor)	No (bound to specific MNO due to licensed anchor)	Yes (MNO agnostic, connected to EPC or MF-CN)

Source: From LTE to LTE-Advanced Pro and 5G', M. Rahnema, M. Dryjanski, Artech House 2017

https://www.grandmetric.com/blog/2019/01/07/lte-unlicensed-spectrum/

DEMAND FOR WIDER CHANNELS



Aerospace and defence

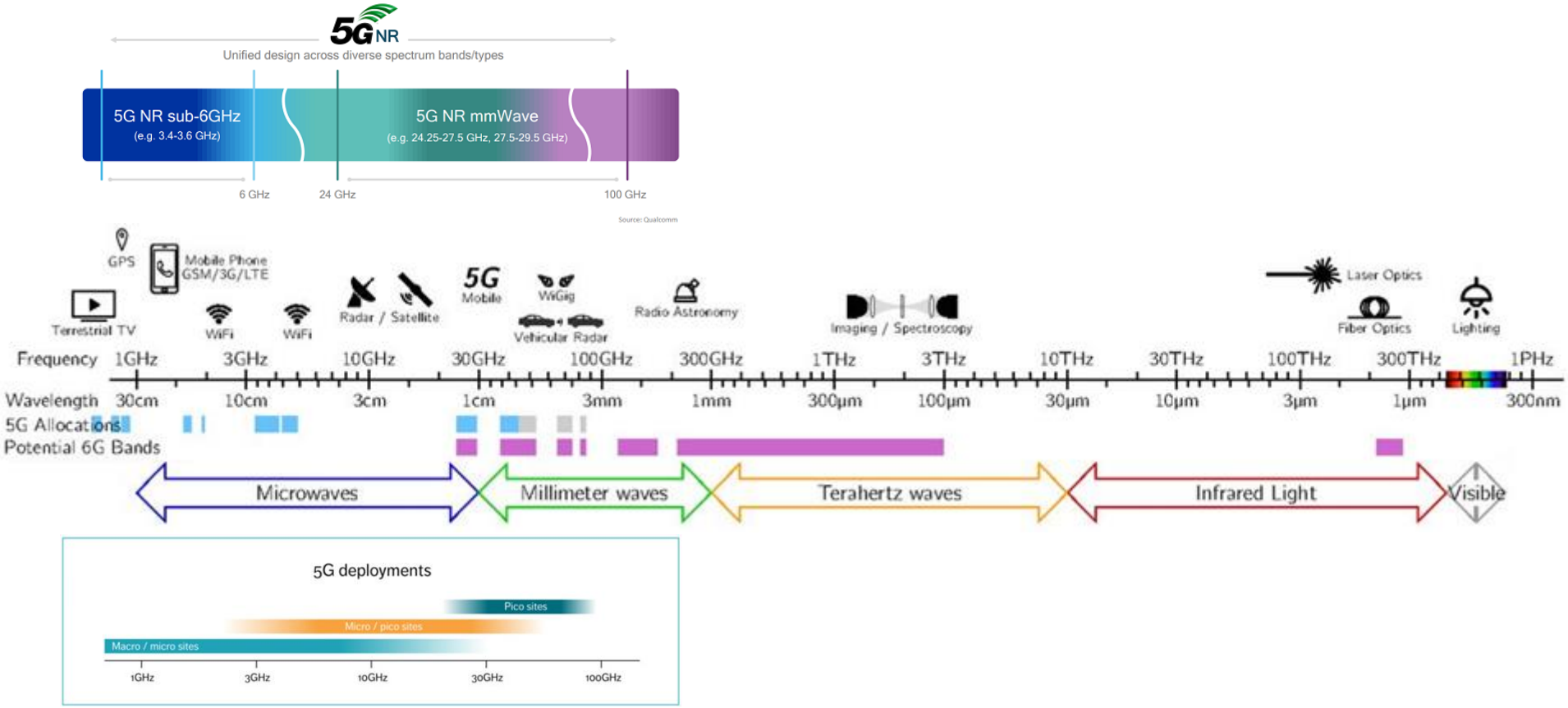
Satellite communications

https://www.4g-lte.net/5g/5g-is-coming-why-mmw-millimeter-wave

TOPICS (CONT.)

- Spectrum („6G“?)
  - Terahertz gap

MOVING TO 6G AND ABOVE 100 GHZ



- The terahertz spectrum range is in the sub-millimetre range, or 300GHz, between high-frequency infrared (IR) and just below optical physical light.
- Terahertz (THz) frequency range (0.1-3THz) is the last span within the whole electromagnetic wave spectrum, and is revered in the scientific world as THz Gap.
- Currently, the state of the art is in the 60GHz spectrum range, at millimetre wave.

