Advanced Wireless Communications, 2022

Academic course for 4th year engineering students

Sami Shamoon College of Engineering

Radio Services identifier DOI 10.13140/RG.2.2.35017.90722

More info in my Wiley book 'Radio Spectrum Management: Policies, Regulations and Techniques' appears also in Amazon. The Book is already published in Chinese

1. Broadcasting
   1. Broadcasting Delivery and RF bands
   2. Broadcasting Video (TV)
   3. Broadcasting Audio (radio AM/FM)
2. Land Mobile
3. Fixed
4. Satellites
5. Radar
6. Short Range Devices

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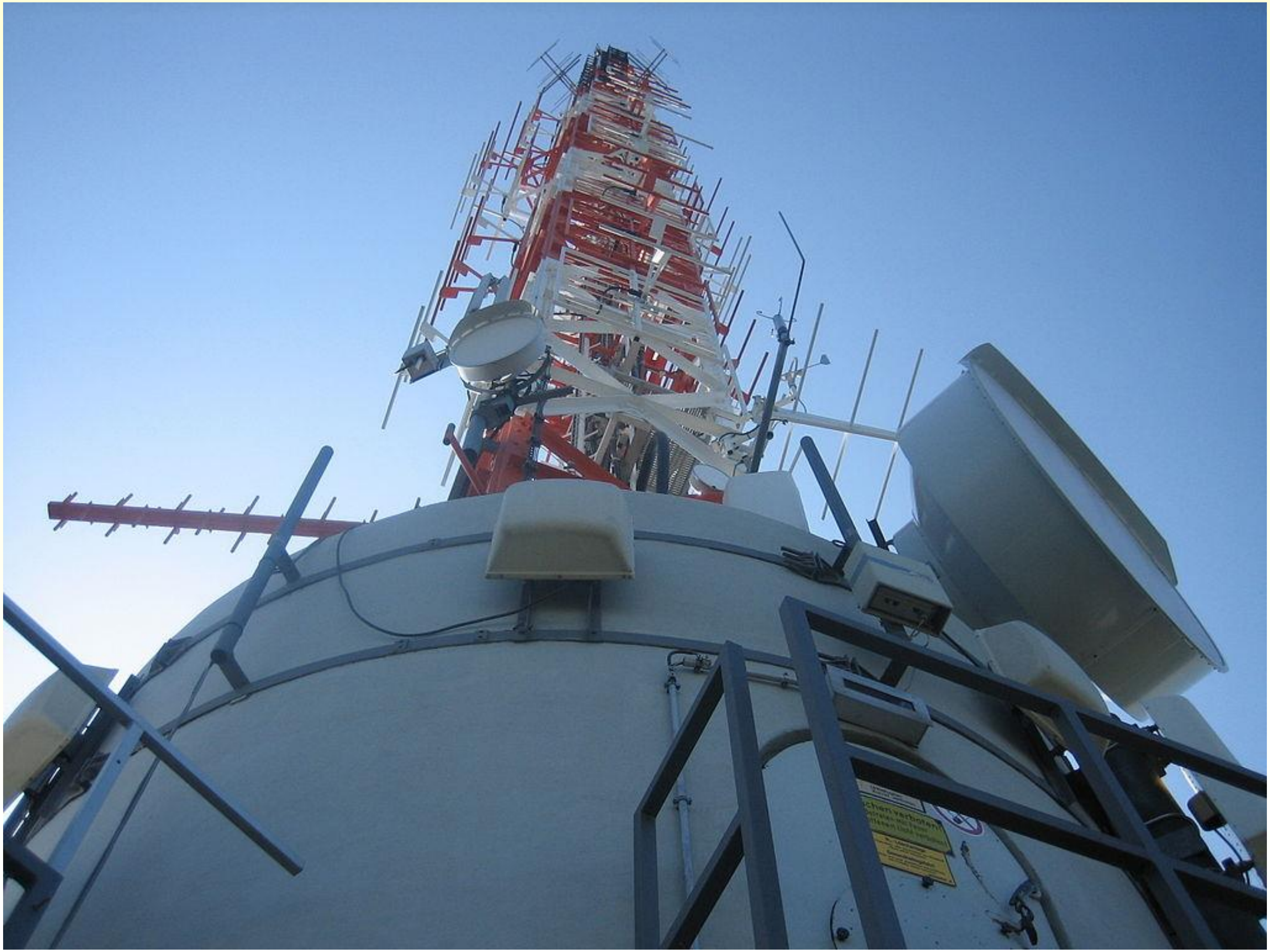
כל החומר בהרצאות הנו מקורי או 'שימוש הוגן ביצירות לצרכי הוראה ומחקר'

Last updated on
13 January 2023

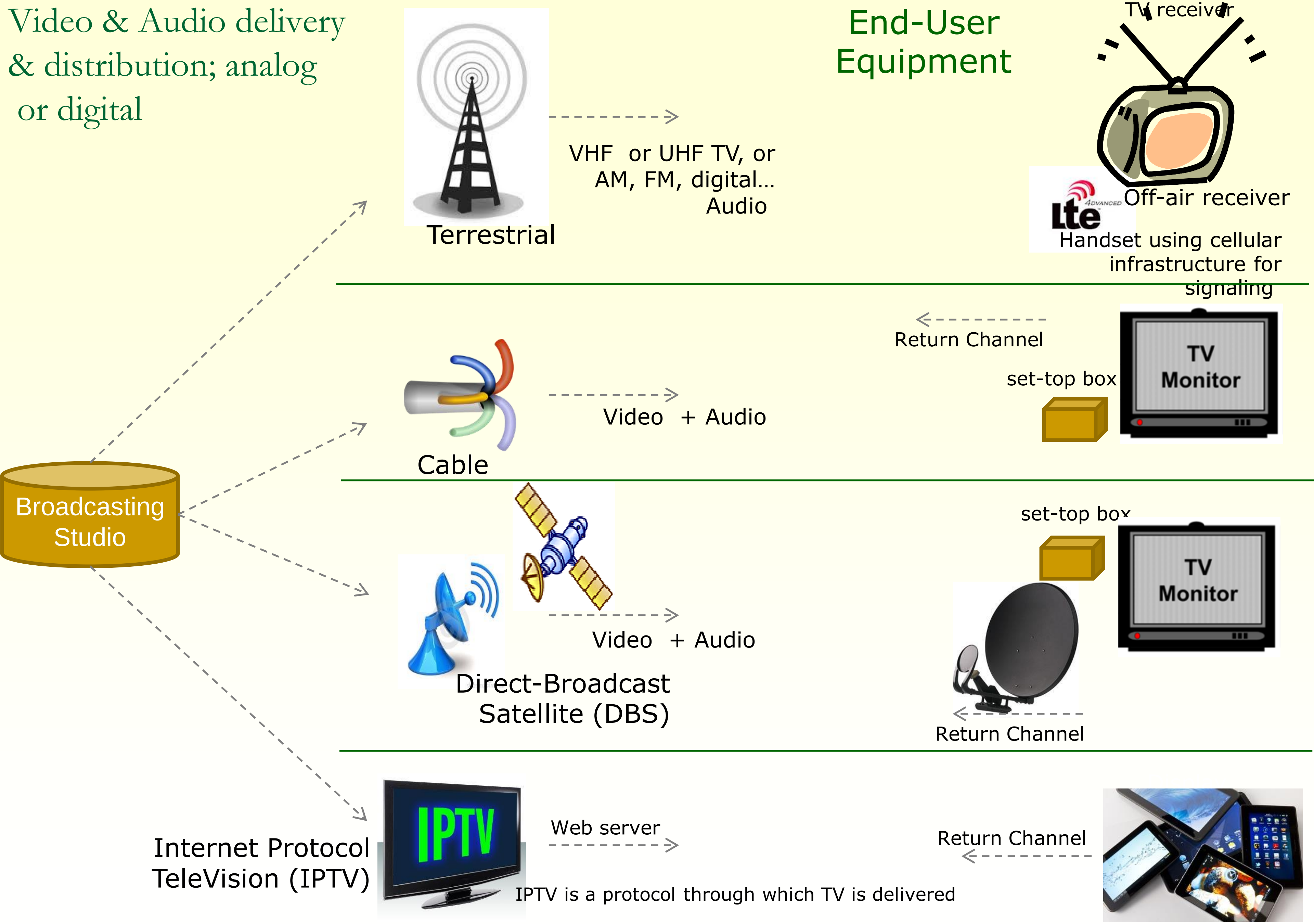
Not all slides will be presented during the academic course

Dr. Haim Mazar (Madjar), ITU & World-Bank expert;
reelected vice-chair ITU-Radio Study Group 5 (terrestrial services)

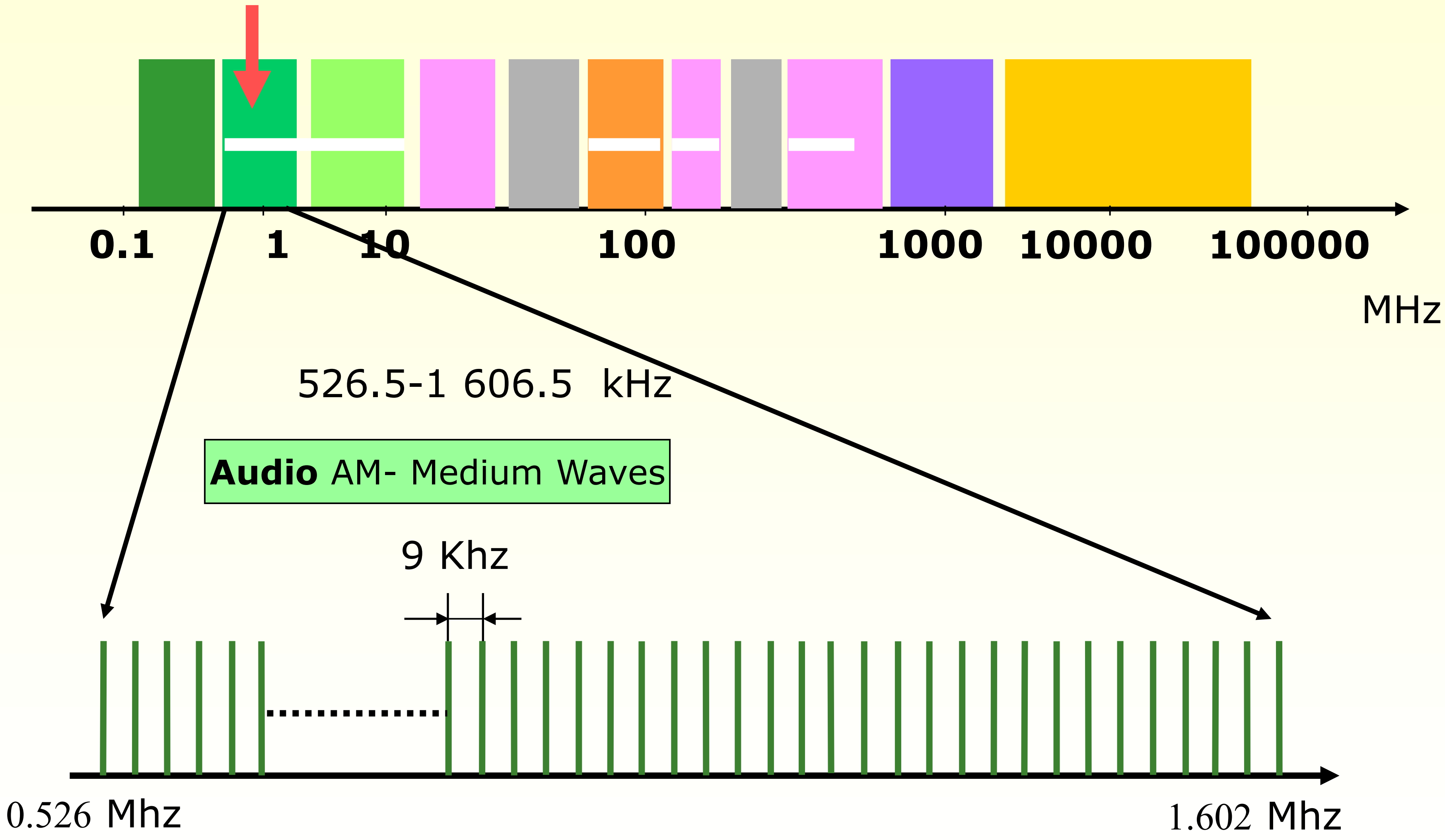
Broadcasting: Video, Audio and Data



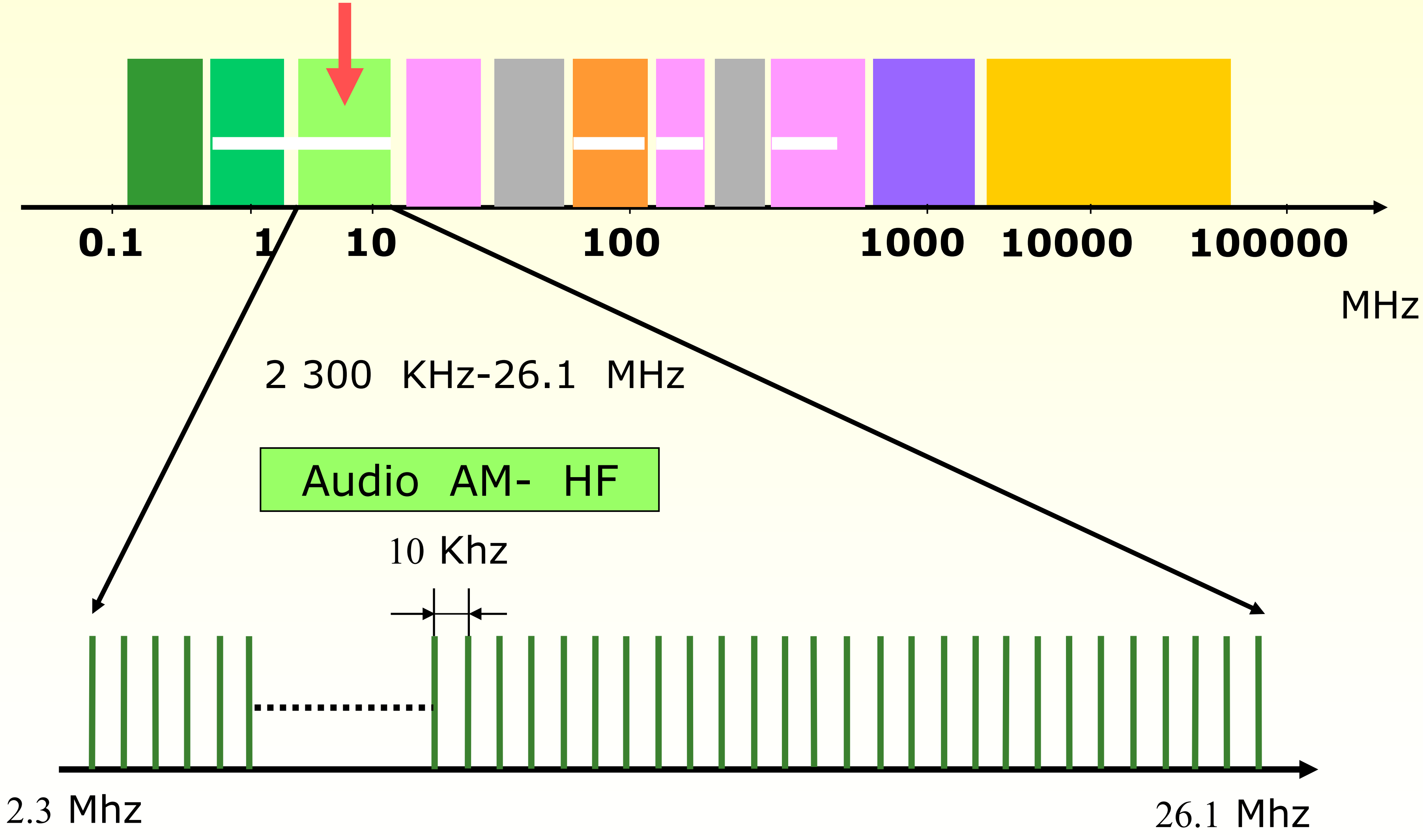
Video & Audio delivery & distribution; analog or digital



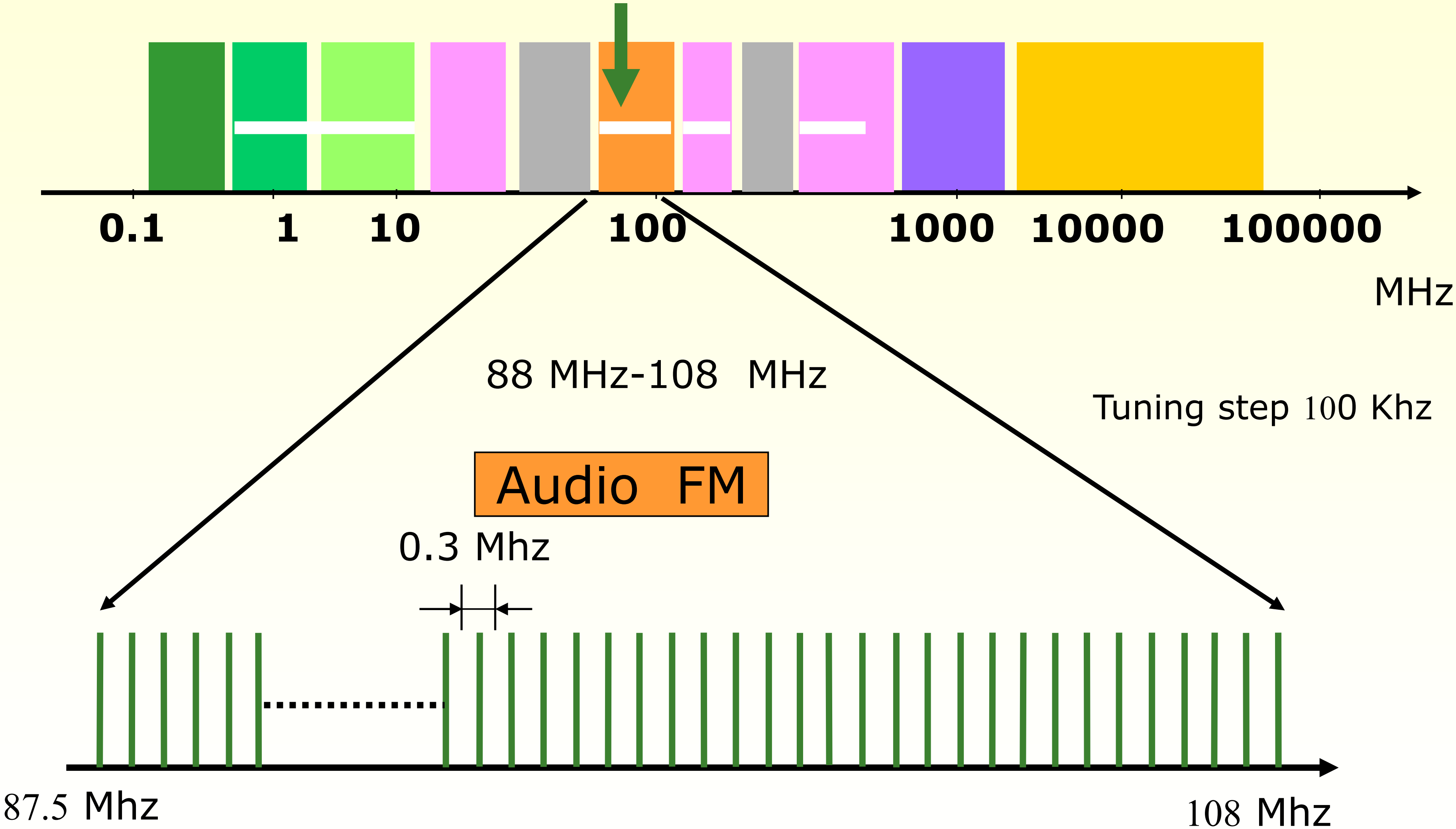
Frequency Bands- Audio AM medium-waves



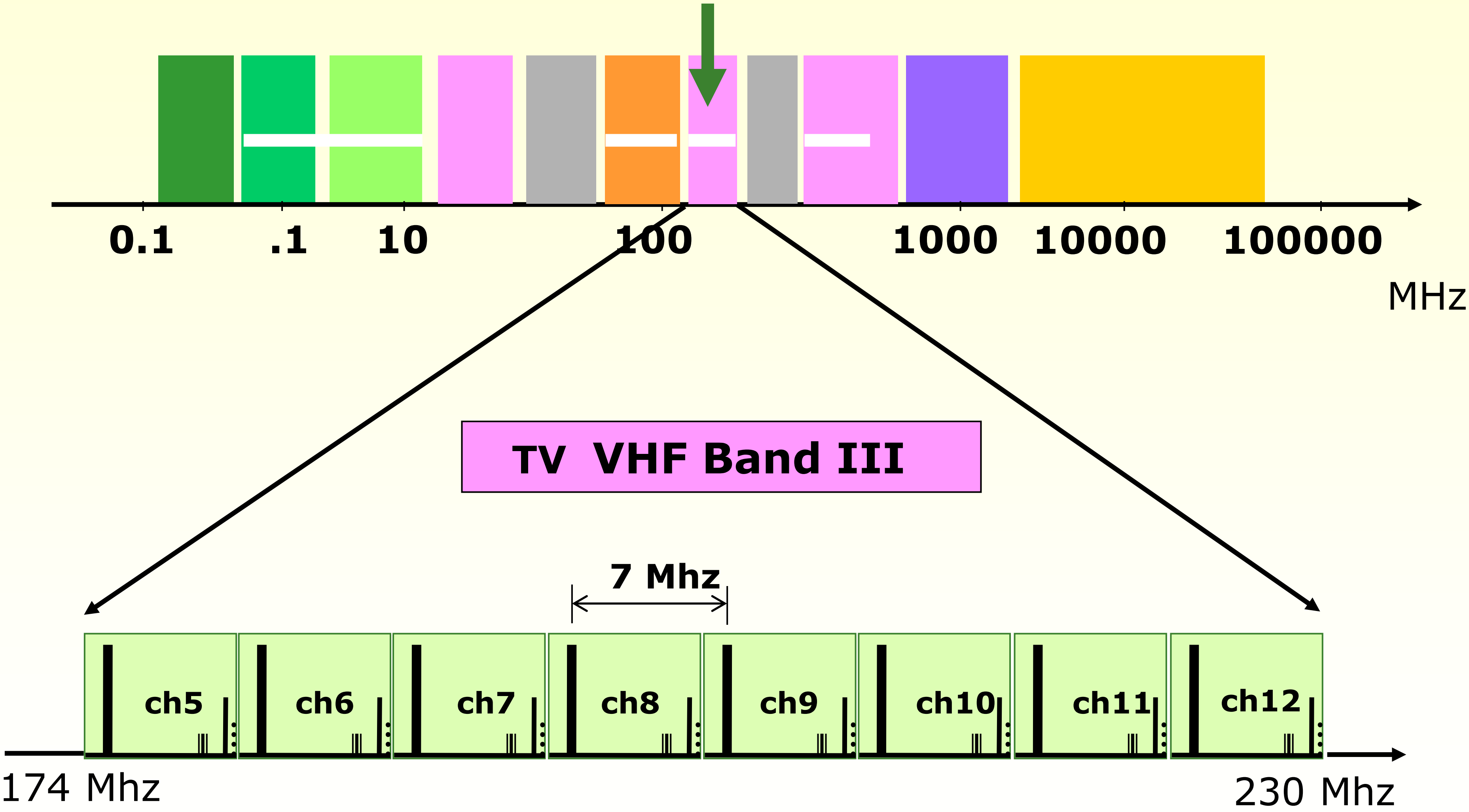
Frequency Bands- Audio AM HF



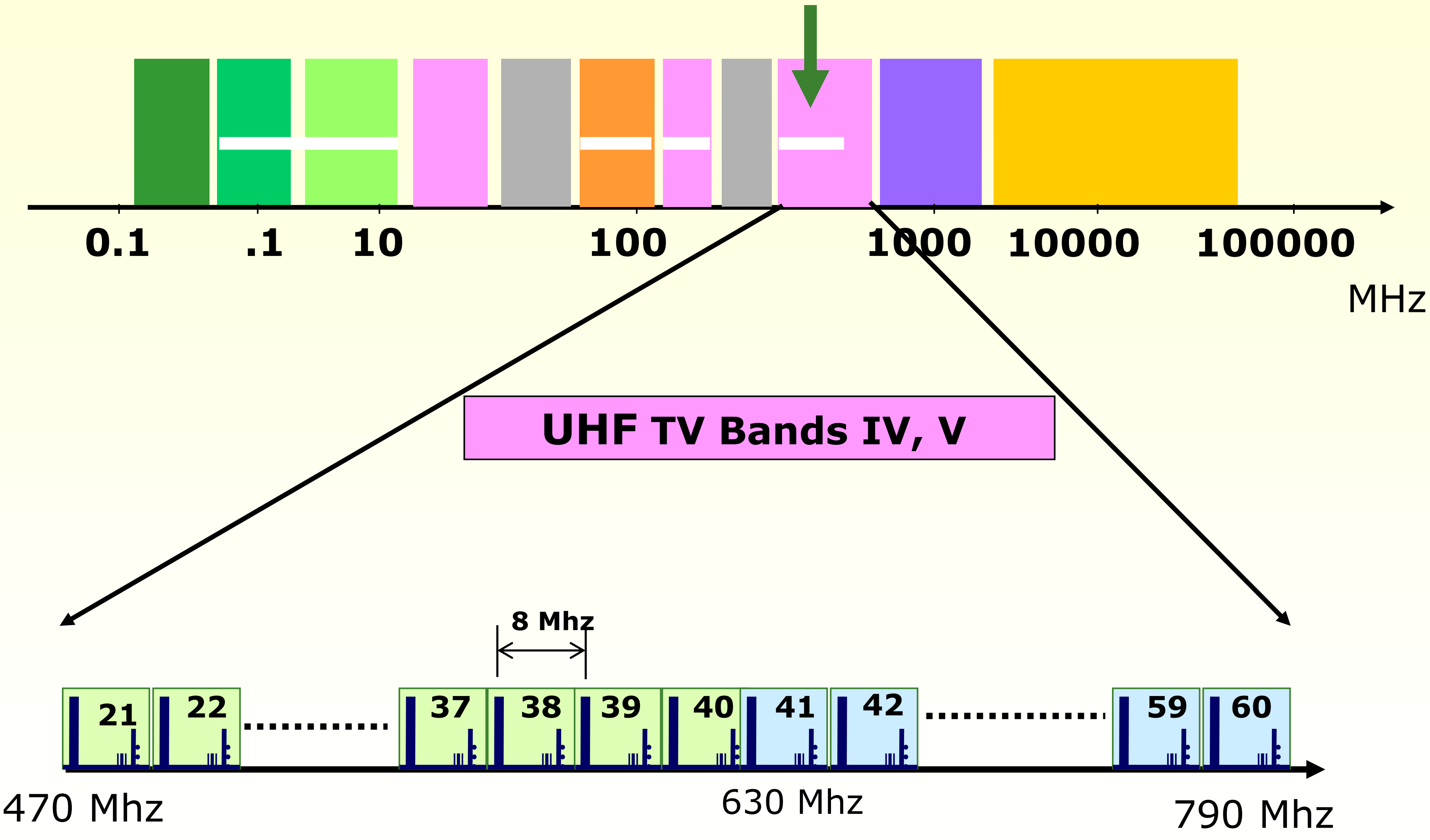
Frequency Bands- Audio FM



Frequency Bands- Video VHF; Region 1



Frequency Bands- Video UHF; Region 1



Designation of broadcasting bands mainly in Western Europe, Africa & Asian countries

Band	RF (MHz)	TV Channels' number starting at (MHz)	Ch. Separation
Band I	47-68	2:47 (MHz), 3:54; 4:61 (MHz).	7 MHz
Band II	87.5-108*	FM Channels; 100 kHz channel separation	
Band III	174-230	5:174, 6:181; 7:188; 8:195; 9:202; 10:209; 11:216; 12:223 (MHz).	
Band IV	470-582**	21:470; 22:478; 23:486; 24:494; 25:502; 26:510; 27:518; 28:526; 29:534: 30:542; 31:550; 32:558; 33:566; 34:574 (MHz).	8 MHz
Band V	582-862	35:582; 36:590; 37:598; 38:606; 39:614; 40:622; 41:630; 42:638; 43:646; 44:654; 45:662; 46:670; 47:678; 48:686; 49:694; 50:702; 51:710; 52:718; 53:726; 54:734; 55:742; 56:750; 57:758; 58:766; 59:774; 60:782; 61:790; 62:798; 63:806; 64:814; 65:822; 66:830; 67:838; 68:846; 69:854 (MHz)	

* 87.5–108 MHz: FM radio broadcasting is known as Band II internationally;

** UK defines Band IV 470 to 614 MHz, and Band V 614 to

RF Broadcasting video & audio bands in **Israel** https://kanweb.blob.core.windows.net/download/files/tedarim1505.pdf

Designation of Americans Broadcasting Bands

Band	RF (MHz)	TV Channels’ number starting at (MHz)
Band I (VHF low)	54-88	2:54; 3:60; 4:66; 5*:76; 6**:82 (MHz)
Band II (international)	87.5-108	FM Channels; 100 kHz channel separation
Band III (VHF-high)	174-216	7:174; 8:180; 9:186; 10:192;11:198; 12:204; 13:210 (MHz)
UHF Bands	470-698	14:470; 15:476; 16:482; 17:488; 18:494; 19:500; 20:506; 21:512; 22:518; 23:524; 24: 530; 25:536; 26:542; 27:548; 28:554; 29:560; 30:566; 31:572; 32:578; 33:584; 34: 590; 35:596; 36:602; 37:608; 38:614; 39: 620; 40:626; 41:632; 42:638; 43:644; 44:650; 45:656; 46:662; 47:668; 48:674; 49:680; 50:686; 51:692 (MHz)

** Channel 5 starts at 76 MHz and not 72 MHz;
** Channel 6: 82-88 MHz; the analog TV’s audio operates at 87.75 MHz, can be received as a normal 88.1-107.9 MHz FM radio.
At 698-890 MHz, in Americas Region 2, Mobile is co-primary with Broadcasting. Taking into account Cognitive Radio Systems & White Spaces, the coexistence of Mobile and Broadcasting is difficult; so, TV channels 52-83 starting at 698 to 884 MHz are not active. Moreover, channel 51 is adjacent to cellular A-Block of the 700 MHz band; therefore, USA & Canada restrict broadcasting; see FCC Public Notice DA-11-1428A1 and Industry Canada Advisory Letter - Moratorium on the Use of Television Channel 51

Technical Parameters of the TV systems

The three Analogue (or Analog) TV standards

<table>
<tr><th></th><th>Lines per frame (visible lines)</th><th>Fields per second</th><th>Line Frequency (Hz)</th><th>Video Bandwidth (MHz)</th><th>Colour subcarrier (MHz)</th><th>Subcarrier Modulation</th><th>Year implemented</th></tr>
<tr><td>NTSC</td><td>525 (480)</td><td>59.94</td><td>15,734.264</td><td>4.2</td><td>3.58</td><td rowspan="2">Quadrature Amplitude (QAM)</td><td>1954</td></tr>
<tr><td>PAL</td><td rowspan="2">625 (576)</td><td rowspan="2">50</td><td rowspan="2">15,625. Only for PAL-M 15,734.264</td><td rowspan="2">5; 5.5; 6</td><td rowspan="2">4.43; PAL-M 3.58, PAL-N 3.58</td><td rowspan="2">1967</td></tr>
<tr><td>SECAM</td><td>Frequency (FM)</td></tr>
</table>

median field strength

Band	**I**	**III**	**IV**	**V**
dB(μV/m)	+48	+55	+65	+70

The Three Digital TV Standards (Aware Channel Separation)

<table>
<tr><th></th><th>Reception speed</th><th>Scanning Lines</th><th>Image size Pixels</th><th>Modulation</th></tr>
<tr><td>ATSC</td><td>Portable</td><td>1125</td><td>1920x1080</td><td>Single 8-VSB carrier codes</td></tr>
<tr><td>DVB-T</td><td rowspan="2">< 90 km/h, for 8k carriers; <180 km/h, 2k</td><td rowspan="2" colspan="2">Flexible</td><td rowspan="2">OFDM</td></tr>
<tr><td>ISDB-T</td></tr>
</table>

See Mazar 2009 at http://eprints.mdx.ac.uk/133/2/MazarAug08.pdf p. 20

Digital television broadcasting systems Report ITU-R BT.2140

- ATSC DTV – Advanced Television Systems Committee – (System A)
- ATSC-M/H – Advanced Television Systems Committee Mobile & Handheld
- DTMB – GB 20600-2006: “Framing structure, Channel coding and modulation for digital TV terrestrial broadcasting system” (System D)
- DVB-H – Digital Video Broadcasting Handheld
- DVB-T – Digital Video Broadcasting Terrestrial – (System B)
- ISDB-T – Integrated Services Digital Broadcasting Terrestrial – (System C)
- T-DMB compatible with T-DAB (Rec. ITU-R BT.1833, ETSI TS 102 427 and ETSI TS 102 428)
- ISDB-T_{SB} – Integrated Services Digital Broadcasting-Terrestrial Sound Broadcasting – (Rec. ITU-R BT.1833 Multimedia System F)
- FLO – Forward Link Only (Recommendation ITU-R BT.1833, Multimedia System M, TIA-1099)

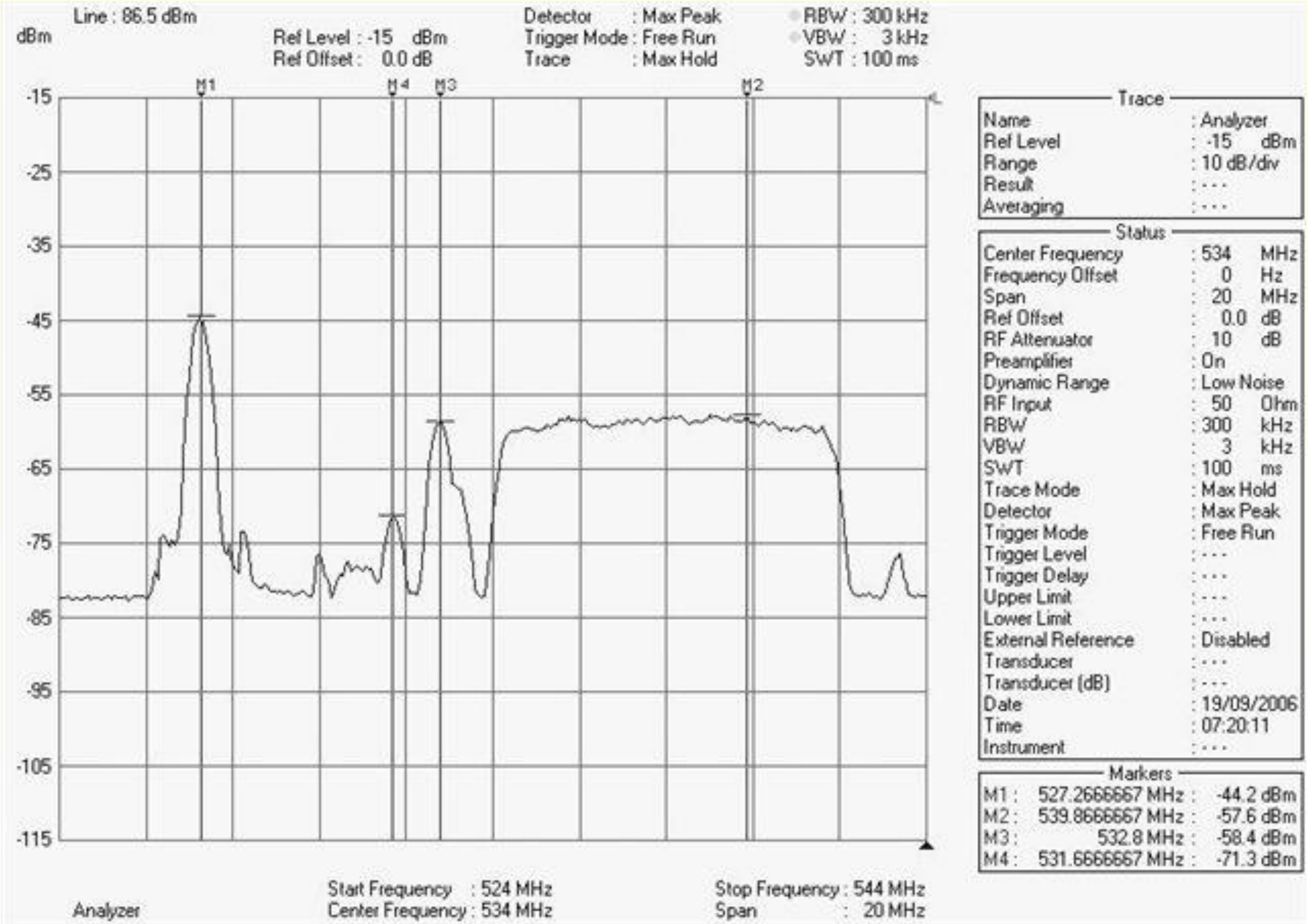
Digital TV Standards; Report ITU-R BT.2140 Table 2

