Spectrum Management

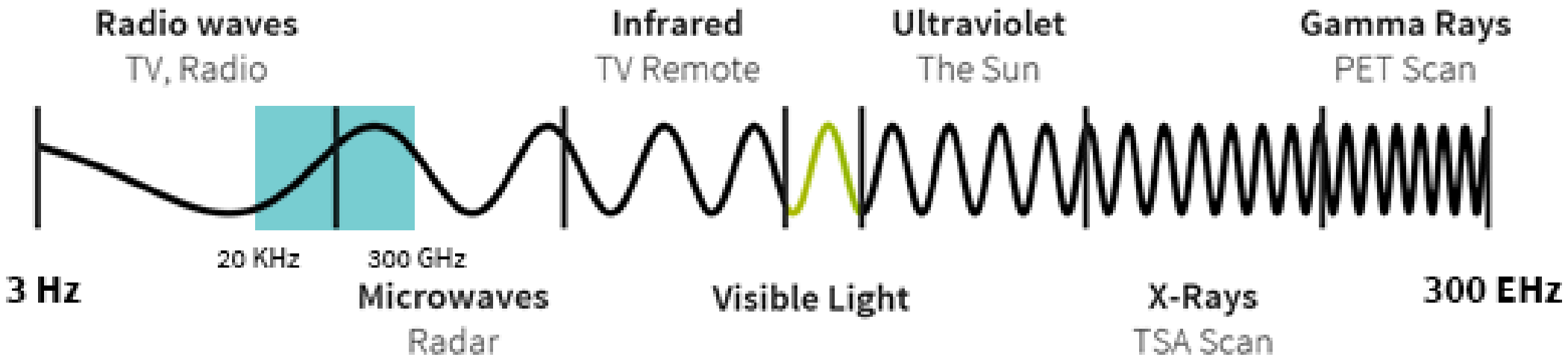
27 April 2020

Guest lecture – Chalmers University

Per Hjalmar Lehne, Telenor Research - per-hjalmar.lehne@telenor.com – +47 916 94 909

Why should we care about spectrum?

- Spectrum refers to the invisible radio frequencies that wireless signals travel over.
- Those signals are what enable us to make calls from our mobile devices, tag our friends on Instagram, call an Uber, pull up directions to a destination, and do everything on our mobile devices



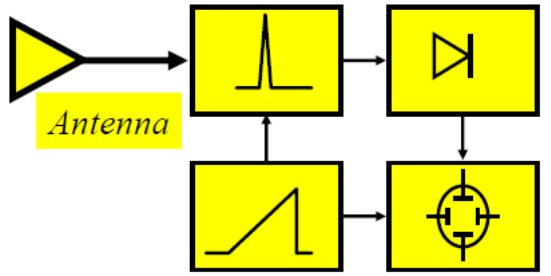
Spectrum Management

- Support material:
  - Tjelta T., Struzak R. Spectrum management overview, *The Radio Science Bulletin*, No 400, March 2012

What is spectrum?

$$S(\omega) = \int_{-\infty}^{\infty} f(t)e^{-j\omega t}dt$$

- **Mathematical concept?**
  - An abstract concept of no practical value, only later accepted as a mathematical tool
    - 1822: Concept of spectrum (J.B.Fourier, 1768-1830)
- **Measurable physical quantity?**
  - A physical object.
    - 1888 Hertz experiments
  - Radio waves can transport energy and information at distance with no wires
    - 1895: Marconi and Popov experiments & applications
- **Common (public) resource?**
  - A natural freely accessible public resource: everybody can profit from its exploitation
    - 1901: First transatlantic wireless transmission
- **Marketed commodity?**
  - A commodity is either grown or produced naturally in the environment
    - The prices of these commodities are primarily based on their demand and supply.



Contents

- What is spectrum? A brief history of spectrum management
- Global, regional and national regulations
- Spectrum for mobile and wireless
- Spectrum sharing and trading concepts
- EMF
- Future spectrum management enablers – cognitive radio

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Commercial use of spectrum started with maritime radio telegraphy

- **Intense unregulated competition resulted in interference and commercial restrictions on use**
- The Marconi Wireless Company was very aggressive in its effort to create a monopoly, by establishing shore stations and prohibiting handling messages from ships not using Marconi equipment
- Others, e.g. Telefunken, did the same

Guglielmo Marconi (1874 – 1937)

1902 Prince Henry of Prussia attempts to send a message from his ship to President Roosevelt of the U.S

Refused handled by a Marconi operator

Contacts Kaiser Wilhelm of Prussia who proposes an international Convention to regulate maritime communications

1903 Preliminary Conference on Wireless Telegraphy

Proposes a protocol to require all stations to inter-communicate and to accept messages from all ships

1906 The first International Radiotelegraph Convention was signed

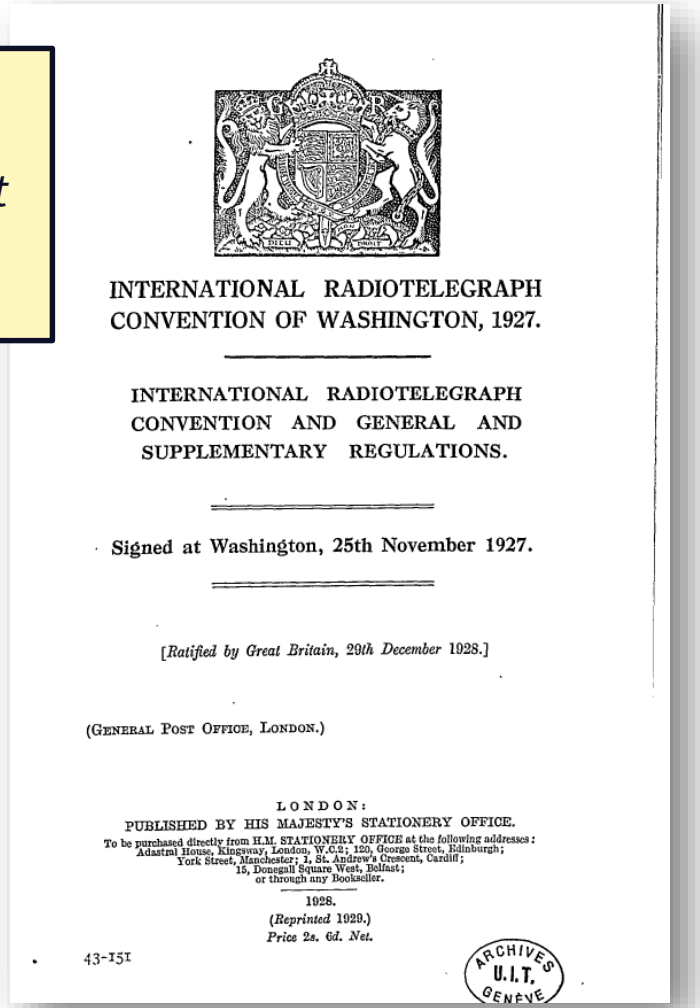
1912 The Titanic disaster

The 2nd International Radiotelegraph Conference agreed on a common wavelength for ships' radio distress signals

The birth of spectrum management came with the rise of broadcast radio

Agreements on global spectrum usage also created an environment for business and economy of scale.

- 1927
  - General and Supplementary regulations
  - Articles about frequency allocations
  - Frequencies are allocated to specific service:
    - Fixed, Mobile, Broadcast, Amateur, ..
  - The creation of the International Radio Consultative Committee – CCIR
    (Comité consultatif international pour la radio)
  - Became part of ITU in 1932 – Name change to ITU-R in 1992
    - ITU Radiocommunication Sector
    - http://www.itu.int/ITU-R



INTERNATIONAL RADIOTELEGRAPH CONVENTION OF WASHINGTON, 1927.

INTERNATIONAL RADIOTELEGRAPH CONVENTION AND GENERAL AND SUPPLEMENTARY REGULATIONS.

Signed at Washington, 25th November 1927.

[*Ratified by Great Britain, 29th December* 1928.]

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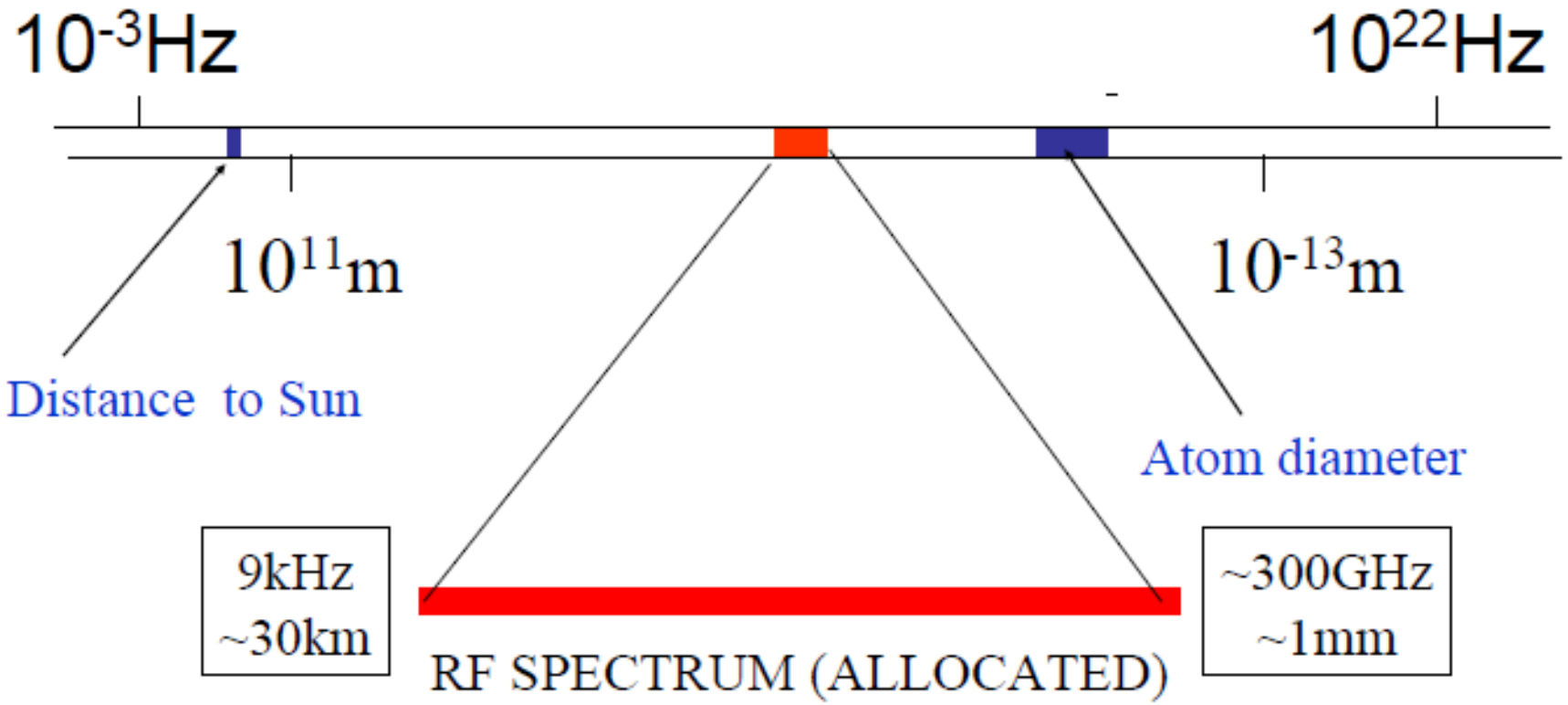
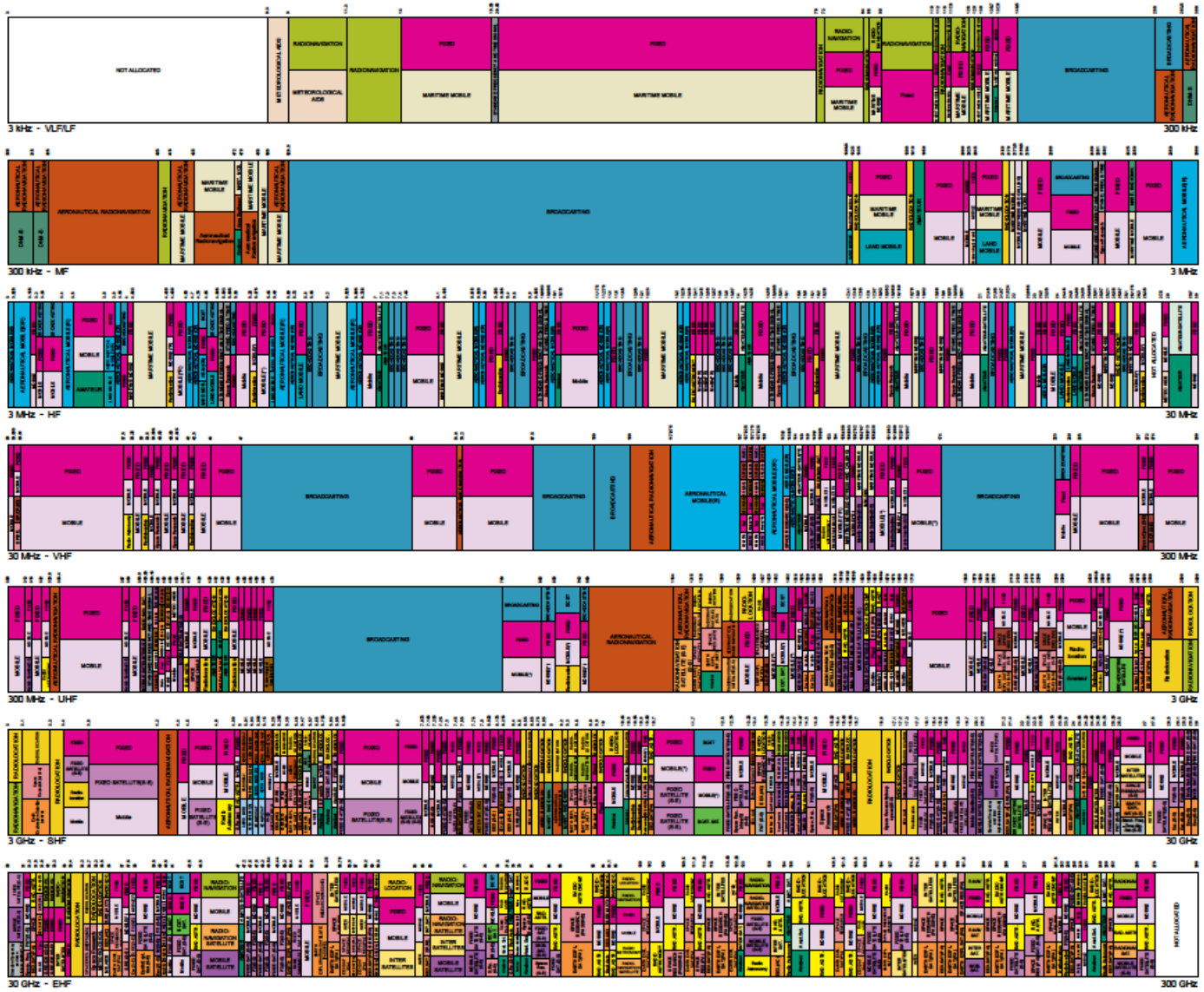
What part of spectrum is regulated?