MOVING TO 6G AND ABOVE 100 GHZ

- 5G won't be able to accommodate the growing demand for bandwidth. Terahertz-frequency networks, with their larger capacity and smaller power needs, will be the better option.

- Terahertz tech is quite promising for high-speed information transmission between electronic devices; building wireless local area networks (WLAN) and wireless personal area networks (WPAN) of new generation.

- The standard IEEE 802.15.3d-2017 has been approved on 28th September 2017 and published on 12th October 2018 as the worldwide first wireless communications standard operating at the 300 GHz frequency range. Nominal PHY data rate of 100 Gbps.

RADIO REGULATIONS

- **RR (Edition of 1982), WARC-79**
- **927** The frequency band 275-400 GHz may be used by administrations for experimentation with, and development of, various active and passive services. In this band a need has been identified for the following spectral line measurements for passive services:
  - radio astronomy service: 278-280 GHz and 343-348 GHz;
  - Earth exploration-satellite service (passive) and space research service (passive): 275-277 GHz, 300-302 GHz, 324-326 GHz, 345-347 GHz, 363-365 GHz and 379-381 GHz.

RADIO REGULATIONS

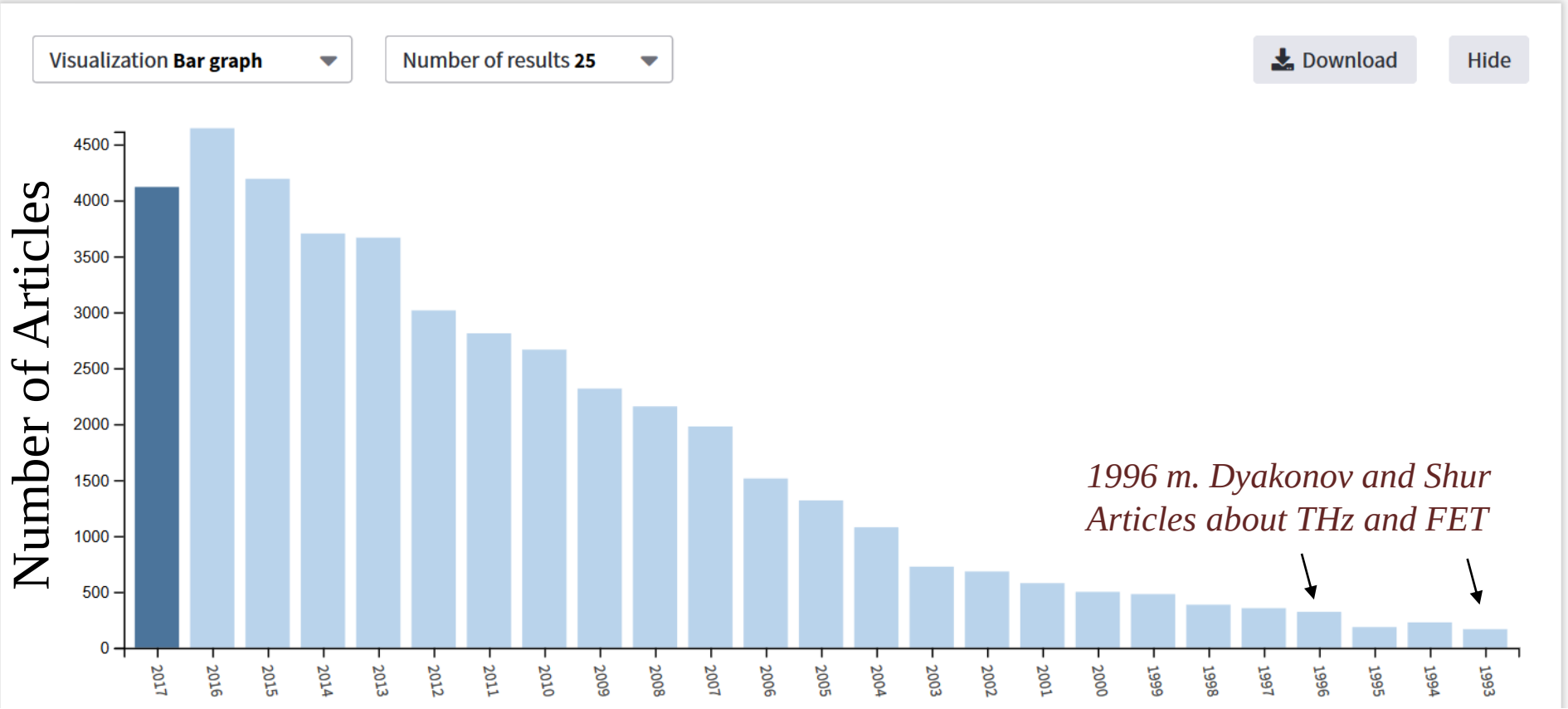
- **RR (Edition of 1982, revised in 1985 and 1986)**
- **927** (NOC)
- **RR (Edition of 1990)**
- **927** (NOC)
- **WARC-92**
- **927** (NOC)
- **RR (Edition of 1990, revised in 1994), WARC-93**
- **927** (NOC)
- **RR (Edition of 1990, revised in 1996), WRC-95**
- **S5.565** (NOC)
- **RR (Edition of 1998), WRC-97**
- **S5.565** (NOC)
- **RR (Edition of 2001), WRC-2000**
- **Just a few bands were added**