Standard	Channels	Modulation	Applicable standards
ATSC	6 MHz	8-VSB	A/52, A/53, A/65, A/153
DTMB	6,7 and 8 MHz	Single carrier (QAM)/OFDM	GB 20600-2006
DVB-T	6, 7 and 8 MHz	OFDM	EN 300 744
DVB-H	5, 6, 7 and 8 MHz	OFDM	EN 302 304
ISDB-T	6, 7 and 8 MHz	Segmented OFDM	ARIB STD-B31
T-DMB	1.75 MHz	OFDM	ETSI TS 102 427 and ETSI TS 102 428
FLO	5, 6, 7 and 8 MHz	OFDM	TIA 1099
ISDB-T_{SB}	0.43, 0.50, 0.57 MHz 1.29, 1.50, 1.71 MHz	Segmented OFDM	ARIB STD-B29

All systems operate at UHF/VHF bands; except T-DMB at VHF/1.5 GHz

TV Analog ch. 28 (526-534 MHz) adjacent to Digital ch. 29 (534-542 MHz)

19/09/06; measured by author; M1-an. Video,M4-an. synch,M3-an. sound, M2- dig. OFDM

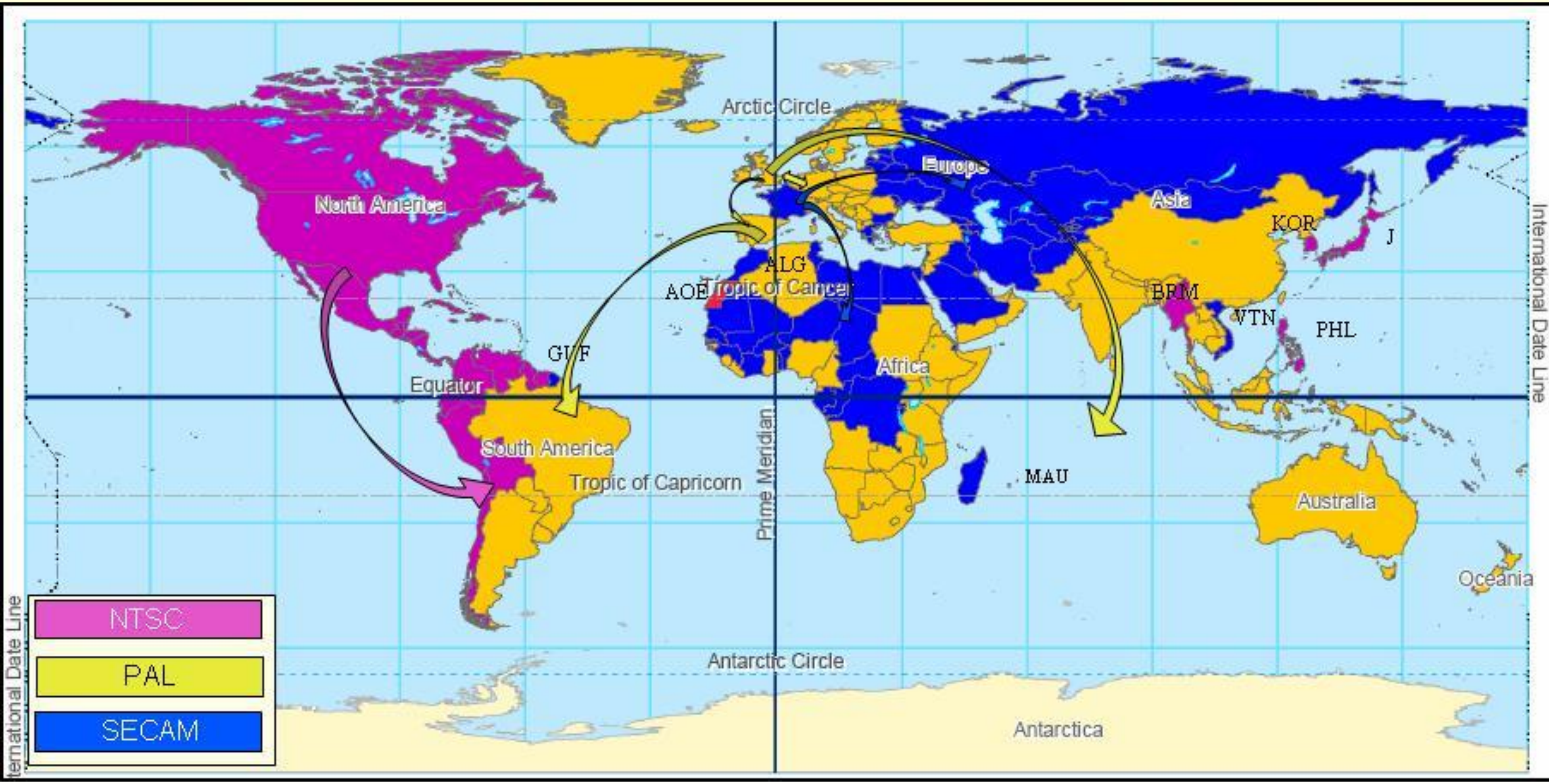


Digital Switchover and Digital Dividends

1. Switchover requires homes to upgrade aerials & their direction
2. Regional & International http://www.itu.int/dms_pub/itu-d/ activities
3. Digital dividend (DD) releases RF at Switchover
4. RF used for broadcasting is freed-up for other wireless services
5. Digital TV needs less spectrum than analog TV
    1. Video compression transmits numerous digital subchannels, using the same RF used to transmit one analog TV channel
    2. Digital transmissions require less guard-band on either side, as less prone to interference from adjacent channels
6. World Radio Conference (WRC)
    1. WRC-07, 800 MHz band (790–862) DD 1
    2. WRC-12, 700 MHz band (694/698–790) DD 2

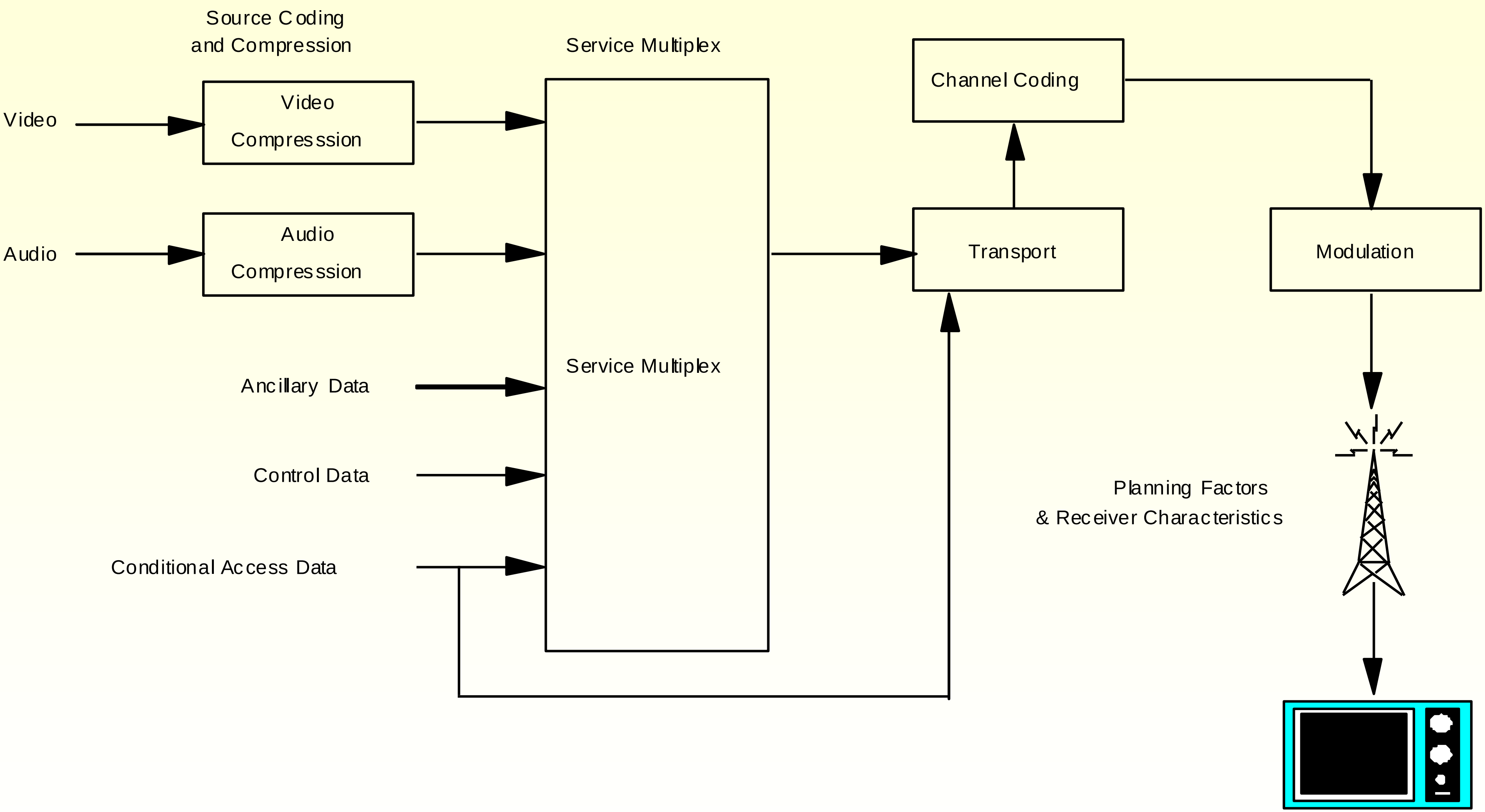
TV colours; analogue TV around the world

Influence of language (English or French) and colonialism

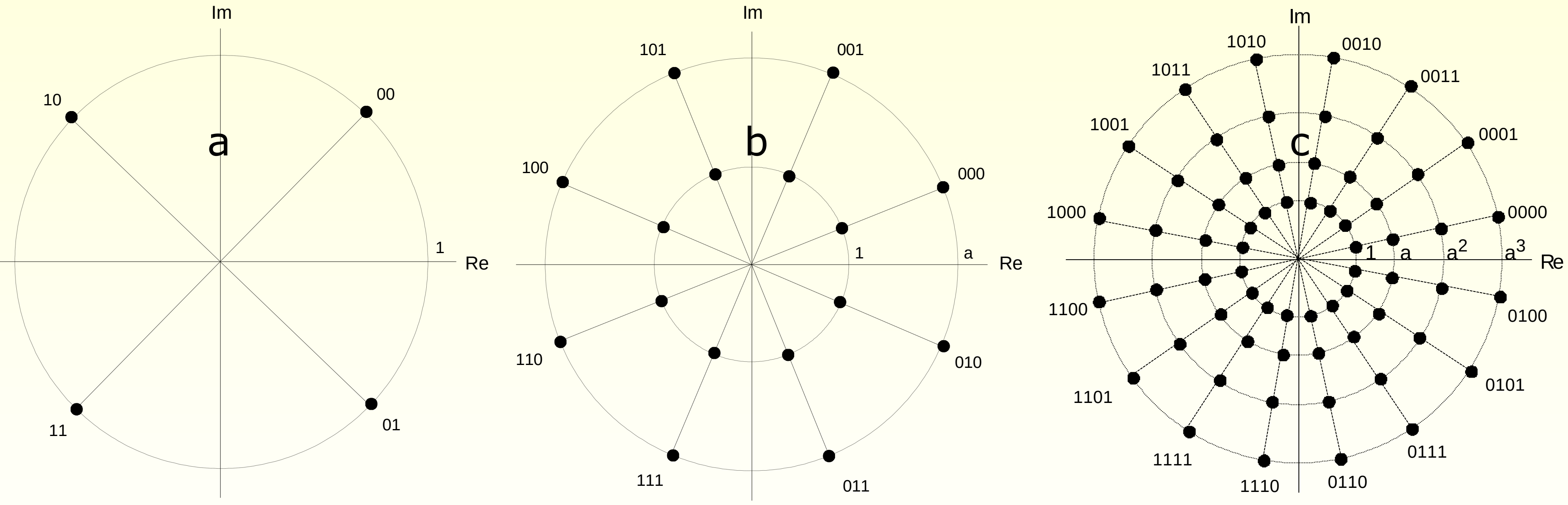


See http://eprints.mdx.ac.uk/133/2/MazarAug08.pdf p. 184

Digital Terrestrial Television Broadcasting (DTTB) system model DTTB Handbook



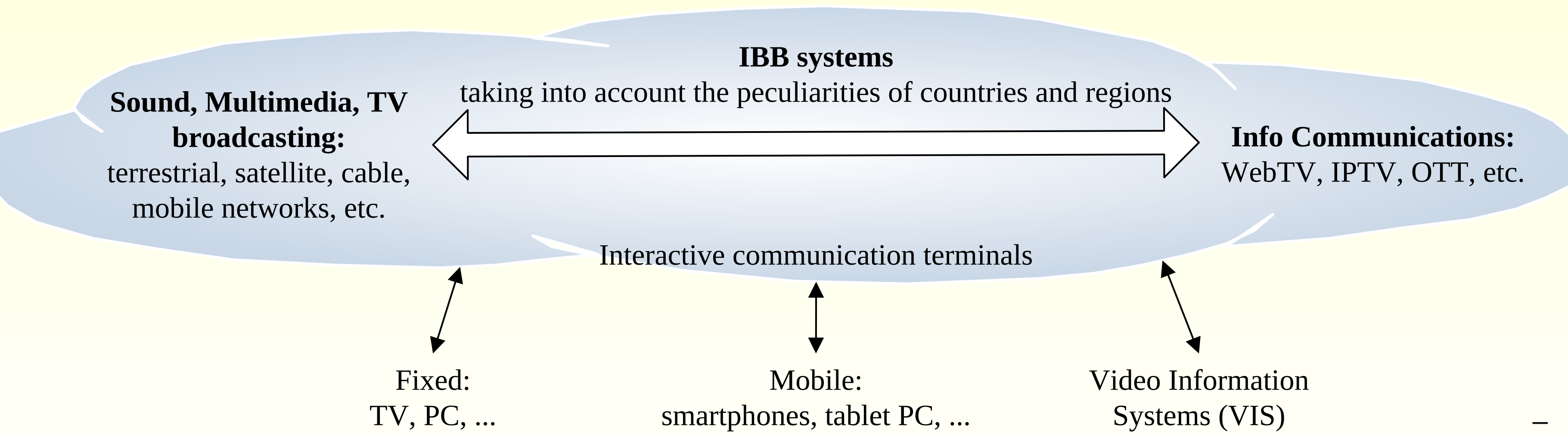
DTTB Constellation diagrams of a) DQPSK, b) 16-DAPSK and c) 64-DAPSK



media & means for Tx and Rx of information & interactive services of sound, multimedia & TV broadcasting fig 1 in Rep ITU-R BT.2295

(

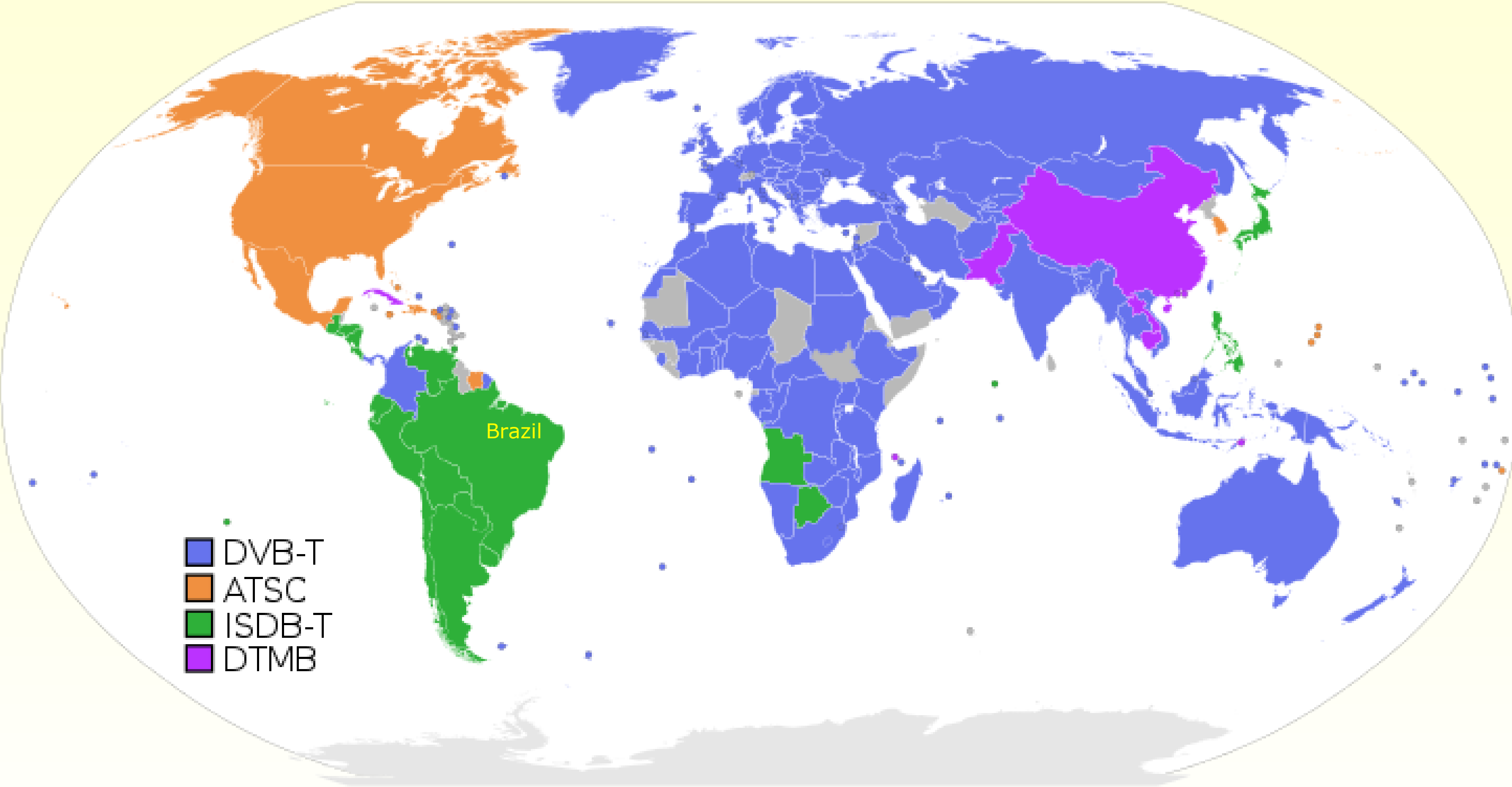
Those are the digital terrestrial broadcasting systems (TV and sound) : ATSC, DAB, DRM, DTMB, DVB-T, DVB-H, DVB-SH, DVB-T2, IBOC, ISDB-T family, RAVIS, T-DMB, AT-DMB.



Integrated Broadcast-Broadband (IBB) systems integrate both traditional broadcasting (terrestrial, satellite, cable) and broadcasting in mobile networks as well as other types of broadcasting

See also Recommendation ITU-R BT.2037 and Report ITU BT.2267

Digital Terrestrial Television (DTT) broadcasting systems by country



See http://en.wikipedia.org/wiki/File:Digital_broadcast_standards.svg 1 Nov. 2020

DVB-T2 VHF/UHF min equivalent field strength (dB(μV/m))

VHF / UHF	Fixed	Portable outdoor/urban	Portable indoor/urban	Mobile/rural	Handheld portable outdoor	moving vehicle* 1.54 MHz BW	moving vehicle* 7.71 MHz BW
Min. C/N	20.0	17.9	18.3	10.2	9.8	10.2	10.2
Equivalent noise band width (MHz)	6.66 7.77	6.66 7.77	6.66 7.77	1.54 7.71	6.66 7.77	1.54 not available	6.66 7.71
Ant. Gain relative to half dipole (dBd)	7 11	-2.2 0	-2.2 0	-2.2 0	-17 -9.5	-17 -	-17 -9.5
Man-made noise (dB)	2 0	8 1	8 1	5 0	0 0	0 -	0 0
Penetration loss (building or vehicle) (dB)	0 0	0 0	9 11	0 0	0 0	8 -	8 8
Min. median equivalent field strength (dB(μV/m))	41.3 48.2	52.4 54.1	62.4 66.8	39.5 49.5	51.1 54.2	57.8 -	64.1 67.5

* Handheld mobile Class H-D/ integrated antenna

DVB-T1 and DVB-T2 protection ratios: C/N and C/I (dB)

Rec. BT.1368 tables 1&15, BT.2033 tables 1&2 & EBU Technical Reports TR 022 & Tech 3348 (for DVBT-2)

Modulation	Bit rate (Mbit/s)		C/N (dB)		C/I (dB)	
	DVBT-1	DVBT-2	DVBT-1	DVBT-2	DVBT-1	DVBT-2
QPSK	≈ 7	≈ 10*	6.9	3.1*	7	4.5
16-QAM	≈ 13	≈ 20*	13.1	8.9*	13	10.3
64-QAM	≈ 20	≈ 30*	18.7	13.6*	19	15.1
256-QAM	no256QAM	≈40*	-	18.1* (19.7)	-	19.7

* from EBU report Tech 3348 Table 2.1; all other values are from Recommendation ITU-R BT.2033 such as (19.7). The *C/N* DVBT-2 are calculated at BER=10^{-6} after BCH(Bose, Chaudhuri, Hocquenghem) code

RF Digital Dividend in Israel

Confirmed on 9 Feb 2020 by Nisim Tal nisim@rashut2.org.il;
ניסים טל, סמנכ"ל הנדסה

1. 28 digital Transmitters, with two 8 UHF MHz channels cover all Israel with 5 programs (1, 2, 10, 33, 99)

2. Thus instead of
   1. 45 analog UHF and additional VHF Transmitters covering only one program - ch.1;
   2. and 15 analog Transmitters at UHF covering only one program- ch. 2.

2 digital 8 MHz UHF channels cover all Israel

Channel 29

Channel 26

Channel 29

See http://www.rashut2.org.il/idan_map.asp 5 Feb 2020

Questions to be asked about TV delivery

1. Except competition to satellites and cable, do we really need over-the-air terrestrial TV?
2. Which Standard: DVB-T, ISDB-T? ATSC? DMB-T? (check Channel Separation)
3. Free view or paid? Will HD be free also? HD or Ultra HD, 3D?
4. How many programs to transmit? Subsidise set-top box?
5. Business model of DVB-H? Cellular Operators or Broadcasters transmit the DVB-H? Which Regulator?

Coexistence TV and Cellular (1)
LTE parameters in 800 MHz

ETSI and3GPP band plan for Band Class 20

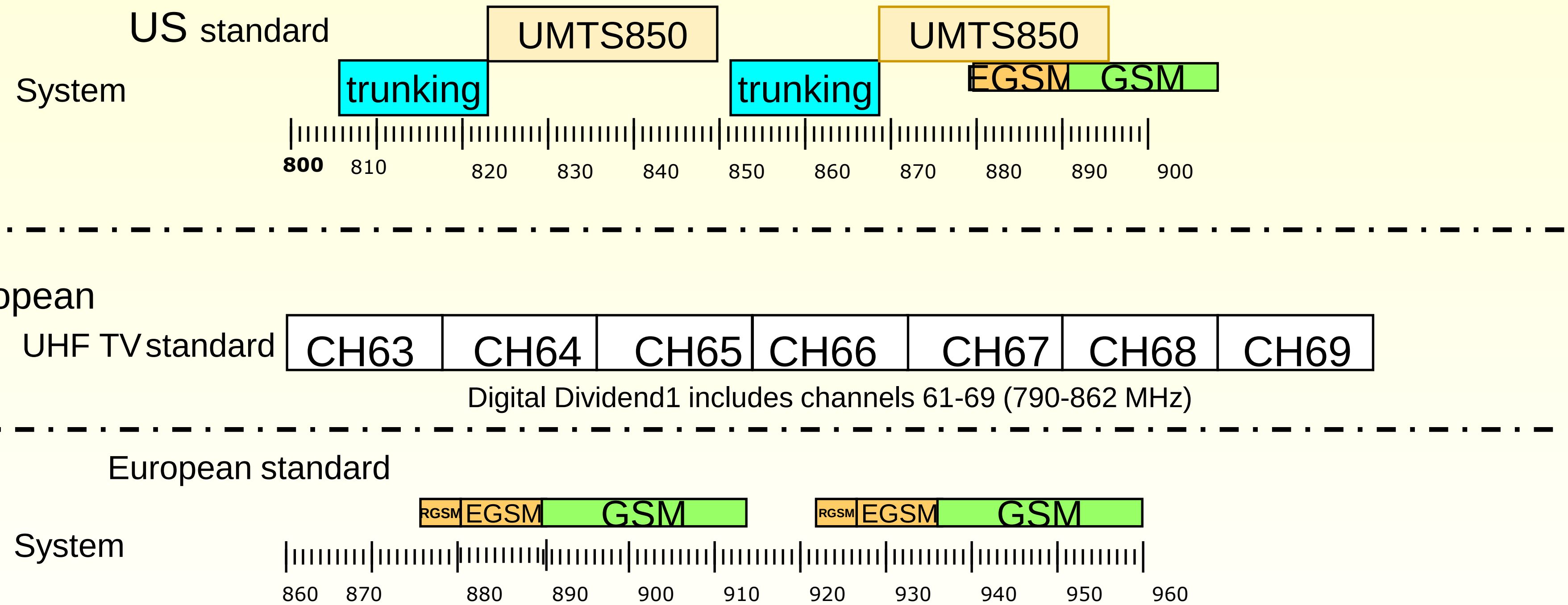
3GPP bandplan for class 20	Downlink (DL) operating band BS transmit UE receive			Uplink (UL) operating band BS receive UE transmit			Duplex Mode
	F_{DL_low} – F_{DL_high}			F_{UL_low} – F_{UL_high}			
20	791 MHz	–	821 MHz	832 MHz	–	862 MHz	FDD

3GPP bandplan for class 20	TX - RX carrier centre frequency separation
20	41 MHz

Coexistence TV and Cellular (see also specific slide in Land mobile)(1)
Digital Dividend 790-862 MHz: Present 800/900 MHz Cellular, Trunking & TV allocations

04 July 2010

European and American RF allocations



Calculation of minimum field strength (App1 to Ann 2 ITU-R BT 1368)

- P_n = $F + 10 \log (k\, T_0\, B)$
- $P_{s\,min}$ = $C/N + P_n$
- A_a = $G + 10 \log (1.64\lambda^2/4\,\pi)$
- φ_{min} = $P_{s\,min} - A_a + L_f$
- $E_{min} = \varphi_{min} + 120 + 10 \log (120\,\pi) = \varphi_{min} + 145.8$
- $E_{med} = E_{min} + P_{mmn} + C_l$ for roof top level fixed reception
- $E_{med} = E_{min} + P_{mmn} + C_l + L_h$ for portable outdoor and mobile Rx
- $E_{med} = E_{min} + P_{mmn} + C_l + L_h + L_b$ for portable indoor & mobile hand-held Rx

$C_l = \mu \cdot \sigma_t$ $\qquad \sigma_t = \sqrt{\sigma_b^2 + \sigma_m^2}$

Calculation of minimum field strength (Cont'd)

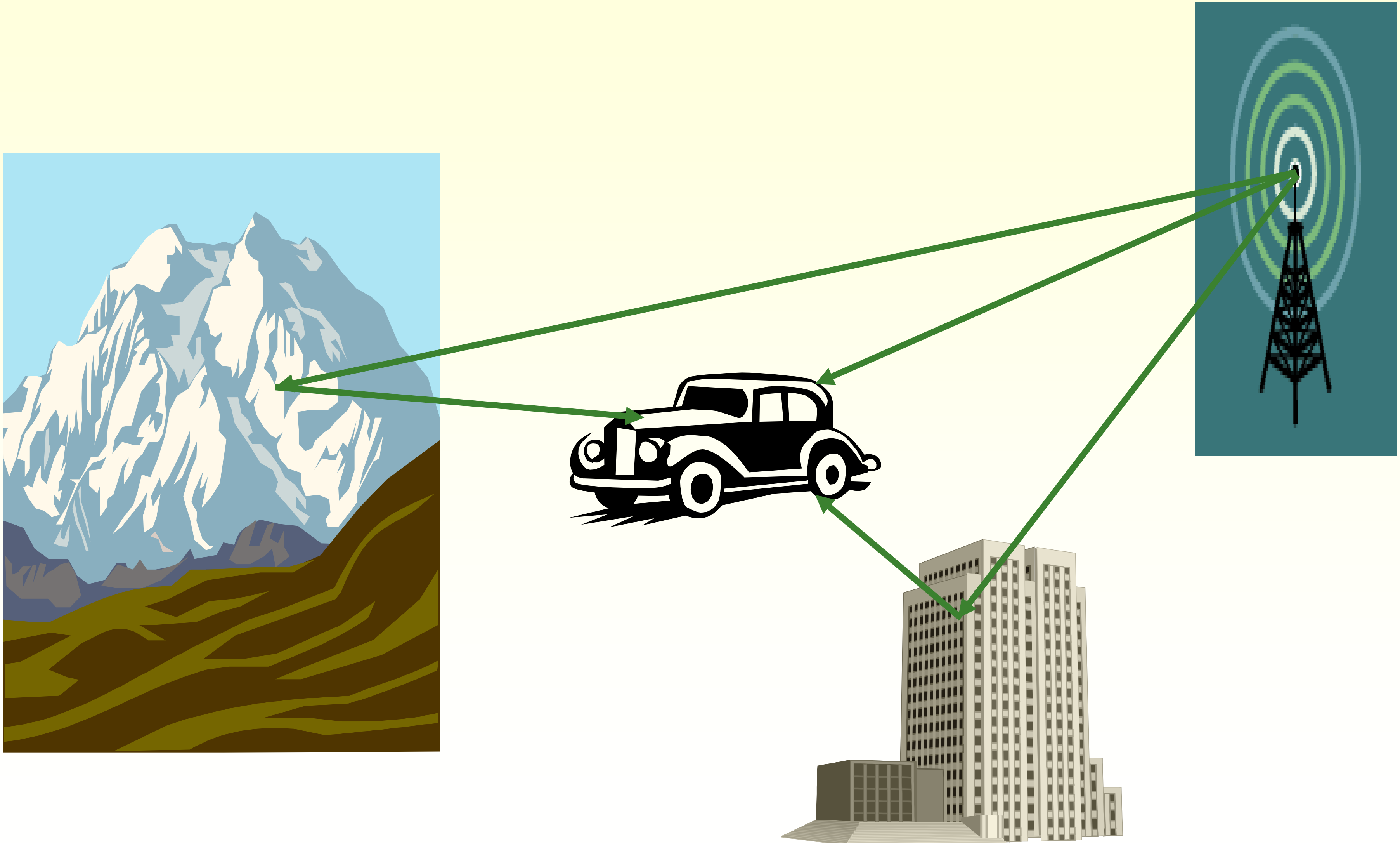
- P_n : receiver noise input power (dBW) F :receiver noise figure (dB)
- k : Boltzmann's constant ($k = 1.38 \times 10^{-23}$ (J/K)) T_0 : absolute temperature ($T_0 = 290$ (K))
- B : receiver noise bandwidth ($B = 7.61 \times 10^6$ (Hz))
- $P_{s\,min}$: minimum receiver input power (dBW)
- C/N : RF S/N at the receiver input required by the system (dB)
- A_a : effective antenna aperture (dBm^2)
- G : antenna gain related to half dipole (dBd)
- λ : wavelength of the signal (m)
- φ_{min} : minimum pfd at receiving place (dB(W/m^2))
- L_f : feeder loss (dB)
- E_{min} : equivalent minimum field strength at receiving place (dB(μV/m))
- E_{med} : minimum median equivalent field strength, planning value (dB(μV/m))
- P_{mmn} : allowance for man-made noise (dB)
- L_h : height loss (reception point at 1.5 m above ground level) (dB)
- L_b : building or vehicle entry loss (dB) C_l : location correction factor (dB)
- σ_t : total strd deviation (dB) σ_m strd deviation macro-scale ($\sigma_m = 5.5$ (dB))
- σ_b : strd deviation building entry loss (dB)
- μ : distribution factor being 0.52 for 70%, 1.28 for 90%, 1.64 for 95% and 2.33 for 99%.