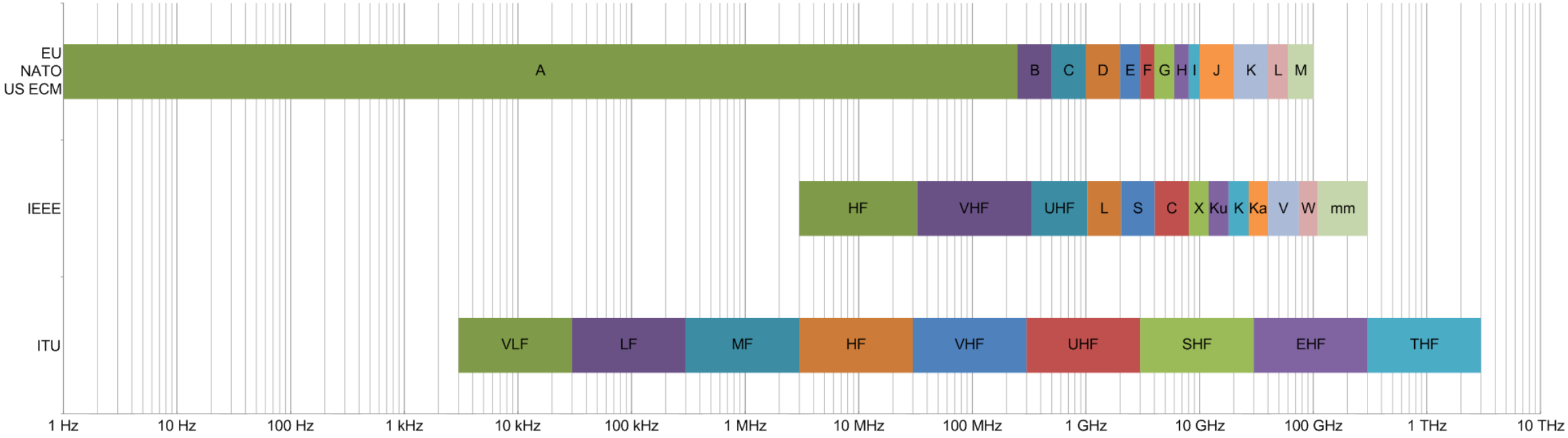
NORWAY

FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM



Frequency band designations



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Spectrum is today managed on three levels

- **Global level:**
  - By the *International Telecommunications Union Radio Sector* – ITU-R, the continuation of CCIR (www.itu.int)
    - From 1947 ITU is a UN Agency
- **The regional level:**
  - In Europe by CEPT/European Communications Committee (ECC) (www.cept.com/ecc)
- **The national level:**
  - The national regulators:
  - In Sweden: The Swedish Post and Telecom Authority – PTS (www.pts.se)
  - In Norway: the National Communications Authority – NKOM (www.nkom.no)
  - Other influencal national regulators are Ofcom in the UK (www.ofcom.org.uk) and FCC in the US (www.fcc.gov)

European Conference of Postal and Telecommunications Administrations

- 48 European countries cooperating to regulate posts, radio spectrum and communications networks

Nasjonal kommunikasjons-myndighet

Global management:

The International Telecommunications Union Radiocommunication Sector – ITU-R

- **The ITU Radiocommunication Sector (ITU-R)**
  - One of the three sectors of the International Telecommunication Union (ITU) and is responsible for radio communication.
- **Role:**
  - Manage the international radio-frequency spectrum and satellite orbit resources
  - Develop standards for radiocommunication systems with the objective of ensuring the effective use of the spectrum.
- **The strategic goal of the ITU-R is threefold**, and includes (source: www.itu.int):
  - To ensure **interference-free operations of radiocommunication systems** by implementing the Radio Regulations and regional agreements;
  - To establish Recommendations intended to **assure the necessary performance and quality** in operating radiocommunication systems;
  - To seek ways and means to ensure the **rational, equitable, efficient and economical use of the radio-frequency spectrum** and satellite-orbit resources and to promote flexibility for future expansion and new technological developments.

ITU-R is required to allocate spectrum and register frequency allocation, orbital positions and other parameters of satellites, "in order to avoid harmful interference between radio stations of different countries"

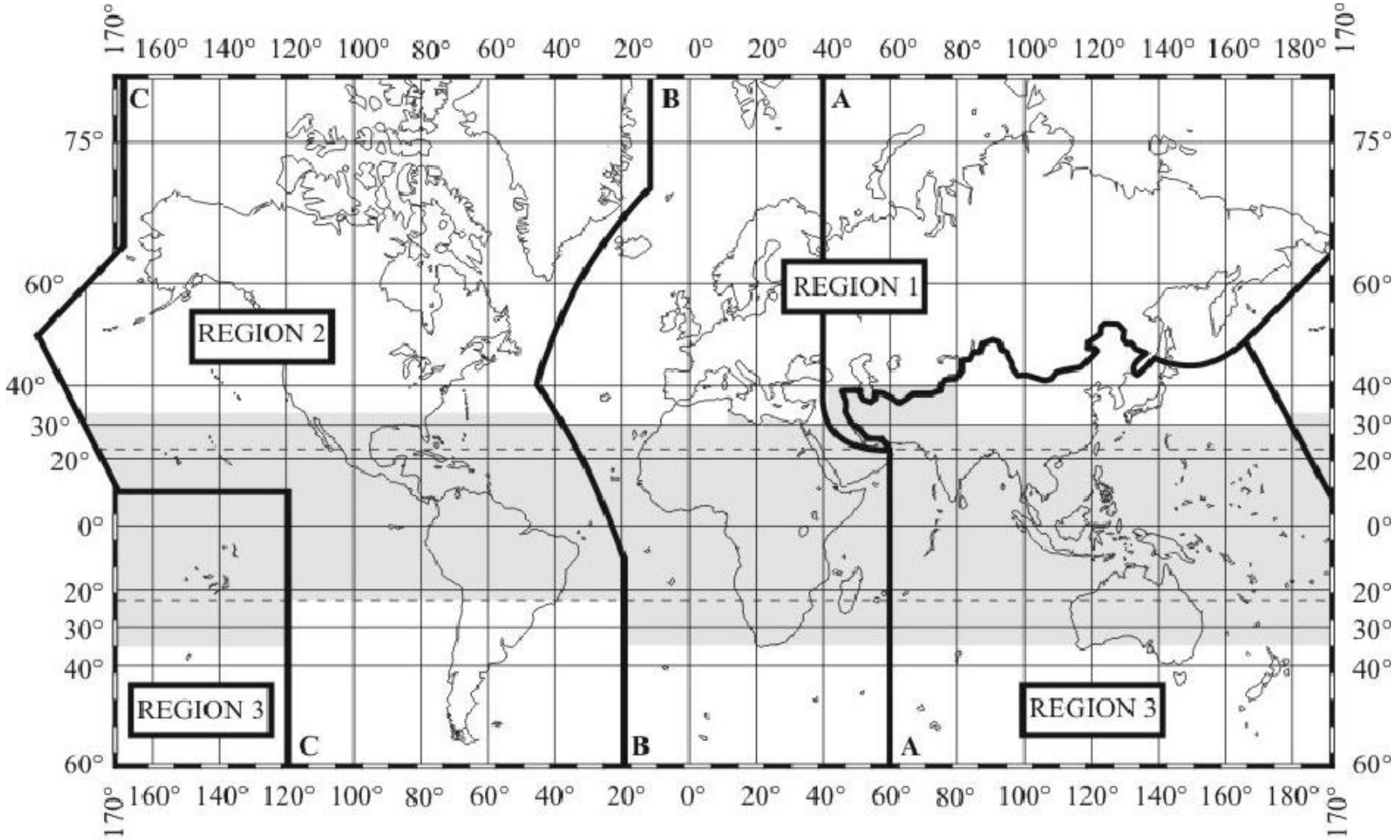
ITU-R World Radio Conference (WRC) is the highjeste level of decision for global spectrum management

- World Radio Conferences (WRC) are held every three to four years.
  - Last one was in 2019 – WRC-19; the upcoming is in 2023 – WRC-23
- Previous to WRC-19 a number of Mobile service bands have been identified for IMT (IMT-2000, IMT-Advanced, IMT-2020)
- WRC-19 allocated several new bands above 26 GHz for IMT-2020
- Bands already identified for IMT is also identified for IMT-2020

- ***IMT:*** *International Mobile Telecommunications*
- ***IMT-2000:*** *3G technology*
- ***IMT-Advanced:*** *4G technology*
- ***IMT-2020:*** *5G technology*

The ITU-R regions

To ease the global harmonization, some regional differences are recognized.



The ITU-R Radio Regulations (RR) are issued every three to four years

- **An International Treaty** that defines how radio waves and satellite orbits should (or should not) be used and managed
  - Ratified by, and legally binding in, all countries (~190 in total)
    - Basic set of rules
    - Three regions
    - Frequency allocation table - FAT
    - Frequency Plans' databases
    - Master International Frequency Register (MIFR) database
    - What to do in case of harmful interference
- Discussed and revised on World Radio Conferences (WRC)

Definitions from the RR

		Example
Administration:	Any **governmental department or service** responsible for discharging the obligations undertaken in the Constitution of the International Telecommunication Union, in the Convention of the International Telecommunication Union and in the Administrative Regulations.	The Swedish Post and Telecom Authority (PTS) The Norwegian Communications Authority (NKOM) Ofcom – UK FCC – US
Allocation (of a frequency band):	**Entry in the Table of Frequency Allocations** of a given frequency band for the purpose of its use by one or more terrestrial or space radiocommunication services, or the radio astronomy service under specified conditions. • distribution of frequencies to radio services (on a primary or on a secondary basis)	Example on next slide
Allotment (of a radio frequency or radio frequency channel):	**Entry of a designated frequency channel in an agreed plan**, adopted by a competent conference, for use by one or more administrations for a terrestrial or space radiocommunication service. in one or more identified countries or geographical areas, and under specified conditions. • distribution of frequencies to geographical areas or countries	The 3GPP band designations for mobile
Assignment (of a radio frequency or radio frequency channel):	**Authorization given by an administration** for a radio station to use a radio frequency or radio frequency channel under specified conditions. • distribution of frequencies to users or radio stations.	Operators' licenses

The Frequency Allocation Table (FAT)
ITU-R RR Article 5

890 – 942
FIXED
MOBILE
BROADCASTING
Radiolocation

Primary allocations are written in CAPITAL letters

Secondary allocation are written in Small letters

Allocation to services		
Region 1	**Region 2**	**Region 3**
890-942 FIXED MOBILE except aeronautical mobile 5.317A BROADCASTING 5.322 Radiolocation 5.323	**890-902** FIXED MOBILE except aeronautical mobile 5.317A Radiolocation 5.318 5.325 **902-928** FIXED Amateur Mobile except aeronautical mobile 5.325A Radiolocation 5.150 5.325 5.326 **928-942** FIXED MOBILE except aeronautical mobile 5.317A Radiolocation 5.325	**890-942** FIXED MOBILE 5.317A BROADCASTING Radiolocation 5.327
942-960 FIXED MOBILE except aeronautical mobile 5.317A BROADCASTING 5.322 5.323	**942-960** FIXED MOBILE 5.317A	**942-960** FIXED MOBILE 5.317A BROADCASTING 5.320
960-1 164	AERONAUTICAL MOBILE (R) 5.327A AERONAUTICAL RADIONAVIGATION 5.328	
1 164-1 215	AERONAUTICAL RADIONAVIGATION 5.328	

Regional and national management

- **The regional level is used for harmonization within a geographical area and sometimes to align policies**
  - Europe: CEPT/ECC – European Communications Committee - http://www.cept.org/ecc/
  - Asia: APT – Asia-Pacific Telecommunity - http://www.apt.int/
  - Africa: ATU – African Telecommunications Union - http://www.atu-uat.org/
  - America: CITEL – Inter-American Telecommunication Commission - https://www.citel.oas.org/

- **National regulatory authorities manage spectrum following three different models:**
  - Administrative model – Authority decides in much detail on the rights to use spectrum
  - Trading model – Spectrum is auctioned, especially used for mobile
  - Free model – Spectrum commons, like spectrum for WLAN

Frequency Allocations Table (FAT) – Sweden example

Allokerat band enligt ITU-RR	Allokerade tjänster enligt ITU-RR	Användning	Frekvensband	Duplexband	Anmärkning
890 - 942	FAST RADIO MOBIL RADIO UTOM LUFTFARTSRADIO 5.317A Radiolokalisering	Digitala cellulära system	880 - 915	925 - 960	Blocktillstånd Undantag från tillståndsplikt 2009/114/EG 2009/766/EG 2010/166/EU 2010/167/EU 2011/251/EU
		Övrigt	915 - 916		
		Kortdistansradio (SRD)	916 - 921		
		GSM-R	921 - 925	876 - 880	ECC/DEC/(02)05 ECC/DEC/(02)10
		Digitala cellulära system	925 - 960	880 - 915	Blocktillstånd Undantag från tillståndsplikt 2009/114/EG 2009/766/EG 2010/166/EU 2010/167/EU 2011/251/EU

890 – 942
Digital cellular
Short range devices
GSM-R

https://pts.se/globalassets/startpage/dokument/legala-dokument/foreskrifter/radio/ptsfs-2015_3-allmanna-rad-frekvensplanen.pdf