RR (Edition of 2004), WRC-03
5.565 (NOC)
RR (Edition of 2008), WRC-07
S5.565 (NOC)

ARTICLES ABOUT THZ

Showing 43,275 records for TOPIC: (THz) *OR* **TOPIC:** (terahertz) ...More

Citation report feature not available [?]



Clarivate Web of Science, http://wcs.webofknowledge.com, 2018-08-30

STARTING POINT: OUTCOME OF WRC-12

5.565 A number of bands in the frequency range 275-1 000 GHz are identified for use by administrations for passive service applications. The following specific frequency bands are identified for measurements by passive services:

- radio astronomy service: 275-323 GHz, 327-371 GHz, 388-424 GHz, 426 442 GHz, 453 510 GHz, 623-711 GHz, 795-909 GHz and 926-945 GHz;
- Earth exploration-satellite service (passive) and space research service (passive): 275-286 GHz, 296-306 GHz, 313-356 GHz, 361-365 GHz, 369-392 GHz, 397-399 GHz, 409-411 GHz, 416-434 GHz, 439-467 GHz, 477-502 GHz, 523-527 GHz, 538-581 GHz, 611-630 GHz, 634-654 GHz, 657-692 GHz, 713-718 GHz, 729-733 GHz, 750-754 GHz, 771-776 GHz, 823-846 GHz, 850-854 GHz, 857-862 GHz, 866-882 GHz, 905-928 GHz, 951-956 GHz, 968-973 GHz and 985-990 GHz.

The use of the range 275-1 000 GHz by the passive services does not preclude use of this range by active services. Administrations wishing to make frequencies in the 275-1 000 GHz range available for active service applications are urged to take all practicable steps to protect these passive services from harmful interference until the date when the Table of Frequency Allocations is established in the above-mentioned 275-1 000 GHz frequency range.

All frequencies in the range 1 000-3 000 GHz may be used by both active and passive services. (WRC-12)

WHY IS SHARING NECESSARY AT ALL?

- Assuming, that interference to Radio Astronomy can be handled (operated in very high remote areas only!) the most critical passive service w.r.t. THz Communication is Earth Exploration Satellite Service (EESS):

  - Transmission in remaining bands only would allow
    - small bandwidths
    - distributed over entire THz range

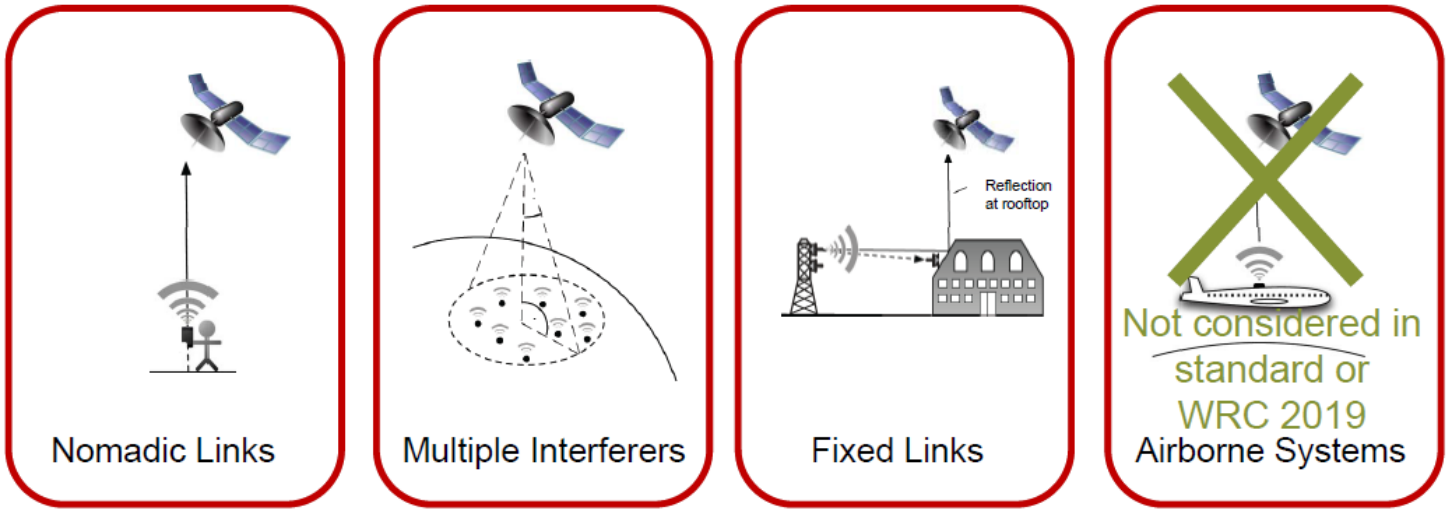
    Not feasible for data rates >> 10 Gbit/s