Planning, Protection of land mobile and fixed systems from terrestrial digital video and audio broadcasting systems

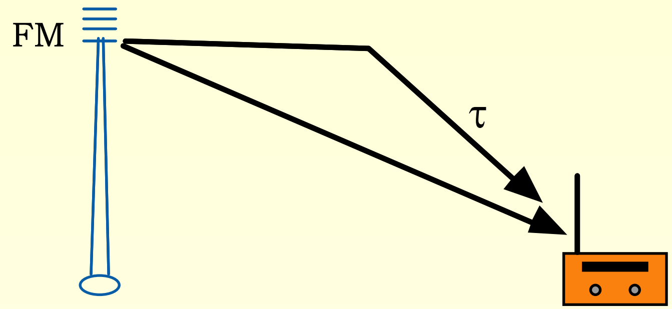
1. Rec. ITU-R M.1767: Protection of land mobile systems from terrestrial digital video and audio broadcasting systems in the VHF and UHF shared bands allocated on a primary basis
2. Rec. ITU-R F.1670: Protection of fixed wireless systems from terrestrial digital video and sound broadcasting systems in shared VHF and UHF bands

These two Recommendations were drafted by the author of this lecture

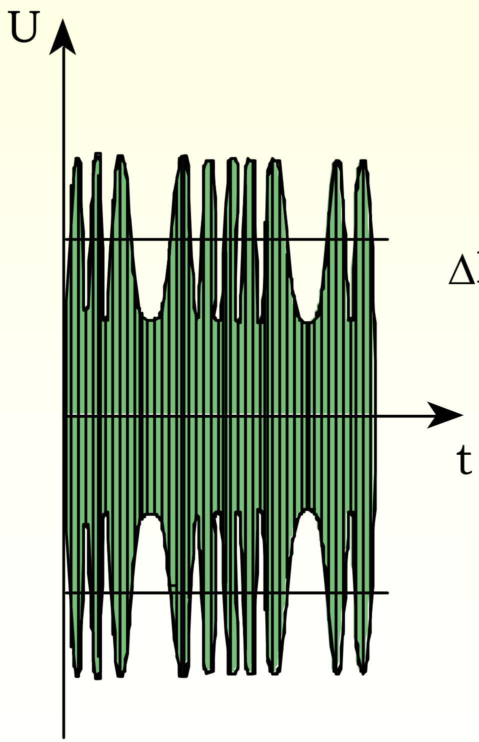
Multipath Distortion in Broadcasting



Multipath Distortion in FM and capture effect



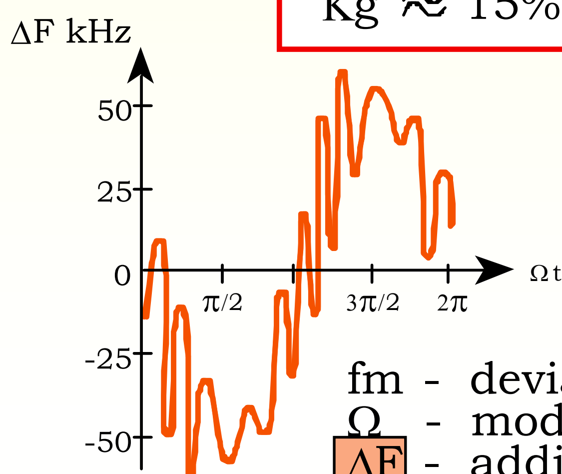
$$u_{in} = U_{in}\{\cos[\omega_0 t + \Psi(t)] + k\cos[\omega_0 t - \omega_0\tau + \psi(t-\tau)]\}$$

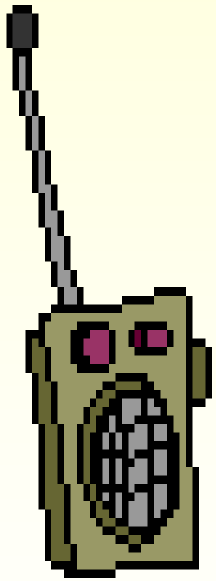


$K = 0.25$
$\tau = 50\ \mu s$

$$\Delta F = 2f_m . \mathrm{Sin}\frac{\Omega\tau}{2} . \ \mathrm{Sin}(\Omega t + \Omega\tau)$$

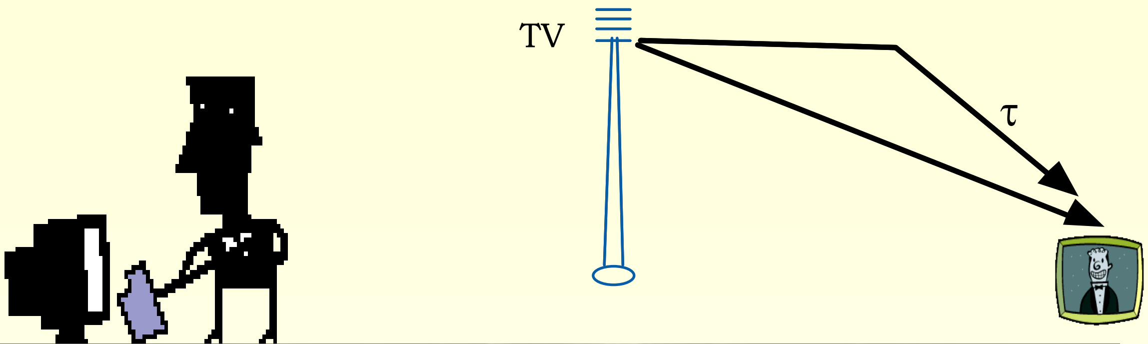
$Kg \approx 15\%$

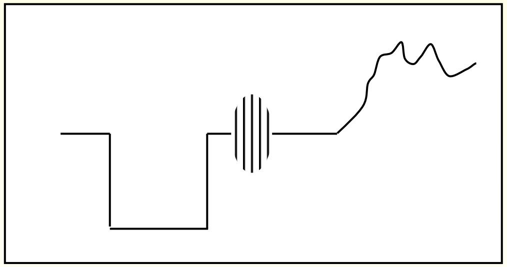


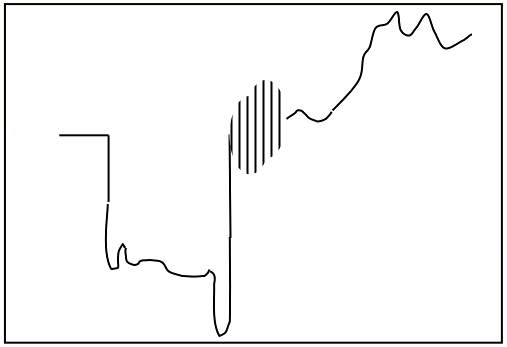


f_m - deviation
Ω - modulation frequency
ΔF - additional deviation

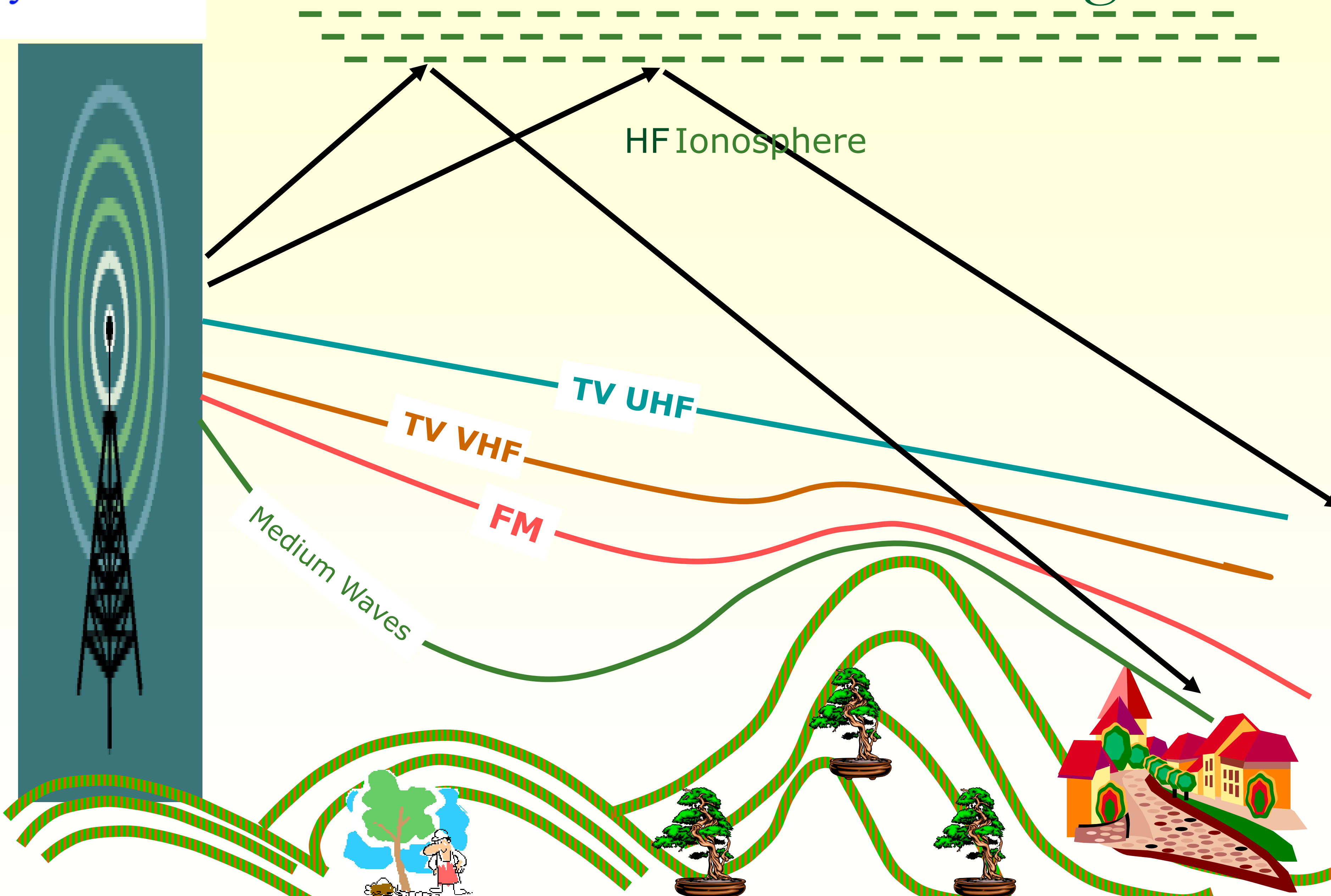
Multipath Distortion in TV







Audio and Video Broadcasting

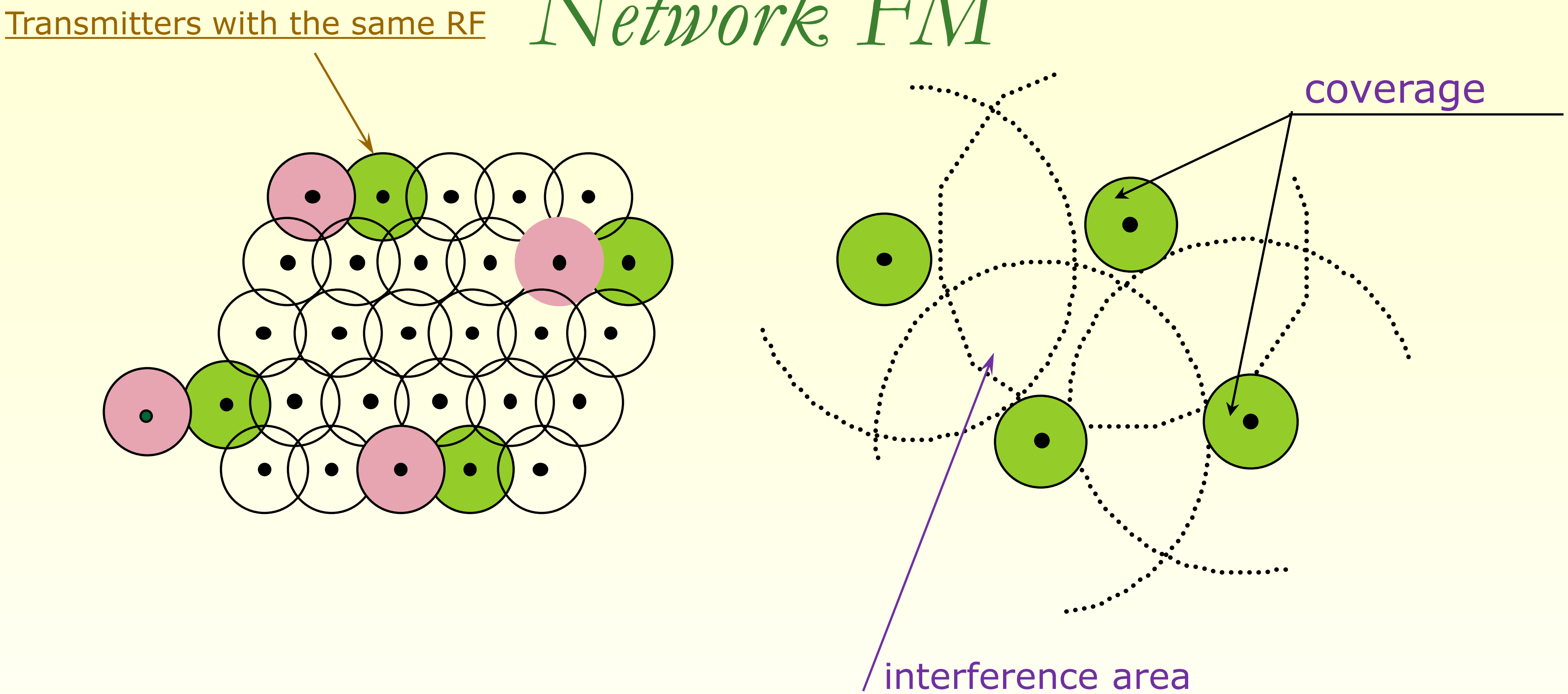


AM transmitters in Israel

Yosi Menashe, Bezeq
1 December 2014

Dr. Haim Mazar (Madjar) haimma1@ac.sce.ac.il h.mazar@a

Network FM

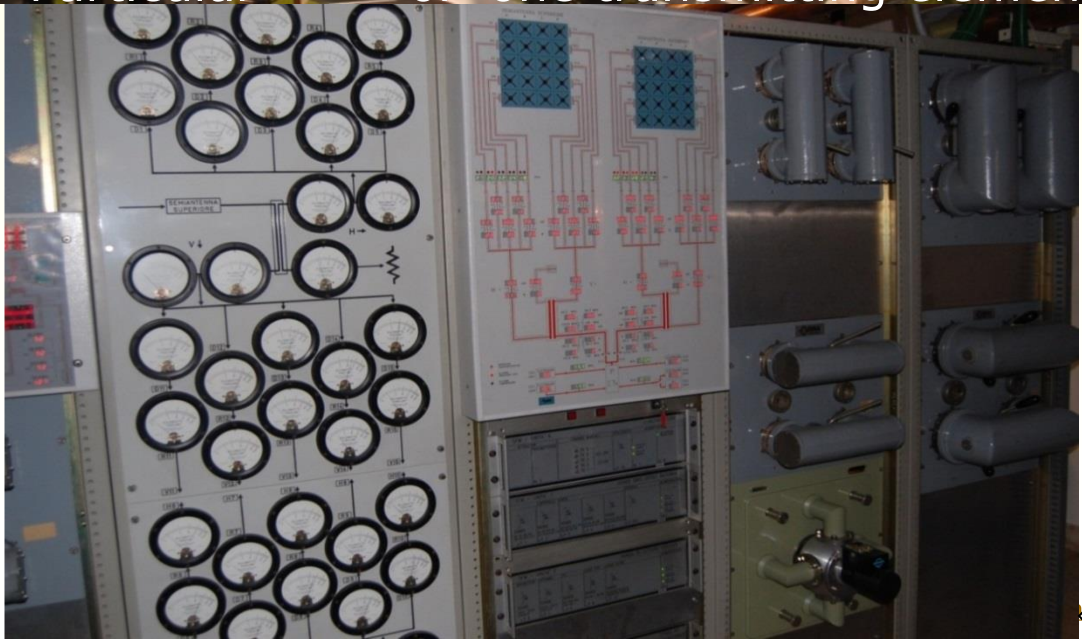


0 200 400 △ f,kHz

FM sound broadcasting at VHF (Doc. 6A 360)

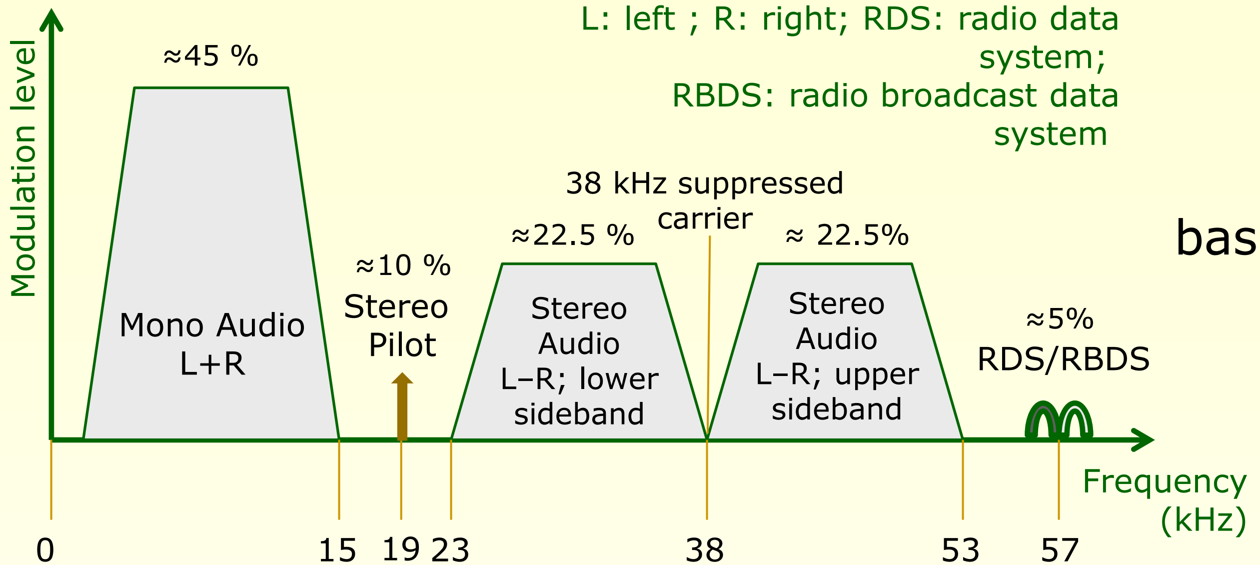
Particular of one transmitting element

FM station in the Vatican



Antenna control panel

FM Modulation



FM radio was first deployed in monaural in 1940; in 1960, FM stereo was introduced. The most prevalent wireless terrestrial sound in the world today is still the Frequency Modulation FM radio, operating worldwide 87.5-108 MHz. In the West European countries and the US, the max deviation is ± 75 kHz; in the ex-USSR and in some other European countries, it is ± 50 kHz; see Rec. ITU-R BS.450. the carrier frequencies, which define the nominal placement of the RF channels within the band, for both monophonic and stereophonic transmissions, are integral multiples 200 kHz in America, of 100 kHz in Europe and 50 kHz in Italy. So, some American FM radio receivers, with odd center frequency channel-spaced every 200 kHz, cannot operate in Europe.

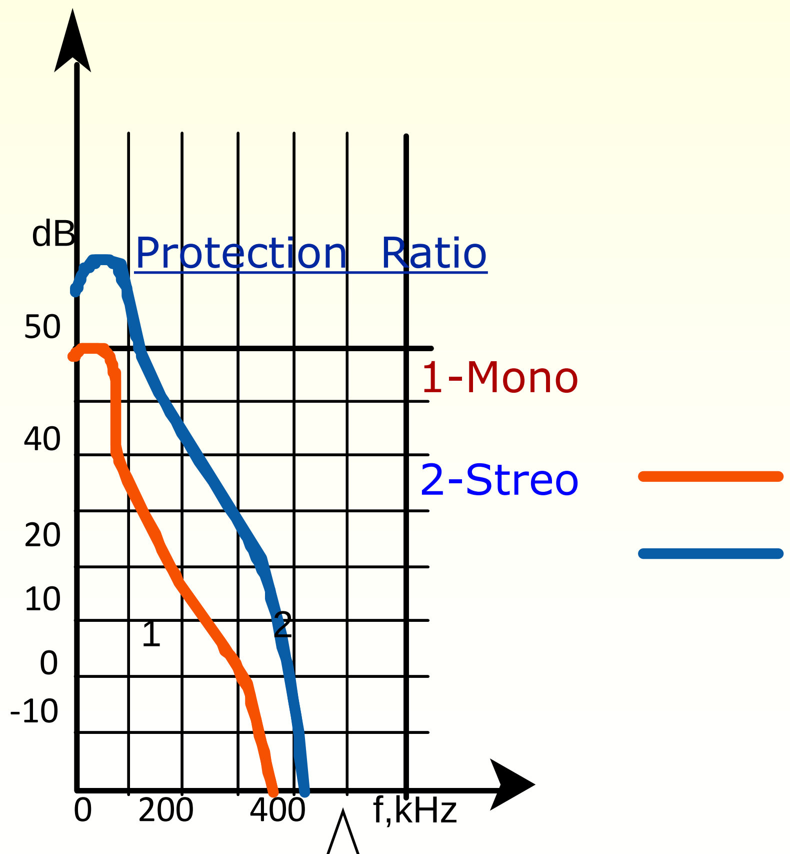
Carson's bandwidth rule: $bw = 2(\Delta f + f_m)$, where bw is the total significant (98%) bandwidth, Δf is the peak frequency deviation FM signal from the center frequency and f_m is the highest modulating signal frequency. Defining the ratio $\Delta f/f_m$ as the modulation index β, $\Delta f = \beta f_m$ and $bw = 2(\beta f_m + f_m) = 2(1+\beta)f_m$. The human ears are sensitive to audio signals 20 to 15,000 Hz; for $\beta = 5$ and maximal modulating frequency of 15 kHz, the modulated (peak deviation) monaural signal swings to 5 x 15 kHz = 75 kHz above and below the RF carrier. For this common $\Delta f = 75$ kHz and $f_m = 15$ kHz, $bw = 2(\Delta f + f_m) = 2(75+15)$kHz=180kHz; it is close to the common 200 kHz channel bandwidth. **Bessel Funtions**

As the peak stereo modulating has 53 kHz information, using Carson's rule $bw = 2(1+\beta)f_m = 2(1+\beta)53$ kHz $= (1+\beta)106$ kHz. In order to keep the total bw around 200 KHz, β is approximately 1. Depending on power, peak deviation and β, adjacent (in geography and frequency) FM stations need RF separation up to 400 kHz.

Median field strength for satisfactory service (BS.412 Table 1)

	FM Sound	
Areas	Monophonic dB(µV/m)	Stereophonic dB(µV/m)
Rural	48	54
Urban	60	66
Large cities	70	74

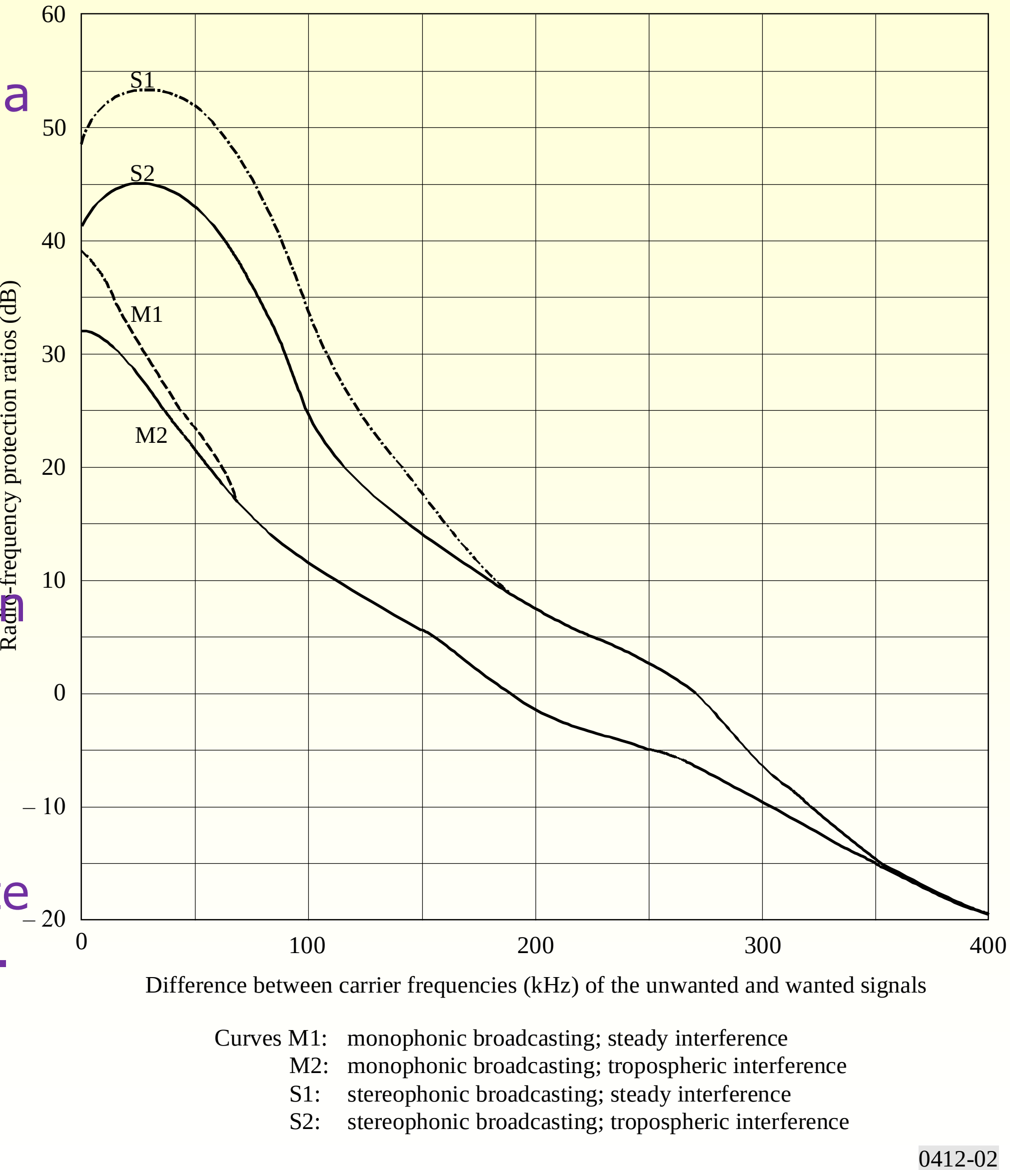
As the stereo signal is modulated on 38.0kHz suppressed carrier, the interference is most sensitive on that 'out of band' frequency



Protection ratios of monophonic & stereo reception (Rec. BS.412 1998)

channels are to be assigned in such a way that the carrier frequencies are integral multiples of 100 kHz; a uniform channel spacing of 100 kHz applies for both mono and stereo transmissions

For carrier frequency differences greater than 400 kHz, the protection ratio values should be substantially lower than –20 dB. The radio-frequency protection ratio value for the particular carrier frequency difference of 10.7 MHz (intermediate frequency) should be below –20 dB.



Advanced Wireless Communications, 2022

Academic course for 4th year engineering students

sce

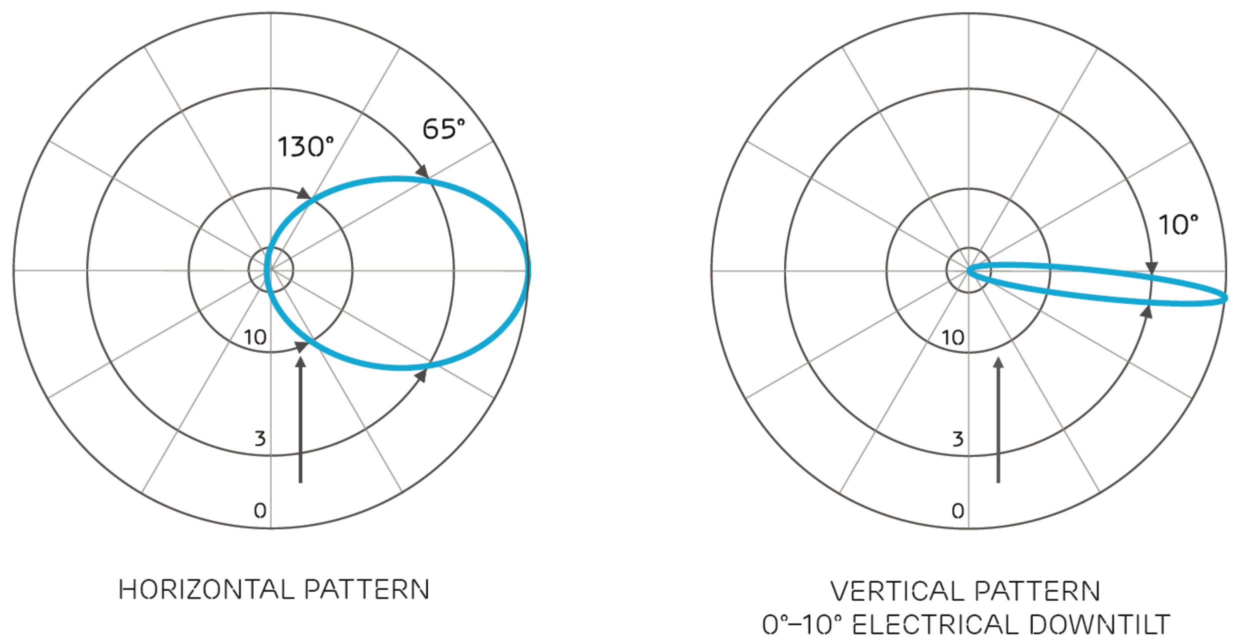
המכללה האקדמית להנדסה ע"ש סמי שמעון

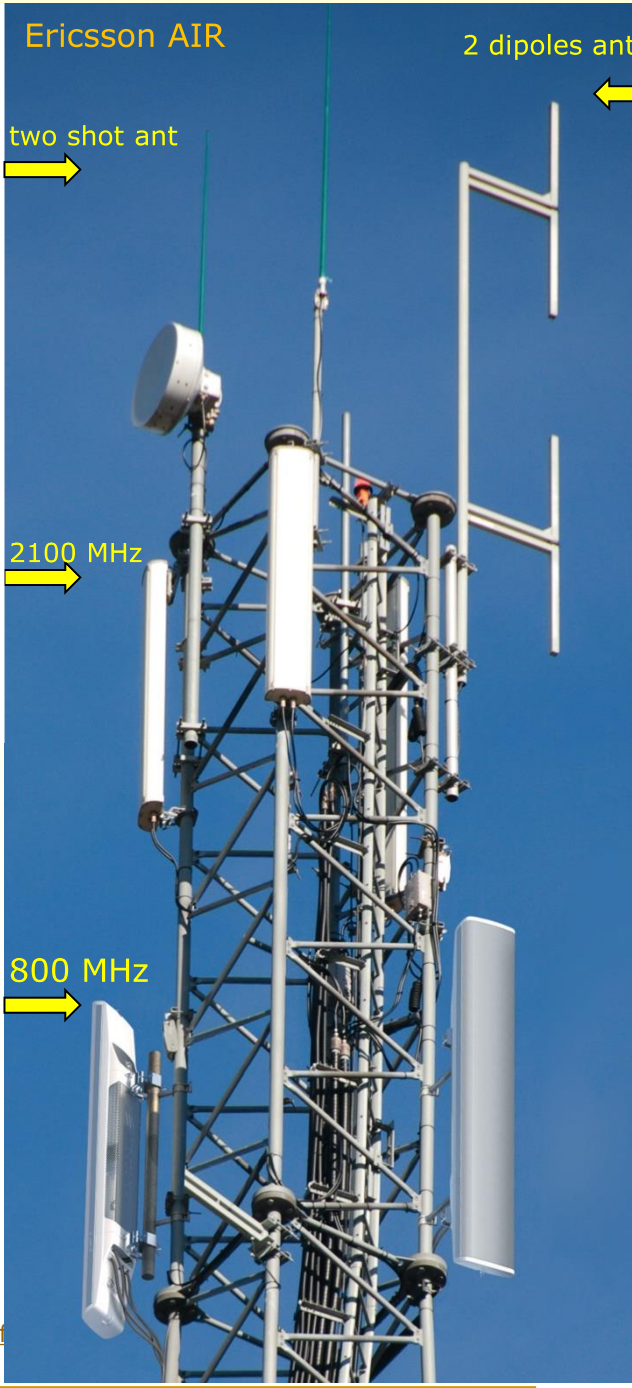
Land Mobile Services (mainly cellular)

http://mazar.atwebpages.com/

3 sector tower site with 3 ant integrated radio 800 MHz units & three 2100 MHz ant

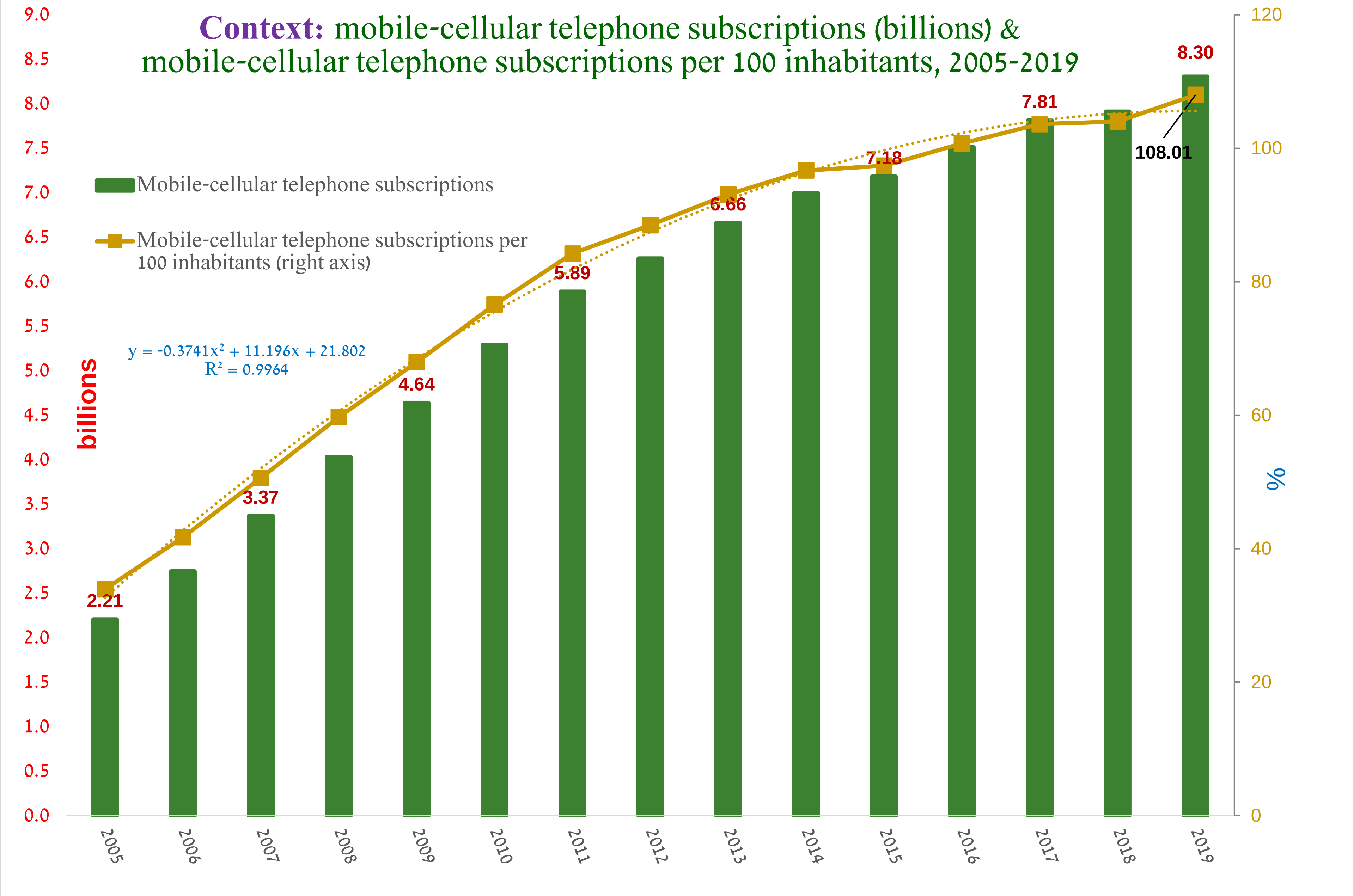
FIGURE 3: AIR antenna characteristics





one X-pol antenna consists of two dipole arrays (has 2 connectors)