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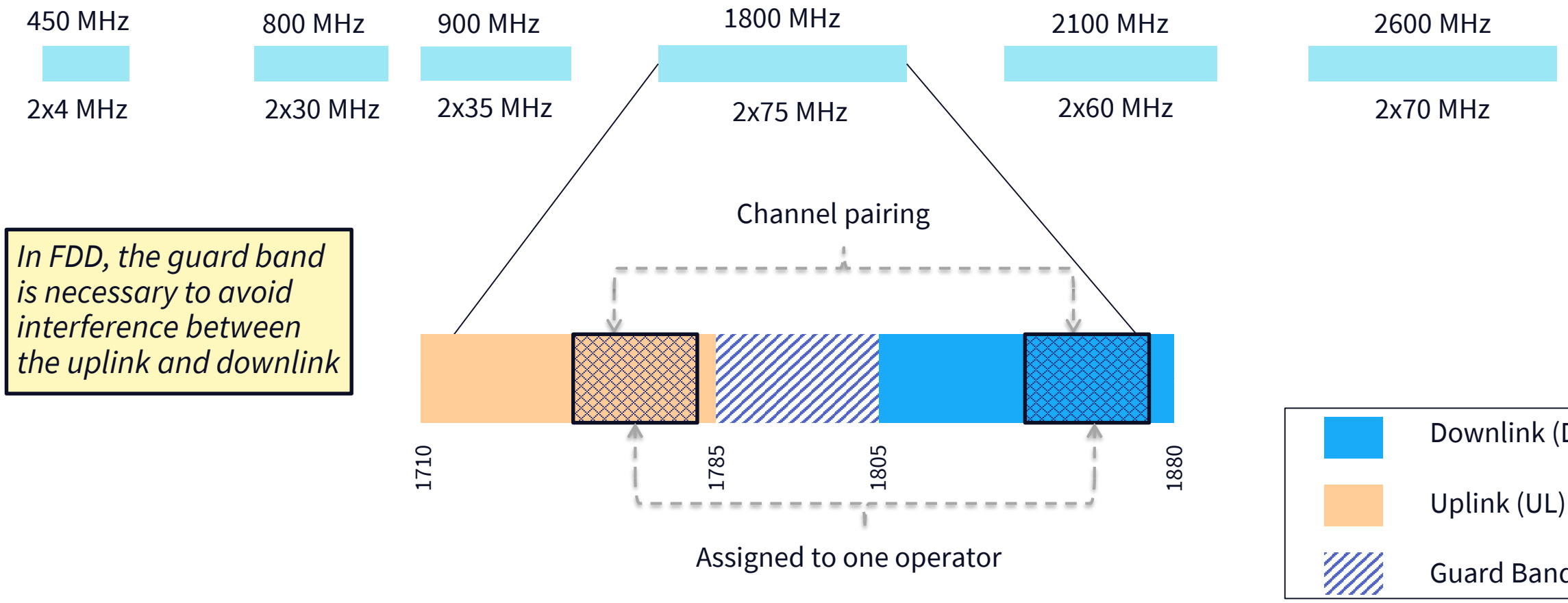
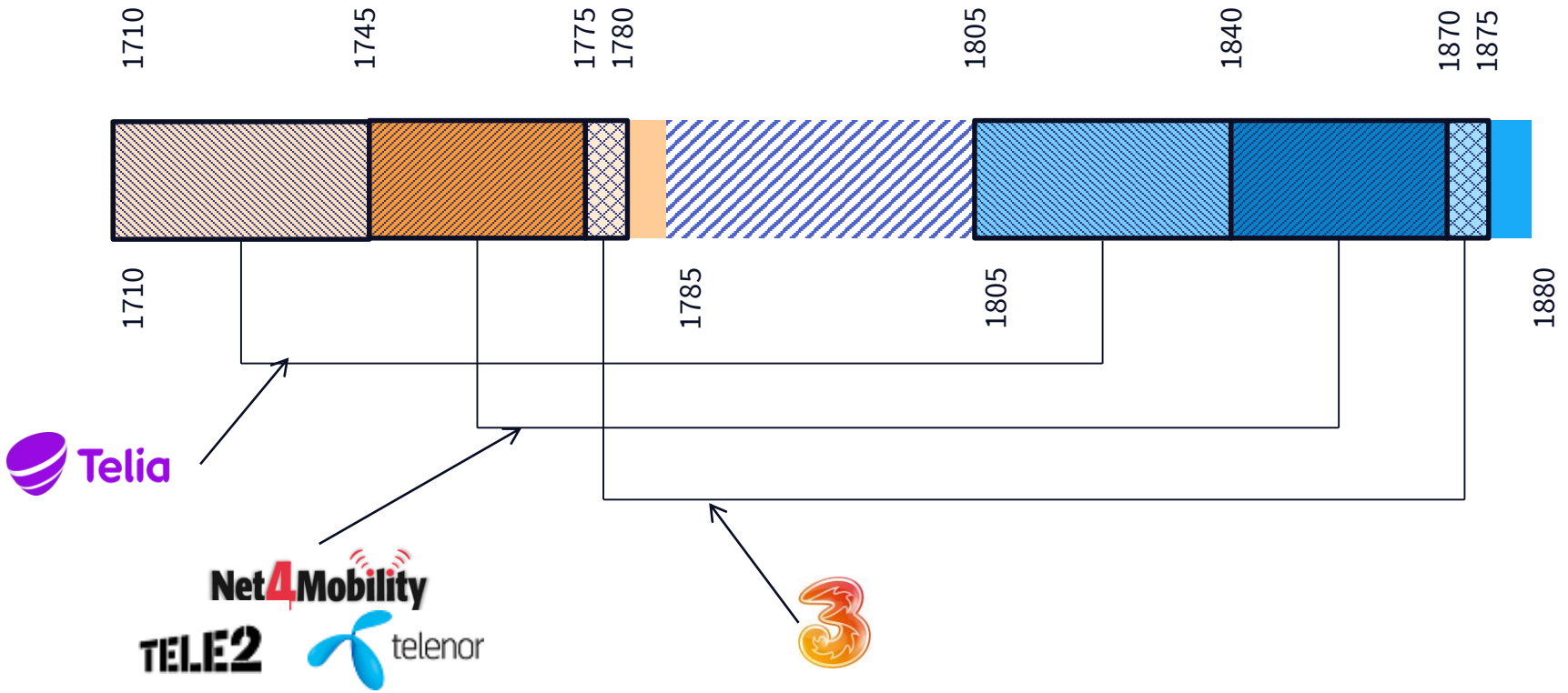
Bands used for mobile systems – FDD



In FDD, the guard band is necessary to avoid interference between the uplink and downlink

Assignments are given to several operators

Example: Band 3; 1800 MHz



Channel plan for mobile bands

- **Channel plan made by 3GPP (https://www.3gpp.org)**
- **Defines Channel numbers and frequencies for uplink and downlink**
  - 2G: ARFCN = Absolute Radio Frequency Channel Number
    - Channel raster = 200 kHz
  - 3G: UARFCN = UTRA Absolute Radio Frequency Channel Number
    - Channel raster = 200 kHz
  - 4G: EARFCN = E-UTRA Absolute Radio Frequency Channel Number
    - Channel raster = 100 kHz
  - 5G: NR-ARFCN = New Radio Absolute Radio Frequency Number
    - Channel raster = 15 kHz, 100 kHz, 60 kHz; dependent on specific band

- **Channel numbers are not the same for 2G, 3G, 4G or 5G in the same bands**
  - ARFCN ≠ UARFCN ≠ EARFCN ≠ NR-ARFCN

Different cellular technologies use different channel numbering

Band 8, «900 MHz»	Channel number range (N_{UL}/N_{DL})	Formula	Frequency range, UL/DL (MHz)
2G/GSM [1] (GPRS, EDGE)	0 – 124; 975 – 1023 $N_{UL} = N_{DL} = N$ (ARFCN)	$F_{UL}=890+0.2*N$ $F_{UL}= 890+0.2*(N-1024)$	**890.0 – 914.8 MHz** **880.2 – 889.8 MHz**
		$F_{DL}=890+0.2*N+45$ $F_{DL}= 890+0.2*(N-1024)+45$	**935.0 – 959.8 MHz** **925.2 – 934.8 MHz**
3G/UMTS [2] (HSPA, HSUPA, HSDPA, HSPA+)	2712 – 2863 (UARFCN)	$F_{UL} = 0.2*N_{UL}+340$	**882.4 – 912.6**
	2937 – 3088 (UARFCN)	$F_{DL} = 0.2*N_{DL}+340$	**927.4 – 957.6**
4G/LTE [3]	21450 – 21799 (EARFCN)	$F_{UL} = 880+0.1*(N_{UL}-21450)$	**880.0 – 914.9 MHz**
	3450 – 3799 (EARFCN)	$F_{DL} = 925+0.1*(N_{DL}-3450)$	**925.0 – 959.9 MHz**

1) 3GPP TS 45.005
2) 3GPP TS 25.104
3) 3GPP TS 36.104

5G: 3GPP TS 38.101

The details on how the channel numerology is defined are found in the relevant 3GPP documents on www.3gpp.org

Channel numbering plan for LTE («IMT-bands») 3GPP TS 36.104, Table 5.7.3-1

E-UTRA Operating Band	Downlink			Uplink		
	F_{DL_low} [MHz]	$N_{Offs-DL}$	Range of N_{DL}	F_{UL_low} [MHz]	$N_{Offs-UL}$	Range of N_{UL}
1	**2110**	**0**	**0 – 599**	**1920**	**18000**	**18000 – 18599**
2	1930	600	600 - 1199	1850	18600	18600 – 19199
3	**1805**	**1200**	**1200 – 1949**	**1710**	**19200**	**19200 – 19949**
4	2110	1950	1950 – 2399	1710	19950	19950 – 20399
5	869	2400	2400 – 2649	824	20400	20400 – 20649
6	875	2650	2650 – 2749	830	20650	20650 – 20749
7	**2620**	**2750**	**2750 – 3449**	**2500**	**20750**	**20750 – 21449**
8	**925**	**3450**	**3450 – 3799**	**880**	**21450**	**21450 – 21799**
9	1844.9	3800	3800 – 4149	1749.9	21800	21800 – 22149
10	2110	4150	4150 – 4749	1710	22150	22150 – 22749
11	1475.9	4750	4750 – 4949	1427.9	22750	22750 – 22949
12	729	5010	5010 – 5179	699	23010	23010 – 23179
13	746	5180	5180 – 5279	777	23180	23180 – 23279
14	758	5280	5280 – 5379	788	23280	23280 – 23379
…						
17	734	5730	5730 – 5849	704	23730	23730 – 23849
18	860	5850	5850 – 5999	815	23850	23850 – 23999
19	875	6000	6000 – 6149	830	24000	24000 – 24149
20	**791**	**6150**	**6150 - 6449**	**832**	**24150**	**24150 - 24449**
21	1495.9	6450	6450 – 6599	1447.9	24450	24450 – 24599
22	3510	6600	6600-7399	3410	24600	24600-25399
23	2180	7500	7500 – 7699	2000	25500	25500 – 25699
24	1525	7700	7700 – 8039	1626.5	25700	25700 – 26039
25	1930	8040	8040 - 8689	1850	26040	26040 - 26689

Regulations restricts out-of-band emissions

- Adjacent Channel Leakage power Ratio – ACLR
  - the ratio of the filtered mean power centred on the assigned channel frequency to the filtered mean power centred on an adjacent channel frequency
    - Table 6.6.2.1-1: Base Station ACLR in paired spectrum (Source. 3GPP TS 36.104)

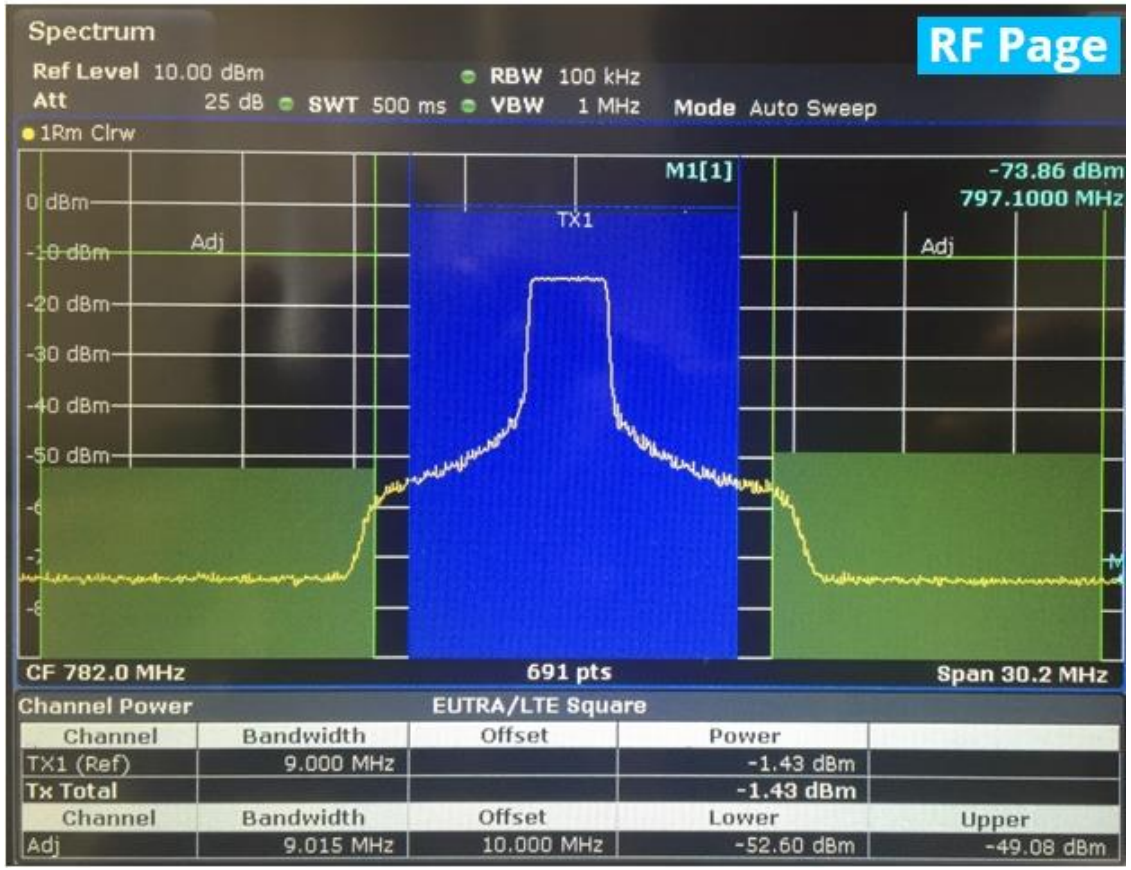
EXAMPLE

Channel bandwidth of E-UTRA lowest/highest carrier transmitted $BW_{Channel}$ [MHz]	BS adjacent channel centre frequency offset below the lowest or above the highest carrier centre frequency transmitted	Assumed adjacent channel carrier (informative)	Filter on the adjacent channel frequency and corresponding filter bandwidth	ACLR limit
1.4, 3.0, 5, 10, 15, 20	$BW_{Channel}$	E-UTRA of same BW	Square (BW_{Config})	45 dB
	2 x $BW_{Channel}$	E-UTRA of same BW	Square (BW_{Config})	45 dB
	$BW_{Channel}$ /2 + 2.5 MHz	3.84 Mcps UTRA	RRC (3.84 Mcps)	45 dB
	$BW_{Channel}$ /2 + 7.5 MHz	3.84 Mcps UTRA	RRC (3.84 Mcps)	45 dB

NOTE 1: $BW_{Channel}$ and BW_{Config} are the channel bandwidth and transmission bandwidth configuration of the E-UTRA lowest/highest carrier transmitted on the assigned channel frequency.