  - Coexistent spectrum usage

    Interference investigations inevitable to have a safe basis for the operation of THz Communications

Remaining Frequency Bands not used by EESS	Total available Bandwidth
286-294 GHz	8 GHz
307-313 GHz	6 GHz
356-361 GHz	5 GHz
366-369 GHz	3 GHz
392-397 GHz	5 GHz
399-409 GHz	10 GHz
411-416 GHz	5 GHz
434-439 GHz	5 GHz

POSSIBLE INTERFERENCE SCENARIOS



Interference Mitigation has to be considered right from the beginning, when developing THz Communications Systems

WRC-19 AI 1.15

- WRC-15 agreed in Resolution 767:
- to have an agenda item for WRC-19 to consider identification of spectrum for land mobile and fixed active services in the range of 275 GHz to 450 GHz while maintaining protection of the passive services identified in the existing footnote 5.565.

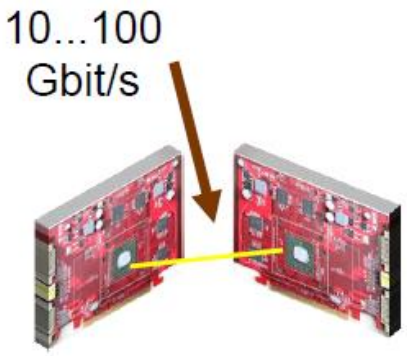
- ITU-R is invited to
  - identify technical and operational characteristics (WP 5A and 5C for the new active services, WP 7C and 7D for existing passive services)
  - study spectrum needs (WP 5A and 5C)
  - develop propagation models (SG 3)
  - conduct sharing studies with the passive services (WP 1A)
  - identify candidate frequency bands (WP 1A)

- ITU-R WP1A is leading the preparation of AI 1.15 and conducting the sharing studies.

PREPARATORY WORK OF WRC-19 AI 1.15

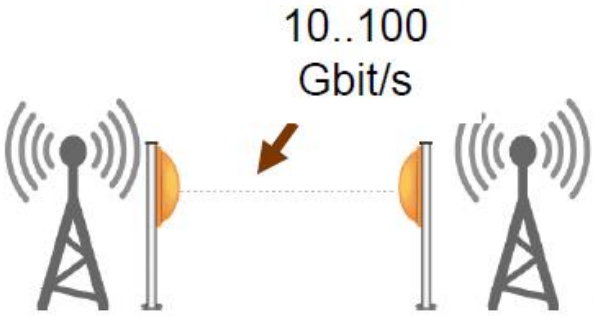
- The supporting Working Parties (WPs 5A, 5C, 7C, 7D and SG3) have finished their tasks.
- Regarding the new active services the reports **ITU-R F.2416 and ITU-R M.2417** have been published. The applications are Close Proximity/Kiosk Downloading, Intra-Device Communications and additional wireless links in data centers (land mobile) and wireless front-/backhaul links (fixed services).
- The frequency bands of interest are
  - between 275 to 450 GHz for land mobile applications.
  - especially, 275-325 GHz and 380-445 GHz for fixed service applications (maybe another band is possible in between).
- WP 1A has conducted sharing studies and preliminary study results are available.
  - For instances in the band 275-296 GHz coexistence with the passive services seems to be possible with no specific conditions. This provides a continues bandwidth of 44 GHz with the existing bands from 252-275 GHz.
  - Other bands for land mobile service are 306-313 GHz, 318-333 GHz and 356-450 GHz.