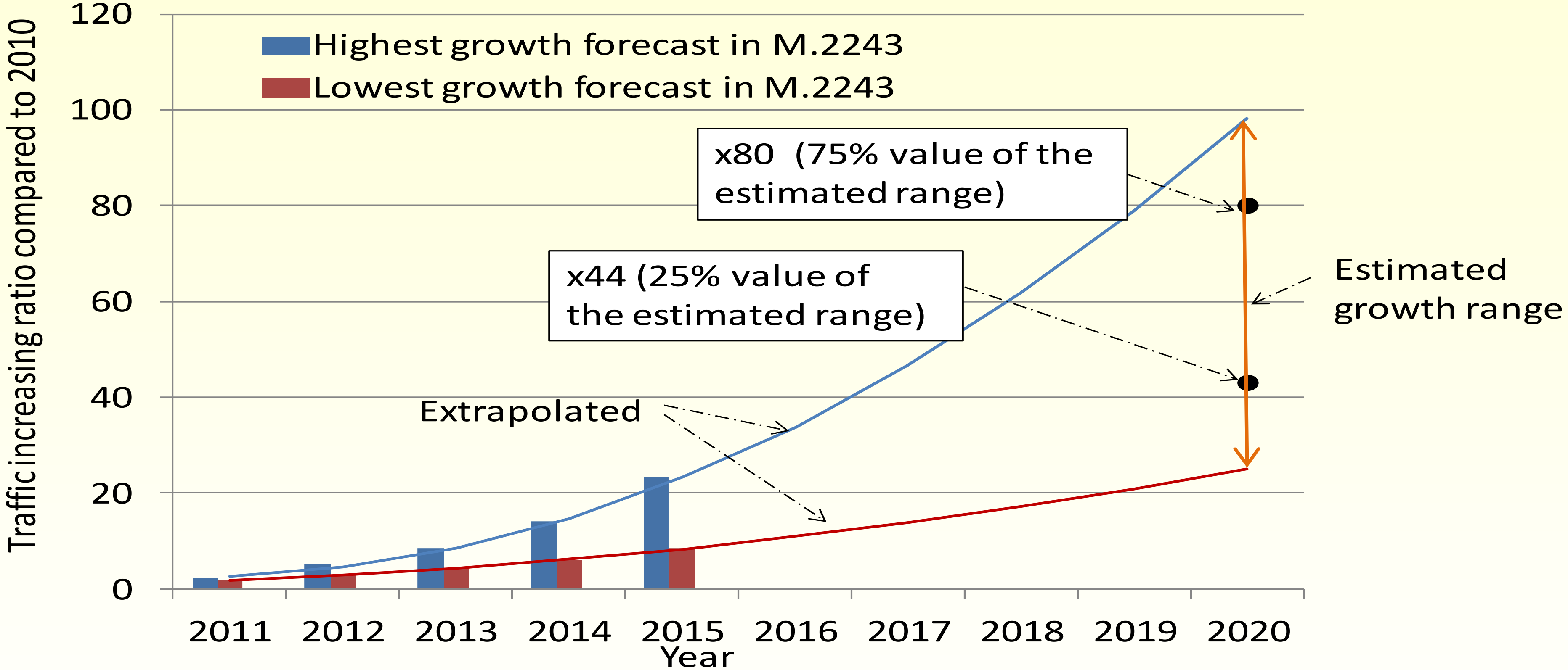
Context: mobile-cellular telephone subscriptions (billions) & mobile-cellular telephone subscriptions per 100 inhabitants, 2005-2019



Mobile traffic forecasts toward 2020 by extrapolation/

M.2290-0 (2014) 'Future spectrum requirements estimate for terrestrial IMT' Fig. 5

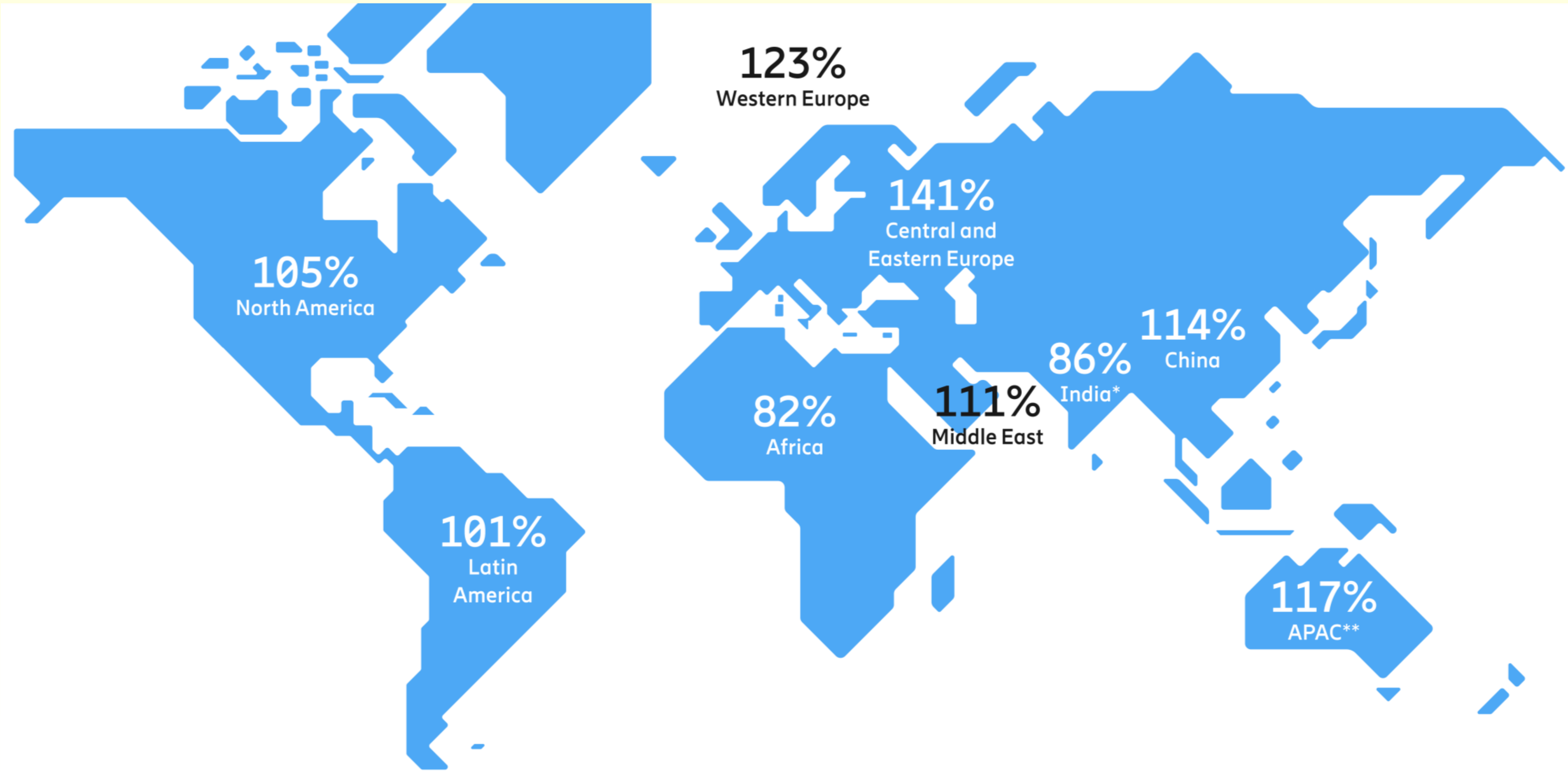
IMT: International Mobile Telecommunications



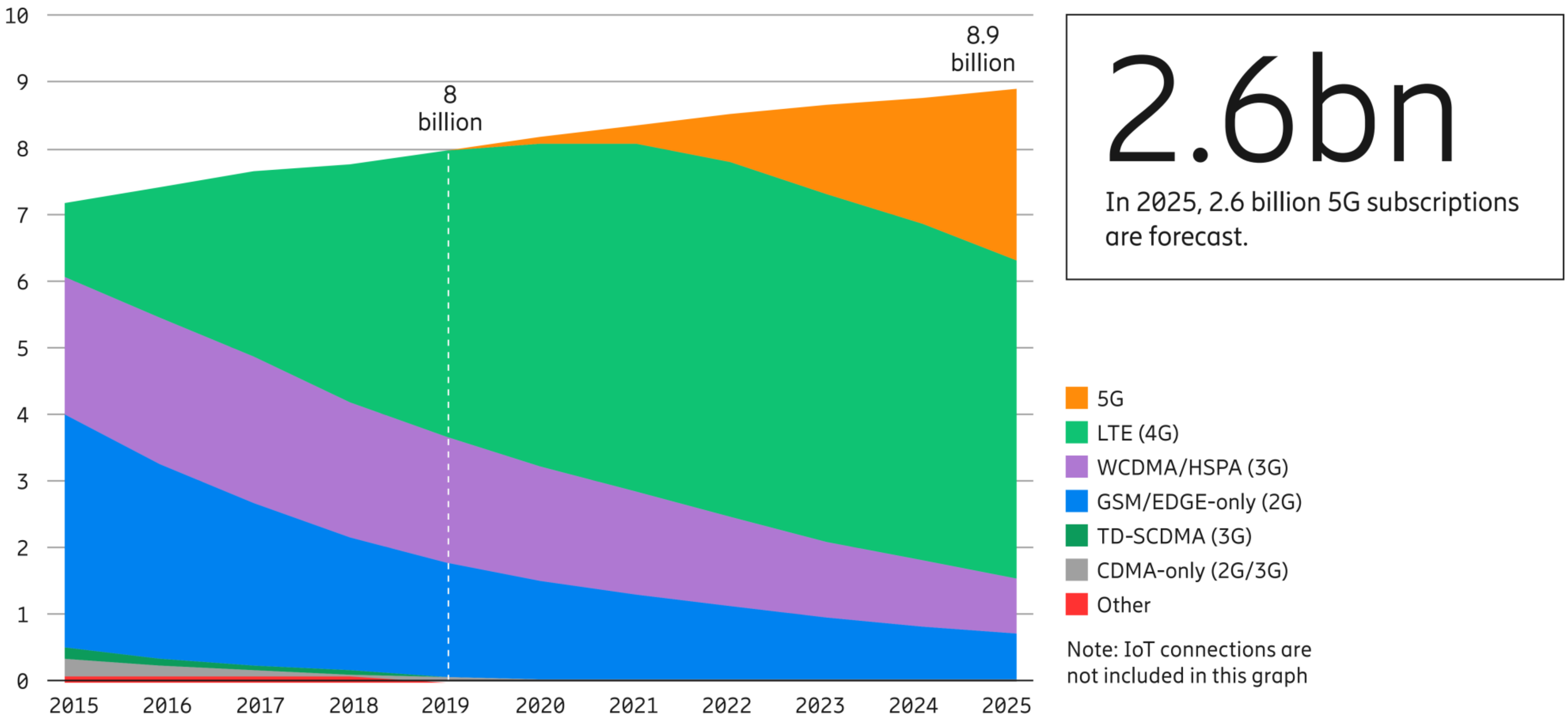
25 to 100-fold growth ratio compared to 2010

Ericsson Mobility Report Nov 2019 Subscription penetration Q3 2019 (percent of population)

1. 5G to cover up to 65 percent of the world's population by the end of 2025 and handle 45 percent of global mobile data traffic
2. Smartphone users to consume a global average of 24 GB per month in 2025 from 7.2 GB currently, as video usage increases and new services become available
3. Total number of cellular IoT connections estimated at five billion by the end of 2025, from 1.3 billion by end of 2019

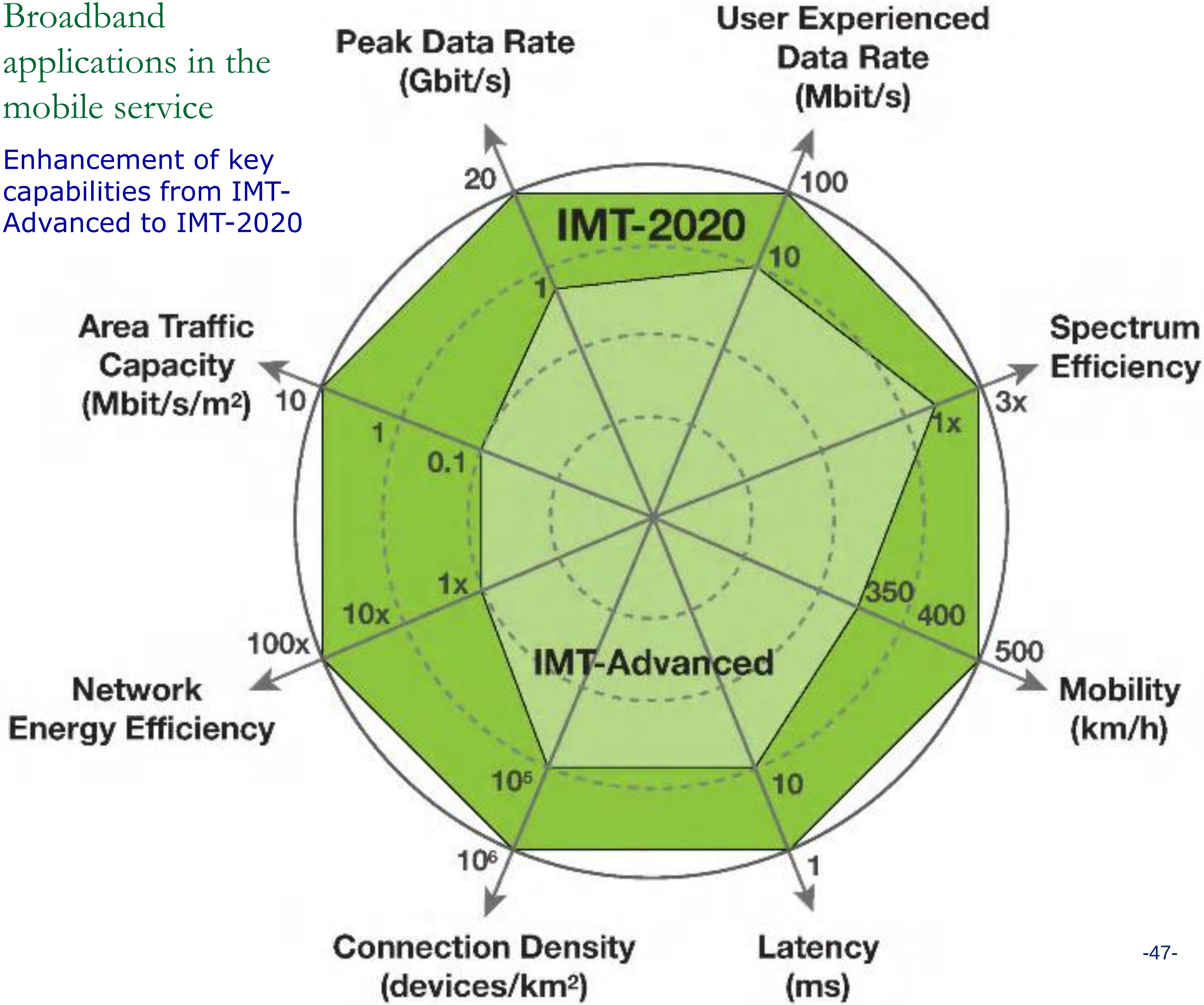


Ericsson Mobility Report Nov 2019 Mobile subscriptions by technology (billion)

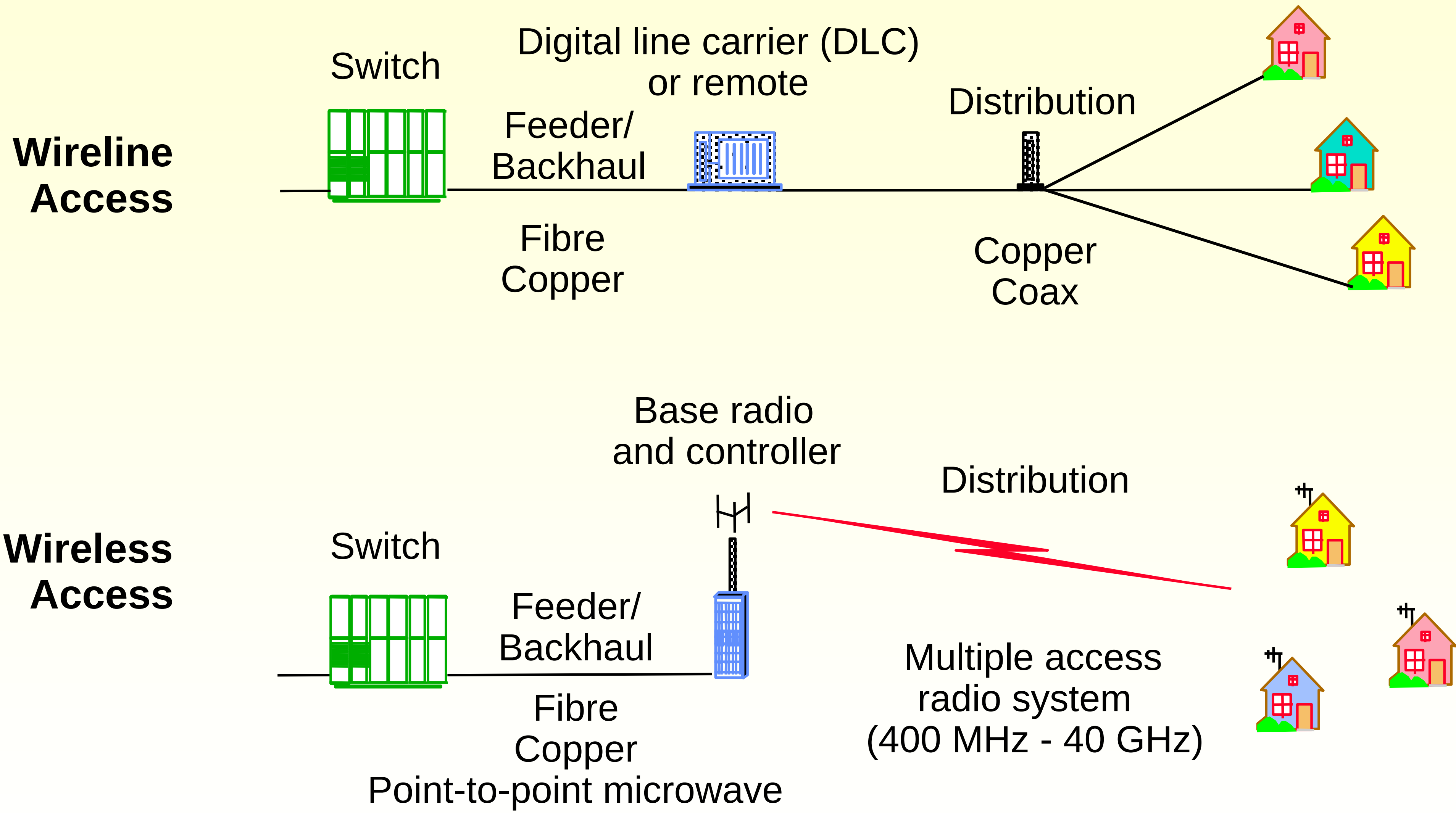


Broadband applications in the mobile service

Enhancement of key capabilities from IMT-Advanced to IMT-2020

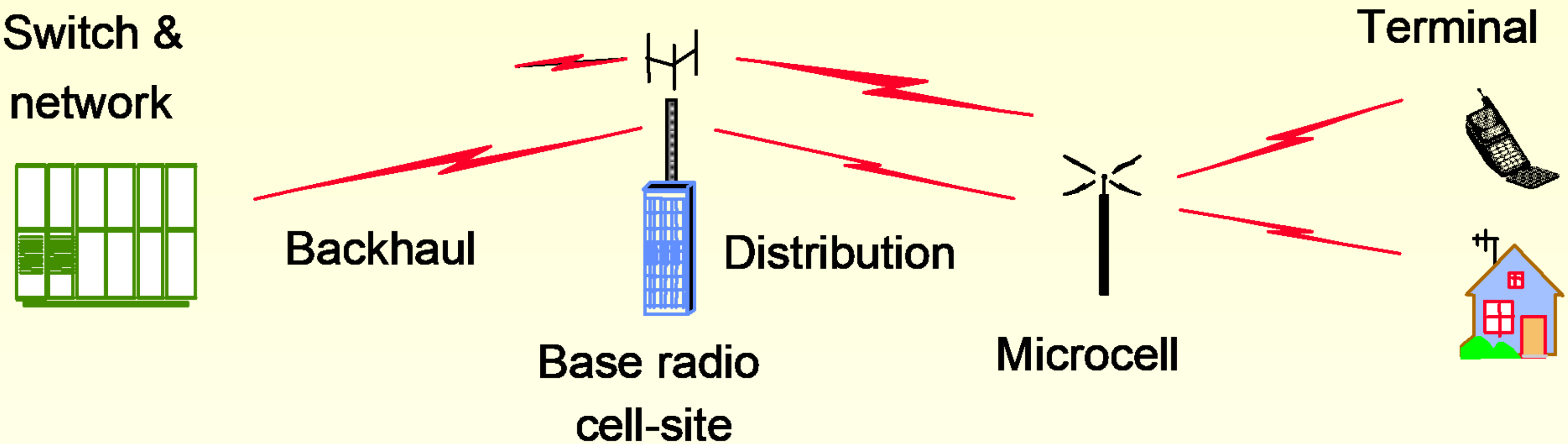


Wireline access and wireless access comparison



ITU LM HB 2001 Fig 1

Wireless access architecture

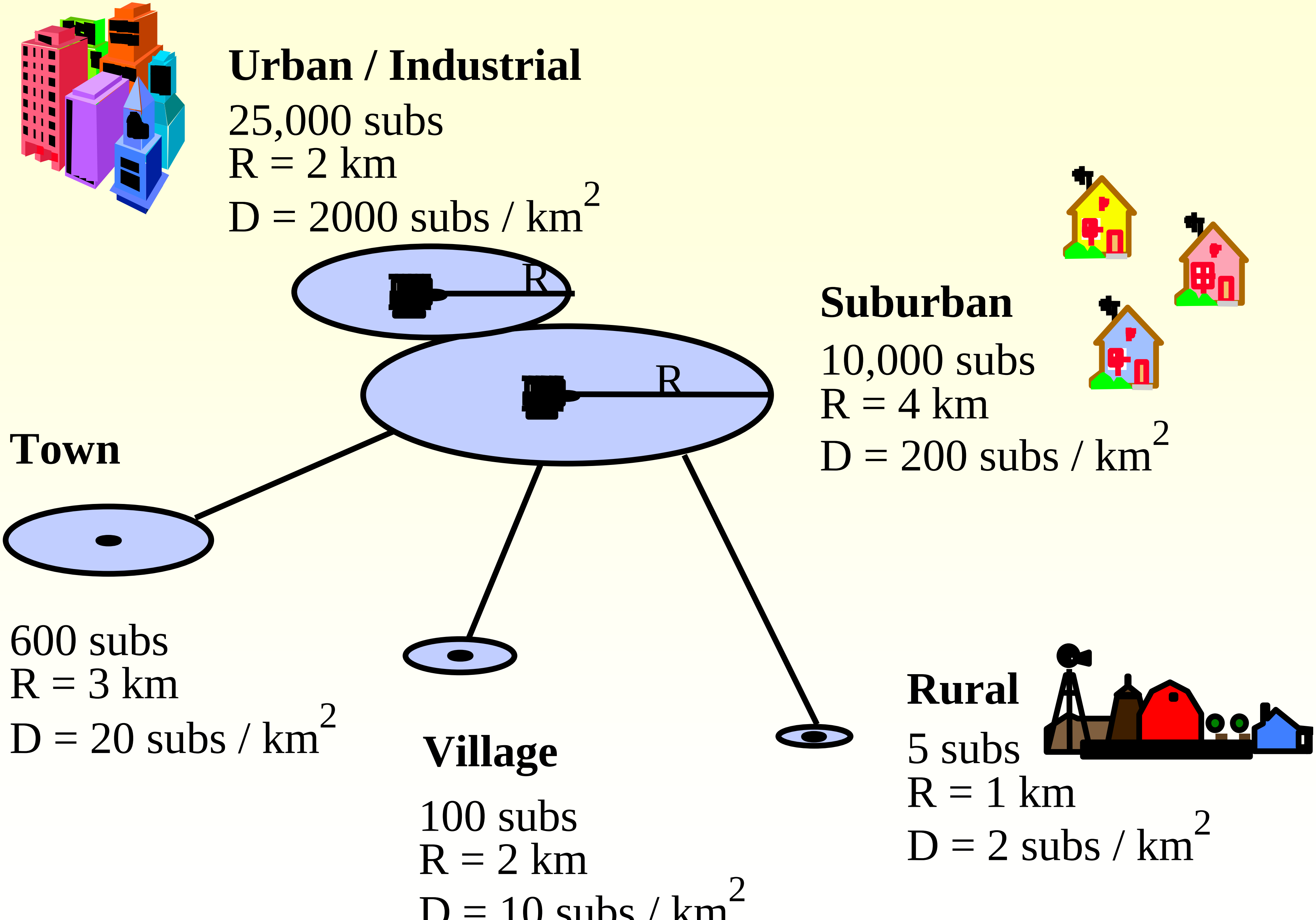


ITU LM HB 2001 Fig 5

➢**Communication Types**

1. **Traffic:** Voice, video and data the user is transmitting
2. **Signaling**: Additional data the system is transmitting per user to control and monitor
3. **Control**: Common data transmitted from BS to all users to synchronize, page, pass information
4. **Random Access**: Used by users mainly to request allocation.

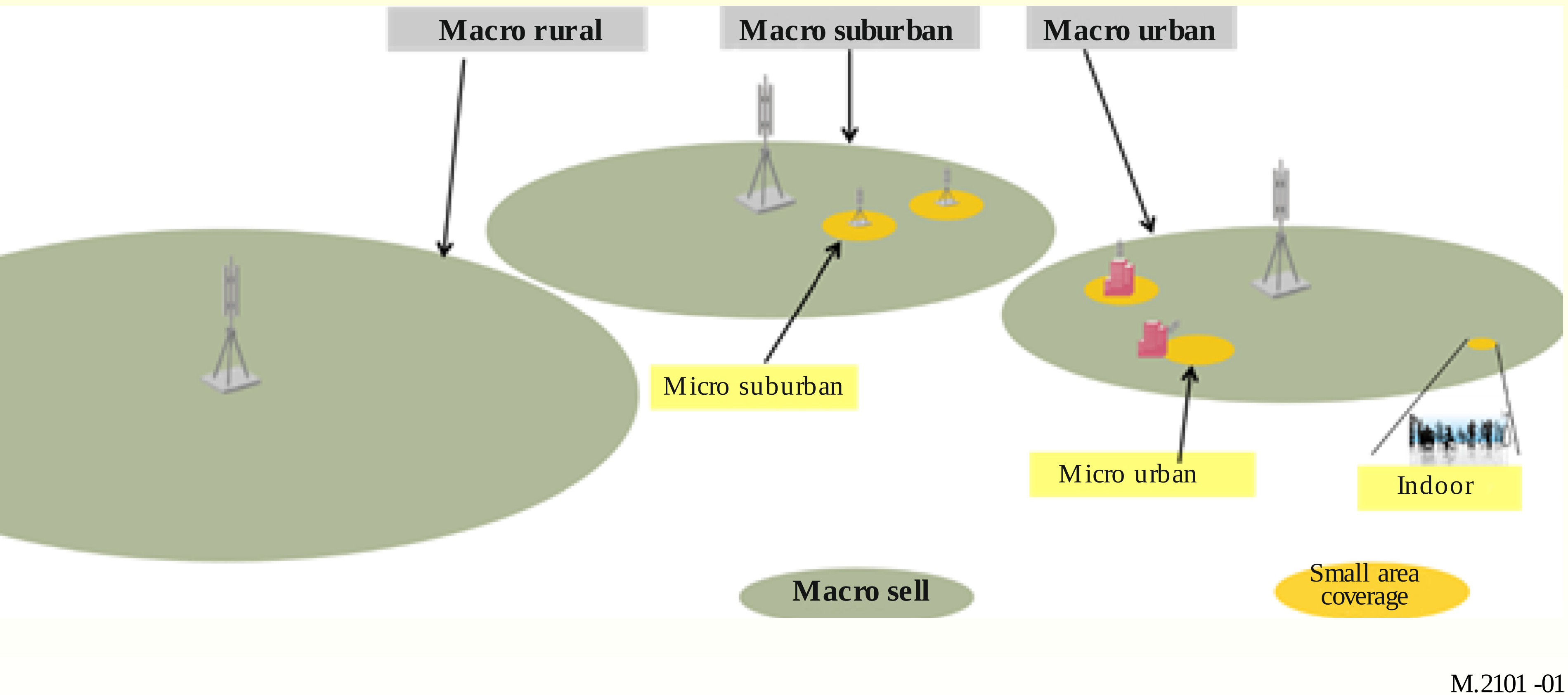
Access requirements: need a family of wireless access solutions to meet diverse requirements



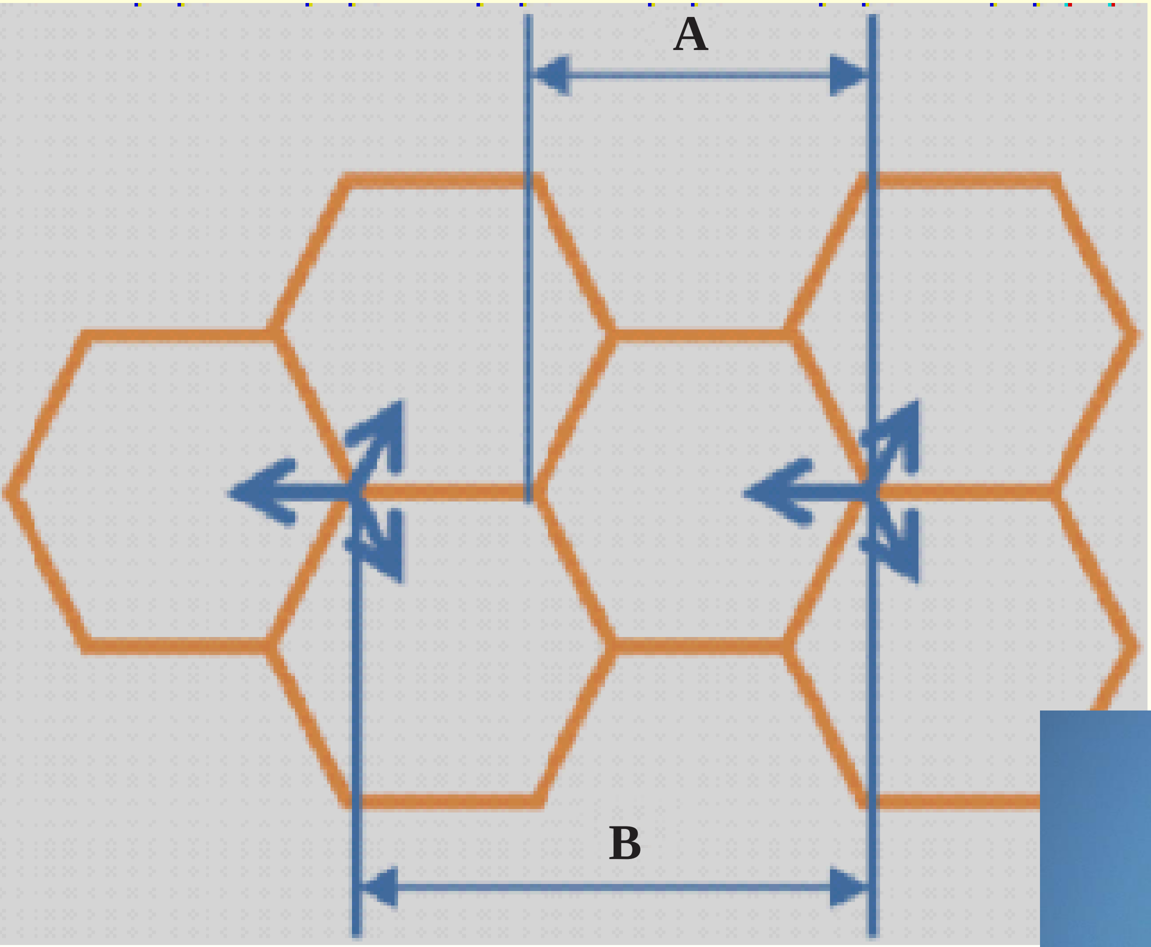
ITU LM HB 2001 Fig 7

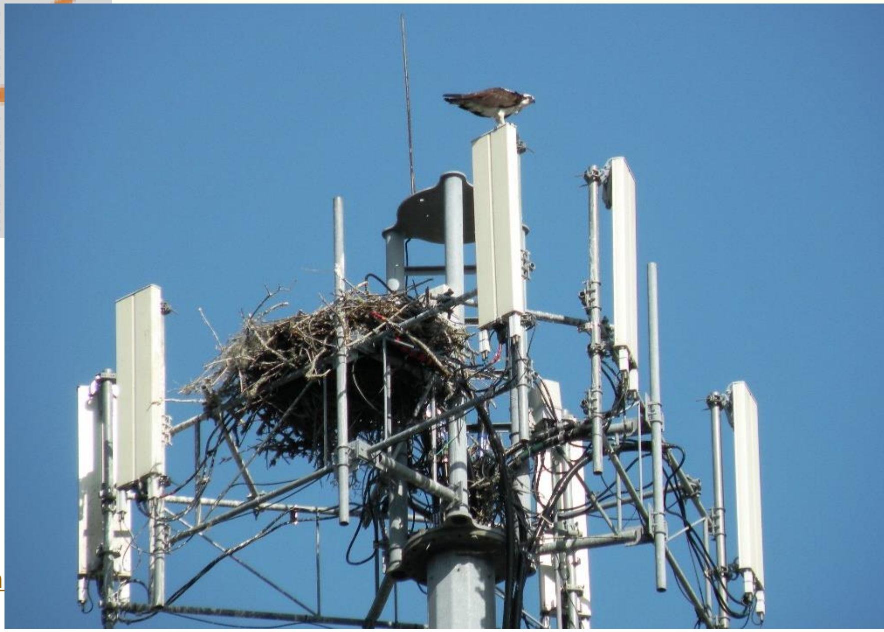
IMT/5G Example deployment scenarios

Recommendation ITU-R M.2101-0 (02/2017) Modelling and simulation of IMT networks and systems for use in sharing and compatibility studies