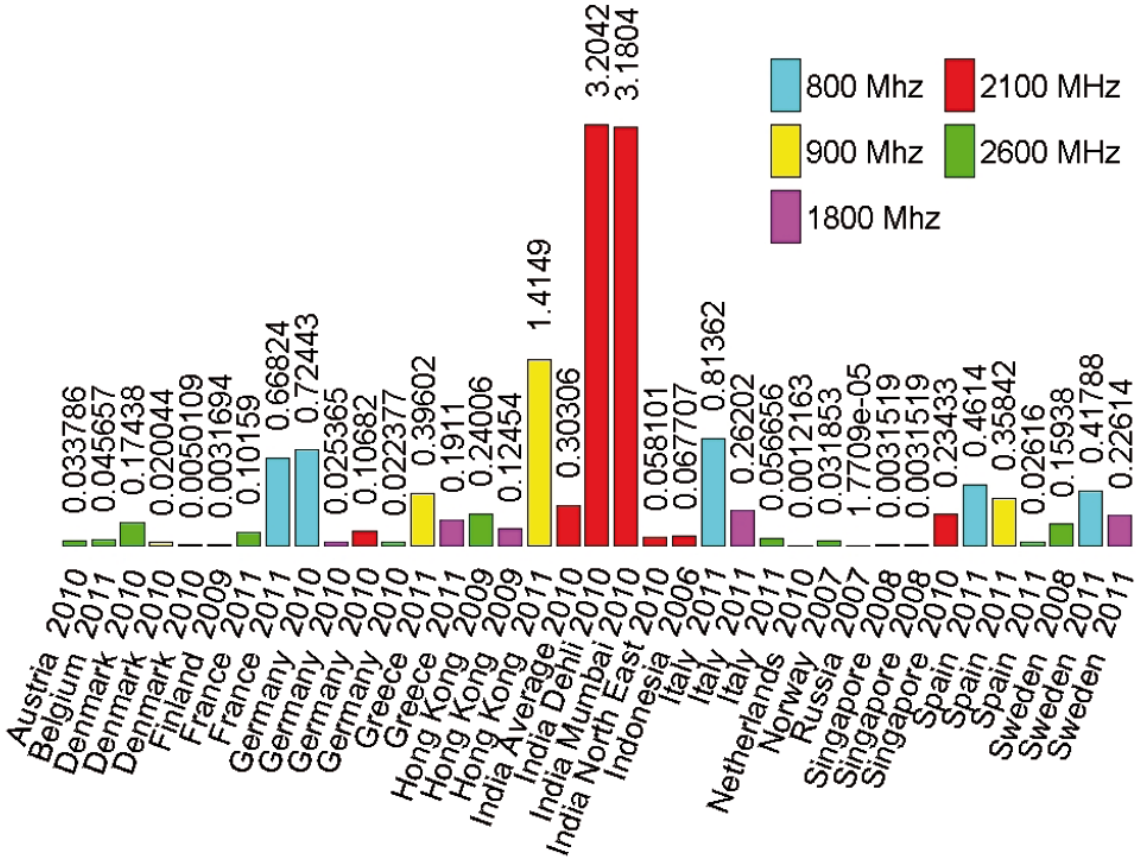
NOTE 2: The RRC filter shall be equivalent to the transmit pulse shape filter defined in TS 25.104 [6], with a chip rate as defined in this table.

Adjacent Channel Leakage power Ratio – ACLR



- The unwanted frequency generated by second or third order intermodulation distortion of the devices which fall near to the transmitting frequency band.
- Cause distortion in other neighboring channel's transmission
- Affects the system efficiency.
- ACLR measured with a reference transmit signal
  - Source: https://www.rfpage.com/aclr-measurement-in-lte/

The common method for assigning spectrum to mobile operators is Auctions



Auction prices given in EUR/MHz/Pop for paired spectrum over a five year period (2006 – 2011)

Example: Swedish 700 MHz auction

2.8 BSEK = 243 M€;

243 M€/40 MHz/10 M (Pop) = 0.6 €/MHz/Pop

PTS

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PTS / News / Press releases / 2018 /

700 MHz auction is closed – auction proceeds were 2,8 billion SEK

12/11/2018

The PTS auction for licences in the 700 MHz band is finished after an auction in two stages. Two bidders won licences for SEK 2,8 billion.

The auction was concluded after 5 days of bidding and 46 bidding rounds, and one additional round which decided the placement in the frequency band.

– Swedish users of mobile services use more and more data every year. Access to the 700 MHz band gives good prerequisites for meeting this increasing demand, said Dan Sjöblom, director-general of PTS.

https://www.pts.se/en/news/press-releases/2018/700-mhz-auction-is-closed--auction-proceeds-were-28-billion-sek/

Summary of the auction results:

Bidder	Licences	Auction proceeds SEK	Amount for coverage SEK
Telia Sverige AB	2×10 MHz, FDD 713-723 MHz 768-778 MHz	1 382 657 650	300 000 000
Net4Mobility HB	2×5 MHz, FDD 723-728 MHz 778-783 MHz	720 968 398	-
Net4Mobility HB	2×5 MHz, FDD 728-733 MHz 783-788 MHz	720 968 398	-

The licences will be issued within a few days and are valid until December 31, 2040.

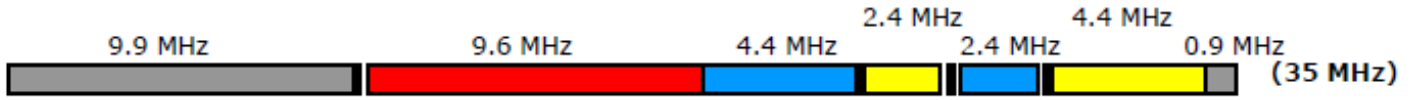
Refarming of spectrum

- In agriculture:
  - Switch from growing one type of product to another: E.g. from potato to carrot.
- In mobile communications:
  - Switch from one technology to another (in the same frequency band) – e.g. from GSM to GSM + UMTS

- Requirements:
  - Licenses are technology neutral
  - (Often) Spectrum holding is contiguous
  - Operators have a minimum amount of spectrum each

Refarming example 900 MHz

Before:



9.9 MHz + 0.9 MHz not allocated

Only red operator are able to refarm from GSM to GSM + UMTS (requires ~10 MHz and contiguous spectrum)

After

Government has:

- **Allocated the unassigned spectrum to the three operators**
- **Reshuffled the spectrum so that all operators have contiguous spectrum**
- **All operators can refarm from GSM to GSM + UMTS**

Refarming will sometimes be necessary in order to allow new technologies to be deployed and improve spectrum utlization.

Legends: **Red operator** | **Blue operator** | **Yellow operator** | **Unassigned**

The value of an amount of spectrum

- **Case Example – Mobile Broadband in Oslo:**
  - Urban part of Oslo: Area: 135 km^2; Population: 560.000 people
  - Expected penetration: 40%
  - Average usage in peak hour: 100 kbit/s (downlink, mobile receive)

Different investments can give you the same performance. Which one is most optimal?

- **Case 1 – 2x10 MHz spectrum:**
  - Traffic / site: 24 Mb/s
  - Number of sites needed: 930

- **Case 2 – 2x20 MHz spectrum:**
  - Traffic / site: 48 Mb/s
  - Number of sites needed: 465

- **Conclusion:**
  - (provided Case 1 is profitable) The value of the additional 2x10 MHz spectrum in this example is equal to the cost of 465 sites (930 – 465)

Unlicensed spectrum – commons

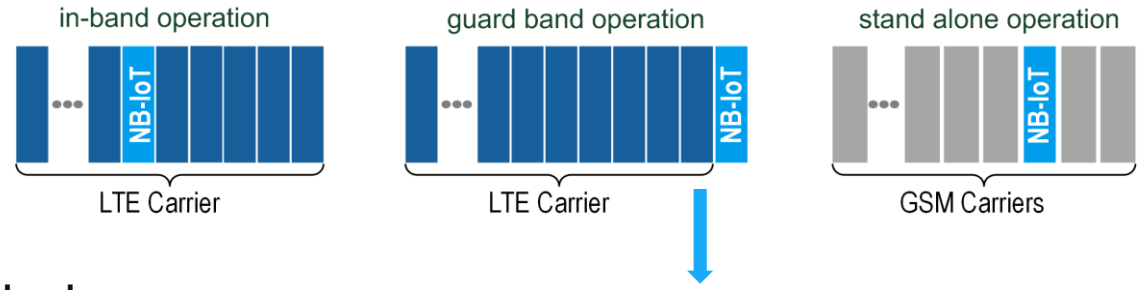
- ISM-bands (Industrial, Scientific and Medicine) – mostly global
  - 2.4-2.5 GHz: Wi-Fi, Bluetooth, etc.
  - 5.725–5.875 GHz: Wi-Fi
  - 433 MHz: e.g remote control (car keys, etc.)

EXAMPLES

- U-NII-bands (Unlicensed National Information Infrastructure) – USA
  - 5.150-5.725 GHz: Wi-Fi
- This spectrum is shared among the users based on a few simple rules
- There is no need for a license to use this spectrum as long as the basic rules are respected:
  - Power (EIRP) and power spectrum density constraints:
    - E.g 100 mW for the 2.4 GHz band; 200 mW – 1 W for the 5 GHz bands

Spectrum for Internet of Things - IoT

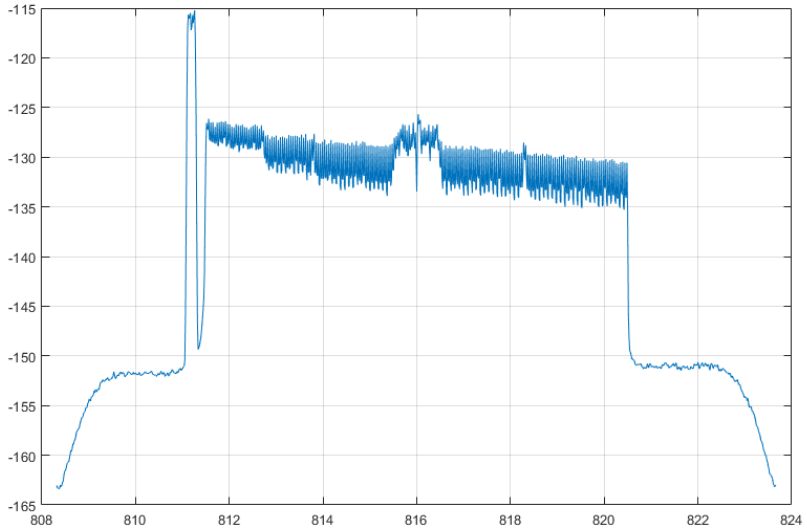
- **Cellular IoT technologies will use parts of the licensed bands**
  - Long Term Evolution for Machines (eMTC/LTE-M)
  - Narrowband IoT (NB-IoT)



- **Proprietary Low Power Wide Area Network (LPWAN) technologies use unlicensed bands:**
  - Europe: 867 – 869 MHz
  - US: 902 – 928 MHz
  - China: 470 – 510 MHz
  - Japan, Korea: 920 – 925 MHz

LoRa Alliance

sigfox



- **Example**:
  - *LoRa and LoRaWAN*: An LPWAN global standard for carrier-operated netwirks, adopted by the LoRa Alliance
  - *SIGFOX*: A French company building wireless networks to connect low energy objects

Spectrum for 5G: Pioneer bands to enable an early start

	US	EU	CJK*
Low band: To enable nationwide and indoor 5G coverage	600 MHz	700 MHz	
Middle band: Up to 400 MHz of continuous spectrum enabling wide channel bandwidth	2.6 GHz 3.55 – 3.7 GHz	3.4 – 3.8 GHz	3.3 – 4.2 GHz 4.4 – 4.9 GHz
High band: To ensure all the performance targets of 5G, for example multi gigabit per second data rates.	28, 37, 39 GHz 57 – 71 GHz (unlicensed)	24.25 – 27.5 GHz	28, 39 GHz

* China-Japan-Korea

Source:
- GSMA Intelligence: Global Mobile Trends 2017
- RSPG16-032 FINAL. http://rspg-spectrum.eu/wp-content/uploads/2013/05/RPSG16-032-Opinion_5G.pdf

5G NR frequency bands

Frequency Range 1 (FR1):

- *Existing and low bands below 6 GHz*

Frequency Range 2 (FR2):

- *New bands in the range 24.25 – 52.6 GHz*

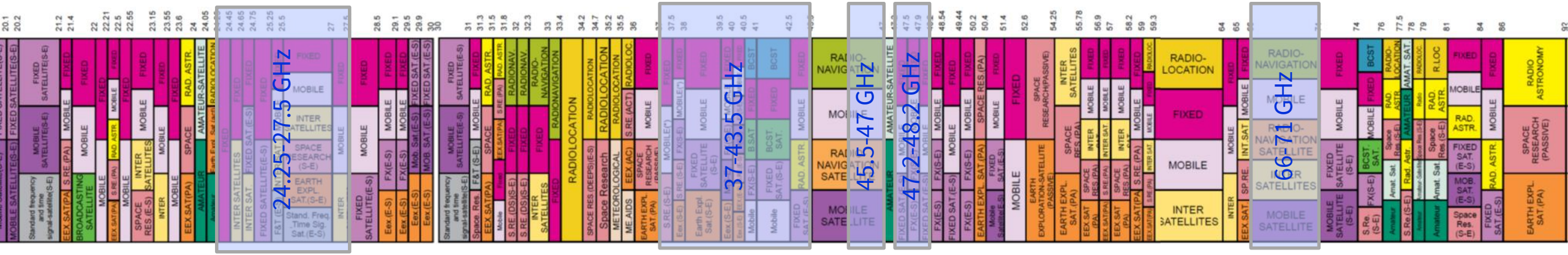
3GPP TS 38.104

NR operating band	Uplink (UL) and Downlink (DL) operating band BS transmit/receive UE transmit/receive F_{UL_low} – F_{UL_high} F_{DL_low} – F_{DL_high}	Duplex Mode
n257	26500 MHz – 29500 MHz	TDD
n258	24250 MHz – 27500 MHz	TDD
n260	37000 MHz – 40000 MHz	TDD
n261	27500 MHz – 28350 MHz	TDD