TARGETED APPLICATIONS

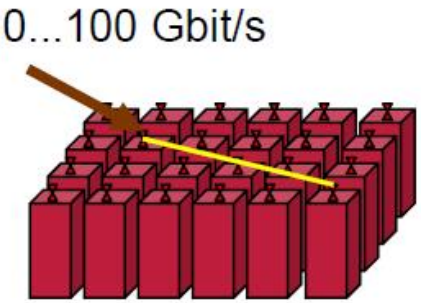


Intra-Device Communication

Kiosk downloads



Backhaul/Fronthaul links

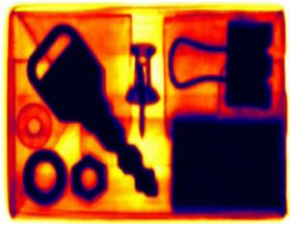


Additional Wireless Links in Data Centers

https://mentor.ieee.org/802.15/dcn/18/15-18-0177-01-0thz-introduction-to-the-h2020-ict-%2009-2017-cluster.pdf
https://thorproject.eu/
https://terapod-project.eu/links/ict-09-2017-cluster/

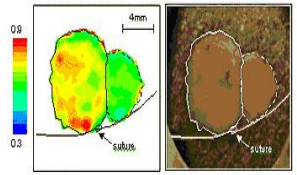
NEW APPLICATION FOR THZ FREQUENCIES

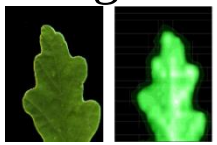
Control



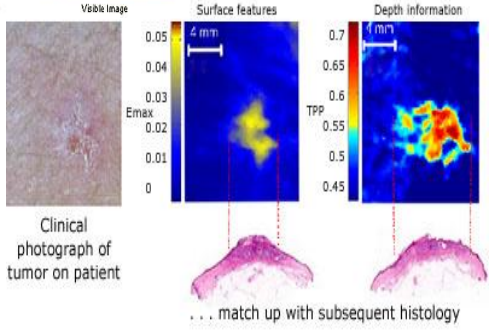
Communications

Biological investigation

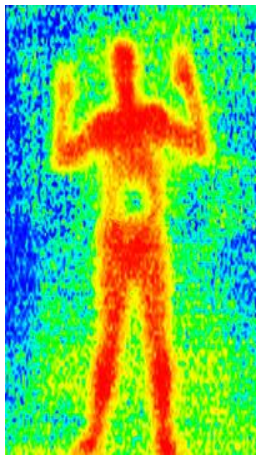




Terahertz images in vivo on patient . . .