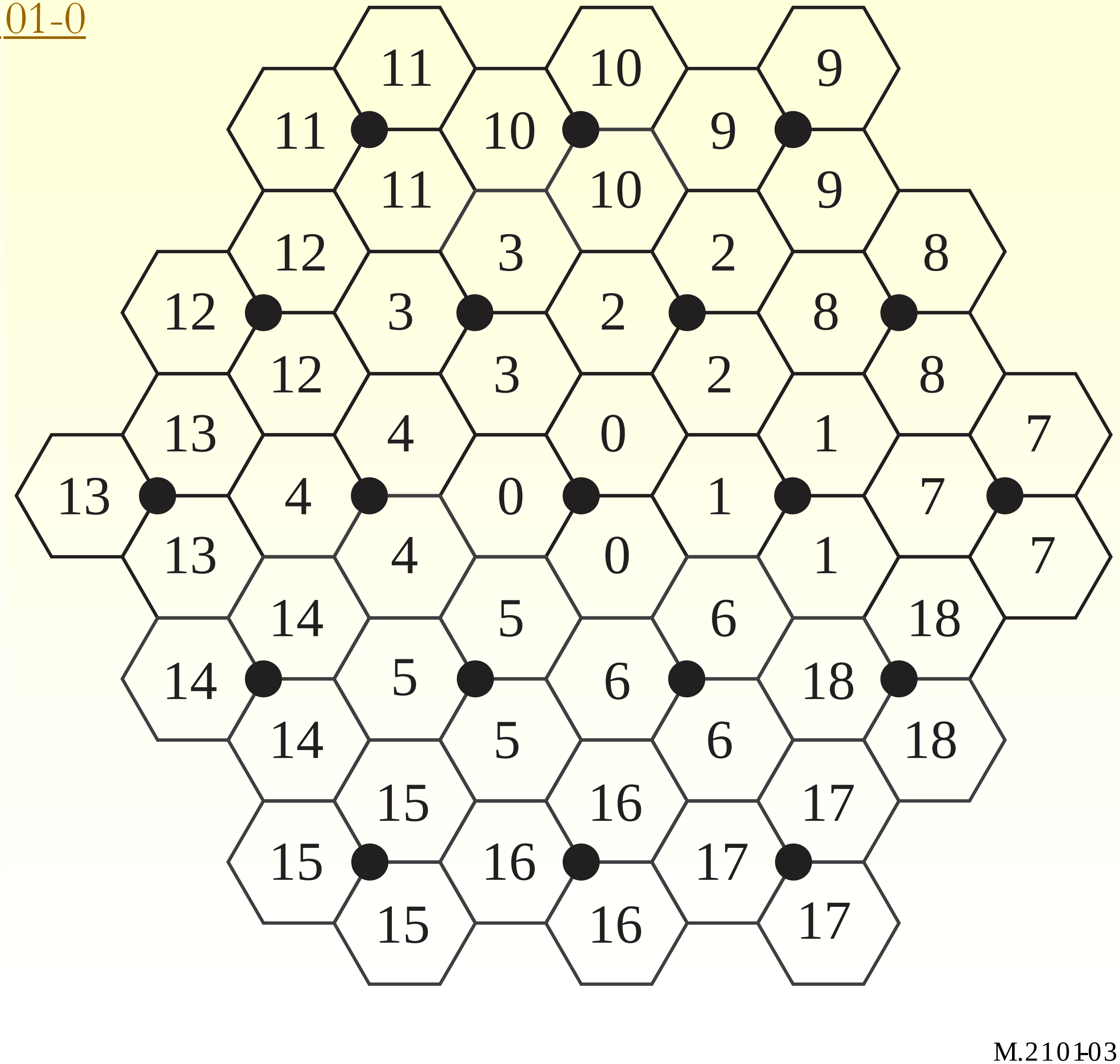


IMT Macro cell geometry M.2101-0

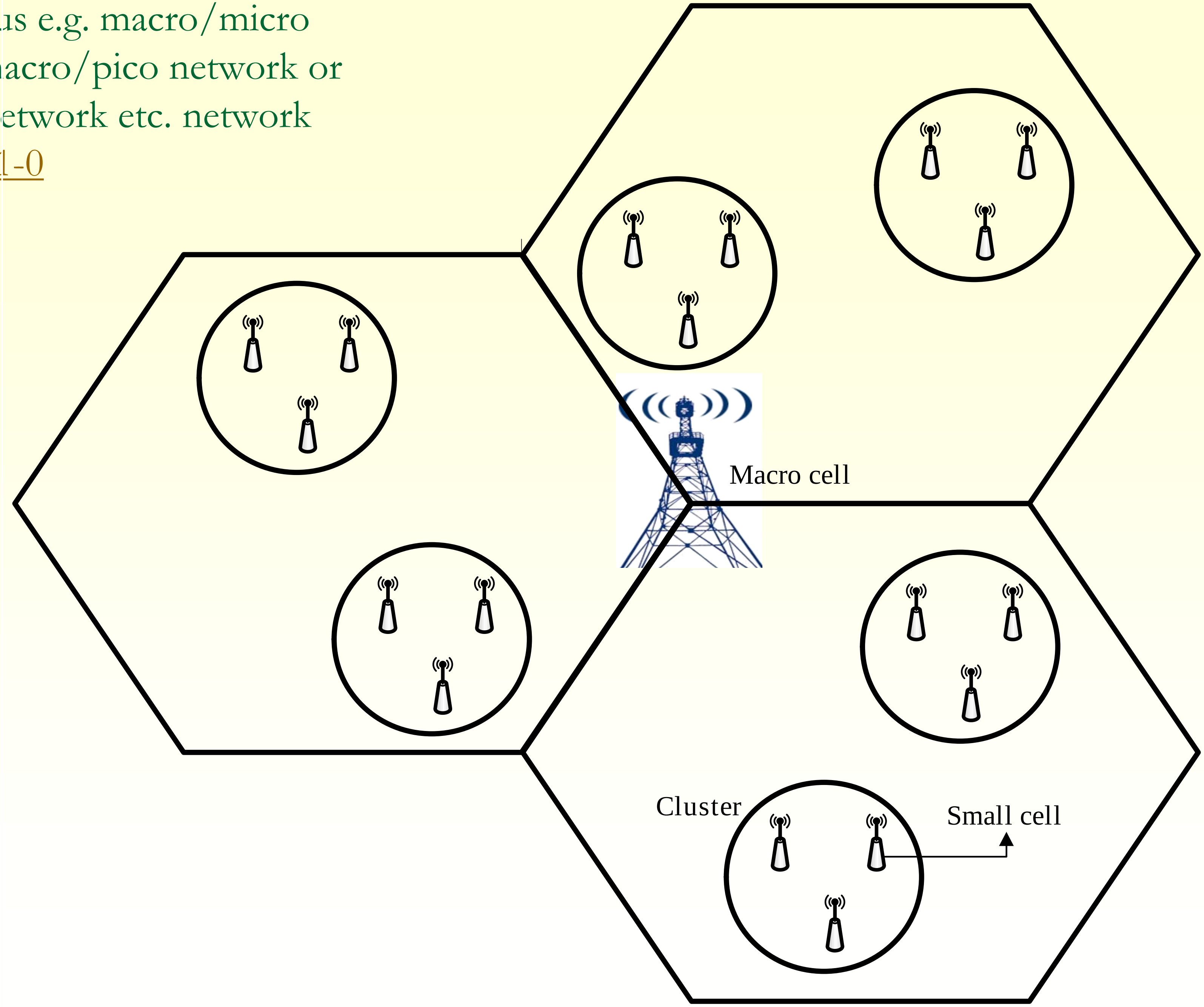




Macro cellular layout (central cluster)M.2101-0

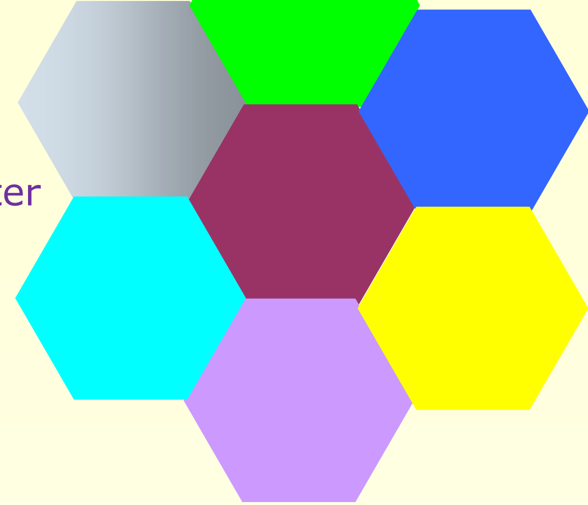


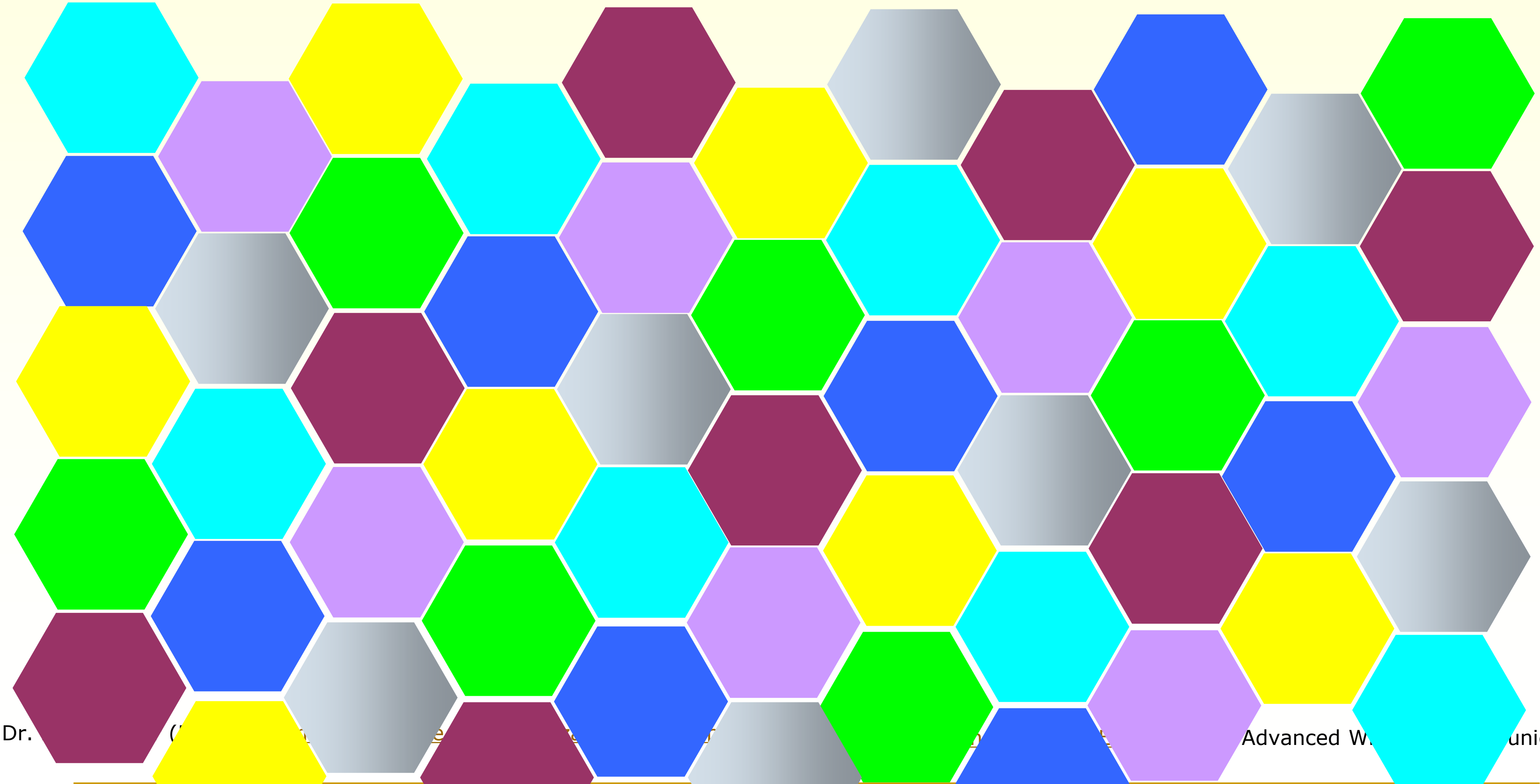
Heterogeneous e.g. macro/micro network or macro/pico network or micro/pico network etc. network layout M.2101-0



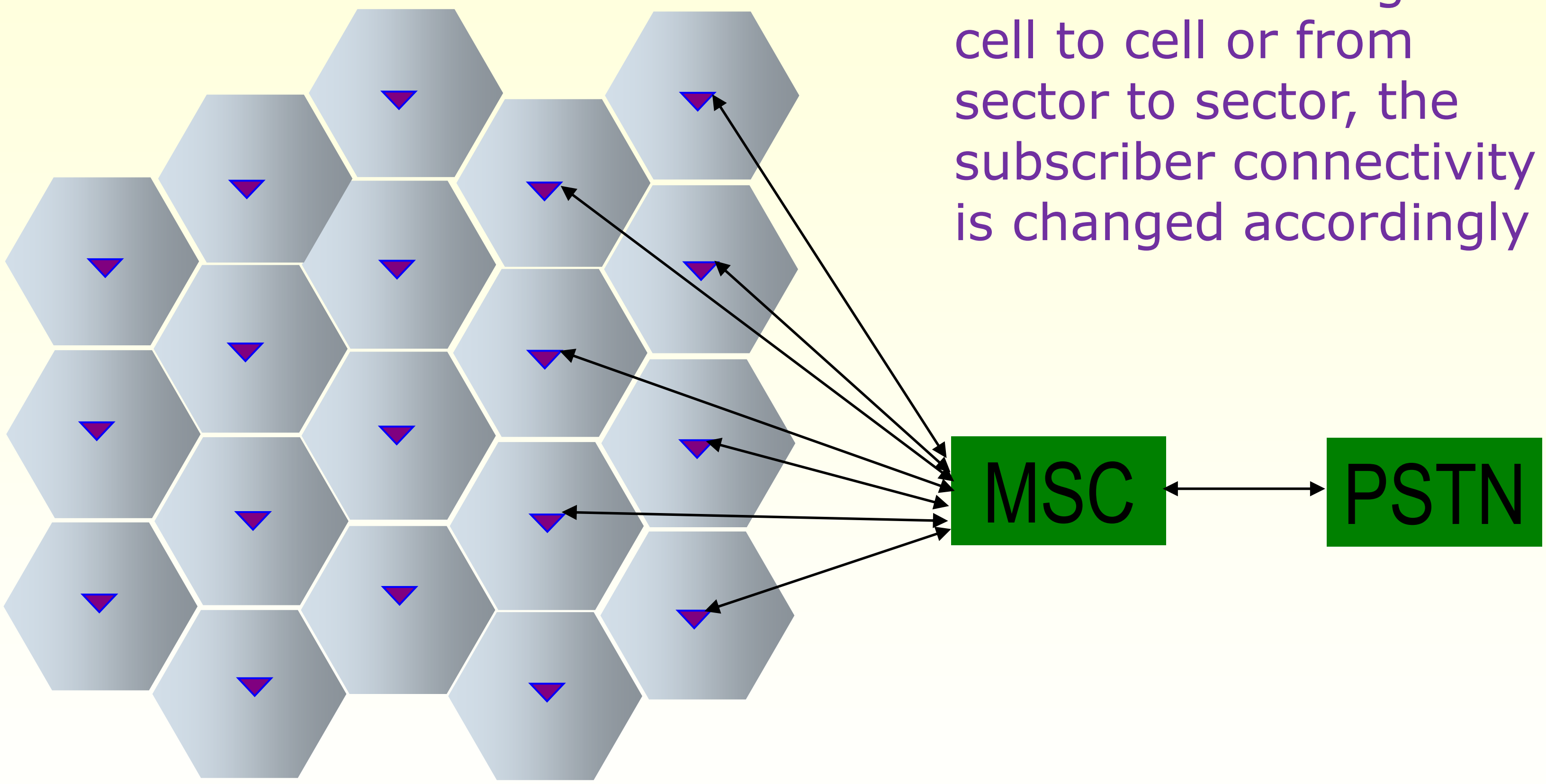
Frequency Reuse;

Dr. Arie Reichman



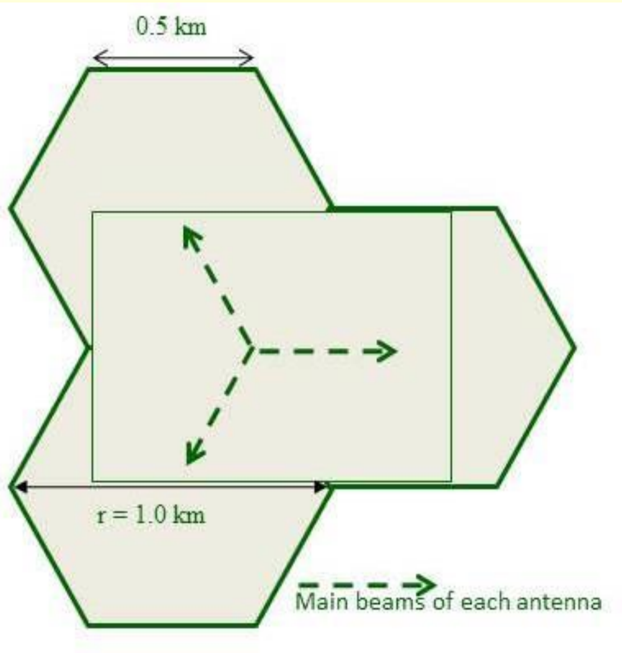


MSC -- Mobile Switching Center; Dr. Arie Reichman

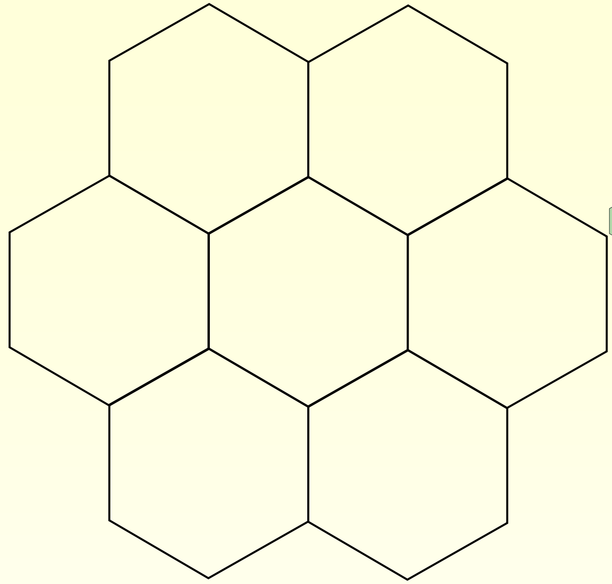


Handover. Moving from cell to cell or from sector to sector, the subscriber connectivity is changed accordingly

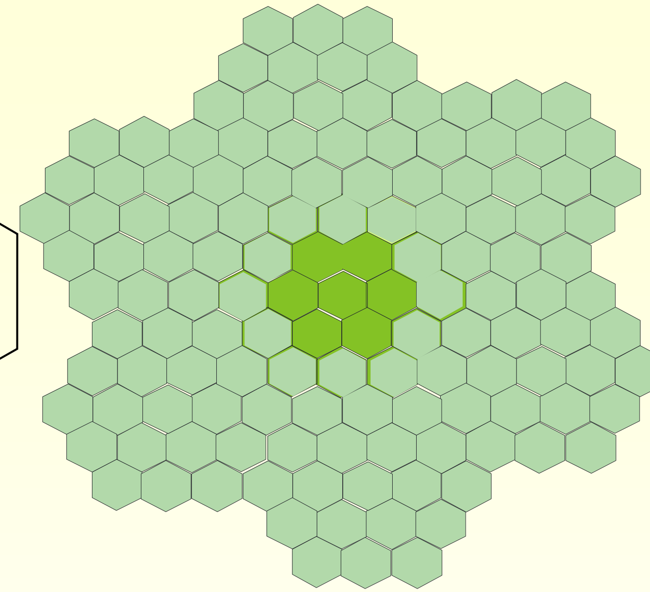
Basic cellular mobile reference network



Tri-sector cells

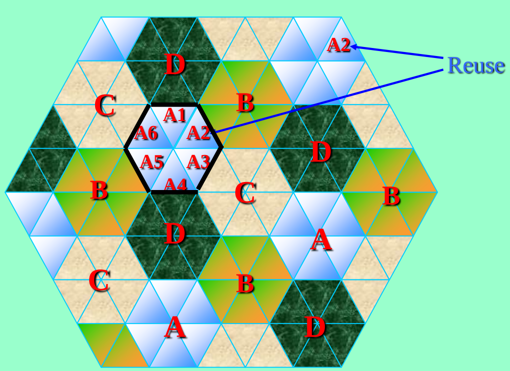


cluster of 7 cells; N (re-use)=7



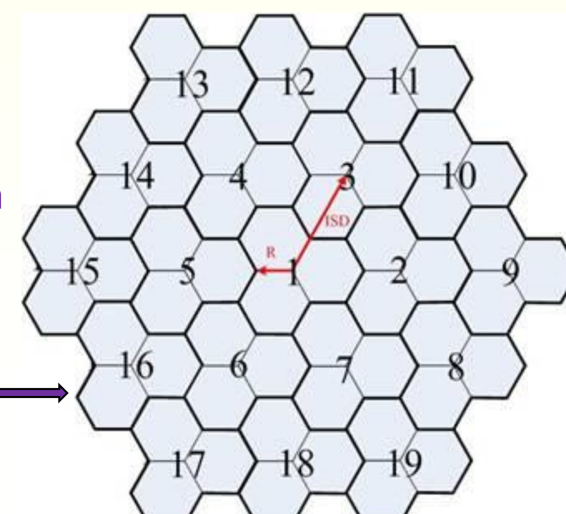
network based on 7 cell reference network unit

Cells with same letter use same RF

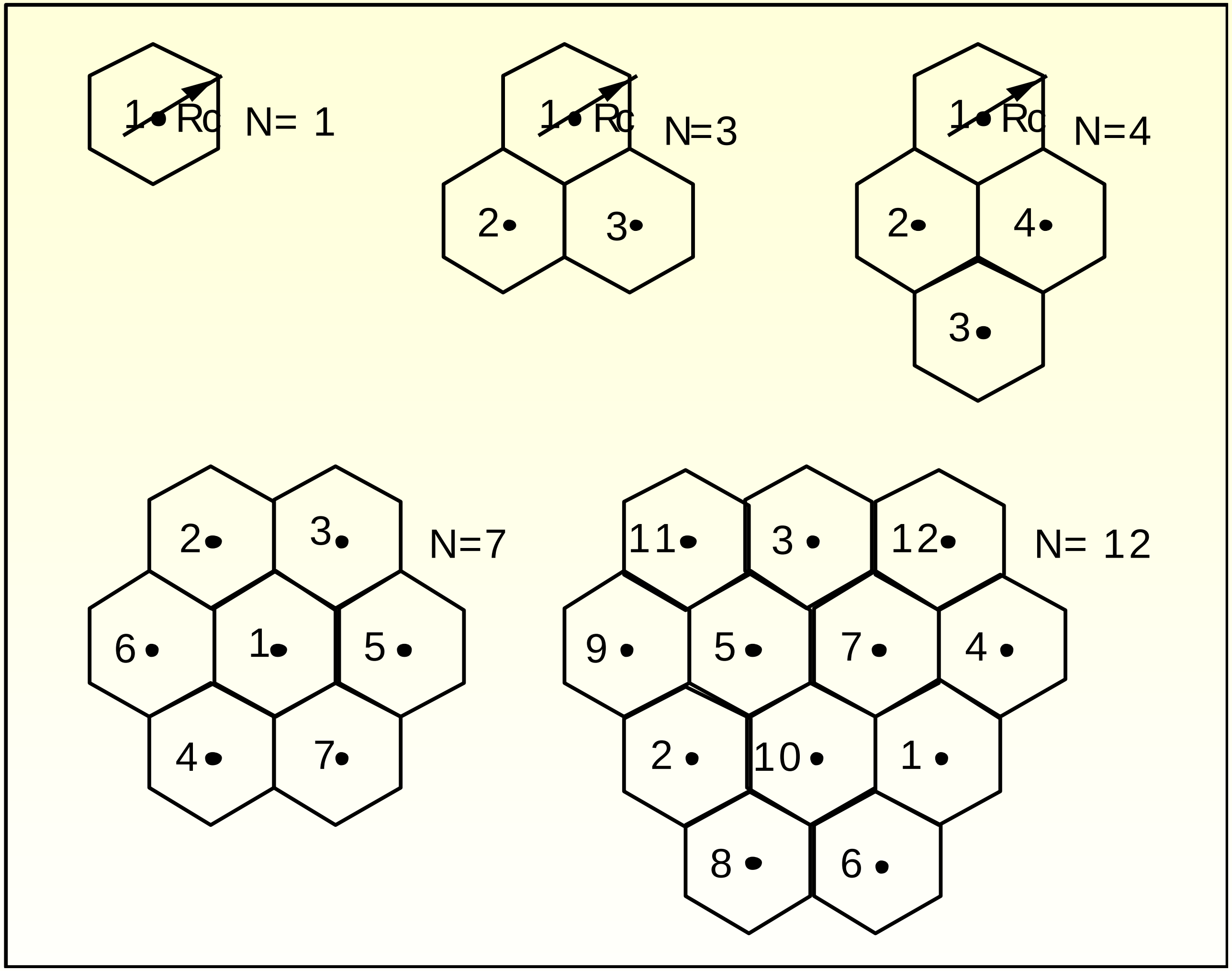


In GSM re-use factor of 25%:each cell might use a quarter of the total BW
In UMTS, each cell has the same carrier frequency, with a re-use factor of 100%; N=1; easier planning

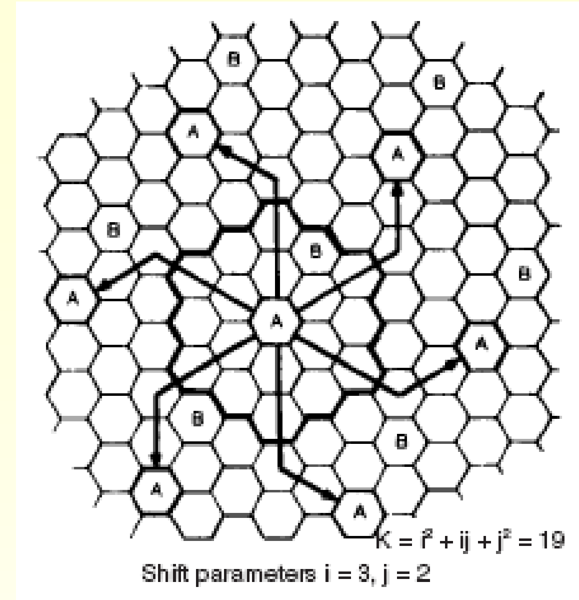
Network composed of 19 BTS (57 sectors), where the BTS are placed in the middle of 3 sectors.



Typical cell clusters and re-use



Smaller N- greater capacity



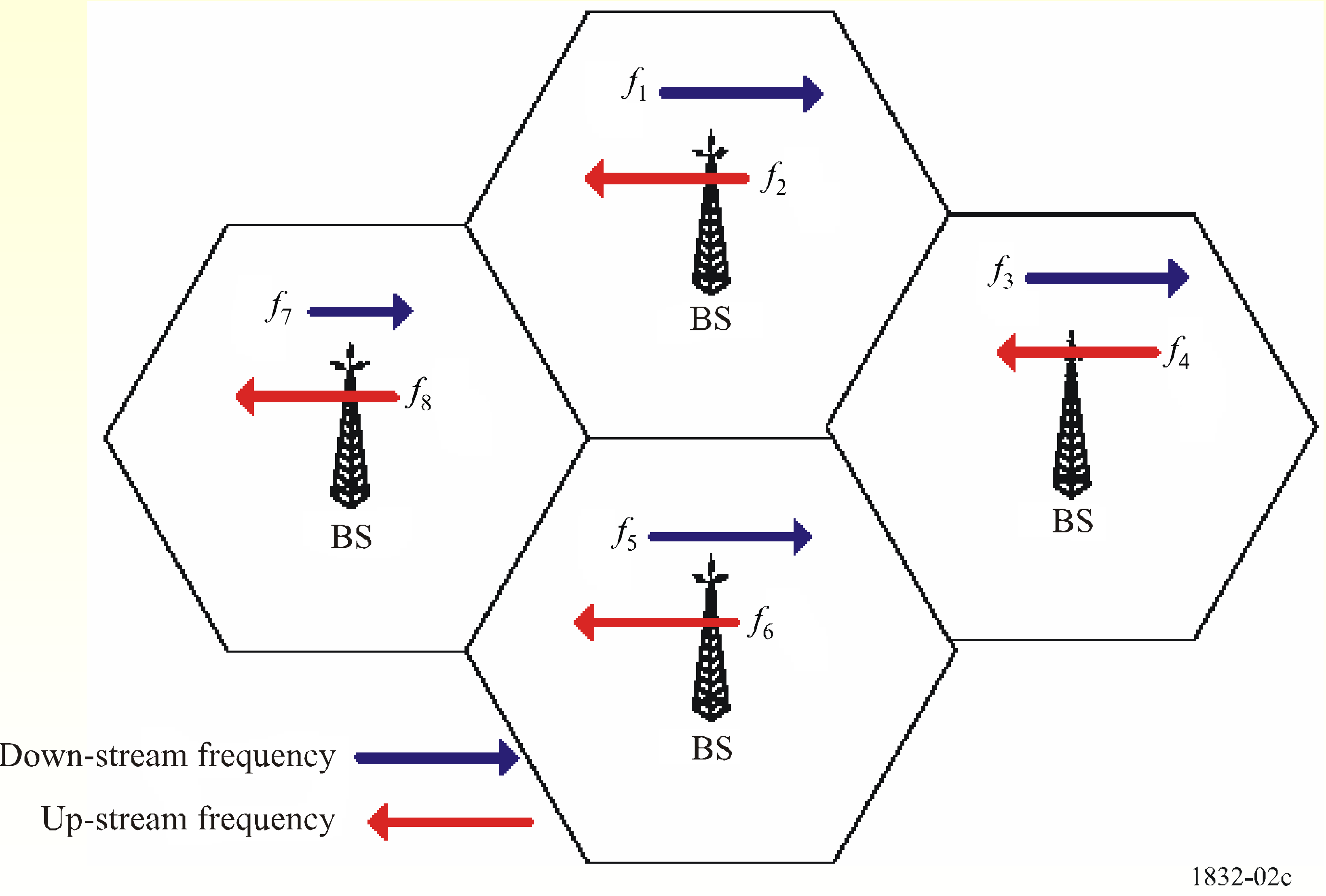
N cell K = 19 reuse pattern,
Lee W.C.Y.

$$d = \sqrt{3k} \times r$$

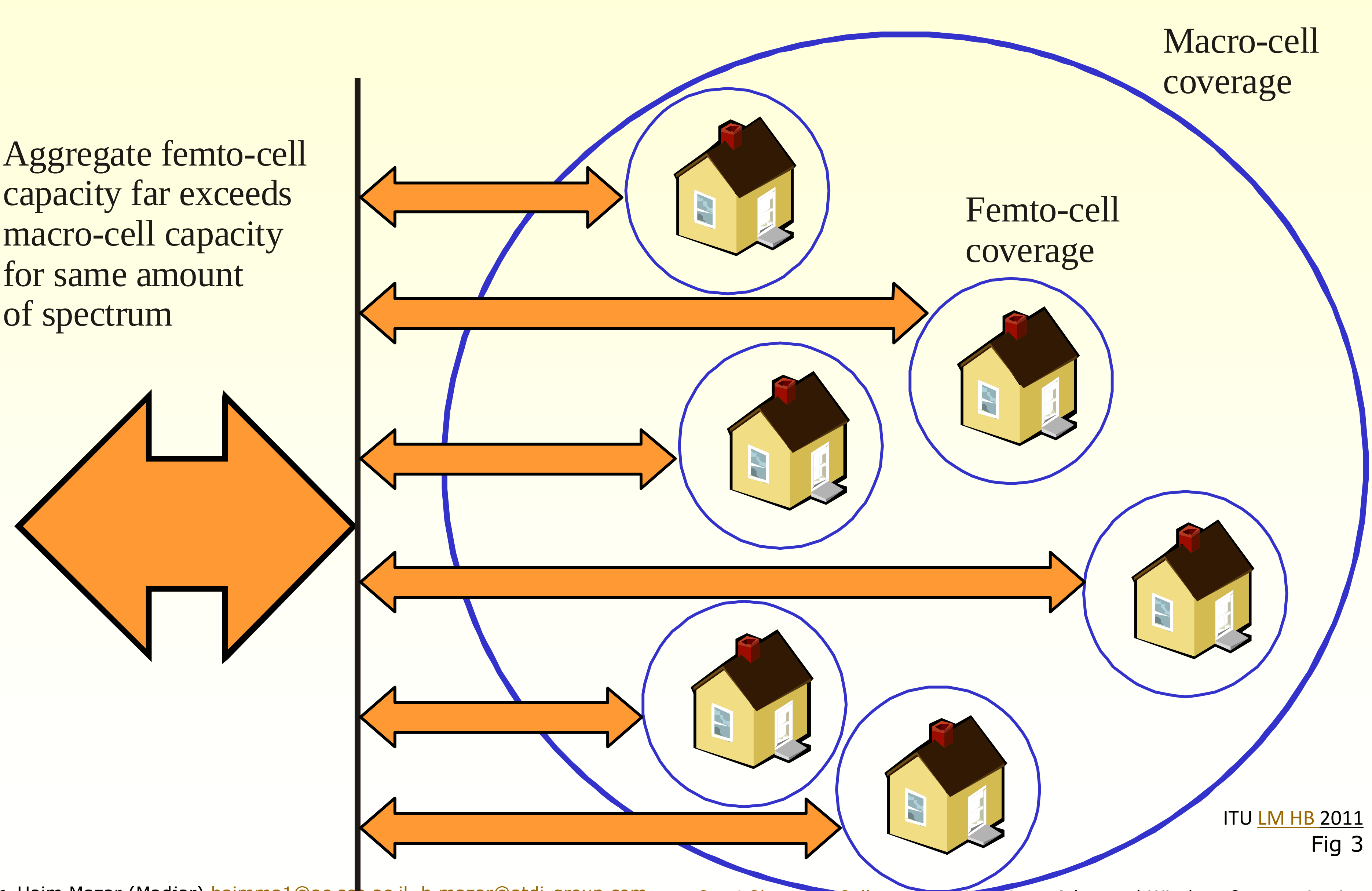
d reuse distance
r cell radius

r is determined by exceeding the min *c/i*

Land Mobile- Up and Down Links



Femto cells used to expand capacity



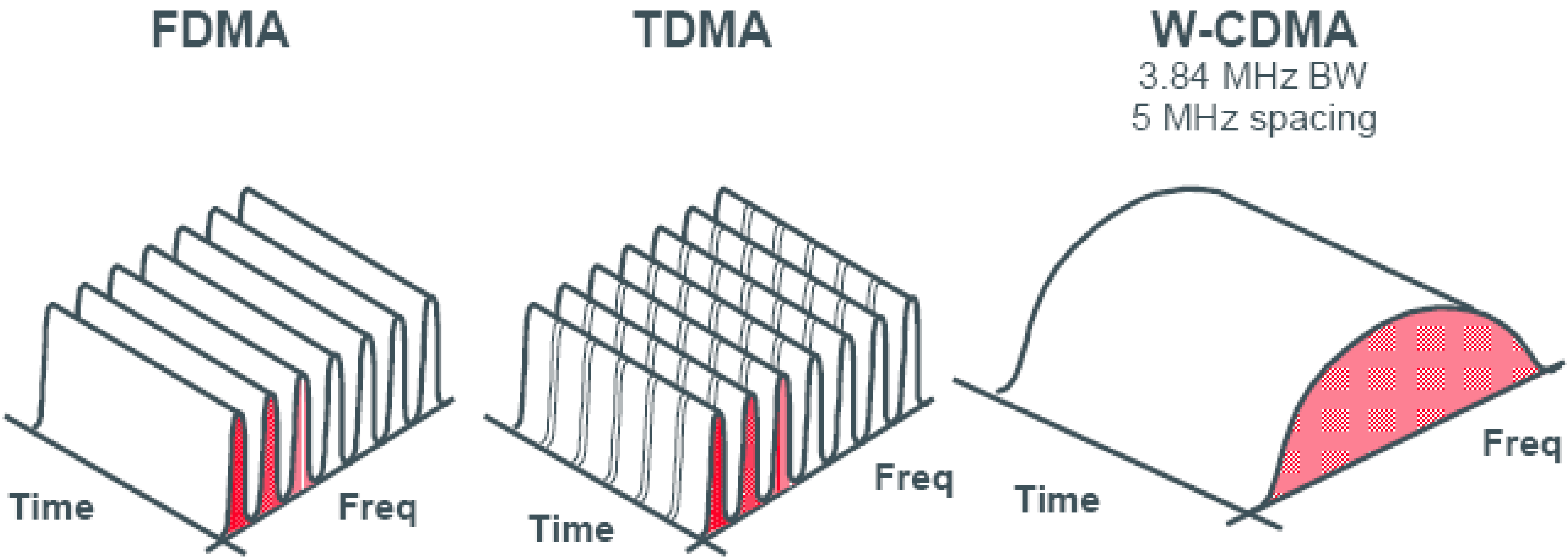
ITU LM HB 2011
Fig 3

Service types and their peak bit rates

Table 2 in Rec ITU-R M.1768-1 (2013)

Service type	Peak bit rate
Very low rate data	< 16 kbit/s
Low rate data and low multimedia	< 144 kbit/s
Medium multimedia	< 2 Mbit/s
High multimedia	< 30 Mbit/s
Super-high multimedia	30 Mbit/s to 100 Mbit/s/1 Gbit/s