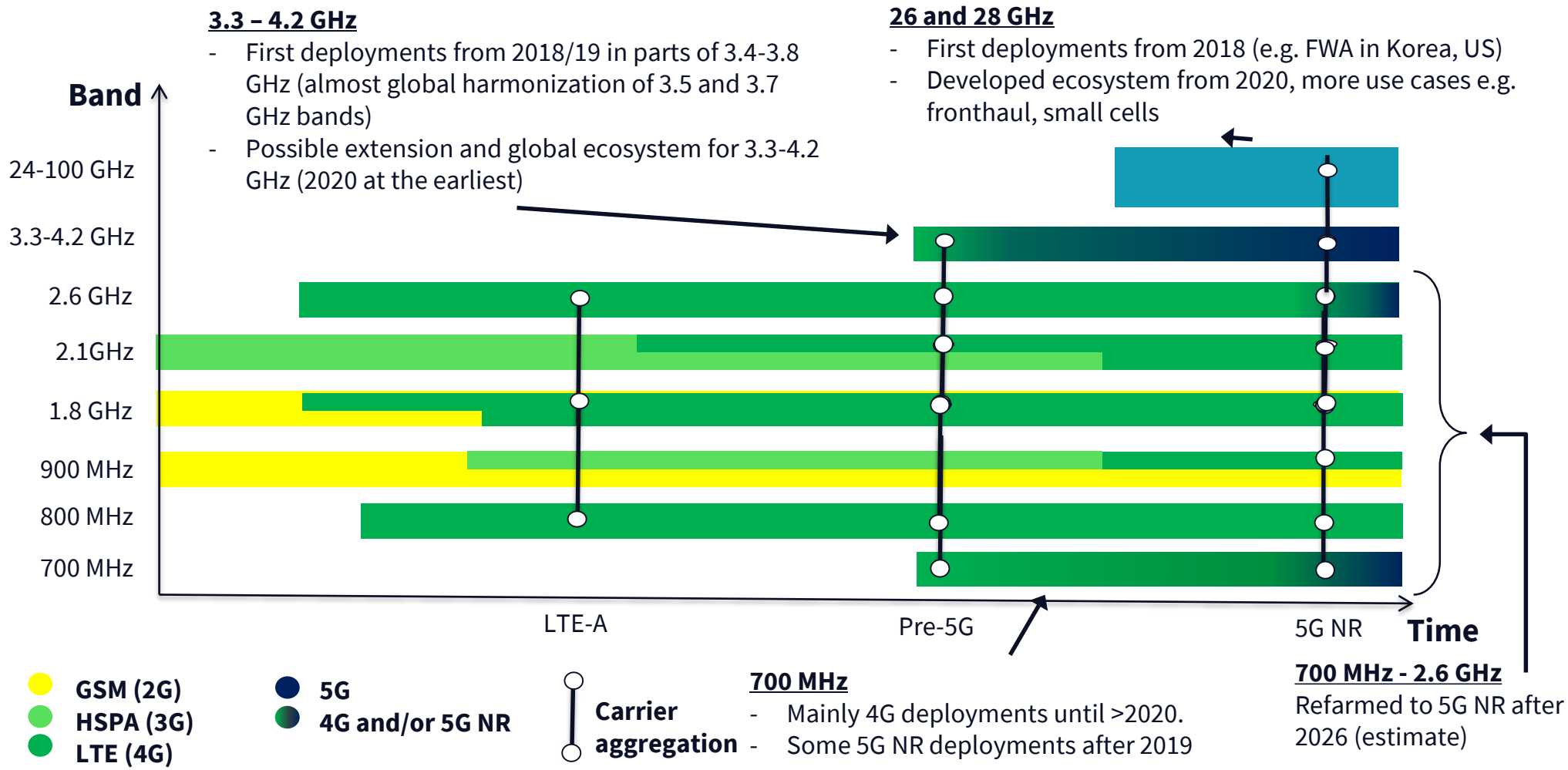
NR operating band	Uplink (UL) operating band BS receive / UE transmit F_{UL_low} – F_{UL_high}	Downlink (DL) operating band BS transmit / UE receive F_{DL_low} – F_{DL_high}	Duplex Mode
n1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
n2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
n3	1710 MHz – 1785 MHz	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
n12	699 MHz – 716 MHz	729 MHz – 746 MHz	FDD
n20	832 MHz – 862 MHz	791 MHz – 821 MHz	FDD
n25	1850 MHz – 1915 MHz	1930 MHz – 1995 MHz	FDD
n28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
n34	2010 MHz – 2025 MHz	2010 MHz – 2025 MHz	TDD
n38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz	TDD
n39	1880 MHz – 1920 MHz	1880 MHz – 1920 MHz	TDD
n40	2300 MHz – 2400 MHz	2300 MHz – 2400 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
n86	1710 MHz – 1780 MHz	N/A	SUL

Spectrum for 5G on higher bands

- Decisions at WRC-19:
  - New frequency bands for IMT-2020 giving a total of 17.25 GHz new bandwidth (see diagram)
  - Protecting sensitive scientific services, a.o EESS (Earth Exploration Satellite Services)
  - A number of frequency bands for HAPS (High Altitude Platforms) between 21 and 48 GHz



Eventually, all current mobile bands will be available for 5G



3.3 – 4.2 GHz

- First deployments from 2018/19 in parts of 3.4-3.8 GHz (almost global harmonization of 3.5 and 3.7 GHz bands)
- Possible extension and global ecosystem for 3.3-4.2 GHz (2020 at the earliest)

26 and 28 GHz

- First deployments from 2018 (e.g. FWA in Korea, US)
- Developed ecosystem from 2020, more use cases e.g. fronthaul, small cells

700 MHz

- Mainly 4G deployments until >2020.
- Some 5G NR deployments after 2019

700 MHz - 2.6 GHz

Refarmed to 5G NR after 2026 (estimate)

Beyond 5G – approaching THz

- Frequencies above 100 GHz are being explored for 6G
  - IEEE 802.15.3d: High Data Rate Wireless Multi-Media Networks, 252-325 GHz
    - Data rates up to 100 Gb/s using BW between 2.16 and 69.12 GHz
- New bands between 275 and 450 GHz have been added to the Frequency Allocation Table
- Advances in devices, circuits, software, signal processing, and systems can make sub-THz and THz communications a commercial reality within the next decade
- In the US, FCC gives “Spectrum Horizon” experimental licenses between 95 GHz and 3 THz, total 21.2 GHz BW

Contents

- What is spectrum? A brief history of spectrum management
- Global, regional and national regulations
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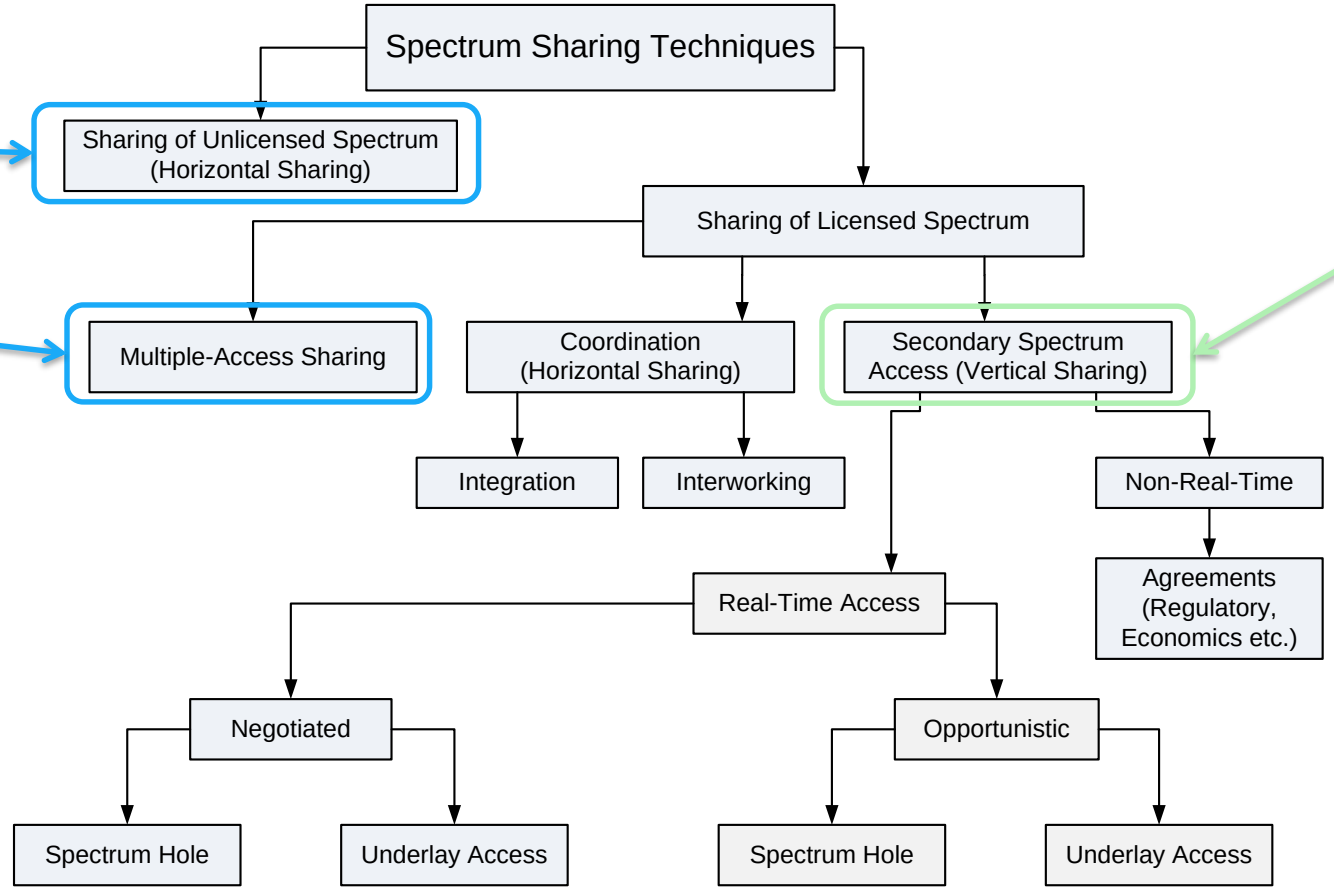
- Spectrum sharing and trading concepts
- EMF
- Future spectrum management enablers – cognitive radio

Future trends: Spectrum sharing and trading

Spectrum commons: Wi-Fi and Bluetooth

Access technologies

Primary and secondary users

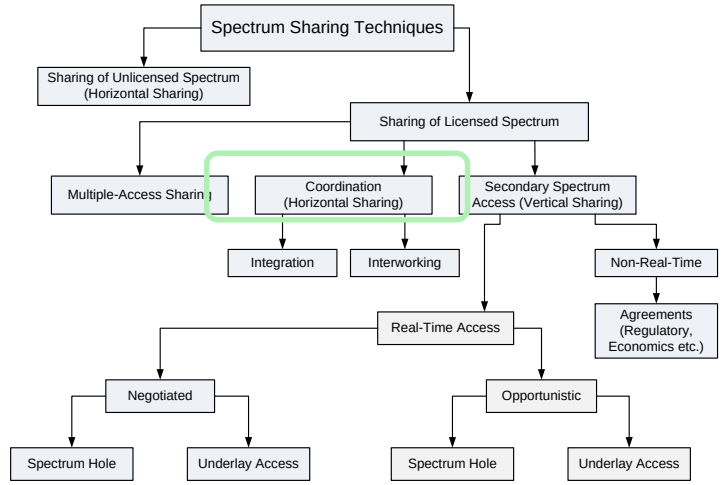


- Source: Wyglinski A M., Nekovee M., Hou Y T. *Cognitive Radio Communications and Networks*. Academic Press (Elsevier), MA, USA. 2010. ISBN 978-0-12-374715-0.

Spectrum pooling

- Network sharing among operators are becoming commonplace
  - The next step in providing more cost-efficient networks
  - Operators share a common network infrastructure: base stations, etc.

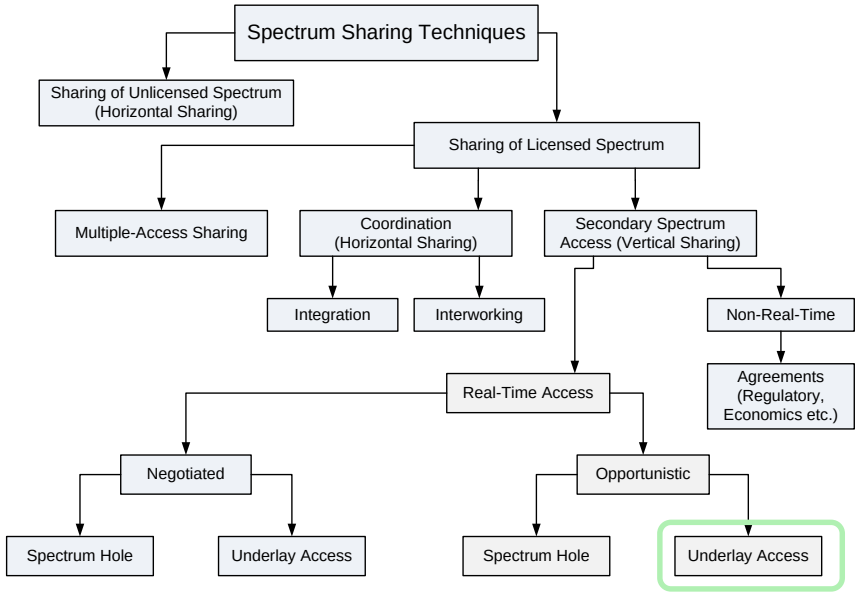
- Network sharing can be done on several levels:
  - Site sharing, RAN sharing, shared core etc.



- Spectrum sharing can be a part of it, if the national regulator allows
  - This is called *spectrum pooling*

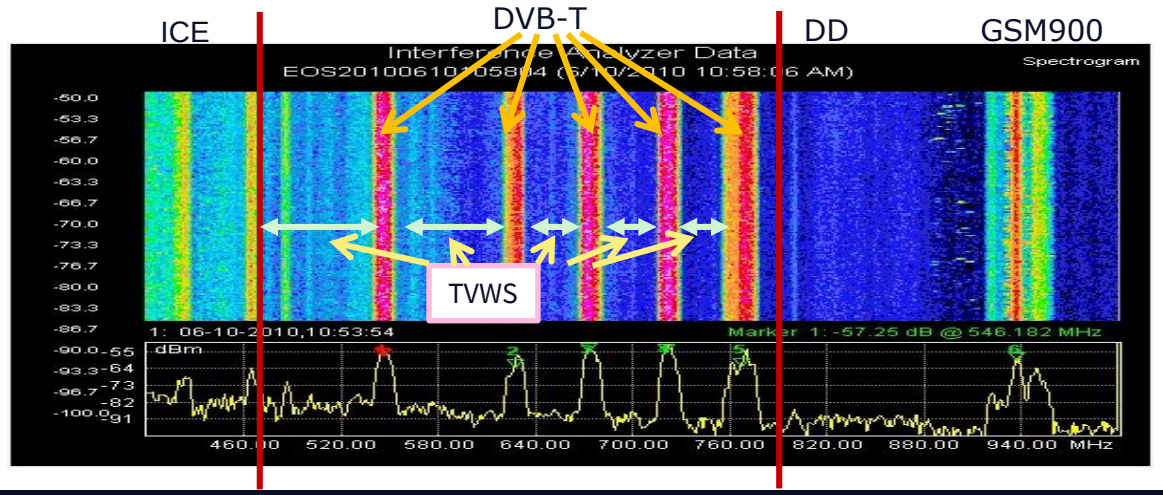
- Telenor and Tele2 are sharing network and spectrum in Sweden through the joint venture Net4Mobility.

Opportunistic access



- **«White Space» access**
  - 'White Space' is a label indicating a part of the spectrum, which is available for a radiocommunication application (service, system) at a given time in a given geographical area on a non-interfering / non-protected basis with regard to other services with a higher priority on a national basis (CEPT Report 24).
- **Primary and secondary users**
- Spectrum holes are identified by use of a database, possibly assisted by sensing
  - Secondary user must not interfere with primary user
- Allowed in the UK and US for the TV-band: 470 – 790 MHz
- Commercial spectrum databases are driven on a licensed basis:
  - E.g. Google and Microsoft

Spectrum scan – Oslo - 2010



Spectrum trading

- Current practices in spectrum trading (CEPT/ECC):
  - "General authorizations" is basically the type of regulation used for licence-exempt bands like the 2.4 GHz ISM band.
    - Frequency bands under general authorization are not tradable.
  - "Individual right of use" is what commonly is referred to as licensed bands, like e.g. the IMT bands.
    - Legal frameworks for spectrum rights are regulated at the national level.
    - Within EU, "rights of use" are transferrable and there is a harmonised regulatory framework in the context of Electronic Communications Networks & Services (ECN&S).
    - The framework also distinguishes between trading and leasing with a focus on trading.
- In Europe, 18 of the 22 CEPT countries allow trading of usage rights. It has been allowed since 1997 (in Denmark) and most of the other countries opened for this between 2002 and 2006.