Security

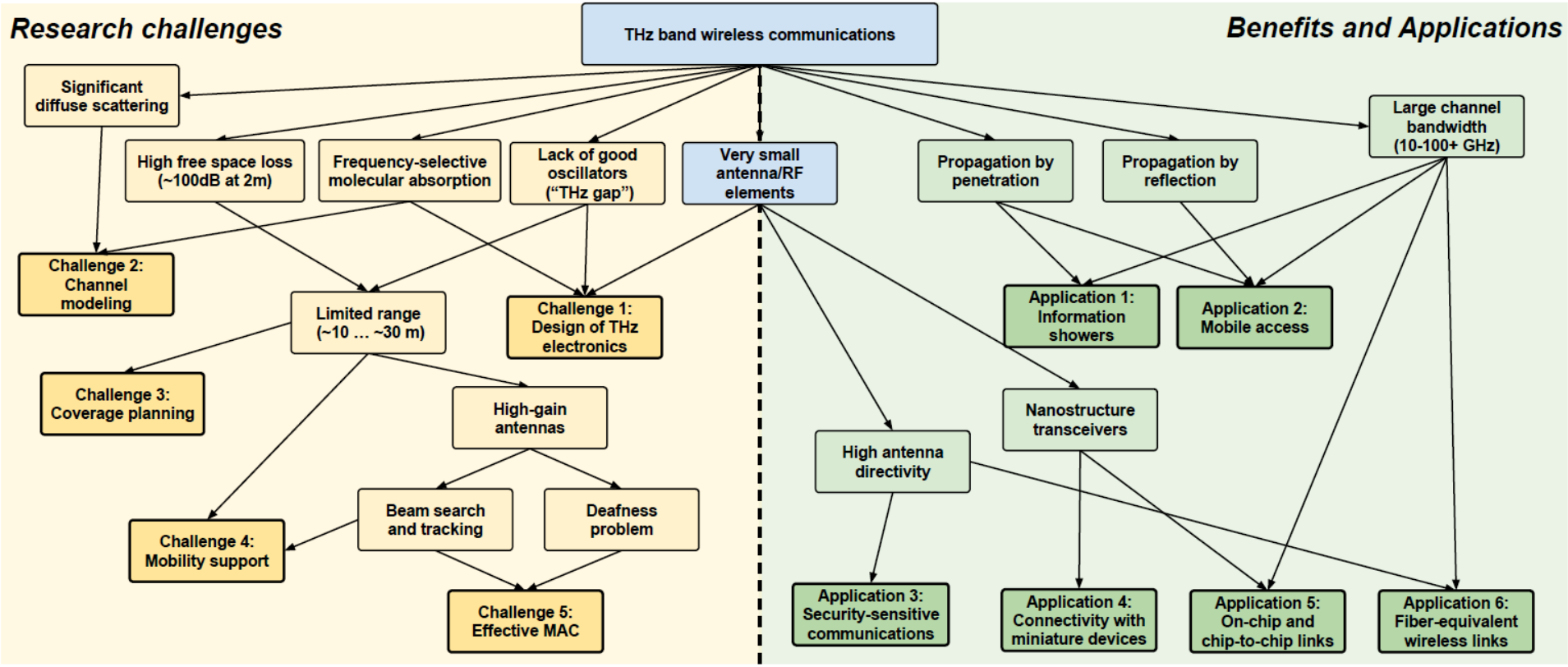


1. A number of solids and liquids are transparent – water is not.

2. Very sensitive to electrical conductivity.

3. Differentiation of cancerous and non-cancerous tissues using non-ionising radiation.

THZ COMMUNICATIONS



Petrov, V., Pyattaev, A., Moltchanov, D., & Koucheryavy, Y. (2016). Terahertz band communications: Applications, research challenges, and standardization activities. In 2016 8th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT) (pp. 1-8). IEEE. DOI: 10.1109/ICUMT.2016.7765354

COMMUNICATIONS

- High-frequency and communication technology at the University of Wuppertal, Germany.
- “Targeting bandwidth up to 20 GHz, targeting speeds of 1 terabyte per second”.
- Professor of this University U. Pfeiffer says “that’s the real challenge but we can communicate over a few metres, up to possibly 100 metres”.
- “So far we have reached 100 Gbps over 1 metre, and the size of the chip was seven millimetres,”
- PolicyTracker, 23 Apr 2019 by Manuel R. Martin

RESEARCH PROJECTS

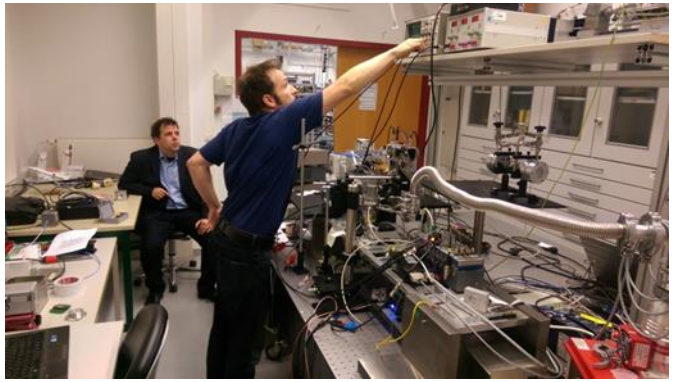
- Six projects from the EU H2020 call ICT-09-2017 have been funded:
  - **DREAM**: D-band Radio solution Enabling up to 100Gb/s reconfigurable Approach for Meshed beyond 5G network
  - **EPIC**: Enabling Practical Wireless Tb/s Communications with Next Generation Channel Coding
  - **TERAPOD**: Terahertz based Ultra High Bandwidth Wireless Access Networks
  - **TERRANOVA**: Terabit/s Wireless Connectivity by Terahertz Innovative Technologies to deliver Optical Network Quality of Experience in Systems Beyond 5G
  - **ULTRAWAVE**: Ultra capacity wireless layer beyond 100 GHz based on millimeter wave Traveling Wave Tubes
  - **WORTECS**: Wireless Optical/Radio Terabit Communications
- One project from the call EU-Japan have been funded:
  - **THOR**: TeraHertz end-to-end wireless systems supporting ultra high data Rate applications
- These seven projects have agreed to form an unofficial cluster in order to try to coordinate some dissemination activities to maximise the impact of the projects.