Frequency/Code/Time Division Multiple Access

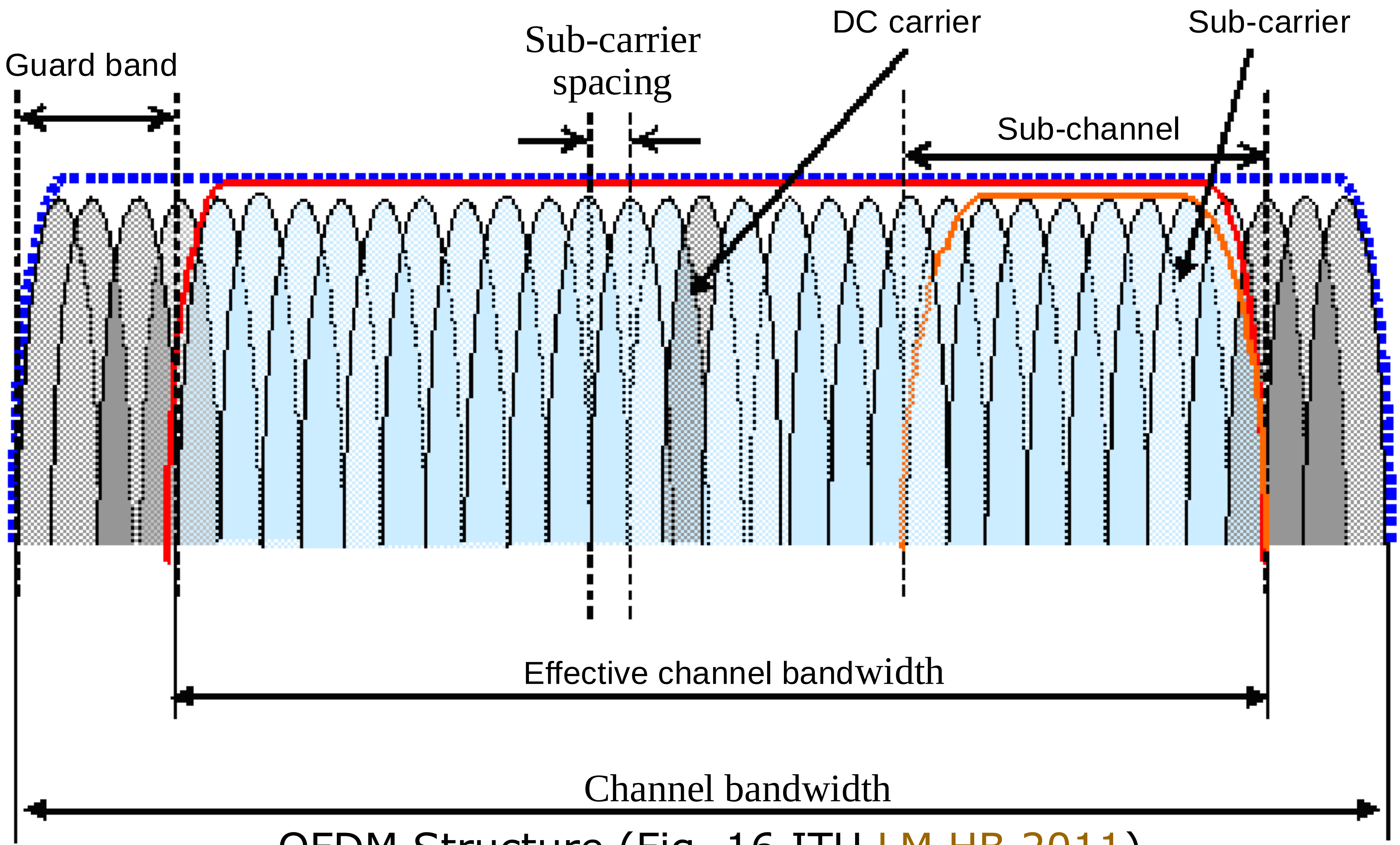


Users separated by **frequency**

Users separated by **frequency and time**

Users separated by **codes**

OFDM the LTE Orthogonal frequency-division multiplexing- structure

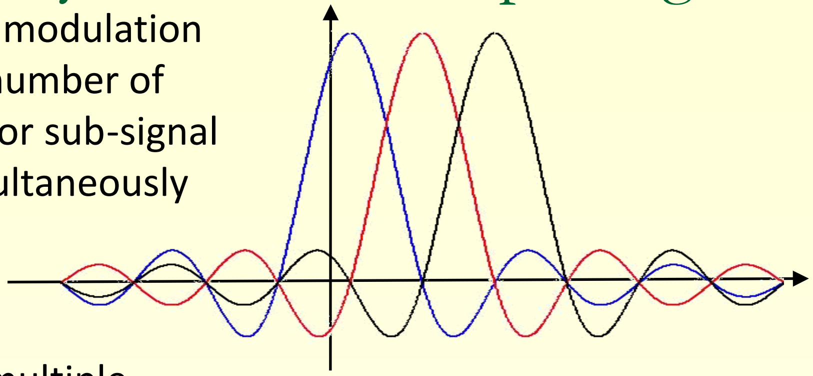


OFDM Structure (Fig. 16 ITU LM HB 2011)

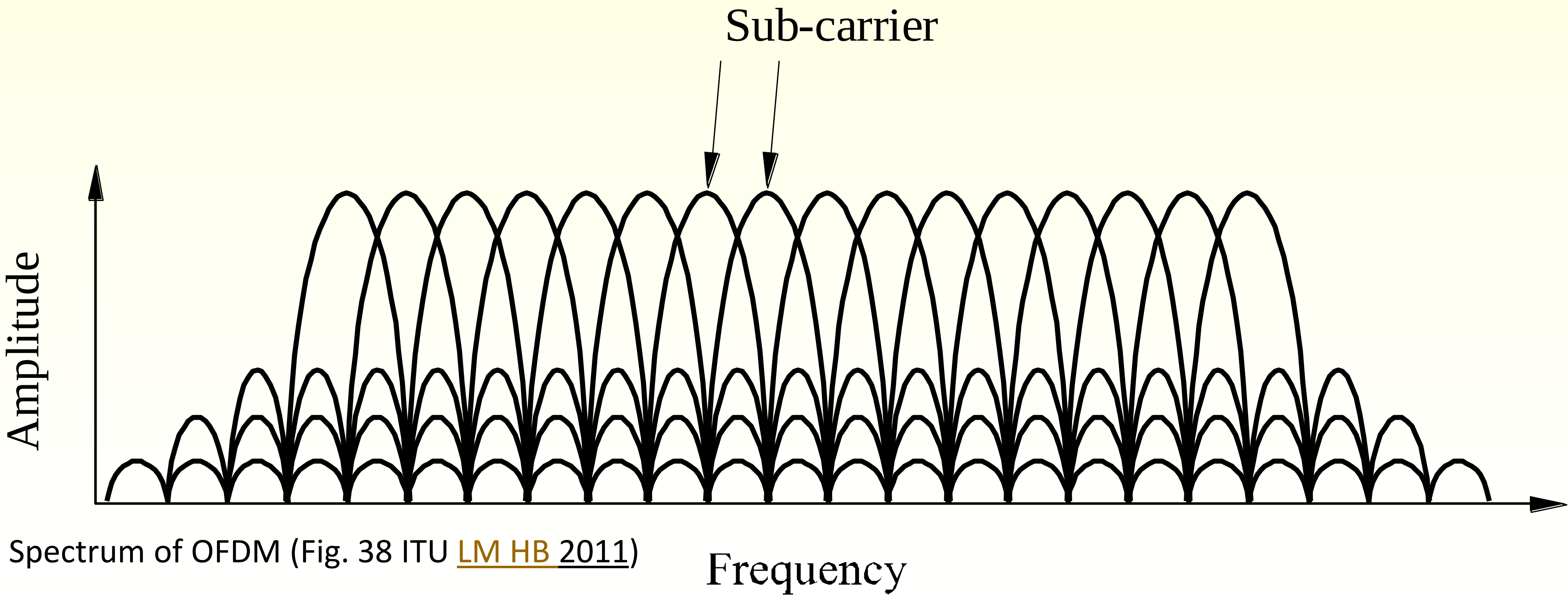
DC- DUAL CELL?

OFDM the LTE Orthogonal Frequency-Division Multiplexing

OFDM (Orthogonal Frequency Division Multiplexing) is an FDM modulation technique that divides a communications channel into a small number of equally spaced frequency bands, each of which carry a portion or sub-signal of the radio signal. These sub-signals are then transmitted simultaneously at different frequencies to the receiver



OFDMA is the "multi-user" version of OFDM.
Orthogonal Frequency Division Multiple Access (OFDMA) is a multiple access scheme for OFDM systems. It works by assigning a subset of subcarriers to individual users.

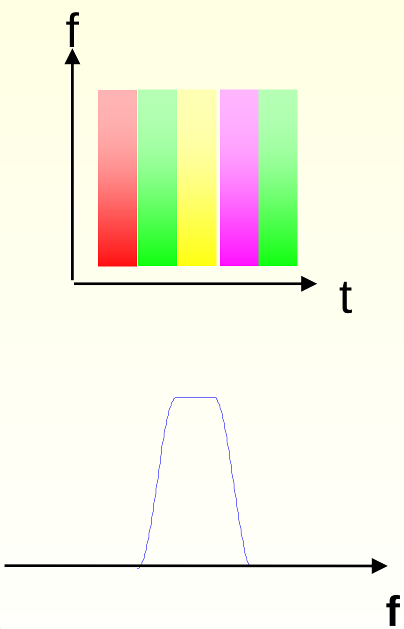


Spectrum of OFDM (Fig. 38 ITU LM HB 2011)

Comparison of Domains Access

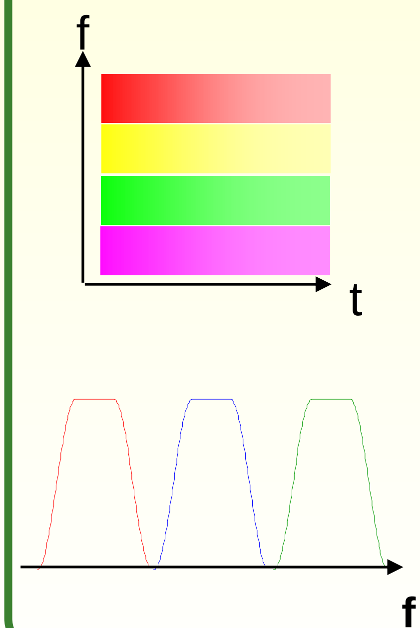
TDMA

- Time Division



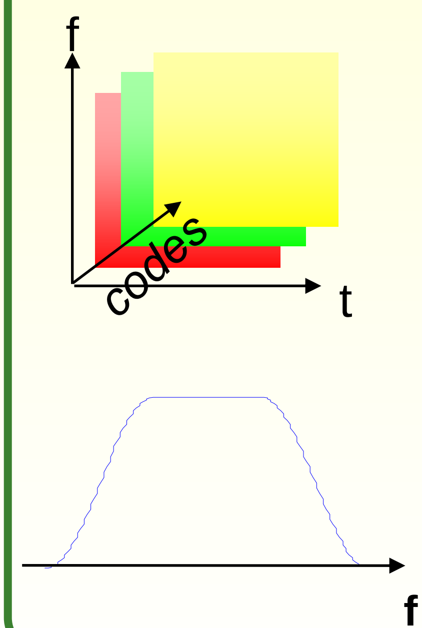
FDMA

- Frequency Division



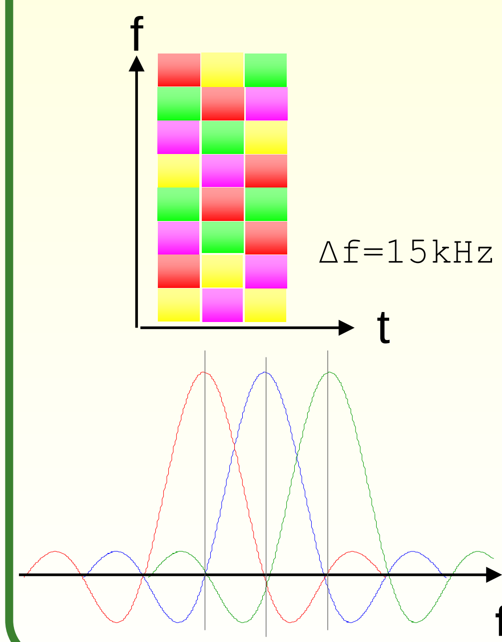
CDMA

- Code Division



OFDMA

- Frequency Division
- Orthogonal subcarriers



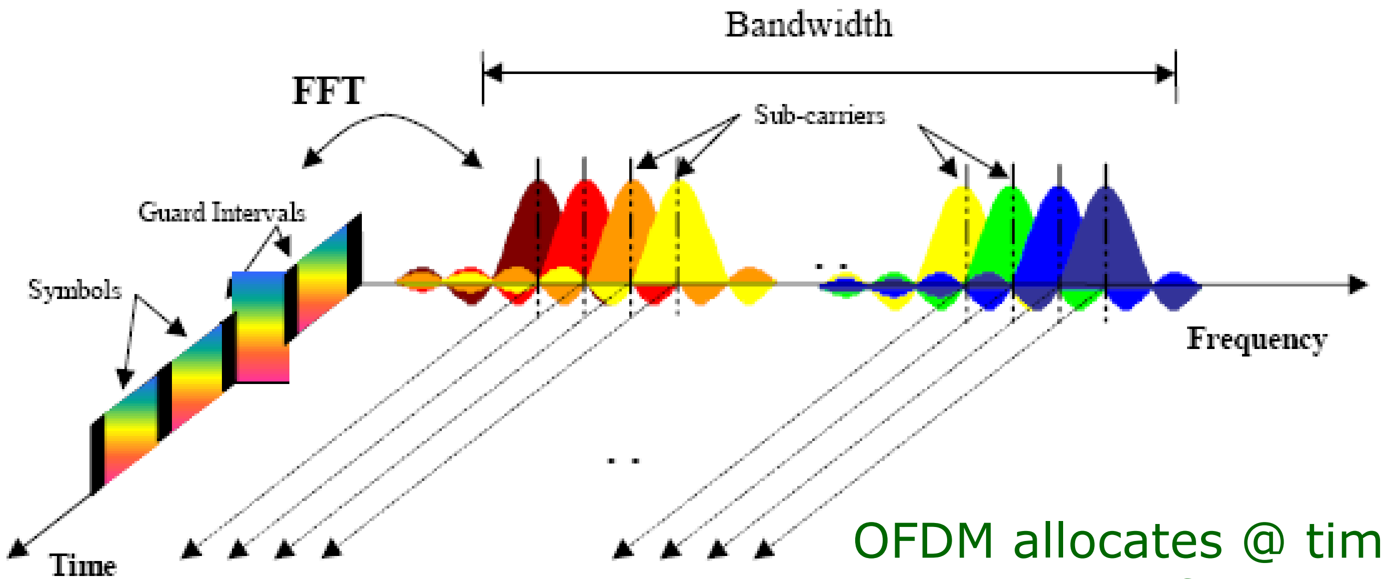
User 1 User 2 User 3 User

OFDMA: better immunity than CDMA to multipath
the part experiencing fading is avoided during allocation

Source: Shalev

OFDM / OFDMA

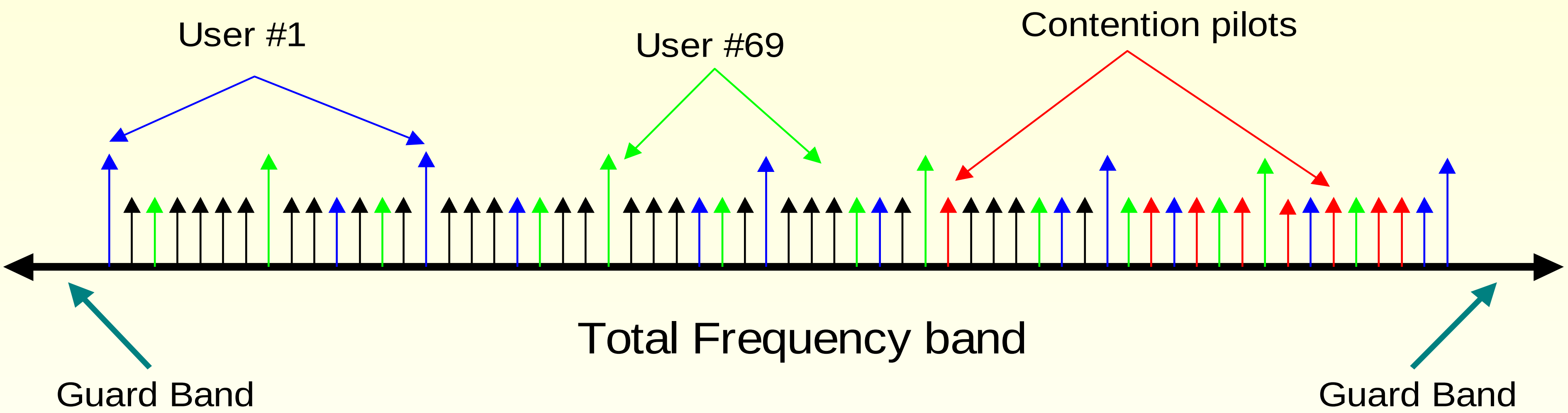
Rohde & Schwarz Seminar



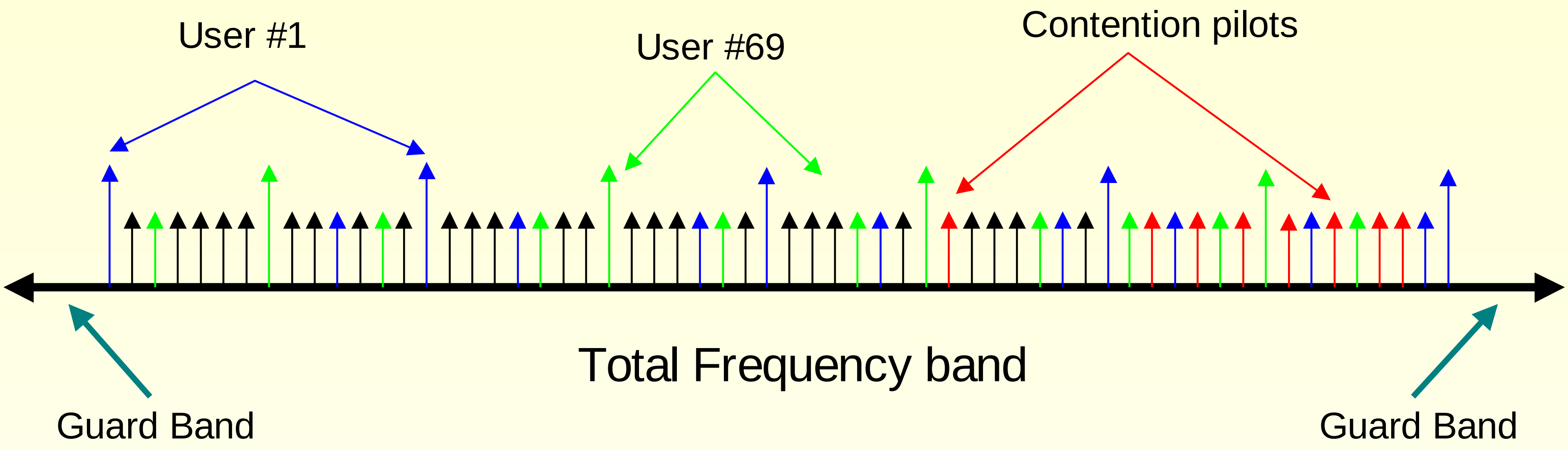
OFDM allocates @ time domain
OFDMA @ time & frequency domain

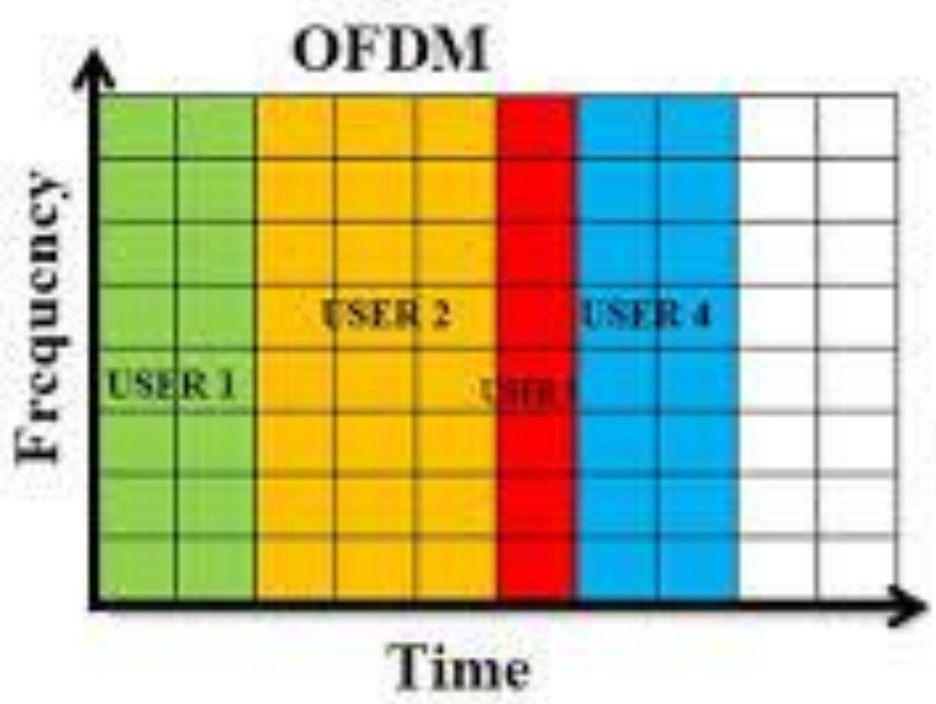
- Each sub-carrier (frequency channel) carries a separate low-rate stream of data
- Frequencies are chosen so that the modulated data streams are orthogonal to each other
- Each sub-carrier is independently modulated
- A guard time is added to each symbol (cyclic prefix)
- Symbol duration is relatively long compared to channel delay spread -> less intersymbol interference

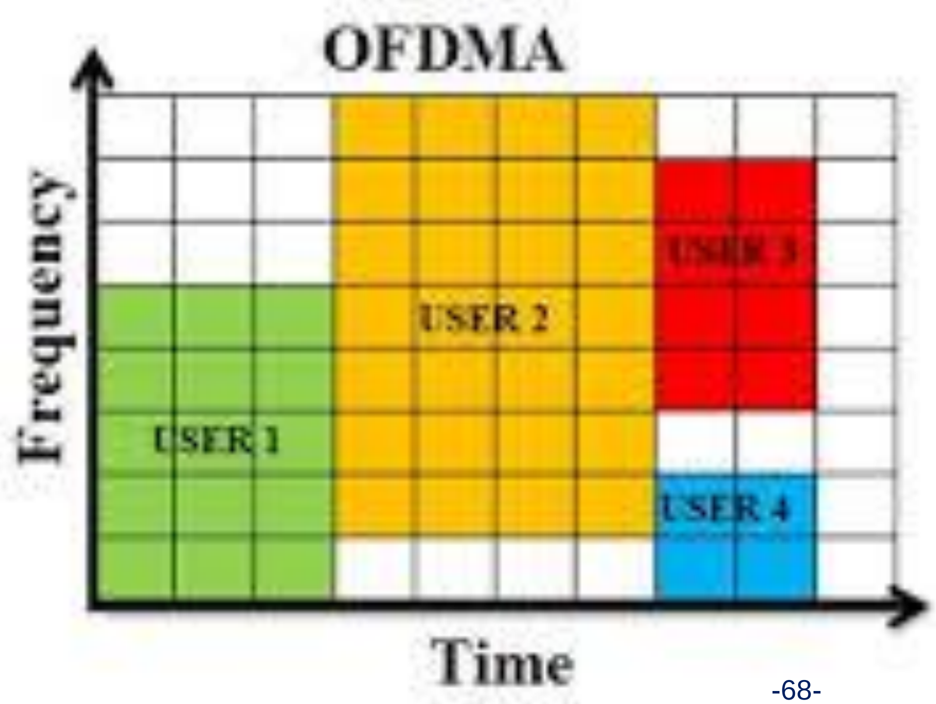
OFDMA for Mobile; Dr. Arie Reichman



- אפנון יעיל לתקשורת ניידת **ללא קו ראיה**


User #1
User #69
Contention pilots
Total Frequency band
Guard Band
Guard Band

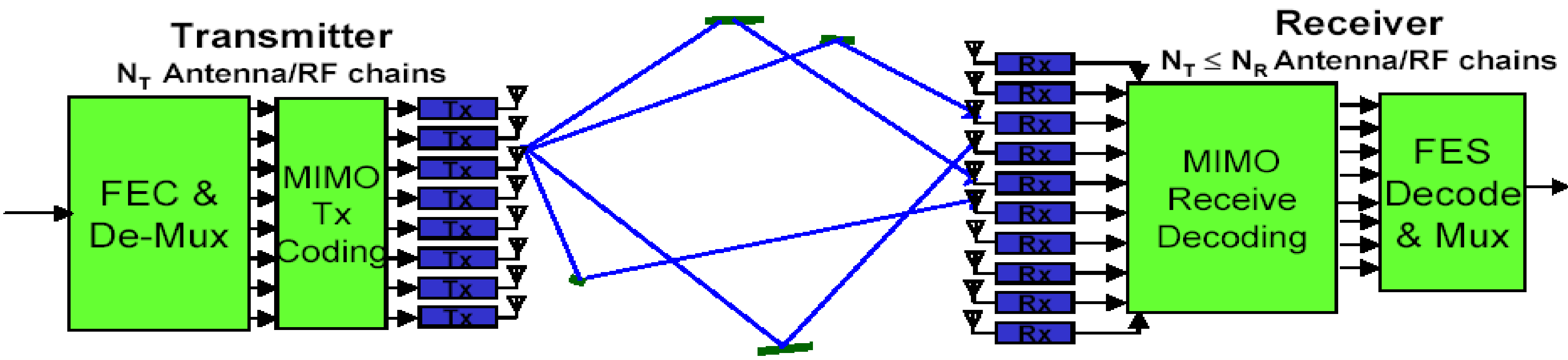

OFDM
Frequency
USER 1
USER 2
USER 4
Time


OFDMA
Frequency
USER 3
USER 2
USER 1
USER 4
Time

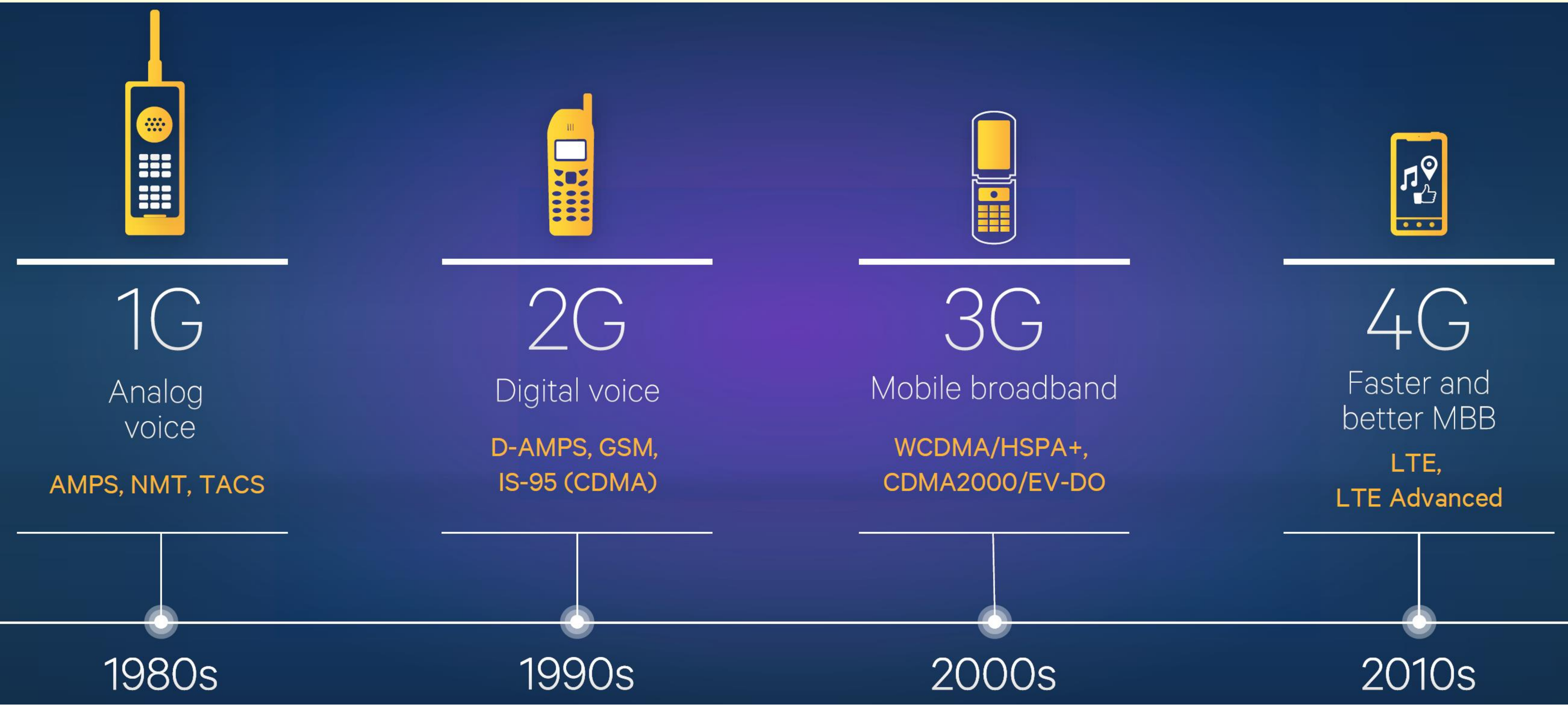
טכנולוגית MIMO (Dr. Arie Reichman)

- **Multiple In Multiple Out**
- ריבוי אנטנות בשידור ובקליטה
- עיצוב אלומות
- קידוד מרחבי
- חלוקה מרחבית
- סיכום משוקלל

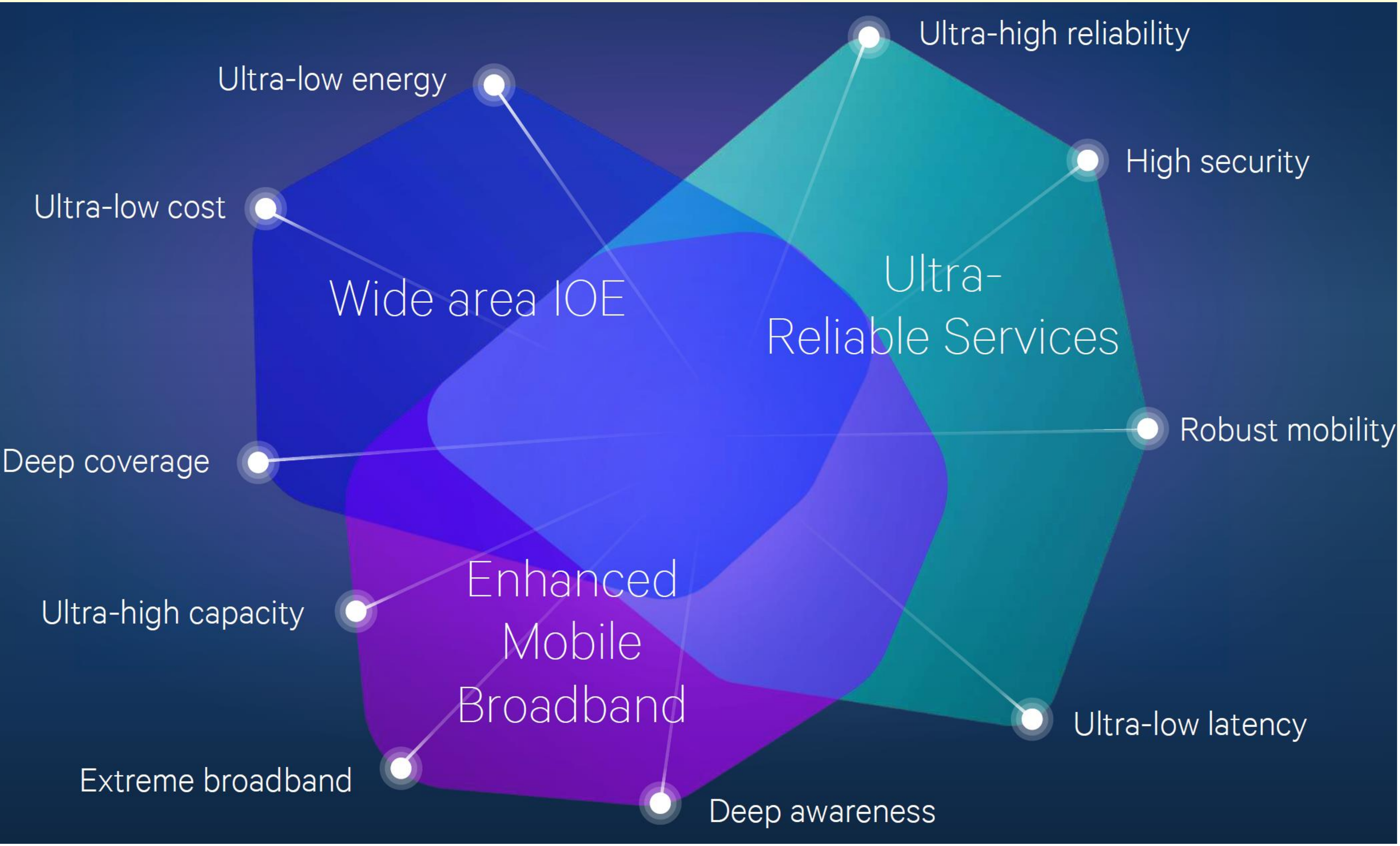
- הגדלת קצבים באותו רוחב סרט
- הגדלת קיבול
- נגד דעיכות
- נגד הפרעות



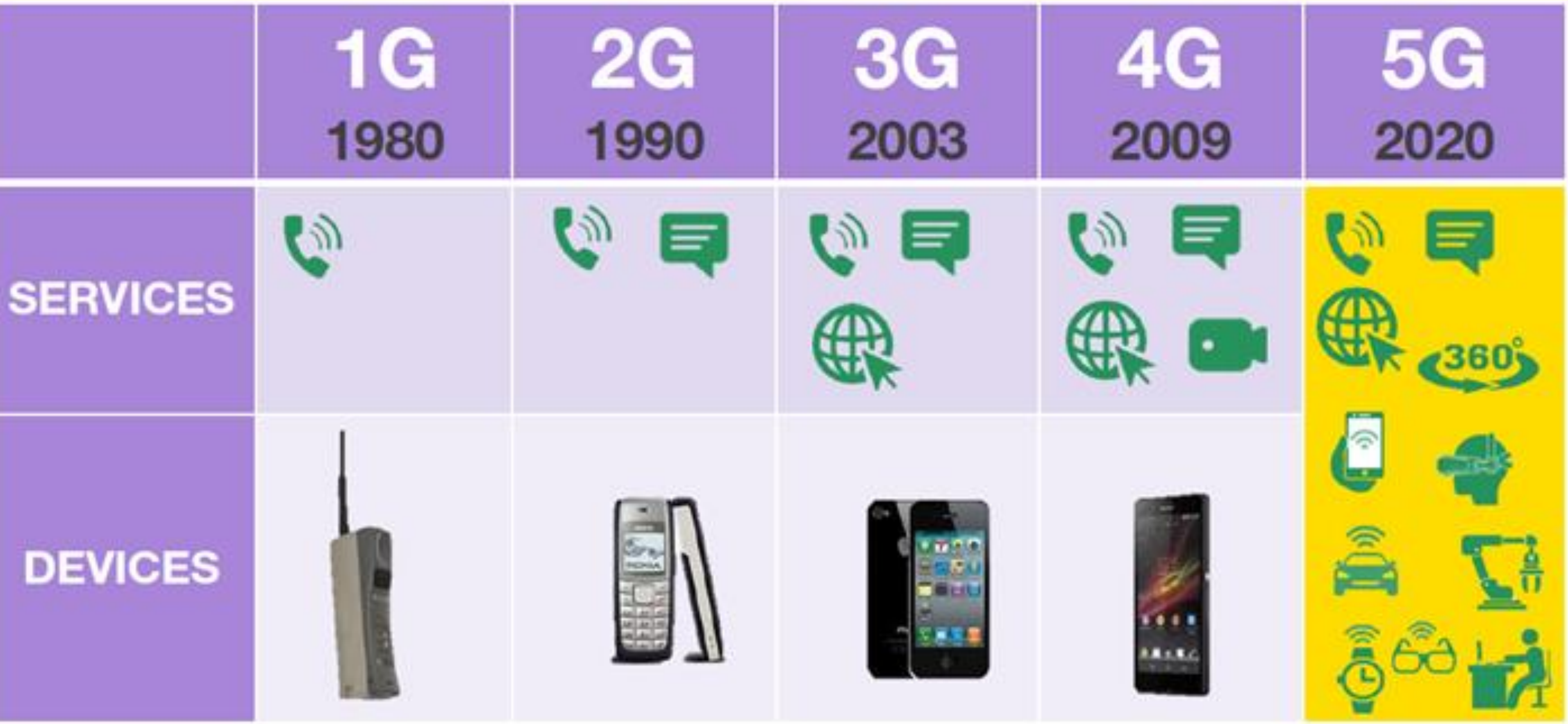
Mobile has made a leap every ~10 years; Dr. Arie Reichman