CEPT/ECC. *Description of Practices Relative to Trading of Spectrum Rights of Use*. ECC Report 169. Paris, May 2011.

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This Room Is Equipped With

Edison Electric Light.

Do not attempt to light with match. Simply turn key on wall by the door.

The use of Electricity for lighting is in no way harmful to health, nor does it affect the soundness of sleep.

EMF = Electromagnetic Fields

- Are electromagnetic fields dangerous to the health?

The New York Times

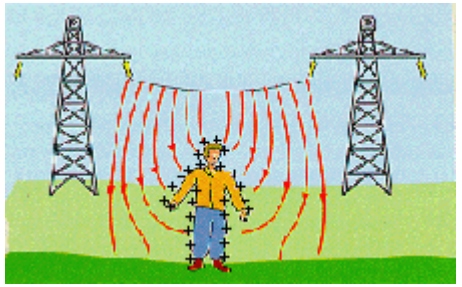
The 5G Health Hazard That Isn't

How one scientist and his inaccurate chart led to unwarranted fears of wireless technology.

Golden Cosmos

What happens when you are exposed to electromagnetic fields?

- Both electric and magnetic fields induce *voltages and currents in the body* but even directly beneath a high voltage transmission line, the induced currents are very small compared to thresholds for producing shock and other electrical effects



- *Heating* is the main biological effect of the electromagnetic fields of radiofrequency fields. (In microwave ovens this fact is employed to warm up food.)
- The heating effect of radiowaves forms the underlying basis for current guidelines

World Health Organization

Main source: World Health Organization (WHO): https://www.who.int/peh-emf/en/

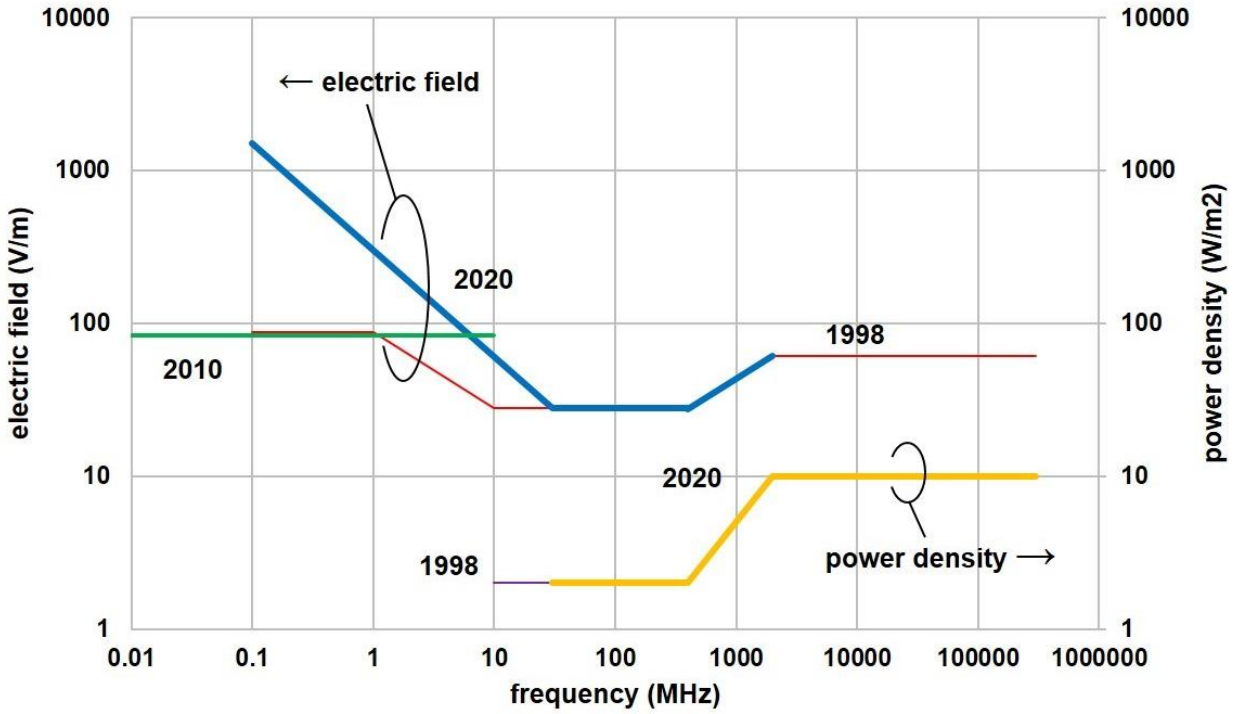
What are safe exposure limits and who makes them?

- Who decides on guidelines?
  - Countries set their own national standards for exposure to EMF
    - Sweden: Strålsäkerhetsmyndigheten; https://www.stralsakerhetsmyndigheten.se/
  - Majority follows guidelines set by the International Commission of Non-Ionizing Radiation Protection (ICNIRP); https://www.icnirp.org/.
    - ICNIRP is an NGO recognized by WHO

ICNIRP
INTERNATIONAL COMMISSION ON NON-IONIZING RADIATION PROTECTION

- What are guidelines based on?
  - Not a precise line between safety and hazard
  - To date, the only health effect from RF fields identified in scientific reviews has been related to an increase in body temperature (> 1 °C)
    - Exposure at very high field intensity found only in certain industrial facilities, such as RF heaters
  - Safety margins used in defining the exposure limits:
    - Factor 10 for workers (1/10, 10 %),
    - Factor 50 for the public (1/50; 2 %)

EMF limiting guidelines defined by ICNIRP



Whole body average reference levels for the general public for the ICNIRP (1998), ICNIRP (2010) and ICNIRP (2020) guidelines, for the 100 kHz to 300 GHz frequency range. Note that the units of the two y-axes (i.e. electric field and power density) are independent of each other. (Source: ICNIRP: https://www.icnirp.org/en/differences.html)

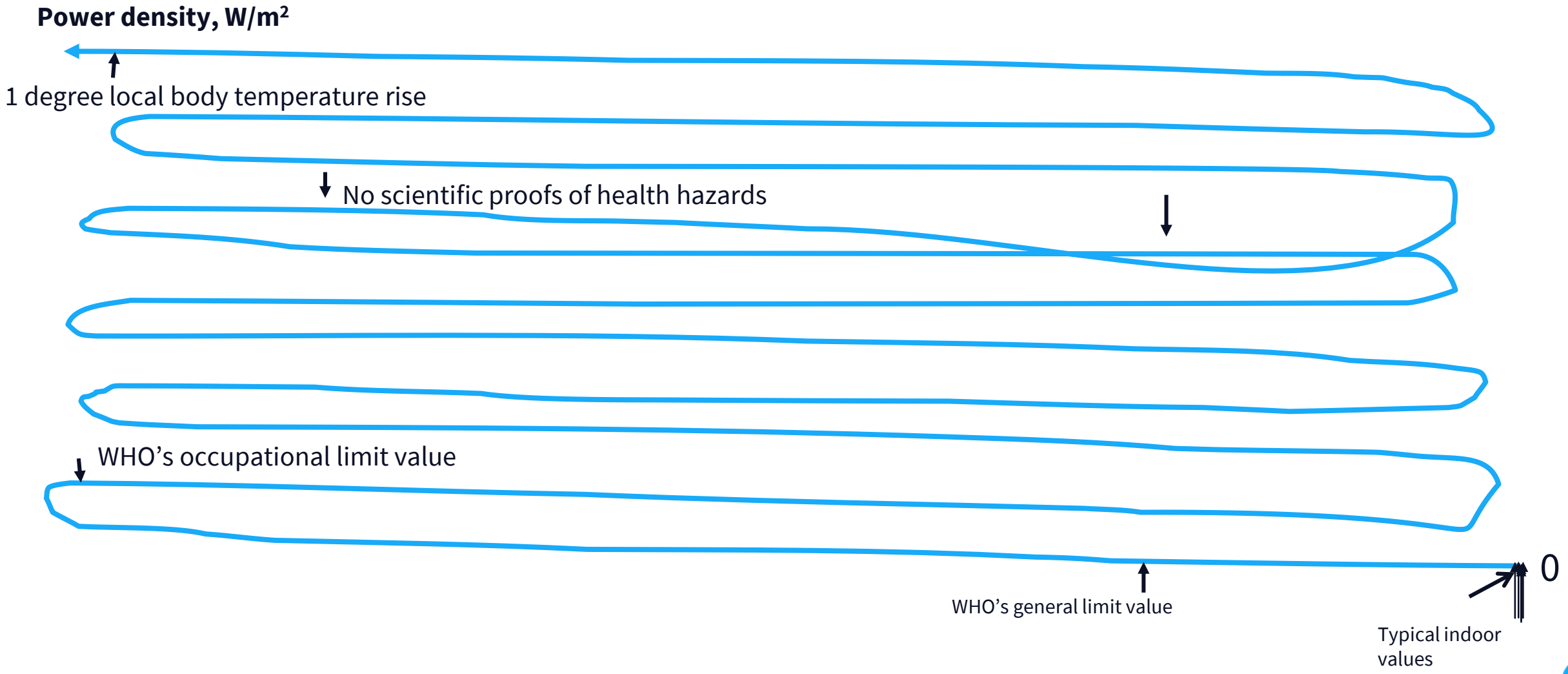
	Mobile phone base station frequency		Microwave oven frequency
Frequency	900 MHz	1.8 GHz	2.45 GHz
	Power density (W/m^2)		
Public exposure limits	4.5	9	10
Occupational exposure limits	22.5	45	

Limits are defined for whole body exposure and local exposure.

What are actual exposure levels?

- Surveys have shown that the RF exposures from base stations range from 0.002% to 2% of the levels of international exposure guidelines (Source: WHO)
  - Depending on a variety of factors such as the proximity to the antenna and the surrounding environment
- A UK test survey done by Ofcom in 2019 shows highest observed levels of 1.5 % (https://www.ofcom.org.uk/__data/assets/pdf_file/0015/190005/emf-test-summary.pdf)

Safety margins into the right perspective



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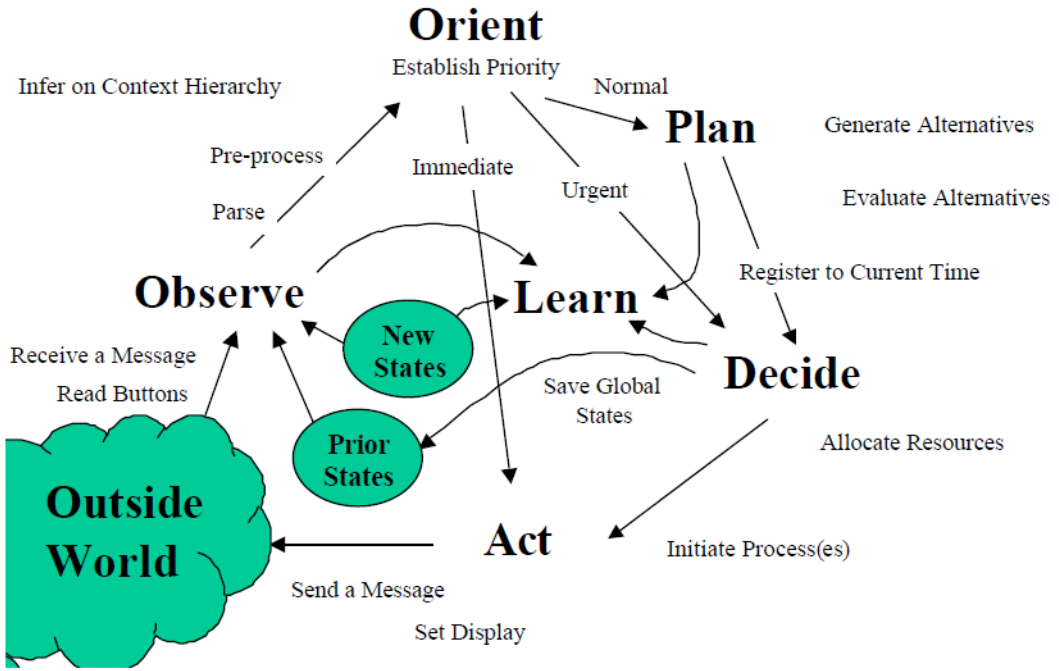
Cognitive Radio – an enabler for new spectrum sharing and trading

- "**a really smart radio** that would be self-aware, RF-aware, user-aware, and that would include language technology and machine vision along with a lot of high-fidelity knowledge of the radio environment"
  - J. Mitola in: EETimes. The inventor of cognitive radio. EETimes, News & Analysis. 28th Nov 2005: http://www.eetimes.com/electronics-news/4056921/The-inventor-of-cognitive-radio.



- **Cognitive radio according to ITU-R:**
  - "A radio system employing technology that allows the system to obtain *knowledge* of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously *adjust* its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to *learn* from the results obtained."