dream terapod ULTRAWAVE

EPIC TERRANOVA THOR

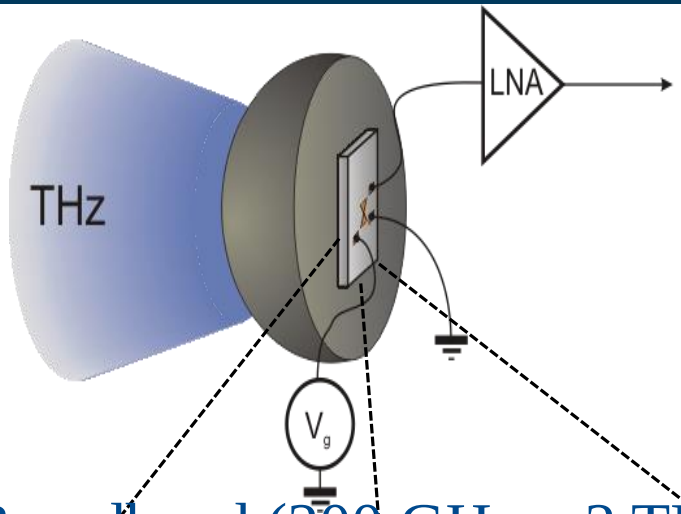
RESEARCH PROJECTS

ESA project with **Vilnius University** Physics Faculty, Noise and THz lab.

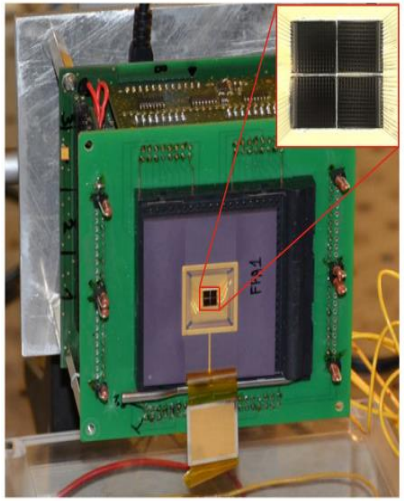


Directive transistor-based THz detectors (THz FET).
Objective 1: to develop directive quasi-optical horn and lens-coupled detectors, which exploit field-effect transistors, operating in the frequency range of 0.3-5 THz.

THZ DETECTORS AT VILNIUS UNIVERSITY



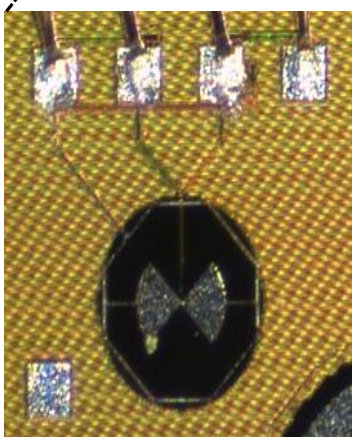
Broadband (200 GHz – 2 THz)

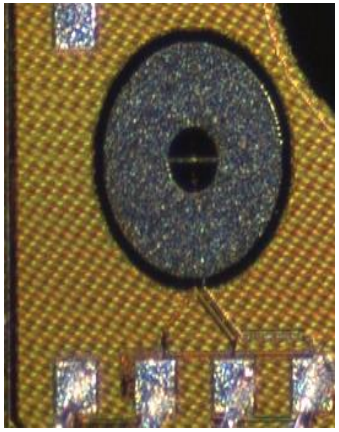


- A stitched 4×12×12 element 150nm CMOS detector array. Resonant frequency 600 GHz (in coop. with GUF)

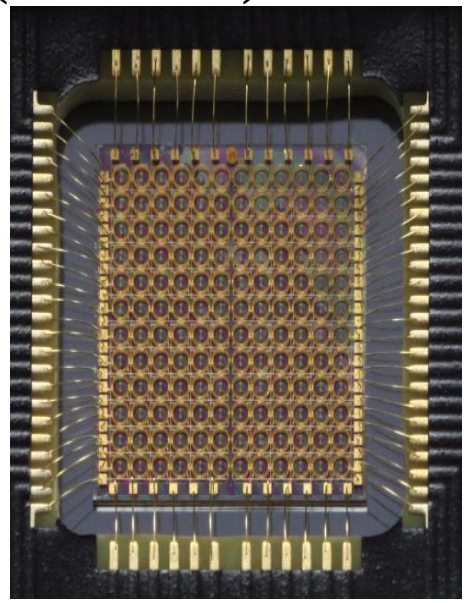
J. Zdanevičius *et al.*, *Journal of Infrared, Millimeter, and Terahertz Waves*, vol. 36, no. 10, pp. 986–997, Oct. 2015.