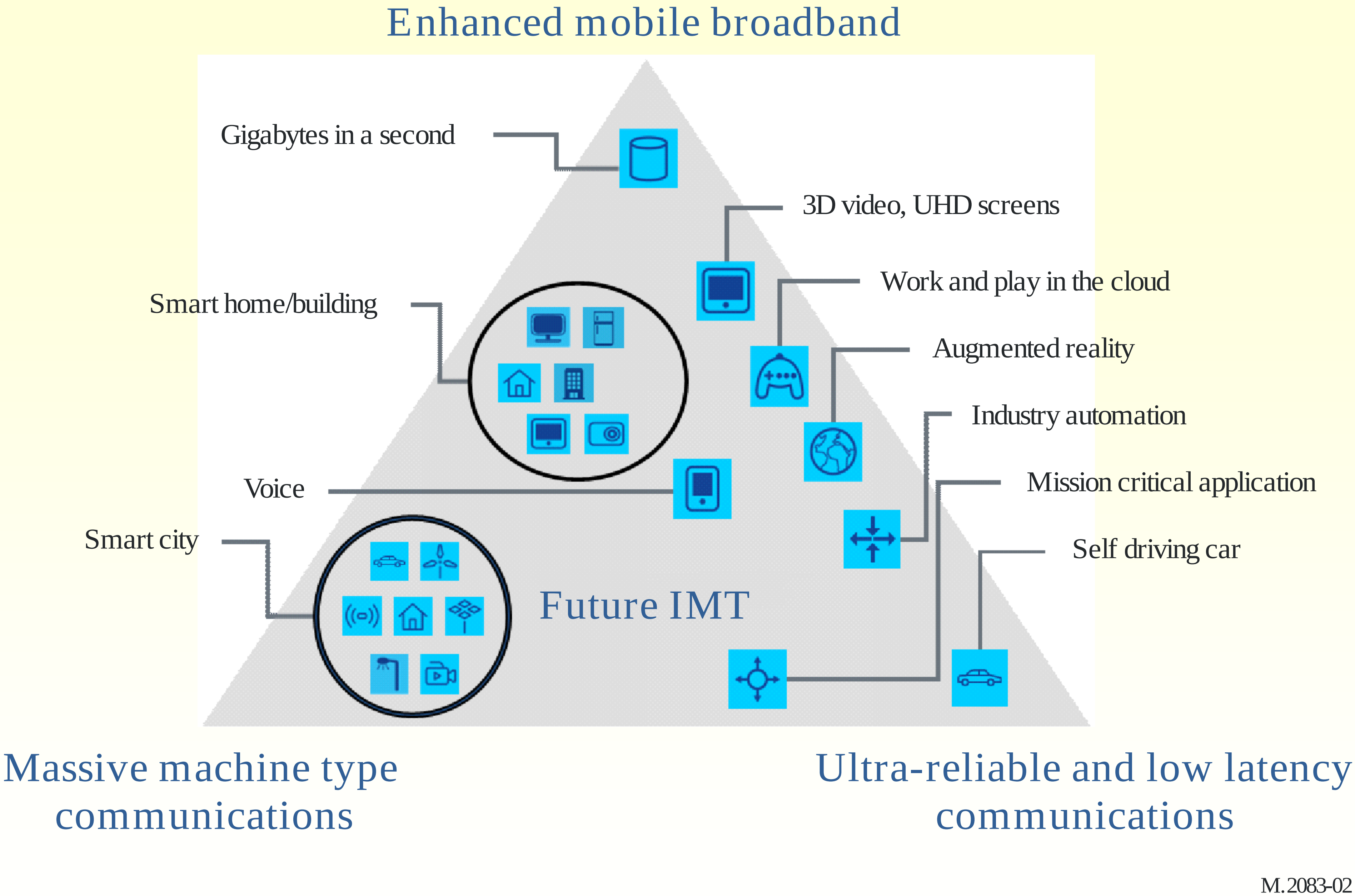
Extreme variation of requirements; Dr. Arie Reichman



Development of the mobile cellular

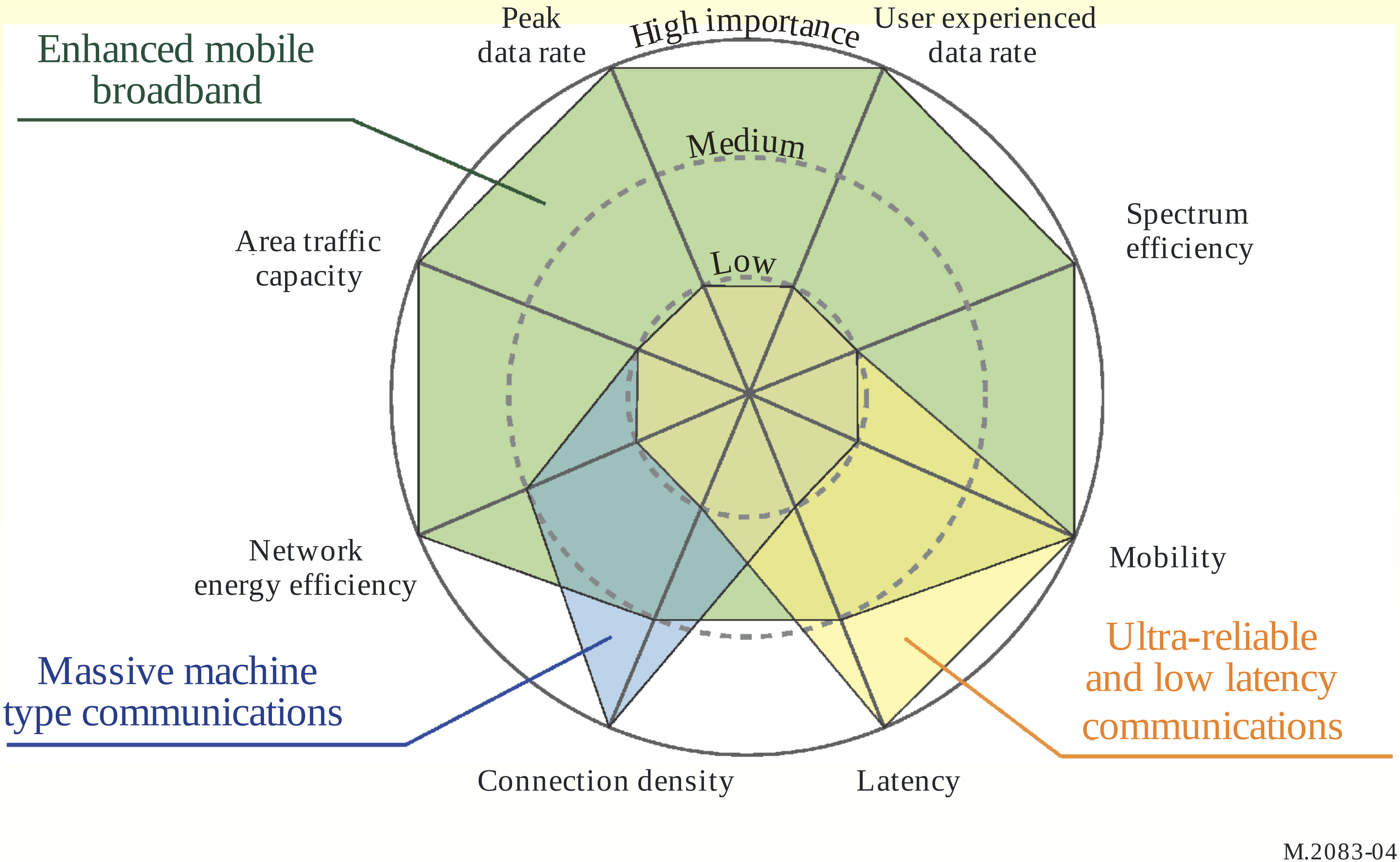


Source: Orange Poland



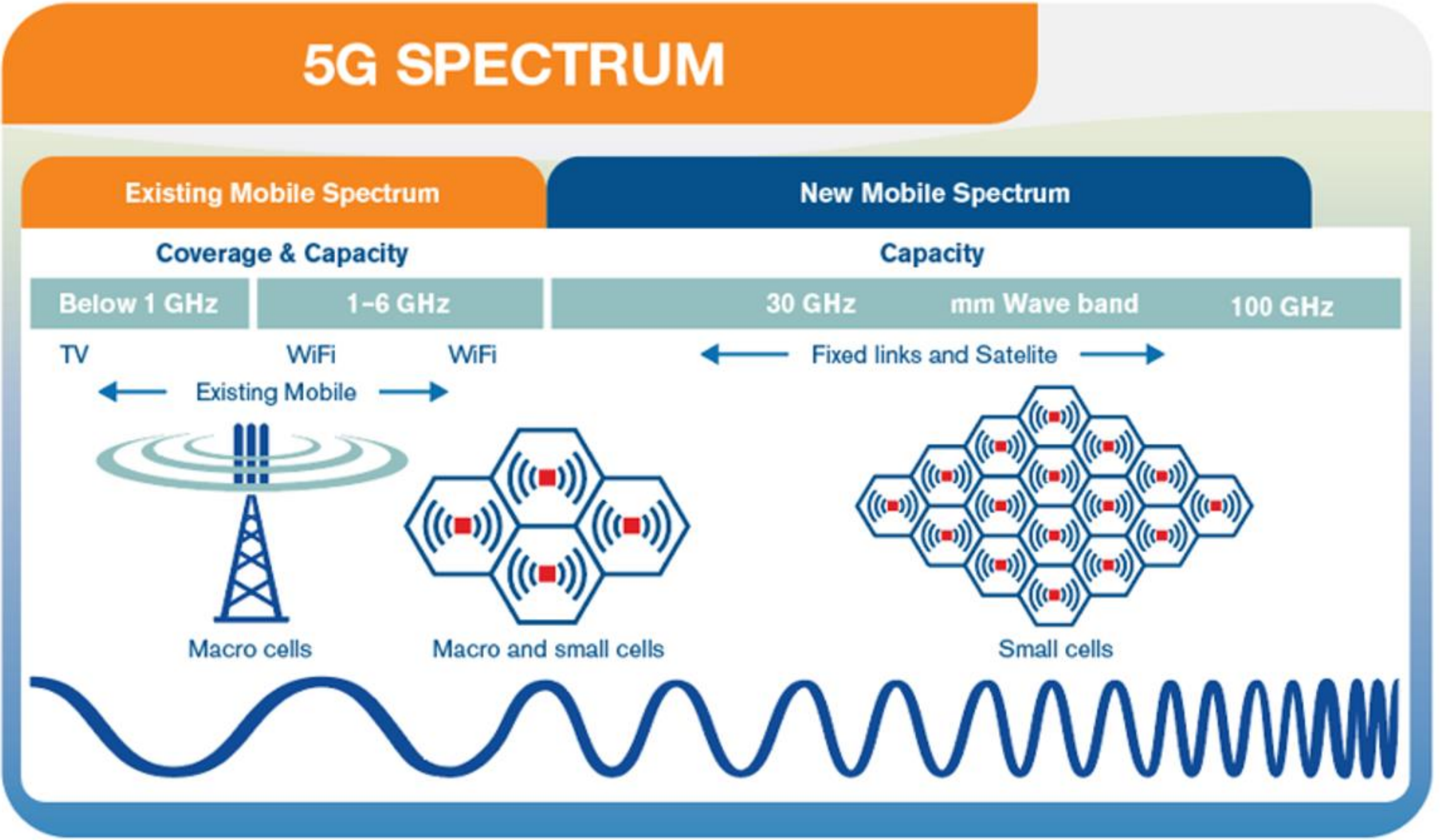
Source: Rec. ITU-R M.2083

Importance of key capabilities in different usage scenarios



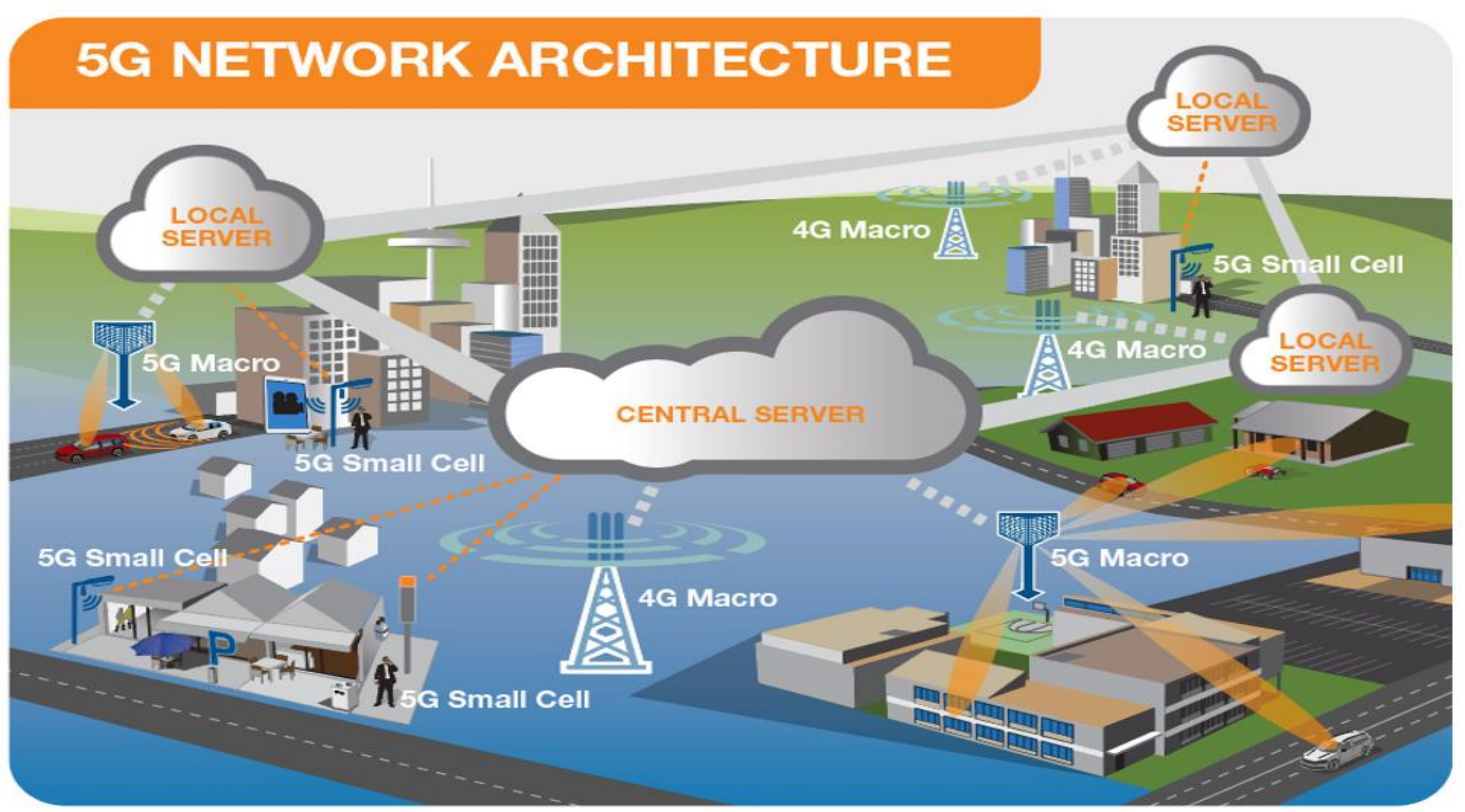
Source: Rec. ITU-R M.2083

Existing and new spectrum to be used for 5G mobile communication services



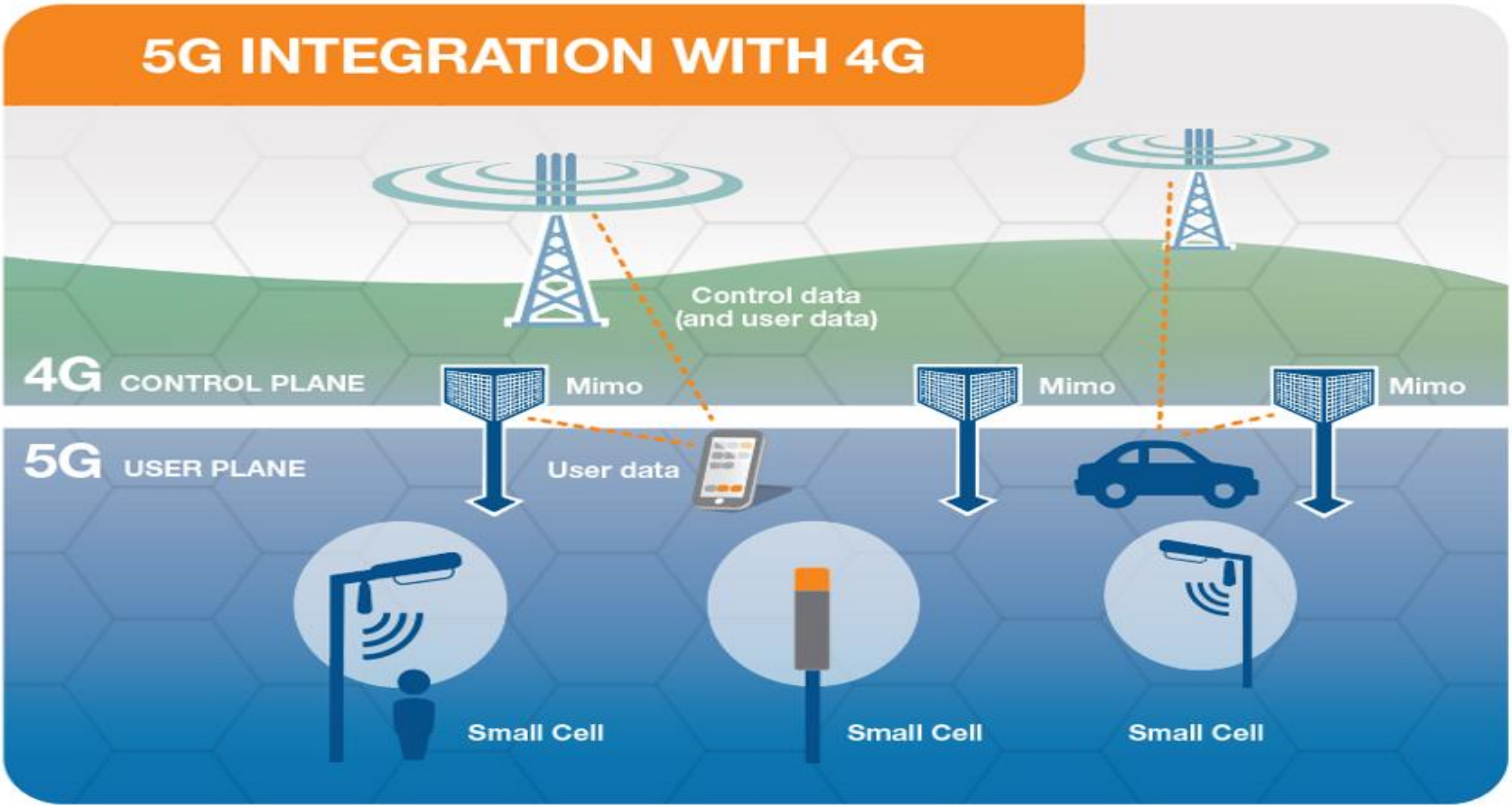
Source: Emf compliance assessments for 5G wireless networks ITU-T K Suppl 13 05/2019

Schematic architecture for 5G mobile communication networks



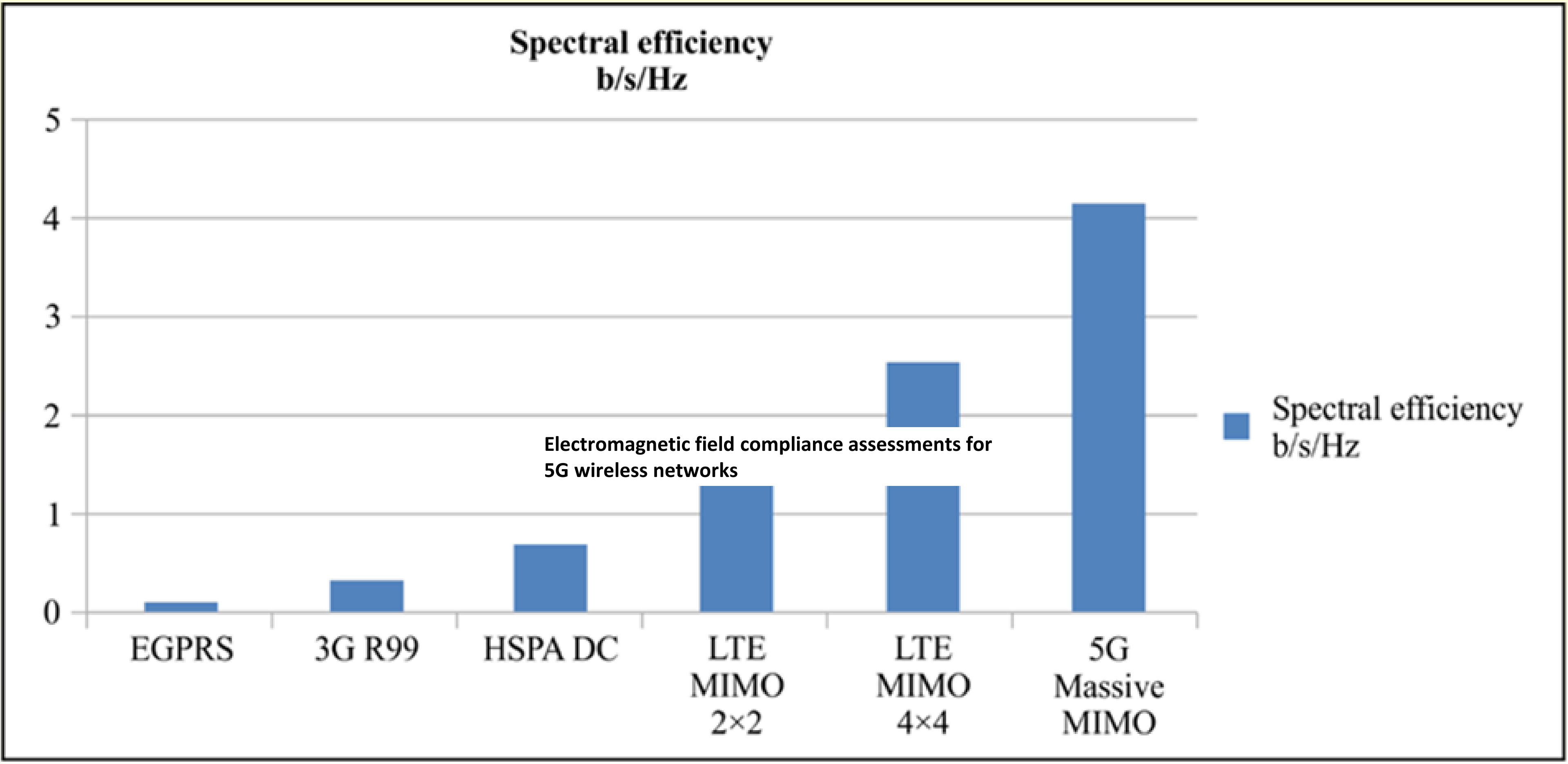
Source: Emf compliance assessments for 5G wireless networks ITU-T K Suppl 13 05/2019

5G networks initially integrated with existing 4G networks



Source: Emf compliance assessments for 5G wireless networks ITU-T K Suppl 13 05/2019

Spectral Efficiency



K Suppl.13(18)_F03

Source: Emf compliance assessments for 5G wireless networks ITU-T K Suppl 13 05/2019

Trade off between Coverage and Capacity (1)

The MCS (Modulation and Coding Scheme) defines the cell coverage & capacity

The code rate (or information rate) of a forward error correction (FER) code is the proportion of the data-stream that is useful (non-redundant): if the code rate is k/n for every k bits of useful information, the coder generates a total of n bits of data, of which n-k are redundant
E.g, The code rate of a convolutional code will typically be 1/2, 2/3, 3/4, 5/6, 7/8, etc., corresponding to one redundant bit inserted after every single, second, third, etc., bit. The code rate of the octet oriented Reed Solomon block code denoted RS(204,188) is 188/204, meaning that 204-188=16 are redundant octets (or bytes), added to each block of 188 octets of useful information
Note that bit/s is a more widespread unit of measurement for the information rate, implying that it is synonymous with net bit rate or useful bit rate exclusive of error-correction codes.

Coding rates (1/2, 2/3, ¾ and 5/6) reduce the system sensitivity

Source: Shalev

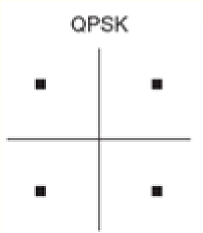
Trade off between Coverage and Capacity (2)

In OFDM *Protection Ratio (PR)*, *C/N* and *C/I* are similar. Intra-protection ratios for co-channel interference are identical to the respective C/N values.

The 64-QAM (see later)imposes higher *PR*s relative to 16-QAM: circa 6 dB; 4 times higher *PR* (for the same CR) is a consequence of 4 times more vector signal density at the I-Q plane.

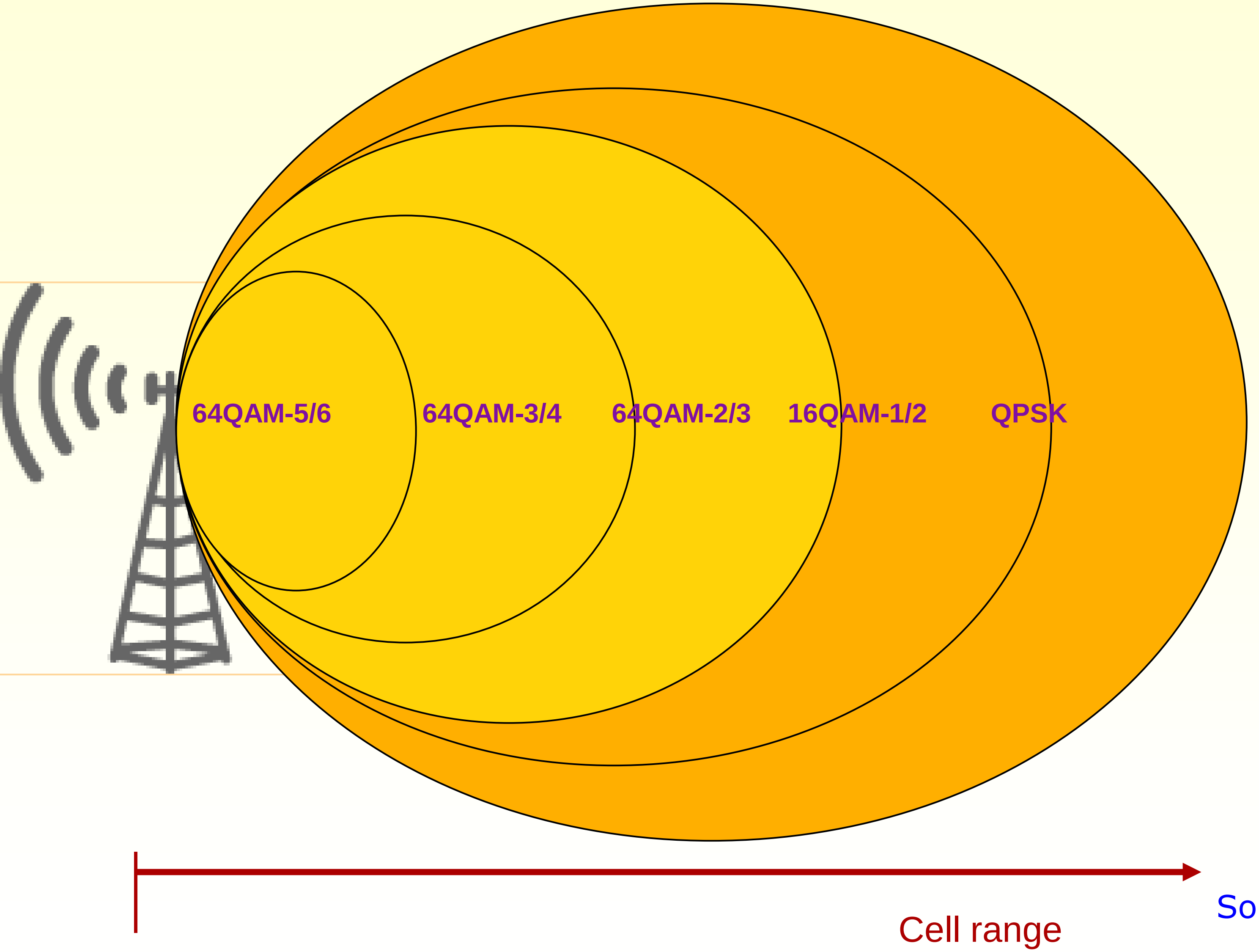
Balance: for the same range higher capacity 64QAM or 16QAM, vs higher Tx power.

Min. distance between points in the constellation indicates the power efficiency, number of points indicates the bandwidth efficiency.



Trade off between Coverage and Capacity (3)

The MCS (Modulation and Coding Scheme) defines the cell coverage & capacity



Source: Shalev

Reference sensitivity & coverage range

Table 22.7 Reference sensitivity.

System	Modulation	Channel BW (MHz)	kTB (dBm)	NF (dB)	SINR (dB)	IM (dB)	REFSENS (dBm)
LTE UE	QPSK 1/3	5	−107.5	9	−1	2.5	−100
	QPSK 1/3	20	−101.4	9	−1	2.5	−94
	64QAM 3/4	5	−107.5	9	17.5	4	−80
	64QAM 3/4	20	−101.4	9	17.5	4	−74
LTE BS	QPSK 1/3	5	−107.5	5	1.5	2.5	−101.5
UMTS UE	QPSK 1/3	3.84	−108.2	9	1.2–21.1 (21.1 dB spreading gain)	2.5	−117

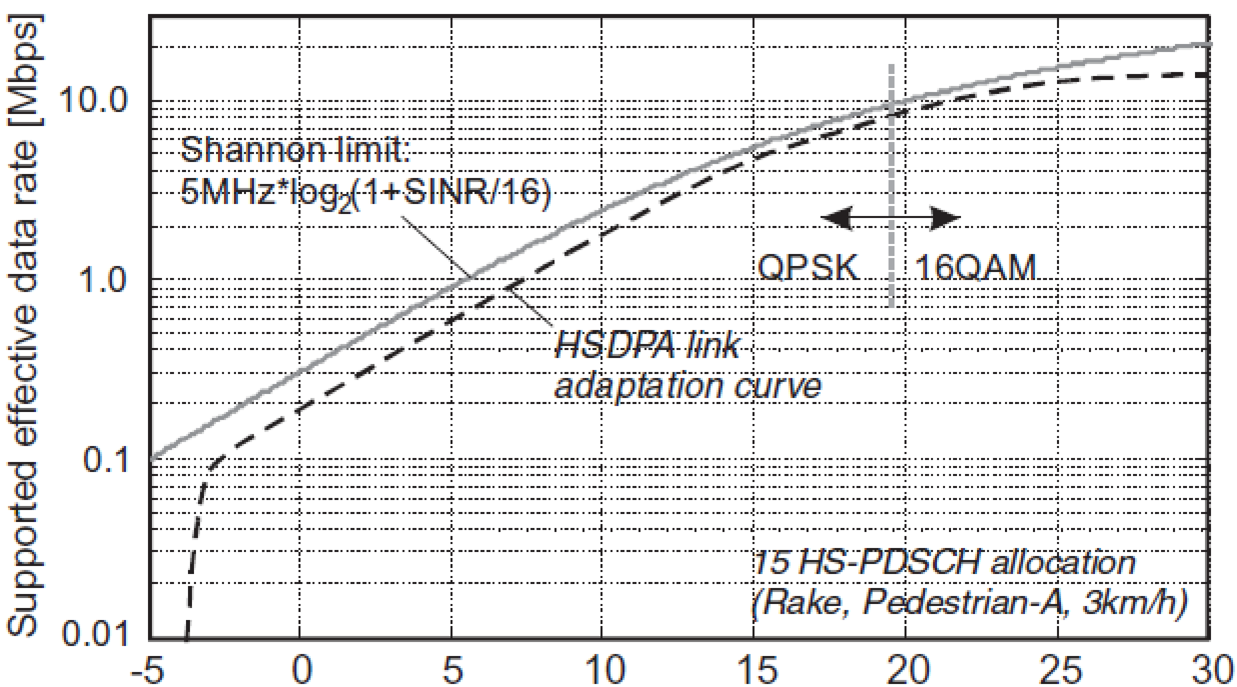
Table 22.8 Downlink range.