Cognitive Radio becomes AI-enabled Radio And Networks

- Cognitive Radio (CR) was proposed to utilize the spectrum efficiently in an opportunistic way
  - Cognitive capability to *sense and gather* information from the surrounding environment and with *reconfigurability* to rapidly adapt the operational parameters according to the sensed information
  - Any user perceives its environment and takes actions that maximize its chance of successfully achieving its goals
- *Artificial Intelligence* (AI) mimics "cognitive" functions that humans associate with other human minds
  - Such as "learning" and "problem solving" is brought to use in CR networks, named AI-enabled Radio and Networks

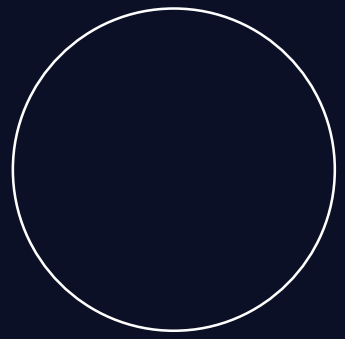
Spectrum management - summary

- Spectrum management became neccesary to avoid interference and regulate competition
  - Maritime communication was the first area
- Spectrum management is done on three levels: global, regional and national
- Global spectrum management is handled by the ITU – a UN body
  - Defines global frequency plans - allocations
- Regional spectrum management is in Europe handled by the CEPT
  - Harmonization and policies
- National spectrum management is done by the regulators
  - Grants licenses – assignments
- Mobile spectrum is usually granted using spectrum auctions
- Certain parts of the spectrum are «commons», which requires no license to use, only conformance to certain rules on emission
  - Wi-Fi and Bluetooth uses commons in the 2.45 GHz band, Wi-Fi also in the 5 GHz band
- New trends are spectrum sharing
  - Spectrum pooling among operators as part of network sharing
  - Opportunistic access of TV white spaces
- Cognitive radio using AI and ML will enable new, dynamic methods of sharing spectrum – becomes AI-enabled radio and networks
- Exposure limits for EMF are defined by the WHO to secure no adverse health effects to both workers and public

Thank you

Per Hjalmar Lehne; Telenor Research, Fornebu, Norway

E-mail: per-hjalmar.lehne@telenor.com



Extras

Frequency band designations

IEEE Standard Radar Band Nomenclature

(*IEEE Std. 521-2002, IEEE Standard Letter Designations for Radar-Frequency Bands)

Designation	Frequency	Wavelength
HF	3 - 30 MHz	100 m - 10 m
VHF	30 - 300 MHz	10 m - 1 m
UHF	300 - 1000 MHz	100 cm - 30 cm
L Band	1 - 2 GHz	30 cm - 15 cm
S Band	2 - 4 GHz	15 cm - 7.5 cm
C Band	4 - 8 GHz	7.5 cm - 3.75 cm
X Band	8 - 12 GHz	3.75 cm - 2.50 cm
Ku Band	12 - 18 GHz	2.50 cm - 1.67 cm
K Band	18 - 27 GHz	1.67 cm - 1.11 cm
Ka Band	27 - 40 GHz	1.11 cm - .75 cm
V Band	40 - 75 GHz	7.5 mm - 4.0 mm
W Band	75 - 110 GHz	4.0 mm - 2.7 mm
mm Band	110 - 300 GHz	2.7 mm - 1.0 mm

ITU Frequency Band Nomenclature

ITU Band	Designation	Frequency	Wavelength
1	ELF	3 - 30 Hz	100,000 km - 10,000 km
2	SLF	30 - 300 Hz	10,000 km - 1000 km
3	ULF	300 - 3000 Hz	1000 km - 100 km
4	VLF	3 - 30 kHz	100 km - 10 km
5	LF	30 - 300 kHz	10 km - 1 km
6	MF	300 - 3000 kHz	1 km - 100 m
7	HF	3 - 30 MHz	100 m - 10 m
8	VHF	30 - 300 MHz	10 m - 1 m
9	UHF	300 - 3000 MHz	1 m - 10 cm
10	SHF	3 - 30 GHz	10 cm - 1 cm
11	EHF	30 - 300 GHz	1 cm - 1 mm

Band Designation Acronyms
Extremely Low Frequency (ELF) Super Low Frequency (SLF) Ultra Low Frequency (ULF) Very Low Frequency (VLF) Low Frequency (LF) Medium Frequency (MF) High Frequency (HF) Very High Frequency (VHF) Ultra High frequency (UHF) Super High Frequency (SHF) Extremely High Frequency (EHF)

Mobile frequency licenses in Norway (frekvens.nkom.no, 25.03.2019)

FDD band	Frequency band	Total available bandwidth	Use/expected use in Norway	Operators	Until
450 MHz	452.5-457.5 462.5-467.5	2 x 4 MHz	?	ICE Norge AS (2x4 MHz)	31.12.19
800 MHz	791-821 832-862	2 x 30 MHz	LTE	ICE Norge AS (2x10 MHz) TeliaSonera Norge AS (2x10 MHz) Telenor Norge AS (2x10 MHz)	31.12.33
900 MHz	880-915 925-960	2 x 35 MHz	GSM, UMTS, LTE	ICE Norge AS (2x5.1 MHz) TeliaSonera Norge AS (2x14.8 MHz) Telenor Norge AS (2x15.1 MHz)	31.12.33,
1800 MHz	1710-1785 1805-1880	2 x 75 MHz	GSM, LTE	Telenor Norge AS (2x20 MHz) TeliaSonera Norge AS (2x20 MHz) ICE (2x20 MHz)	31.12.33, 31.12.28
2100 MHz	1920-1980 2110-2170	2 x 60 MHz	UMTS, LTE	TeliaSonera Norge AS (2x19.8 MHz) Telenor Norge AS (2x19.8 MHz) Mobile Norway (2x19.8 MHz)	31.12.32, 31.12.19
2600 MHz	2500-2570 2620-2690	2 x 70 MHz	LTE	TeliaSonera Norge AS (2x20 MHz) Telenor Norge AS (2x40 MHz) NextNet (2x10 MHz)	31.12.22
3500 MHz	3400-3600	200 MHz	FWA 5G	NextGenTel, Broadnet, Ceragon Networks, Vestlink, Telenor, Get	31.12.22

Mobile frequency licenses in Sweden (www.pts.se, 3.4.2018)

Band	Frequency band	Total available bandwidth	Use/expected use in Sweden	Operators	Until
450 MHz	452.5-457.5 462.5-467.5	2 x 4 MHz	LTE	Net1 Sverige AB	5 mars 2020 till och med den 31 december 2044
800 MHz	791-821 832-862	2 x 30 MHz	LTE	791-801/832-842: Hi3G (2x10 MHz) 801-811/842-852: TeliaSonera (2x10 MHz) 811-821/852-862: Net4Mobility (Telenor+Tele2) (2x10 MHz)	
900 MHz	880-915 925-960	2 x 35 MHz	GSM+UMTS+LTE	925-930/880-885: Hi3G (2x5 MHz) 930-936/885-891: Net4Mobility (Telenor+Tele2) (2x6 MHz) 936-945/891-900: Tele2 (2x9 MHz) 945-950/900-905: Telenor (2x5 MHz) 950-960/905-915: Telia (2x10 MHz)	
1800 MHz	1710-1785 1805-1880	2 x 75 MHz	LTE	1805-1840/1710-1745 Telia (2x35 MHz) 1840-1870/1745-1775 Net4Mobility (Telenor+Tele2) (2x30 MHz) 1870-1875/1775-1780 Hi3G (2x5 MHz)	
2100 MHz	1920-1980 2110-2170	2 x 60 MHz	UMTS	1905-1910 (TDD): SULAB (Telia+Tele2) (5 MHz) 1910-1915 (TDD): Hi3G (5 MHz) 1915-1920 (TDD): Telenor (5 MHz) 1920,3-1940,1/2110,3-2130,1: Telenor (2x19,8 MHz) 1940,1-1959,9/2130,1-2149,9: Hi3G (2x19,8 MHz) 1959,9-1979,7/2149,9-2169,7: SULAB (Telia+Tele2) (2x19,8 MHz)	
2600 MHz	2500-2570 2620-2690	2 x 70 MHz	LTE	2500-2520/2620-2640: Net4Mobility (2x20 MHz) 2520-2530/2640-2650: Hi3G (2x10 MHz) 2530-2550/2650-2670: TeliaSonera (2x20 MHz) 2550-2570/2670-2690: Net4Mobility (2x20 MHz)	

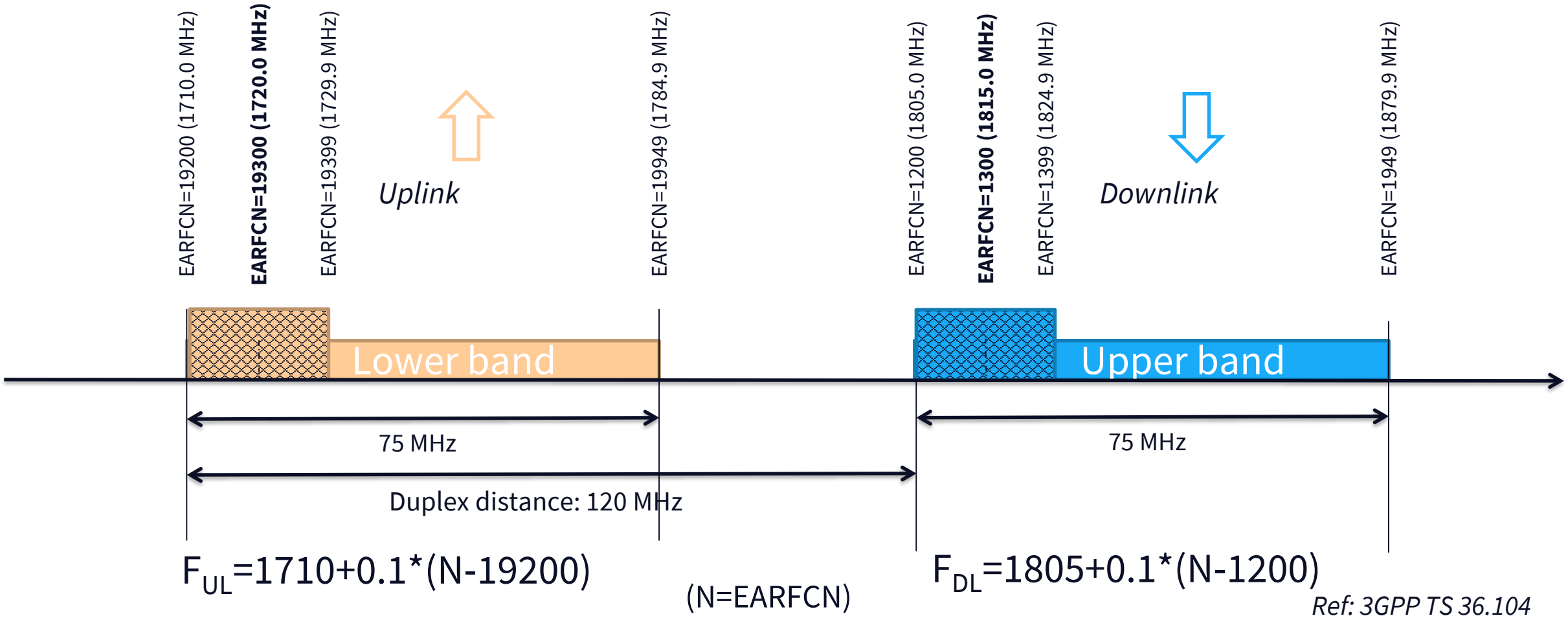
From channel number (ARFCN/UARFCN/EARFCN) to frequency – Downlink

Band	Channel number range (N_{DL})	Formula	Frequency range, DL (MHz)
GSM (GPRS, EDGE)			
Band 8: «900 GSM»	0 – 124; 975 - 1023	F_{DL}=890+0.2*N+45 F_{DL}= 890+0.2*(N-1024)+45	**935.0 – 959.8 MHz** **925.2 – 934.8 MHz**
Band 3: «1800 DCS»	512 - 885	F_{DL} = 1710.2+0.2*(N-512)+95	**1805.2 – 1879.8 MHz**
UMTS (HSPA, HSUPA, HSDPA, HSPA+)			
Band 1: «2.1 GHz»	10562 – 10838	F_{DL} = 0.2*N	**2112.4 – 2167.6 MHz**
Band 8: «900 GSM»	2937 – 3088	F_{DL} = 0.2*N+340	**927.4 – 957.6**
LTE			
Band 7: «2.6 GHz»	2750 – 3449	F_{DL}=2620+0.1*(N-2750)	**2620.0 – 2689.9 MHz**
Band 3: «1800 DCS»	1200 – 1949	F_{DL}=1805+0.1*(N-1200)	**1805.0 – 1879.9 MHz**
Band 8: «900 GSM»	3450 - 3799	F_{DL} = 925+0.1*(N-3450)	**925.0 – 959.9 MHz**

From channel number (ARFCN/UARFCN/EARFCN) to frequency – Uplink

Band	Channel number range (N_{UL})	Formula	Frequency range, UL (MHz)
GSM (GPRS, EDGE)			
Band 8: «900 GSM»	0 – 124; 975 - 1023	F_{UL}=890+0.2*N F_{UL}= 890+0.2*(N-1024)	**890.0 – 914.8 MHz** **880.2 – 889.8 MHz**
Band 3: «1800 DCS»	512 - 885	F_{UL} = 1710.2+0.2*(N-512)	**1710.2 – 1784.8 MHz**
UMTS (HSPA, HSUPA, HSDPA, HSPA+)			
Band 1: «2.1 GHz»	9612 – 9888	F_{UL} = 0.2*N	**1922.4 – 1977.6 MHz**
Band 8: «900 GSM»	2712 – 2863	F_{UL} = 0.2*N+340	**882.4 – 912.6**
LTE			
Band 7: «2.6 GHz»	20750 – 21449	F_{UL}=2500+0.1*(N-20750)	**2500.0 – 2569.9 MHz**
Band 3: «1800 DCS»	19200 – 19949	F_{UL}=1710+0.1*(N-19200)	**1710.0 – 1784.9 MHz**
Band 8: «900 GSM»	21450 – 21799	F_{UL} = 880+0.1*(N-21450)	**880.0 – 914.9 MHz**

Channel numbers LTE FDD
Example: Band 3, LTE 1800, BW=20 MHz



Ref: 3GPP TS 36.104

Dynamic allocation of spectrum in TVWS

- Geolocation database approach is used for White Space Devices (WSD) to access the TVWS spectrum:

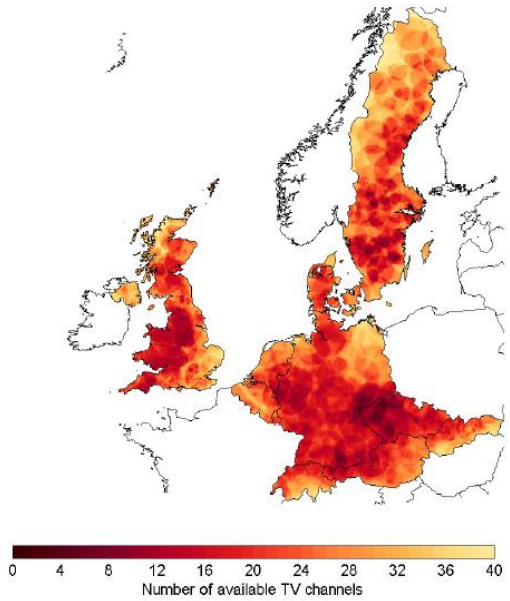
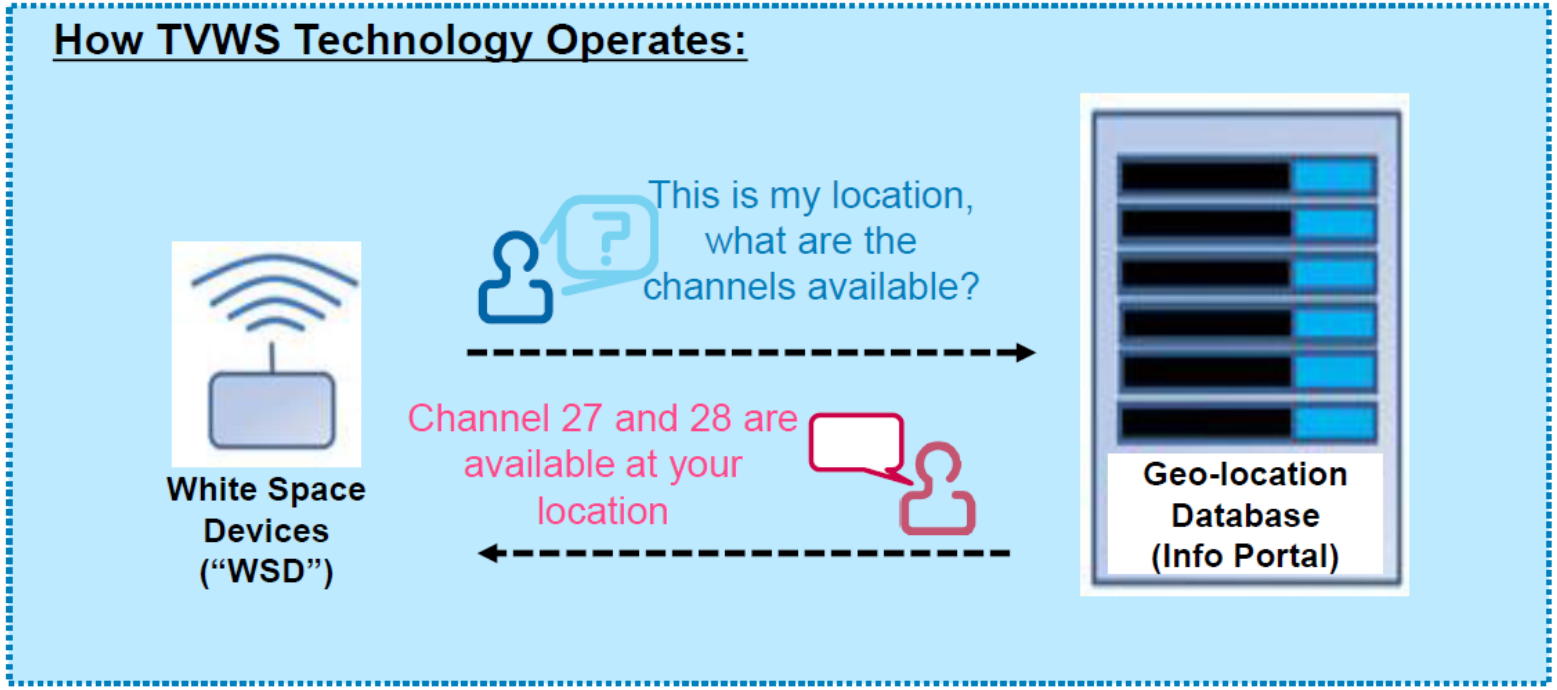


Fig. 2. White space map of $S(\mathbf{x})$ for 11 European countries.