Narrowband (300 GHz)





K. Ikamas, et al., *IEEE Electron Device Letters*, vol. 39, no. 9, pp. 1413–1416, 2018.



- 12×12 element array with broad-band (400 GHz – 1 THz) antenna coupled to 250nm AlGaN/GaN HEMT detectors (in coop. with GUF and FBH)

ACTIVITIES

An ICT Beyond 5G Cluster Workshops with the support of the EC:

- Towards TeraHertz Communications (7 March 2018)
- Second Towards THz Communications (7 March 2019)

EUCNC 2019 June 18-21
European Conference on Networks and Communications | Valencia, Spain

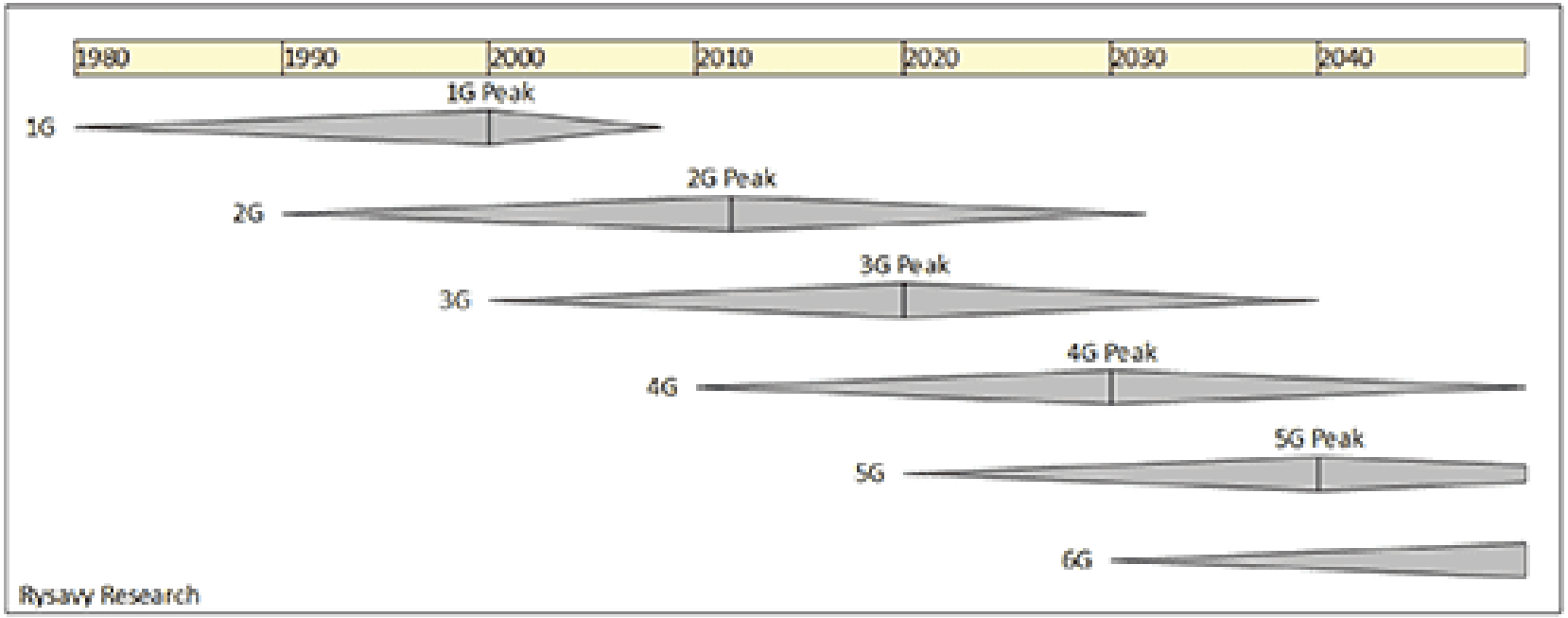
https://www.eucnc.eu/history/

6G WIRELESS SUMMIT
Levi • Lapland • Finland
24-26 March 2019

6Genesis - Finland's University of Oulu project for the 6G-Enabled Wireless Smart Society & Ecosystem (in the framework of Finnish Flagship programme)

http://www.6gsummit.com/presentations/

TIMELINE OF CELLULAR GENERATIONS



THANK YOU

Communications Regulatory Authority Republic of Lithuania

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14 May 2019
Tbilisi, Georgia