Rules for using the TVWS

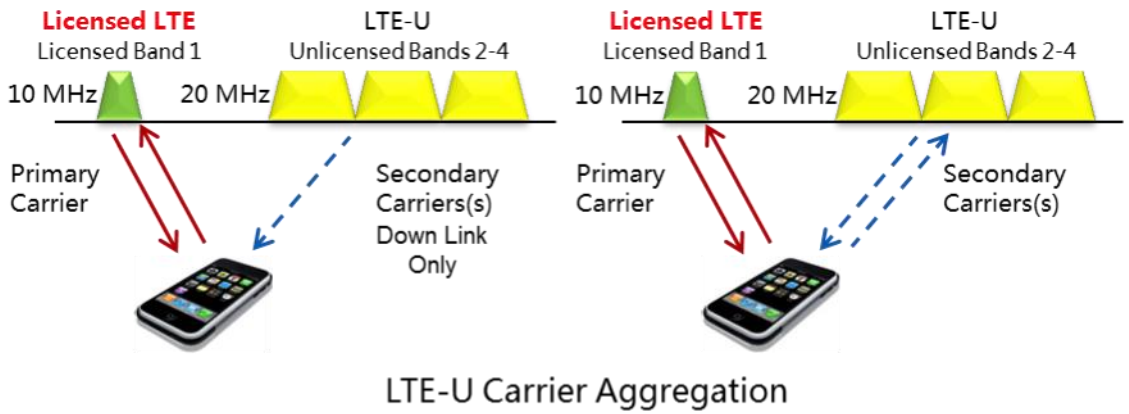
- **Primary system:**
  - DVB-T – digital terrestrial TV
    - 8 MHz channel width (Europe)
    - Tx power up to several kW
  - Also used for PMSE – program making and special events: wireless microphone systems and audio links
    - Narrow channels: 200 – 600 kHz
    - Tx power 0-17 dBm (handheld); 47 dBm for audio p2p links
- **Systems designed to use the TVWS:**
  - IEEE 802.11af – «White-Fi» - Wi-Fi in TVWS
  - IEEE 802.22 – Wireless Regional Area Network (WRAN) – Fixed Wireless Access
  - Weightless – Low Power Wide Area Network (LPWAN) standard developed by the Weightless SIG for IoT

As for sharing unlicensed spectrum, limiting transmitter power is the most important regulation

Parameter	FCC (US)	OFCOM (UK)
Power for FD in adjacent band	Not allowed	Not applicable
Power for FD in non-adjacent band with geo-location capability	30dBm (1W) (36dBm EIRP with 6dB gain antenna)	Not applicable
Power for PPD in adjacent band	16dBm (40mW) (Gain antenna not allowed)	4dBm
Power for PPD in non-adjacent band with geo-location capability	20dBm (100mW) (Gain antenna not allowed)	17dBm
Power for PPD in non-adjacent band without geo-location capability	17dBm (50mW)	

FD: Fixed Device; PPD: Personal Portable device

Combining Licensed and Unlicensed spectrum: Licensed Assisted Access – LAA Example: LTE-U



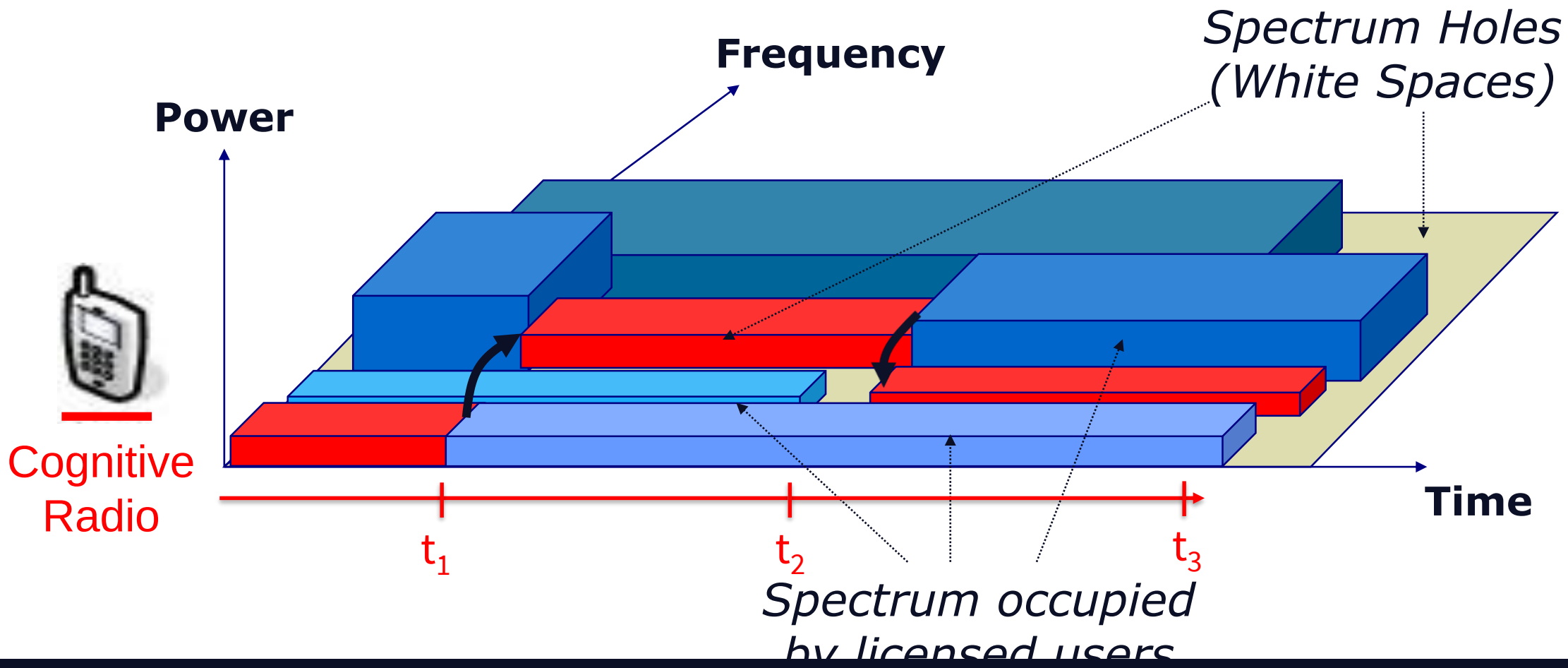
LTE-U Carrier Aggregation

SDL: Supplementary downlink

Spectrum for 5G

- NKOM, PTS:
- Se: https://www.insidetelecom.no/artikler/svenskene-frykter-5g-monopol/434219?utm_source=newsletter_2018-04-06
- http://www.pts.se/globalassets/startpage/dokument/icke-legala-dokument/remisser/2018/radio/20180405-pts-bemotande-konsultationssvar-700-mhz-tilldelning.pdf
- UK:
- https://www.ofcom.org.uk/about-ofcom/latest/features-and-news/results-auction-mobile-airwaves

Cognitive Radio can be used to dynamically access spectrum that is underutilized

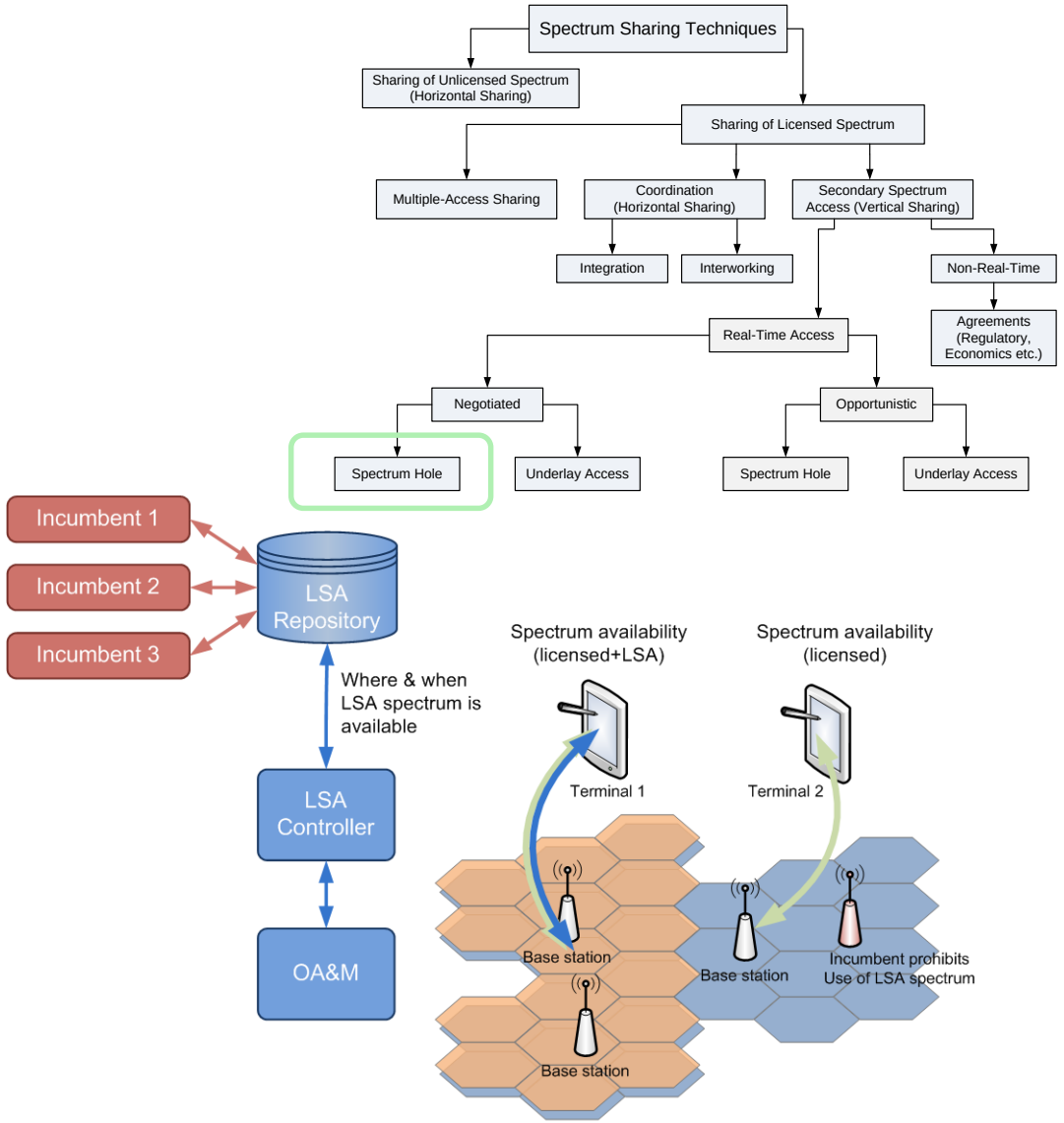


At WRC-15 and in preparation for WRC-19

- Discussion of new spectrum identified for IMT below and above 6 GHz
- New bands 3.4-3.6 GHz and 1.427-1.518 GHz for mobile broadband including, when appropriate, an IMT identification
- Resolution 238 (WRC-15) in preparation for WRC-19
  - determine the spectrum needs for the terrestrial component of IMT
    - in the frequency range between 24.25 GHz and 86 GHz
  - sharing and compatibility studies
    - 24.25-27.5 GHz, 37-40.5 GHz, 42.5-43.5 GHz, 45.5-47 GHz, 47.2-50.2 GHz, 50.4-52.6 GHz, 66-76 GHz and 81-86 GHz, which have allocations to the mobile service on a primary basis; and
    - 31.8-33.4 GHz, 40.5-42.5 GHz and 47-47.2 GHz, which may require additional
    -

Authorized Shared Access (Licensed Shared Access – LSA)

- **A framework to share spectrum between a limited amount of users**
  - The existing spectrum user(s) (“the incumbent(s)”) would share spectrum with one or several licensed LSA users (”LSA licensee(s)”) in accordance with a set of pre-defined conditions
- **The LSA repository**
  - A database containing relevant information on incumbent spectrum use
- **The LSA controller**
  - Computes LSA spectrum availability based on the rules built upon LSA rights of use and the incumbent’s use provided by the LSA repository.
- **The network Operation, Administration & Maintenance (OA&M)**
  - Corresponds to the OA&M of mobile broadband networks.
  - It takes care of the actual management of LSA licensed spectrum, practically translating spectrum availability information into radio resource management commands.



Future trend: Licensed Shared Access (LSA)

- Proposed in 2010 by Qualcomm and Nokia in an answer to a hearing on cognitive technologies by the EU

- LSA is a framework to share spectrum between a limited amount of users
  - Under this concept, the existing spectrum user(s) (“the incumbent(s)”) would share spectrum with one or several licensed LSA users (”LSA licensee(s)”) in accordance with a set of pre-defined conditions
  - the LSA concept is primarily about granting “individual authorisations” of the use of a frequency band which is already licensed to another incumbent usage(s), e.g. defence service, satellite service or wireless camera operation
- Two basic levels of spectrum access are foreseen:
  - *Incumbent user*, who is the current spectrum licensee. This could be an individual license holder or a governmental organisation with priority rights in order to deliver public services (defence, civil aviation, emergency communications,…)
  - *The LSA licensee*, who must not interfere with the incumbent spectrum user. There will also be imposed emission and power limits by the regulator. A spectrum guarantee may also be defined reflecting the rights of the incumbent user.
- A key feature of LSA is to ensure a predictable QoS for all spectrum rights of use holders, network operators and consumers.