Modulation	QPSK 1/3	64QAM 3/4
Reference sensitivity (dB)	−100.0	−80.0
Maximum path loss (dB)	146.0	126.0
Maximum range urban (km)	4.7	1.4
Maximum range rural (km)	30.3	7.8

Sesia S., Toufik I. and Baker M. 2009 (2011 2th edition) LTE, the UMTS Long Term Evolution: from Theory to Practice, John Wiley & Sons

LTE Downlink peak bit rates; Wiley 2009; LTE Technology

Modulation coding		Peak bit rate per sub-carrier/bandwidth combination				
		72/1.4 MHz	180/3.0 MHz	300/5.0 MHz	600/10 MHz	1200/20 MHz
QPSK 1/2	Single stream	0.9	2.2	3.6	7.2	14.4
16QAM 1/2	Single stream	1.7	4.3	7.2	14.4	28.8
16QAM 3/4	Single stream	2.6	6.5	10.8	21.6	43.2
64QAM 3/4	Single stream	3.9	9.7	16.2	32.4	64.8
64QAM 4/4	Single stream	5.2	13.0	21.6	43.2	86.4
64QAM 3/4	2 × 2 MIMO	7.8	19.4	32.4	64.8	129.6
64QAM 4/4	2 × 2 MIMO	10.4	25.9	43.2	86.4	172.8



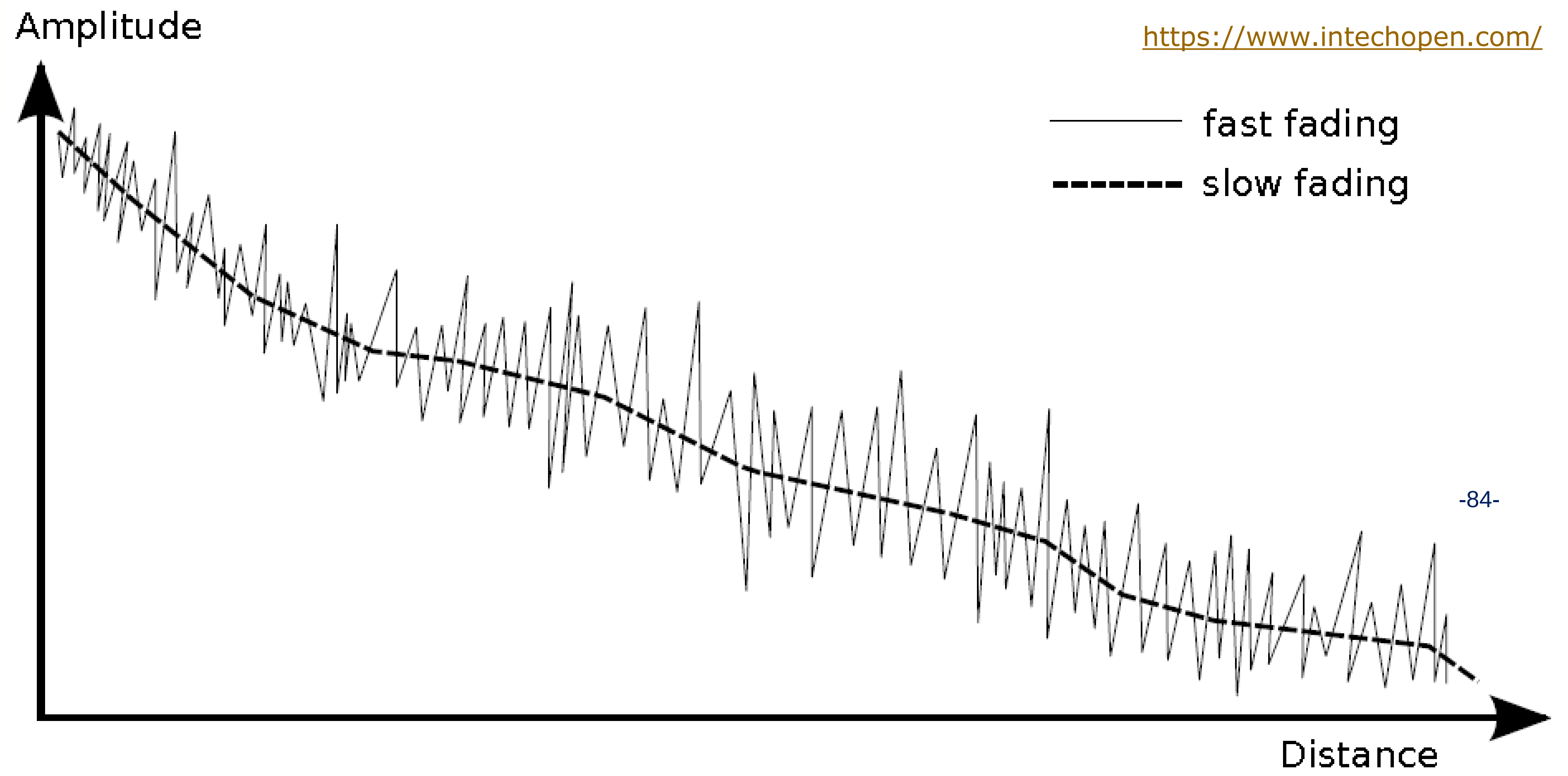
Throughput (Mbit/s) as function of SINR

Remark: true Shannon limit is:

$$c = b \times log_2\left(1 + s / n\right)$$

Sensitivity : Static and Dynamic

- Static: KTBF(SNR)
- Dynamic : KTBF(SNR)+ Fade Margin



GSM Reference Sensitivity (REFSENS)

REFSENS is the minimum mean power received at the Base Tx Station (BTS) or User Equipment (UE) antenna port at which the Bit Error Ratio (BER) shall not exceed a specific value

- GSM 3GPP TS 05.05 (2005) 6.2 for UE & BTS BER 0.001

GSM 900Mhz -104dbm; GSM 1800Mhz UE -102dbm

GSM900 and GSM1800 (DCS 1 800) the normal REFSENS BTS is - 104 dBm.

- For B=0.2 MHz, F (Noise Figure) **8** & **10** dB respectively and co-channel interference C/Ic 9dB the UE, KTBF(C/N) equals:
- for GSM 900 MHz equals -114+10*Log10(0.2)+ **8**+9=-104dBm
- for DCS 1800 MHz equals -114+10*Log10(0.2)+**10** +9 =-102dBm

UMTS Reference Sensitivity (REFSENS)

REFSENS is the minimum mean power received at the Base Tx Station (BTS) or User Equipment (UE) antenna port at which the Bit Error Ratio (BER) shall not exceed a specific value

- UMTS ETSI TS 134 121-1 (2014) 6.2 UE Table 7.3.5-1: Reference sensitivity QPSK REFSENS for BER 0.001 Down Link (DL), for REFSENS as the minimum mean power of DPCH_Ec received at the UE at which the BER shall not exceed 0.1%

Band I (2,100 MHz) dBm/3.84 MHz -117 dBm

Band VIII (900 MHz) dBm/3.84 MHz -115 dBm

For NF 10 dB (9-12dB), the thermal noise floor in the WCDMA channel (3.84MHz) is: -114+10*Log_{10}(3.840)+10 =-98 dBm adding Eb/No (7dB) we get -91 dBm; the DPCH_Ec processing gain (25dB) improves REFSENS to -91 dBm. See also next slide

Regards the difference in REFSENS :In bands where the duplex distance places tougher design constraints on the duplexer: in band I (UL band 1920-1980, DL band 2110-2170 and duplex separation 190 MHz vs Band VIII only 45 MHz separation. May be REFSENS is relaxed due to higher insertion losses; therefore, higher NF is tolerated; this is not the case GSM 900Mhz -104dbm; GSM 1800Mhz -102dbm

An example of UMTS Sensitivity

Transmitter (Base Station)	Value	Calculation
CPICH power [W]	2	
As above in dBm	33	a
NodeB antenna gain [dBi]	19	b
Cable Loss	2	c
Equivalent Isotropic Radiated Power (EIRP) [dBm]	50	d=a+b-c
Receiver (mobile station)		
Thermal noise density [dBm/Hz]	-174	e
Mobile station receiver noise figure [dB]	7	f
Receiver noise density [dBm/Hz]	-167	g=e+f
Receiver noise power [dBm]	-101.16	h=g+10log(3,840,000)
Interference margin [dB]	4	i
Total effective noise interference [dBm]	-97.16	j=h+i
Processing gain [dB]	25	k=10log(3840/12.2)
Required Eb=N0 [dB]	5	l
Static Receiver sensitivity [dBm]	**-117.16**	m=l-k+j
Mobile station antenna gain [dBi]	0	n
Cable loss in the mobile station [dB]	0	o
Fast fading margin [dB]	3	p
Max. path loss [dB]	164.16	q=d-m+n-o-p
Log-normal fading margin [dB] (for 90% reliability)	**6**	r
Soft handover gain [dB], multicell	2	s
In-car loss [dB]	0	t
Body loss	4	bb
Max Allowed Propagation Loss for cell range [dB]	**156.16**	u=q-r+s-t-bb
Indoor Loss	15	z
Received signal strength at Mobile	**-106.16**	y=x-u

y=x d-u

UMTS Reference Sensitivity (REFSENS) (Cont')

Copied from Wiley WCDMA for UMTS: HSPA Evolution and LTE: Harri Holma, Antti Toskala

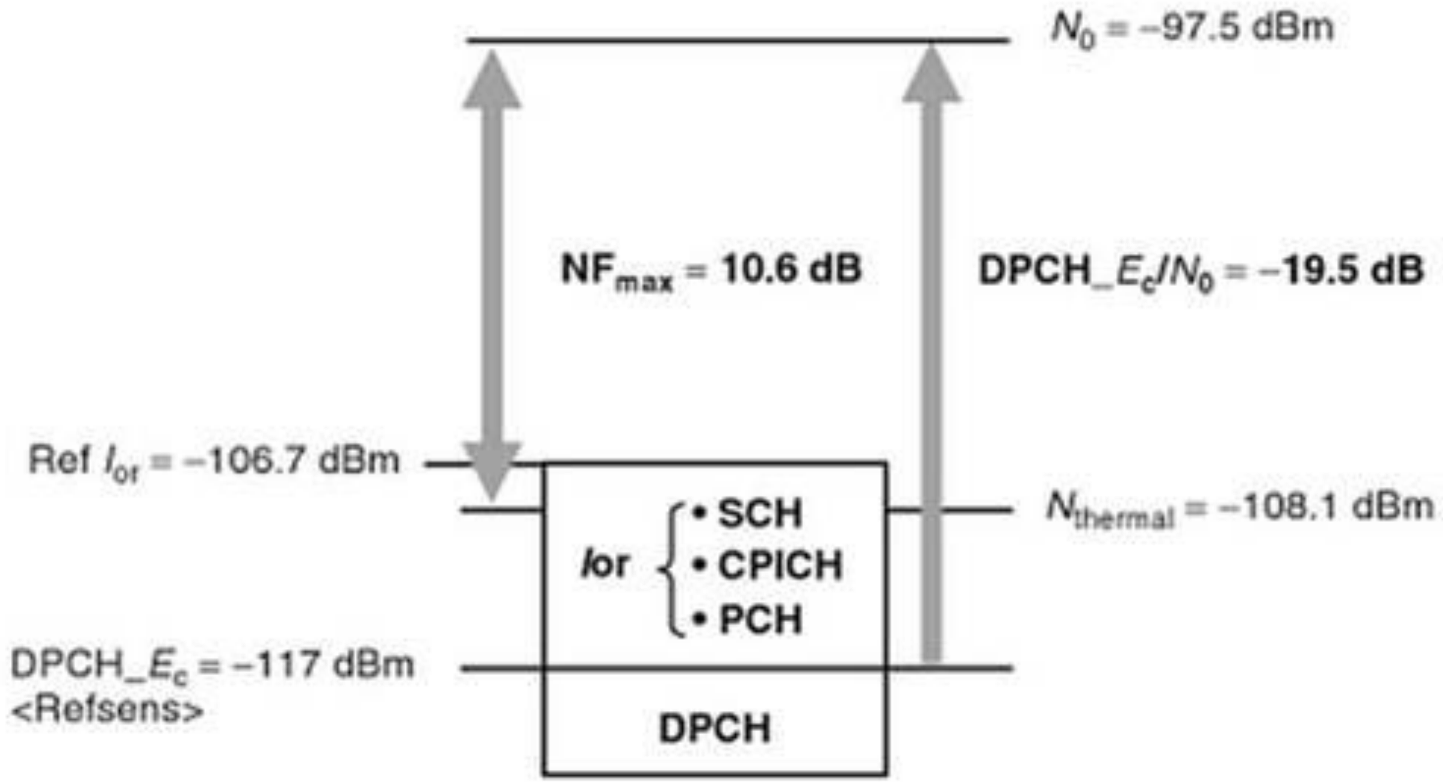


Figure 20.10 WCDMA band I reference sensitivity test case scenario (NF: Noise Figure; $N_{thermal}$: thermal noise power in 3.84 MHz bandwidth at 25 °C)

LTE Reference Sensitivity (REFSENS)

- ETSI TS 136 521-1 (2009) (see also LTE Acronyms) defines: REFerence SENSitivity power level. It is the minimum mean received signal strength applied to both antenna ports at which there is sufficient SINR for a given modulation scheme to meet 95% of the maximum throughput of a reference measurement channel. It is given by REFSENS = kTB + NF + SINR + IM − 3 (dBm), where kTB **is the thermal noise level** in dBm in the bandwidth B, NF is the prescribed maximum noise figure for the receiver, SINR is the requirement for the chosen Modulation and Coding Scheme (MCS), IM is an implementation margin and the -3 dB represents the diversity gain (only in the Up-Link **UL** budget). See 3GPP TS36.101, Section 7.3
- LTE TS 136 521-1 Table 7.3.3-1, For throughput ≥ 95% (as specified in Annexes A.2,2, A.2,3 and A.3..2) the band 3 Down-Link **DL** (1,805 MHz to 1,880 MHz) 5 MHz channel bandwidth, QPSK REFSENS is **−97dBm**; see next slide

LTE Table 7.3.3-1

ETSI TS 136 101 V12.5.0 (2014-11)

Table 7.3.1-1: Reference sensitivity QPSK $P_{REFSENS}$

	Channel bandwidth						
E-UTRA Band	1.4 MHz (dBm)	3 MHz (dBm)	5 MHz (dBm)	10 MHz (dBm)	15 MHz (dBm)	20 MHz (dBm)	Duplex Mode
1			-100	-97	-95.2	-94	FDD
2	-102.7	-99.7	-98	-95	-93.2	-92	FDD
3	-101.7	-98.7	-97	-94	-92.2	-91	FDD
4	-104.7	-101.7	-100	-97	-95.2	-94	FDD
5	-103.2	-100.2	-98	-95			FDD
6			-100	-97			FDD
7			-98	-95	-93.2	-92	FDD
8	-102.2	-99.2	-97	-94			FDD
9			-99	-96	-94.2	-93	FDD
10			-100	-97	-95.2	-94	FDD
11			-100	-97			FDD
12	-101.7	-98.7	-97	-94			FDD
13			-97	-94			FDD
14			-97	-94			FDD
...							
17			-97	-94			FDD
18			-100[7]	-97[7]	-95.2[7]		FDD
19			-100	-97	-95.2		FDD
20			-97	-94	-91.2	-90	FDD
21			-100	-97	-95.2		FDD
22			-97	-94	-92.2	-91	FDD
23	-104.7	-101.7	-100	-97	-95.2	-94	FDD
24			-100	-97			FDD
25	-101.2	-98.2	-96.5	-93.5	-91.7	-90.5	FDD
26	-102.7	-99.7	-97.5[6]	-94.5[6]	-92.7[6]		FDD
27	-103.2	-100.2	-98	-95			FDD
28		-100.2	-98.5	-95.5	-93.7	-91	FDD
30			-99	-96			FDD
31	-99.0	-95.7	-93.5				FDD

Dr. Haim Mazar (Madjar) haimma1@ac.sce.ac.il

LTE TS 136 521-1 Table 7.3.3-1: UE Reference sensitivity QPSK REFSENS (dBm)
Down Link DL FDD RF bands retrieved from Table 5.5-1 of 3GPP TS 36.104 V12.3.0 (2014-03)

	Channel Bandwidth BW (MHz)						
Band	**DL RF (MHz)**	**BW 1.4 MHz**	**BW 3 MHz**	**BW 5 MHz**	**BW 10 MHz**	**BW 15MHz**	**BW 20MHz**
1	2,110-2,170	------		-100	-97	-95.2	-94
2	1,930-1,990	-102.7	-99.7	-98	-95	-93.2	-92
3	1,805-1,880	-101.7	-98.7	-97	-94	-92.2	-91
5	869 -894	-103.2	-100.2	-98	-95	------	
7	2,620-2,690	------		-98	-95	-93.2	-92
8	925-960	-102.2	-99.2	-97	-94	------	
20	791-821	------		-97	-94	-91.2	-90

Spectrum identified for IMT

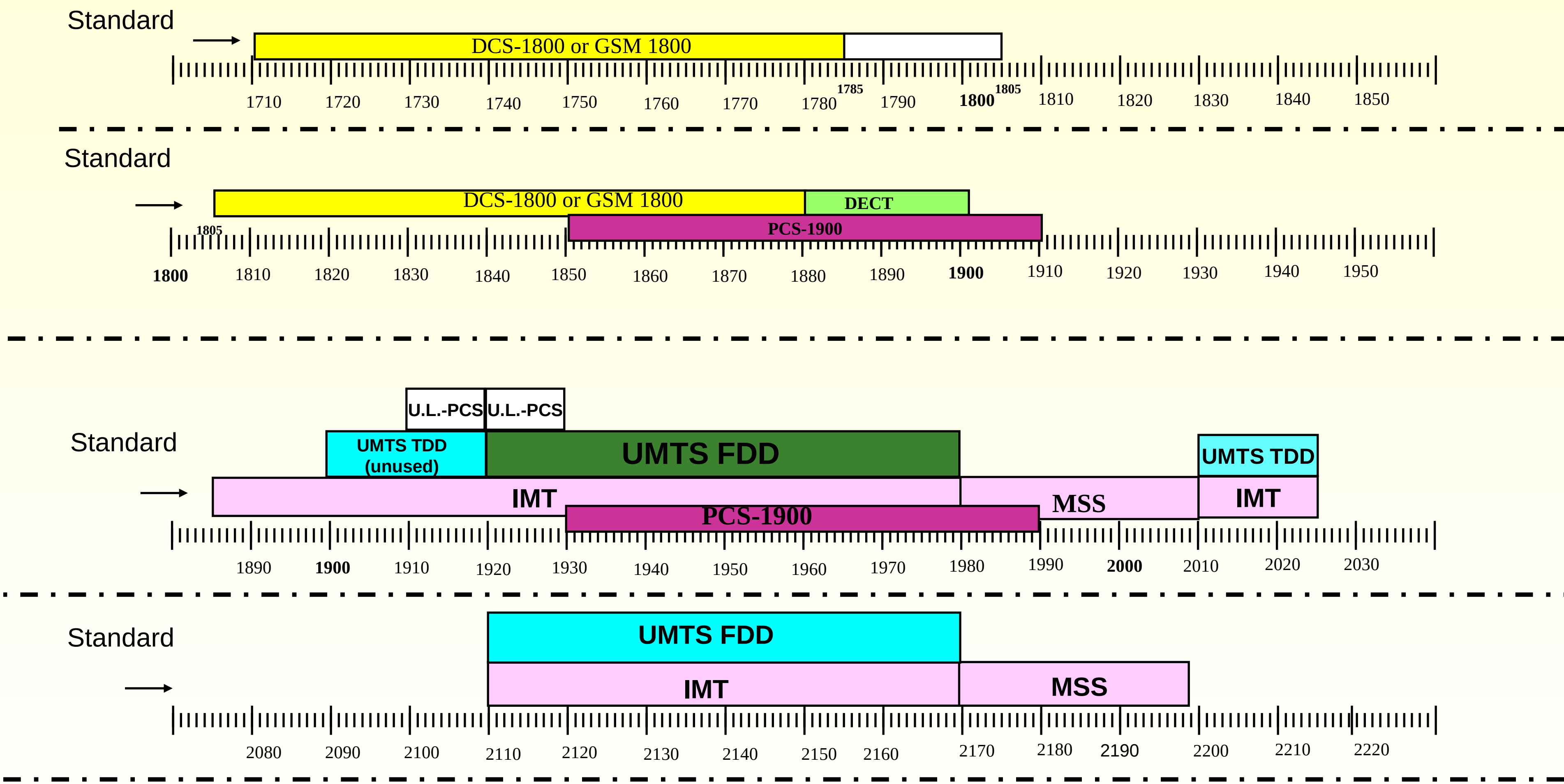
Frequency band (MHz)	Bandwidth (MHz)
450-470	20
470-608	18
614-698	84
698-960	262
1427-1452	25
1452-1492	40
1492-1518	26
1710-2025	315
2110-2200	90
2300-2400	100
2500-2690	190
3300-3400	100
3400-3600	200
3600-3700	100
4800-4990	190
	1,880 MHz (not equally spread over the 3 ITU Regions)

ITU Radio Regulations (2020 edition), Footnotes identifying the band for IMT

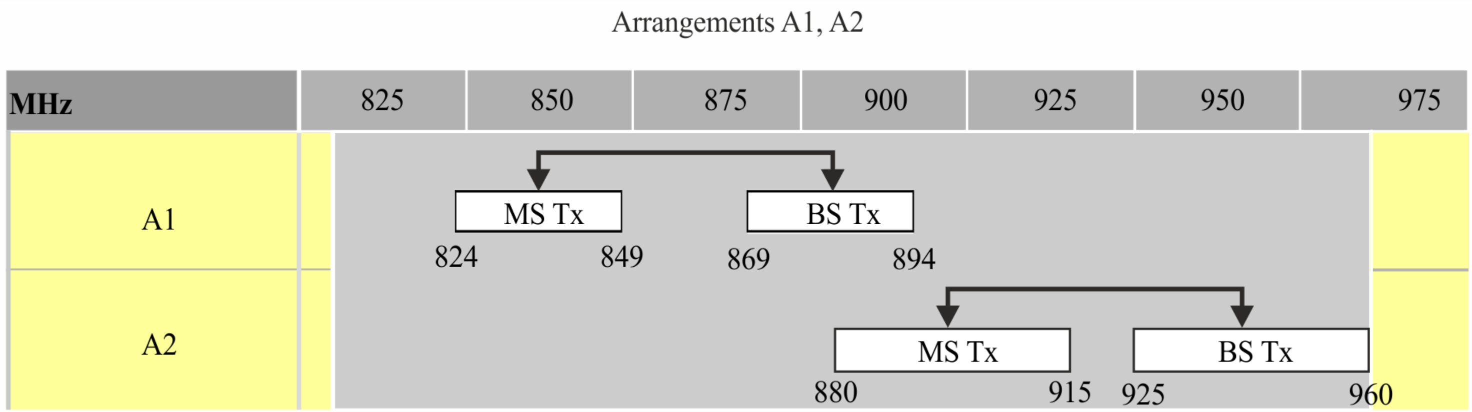
Band	Footnotes identifying the band for IMT		
	Region 1	**Region 2**	**Region 3**
450–470 MHz	**5.286AA**		
470–698 MHz	**-**	**5.295, 5.308A**	**5.296A**
694/698-960 MHz	**5.317A**	**5.317A**	**5.313A, 5.317A**
1 427–1 518 MHz	**5.341A, 5.346**	**5.341B**	**5.341C, 5.346A**
1 710-2 025 MHz	**5.384A, 5.388**		
2 110–2 200 MHz	**5.388**		
2 300–2 400 MHz	**5.384A**		
2 500–2 690 MHz	**5.384A**		
3 300–3 400 MHz	**5.429B**	**5.429D**	**5.429F**
3 400–3 600 MHz	**5.430A**	**5.431B**	**5.432A, 5.432B, 5.433A**
3 600–3 700 MHz	**-**	**5.434**	**-**
4 800–4 990 MHz	**5.441B**	**5.441A, 5.441B**	**5.441B**
24.25–27.5 GHz *	**5.532AB**		
37–43.5 GHz*	**5.550B**		
45.5–47 GHz*	**5.553A**	**5.553A**	**5.553A**
47.2–48.2 GHz*	**5.553B**	**5.553B**	**5.553B**
66–71 GHz*	**5.559AA**		

* revised at WRC-19

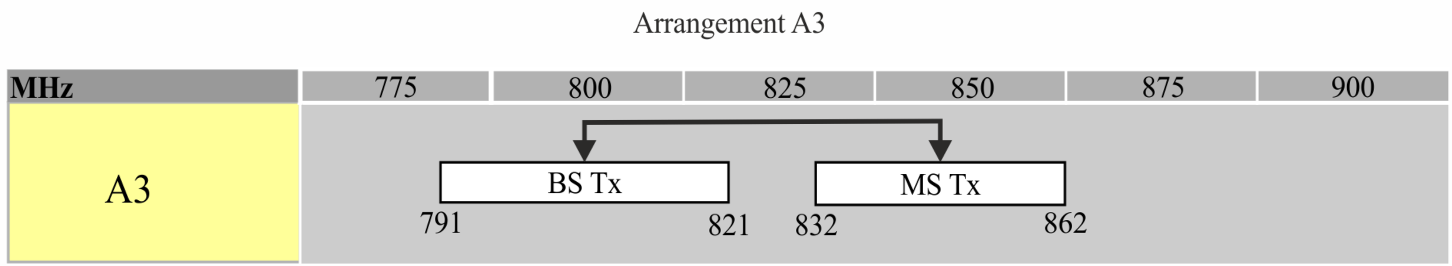
LAND Mobile Standards 1,700-2,200 MHz



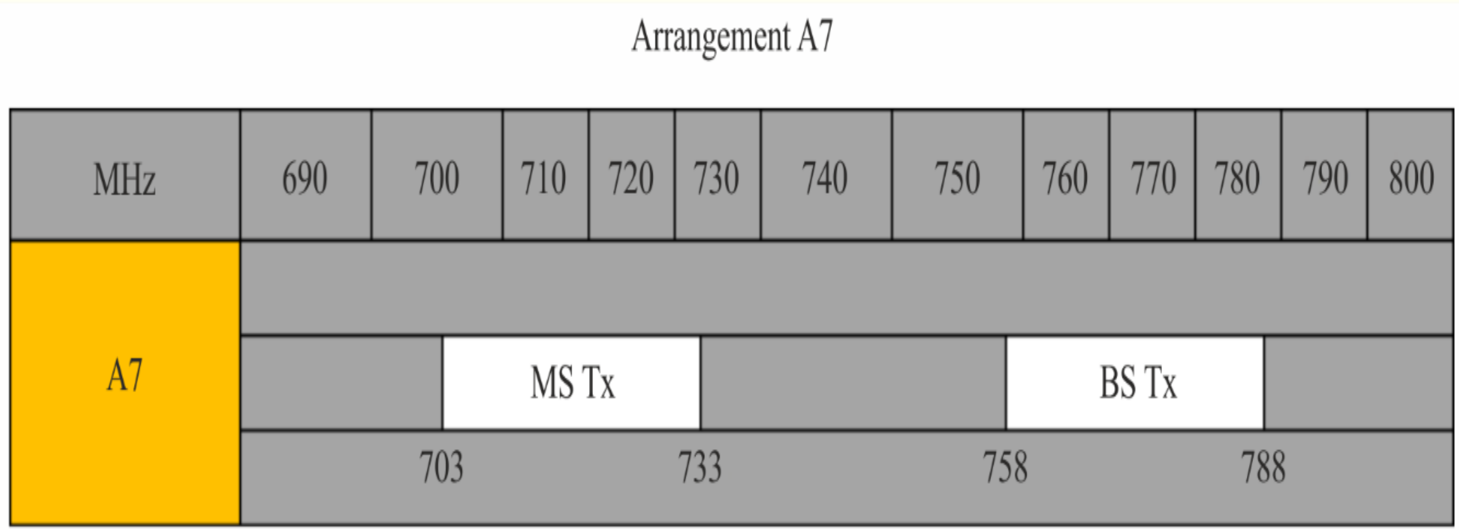
RF spacing in bands identified for IMT-2000. Based on Rec ITU-R M.1036 2020, parts of Fig. 3



Israel: A1 CDMA (Pelephone and Cellcom); A2 GSM (Partner)



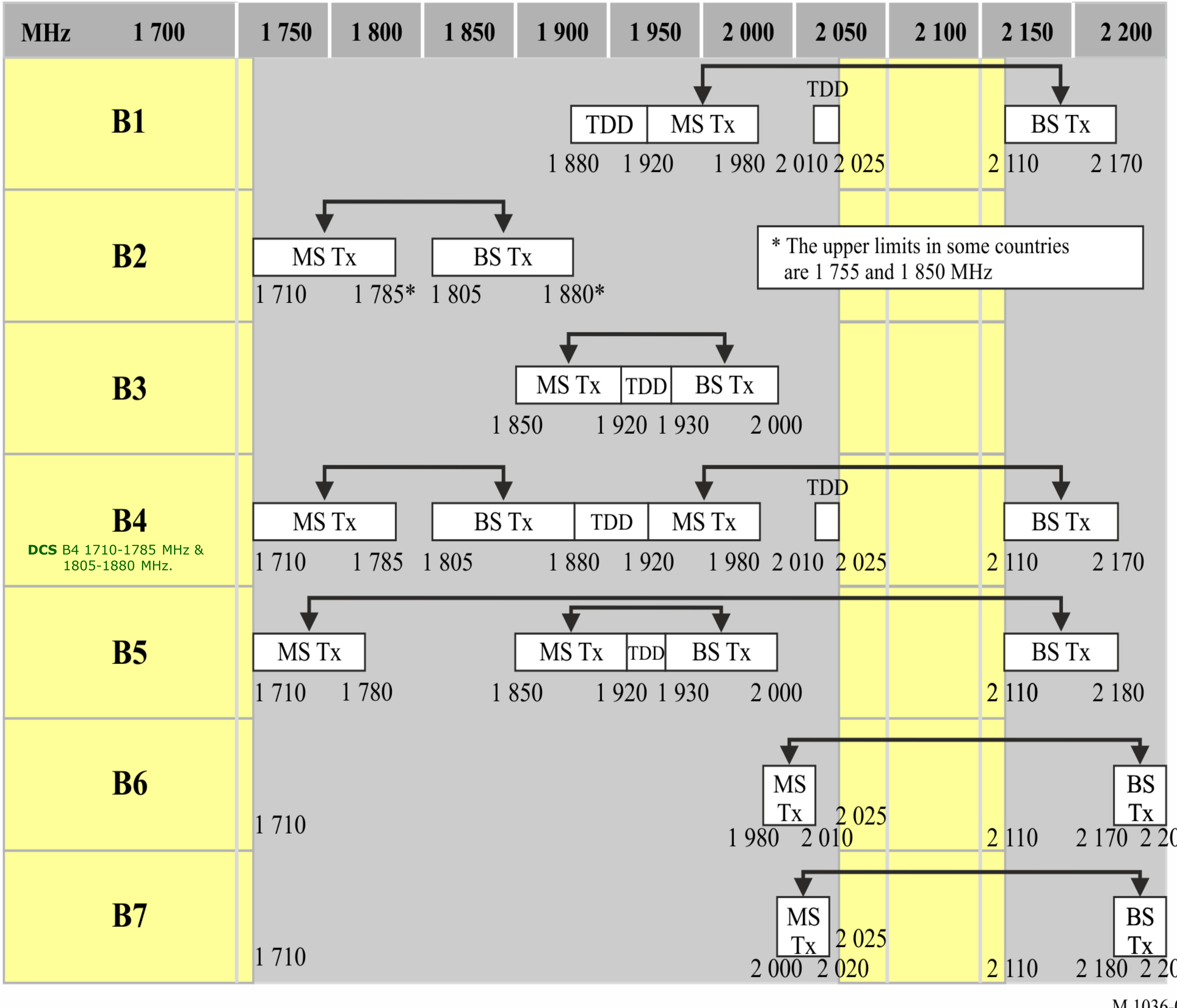
A3 digital-dividend 800 MHz



A7 digital-dividend 700 MHz

Dr. Haim Mazar (Madjar) haimma1@

RF spacing in bands identified for IMT-2000. Based on Rec ITU-R M.1036 Fig 5



1885-2025 MHz UL, & 2110-2200 MHz DL; UMTS. Israel

3GPP TS 36.101 V12.1.0 (2013-09) Table 5.5-1 E-UTRA LTE operating bands

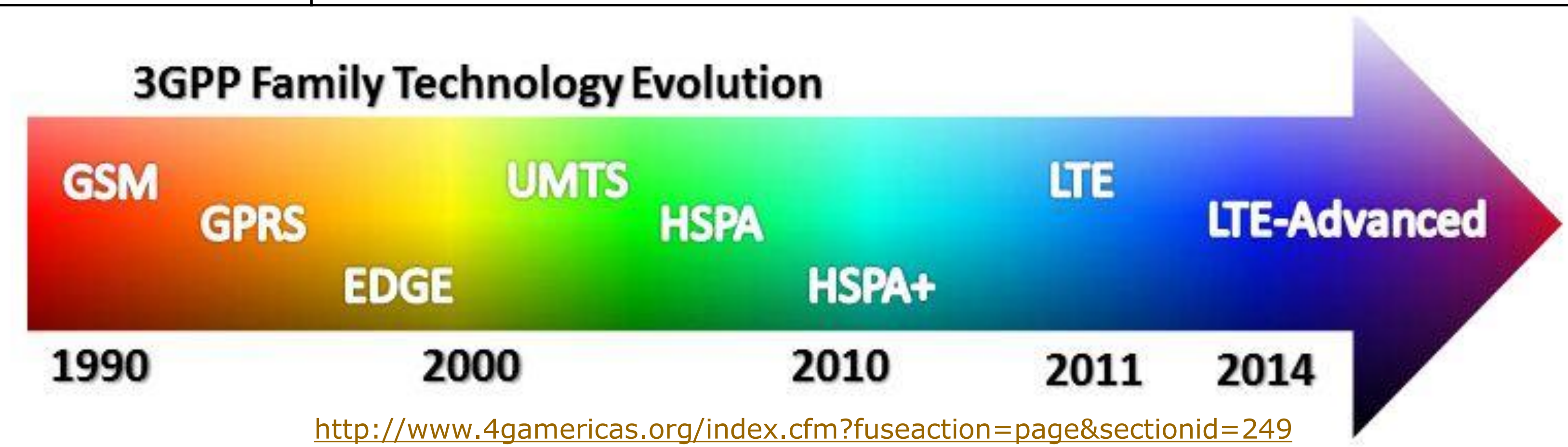
Operating Band	Uplink (UL) operating			Downlink (DL) operating band			Duplex Mode
1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz	FDD
2	1850 MHz	–	1910 MHz	1930 MHz	–	1990 MHz	FDD
3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz	FDD
4	1710 MHz	–	1755 MHz	2110 MHz	–	2155 MHz	FDD
5	824 MHz	–	849 MHz	869 MHz	–	894MHz	FDD
6[1]	830 MHz	–	840 MHz	875 MHz	–	885 MHz	FDD
7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz	FDD
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	FDD
9	1749.9 MHz	–	1784.9MHz	1844.9 MHz	–	1879.9 MHz	FDD
10	1710 MHz	–	1770 MHz	2110 MHz	–	2170 MHz	FDD
11	1427.9 MHz	–	1447.9 MHz	1475.9 MHz	–	1495.9 MHz	FDD
12	699 MHz	–	716 MHz	729 MHz	–	746 MHz	FDD
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz	FDD
14	788 MHz	–	798 MHz	758 MHz	–	768 MHz	FDD
15	Reserved						
16	FDD						
17	704 MHz	–	716 MHz	734 MHz	–	746 MHz	FDD
18	815 MHz	–	830 MHz	860 MHz	–	875 MHz	FDD
19	830 MHz	–	845 MHz	875 MHz	–	890 MHz	FDD
20	832 MHz	–	862 MHz	791 MHz	–	821 MHz	FDD
21	1447.9 MHz	–	1462.9 MHz	1495.9 MHz	–	1510.9 MHz	FDD
NOTE 1: Band 6 is not applicable							

Operating Band	Uplink (UL) operating			Downlink (DL) operating band			Duplex Mode
22	3410 MHz	–	3490 MHz	3510 MHz	–	3590 MHz	FDD
23	2000 MHz	–	2020 MHz	2180 MHz	–	2200 MHz	FDD
24	1626.5 MHz	–	1660.5 MHz	1525 MHz	–	1559 MHz	FDD
25	1850 MHz	–	1915 MHz	1930 MHz	–	1995 MHz	FDD
26	814 MHz	–	849 MHz	859 MHz	–	894 MHz	FDD
27	807 MHz	–	824 MHz	852 MHz	–	869 MHz	FDD
28	703 MHz	–	748 MHz	758 MHz	–	803 MHz	FDD
29	N/A			717 MHz	–	728 MHz	FDD[2]
30	2305 MHz	–	2315 MHz	2350 MHz	–	2360 MHz	FDD
31	452.5 MHz	–	457.5 MHz	462.5 MHz	–	467.5 MHz	FDD
...							
33	1900 MHz	–	1920 MHz	1900 MHz	–	1920 MHz	TDD
34	2010 MHz	–	2025 MHz	2010 MHz	–	2025 MHz	TDD
35	1850 MHz	–	1910 MHz	1850 MHz	–	1910 MHz	TDD
36	1930 MHz	–	1990 MHz	1930 MHz	–	1990 MHz	TDD
37	1910 MHz	–	1930 MHz	1910 MHz	–	1930 MHz	TDD
38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz	TDD
39	1880 MHz	–	1920 MHz	1880 MHz	–	1920 MHz	TDD
40	2300 MHz	–	2400 MHz	2300 MHz	–	2400 MHz	TDD
41	2496 MHz		2690 MHz	2496 MHz		2690 MHz	TDD
42	3400 MHz	–	3600 MHz	3400 MHz	–	3600 MHz	TDD
43	3600 MHz	–	3800 MHz	3600 MHz	–	3800 MHz	TDD
44	703 MHz	–	803 MHz	703 MHz	–	803 MHz	TDD

Benefits resulting from technology choices, evolution to UMTS

Technology	Benefits
GSM/GPRS with coding schemes 1 to 2	IP packet data service delivers effective throughputs of up to 40 kbit/s for four-slot devices
GSM/GPRS with coding schemes 1 to 4	Includes an option for operators to boost speeds of GPRS service by 33%
GSM/GPRS/EDGE	Third-generation technology effectively triples GPRS data rates and doubles spectral efficiency
IMT-2000 CDMA Direct Spread	Supports flexible, integrated voice/data services with peak rates of 2 Mbit/s
HSDPA	An enhancement to UMTS and fully backwards compatible. HSDPA will offer peak data rates of 14.2 Mbit/s

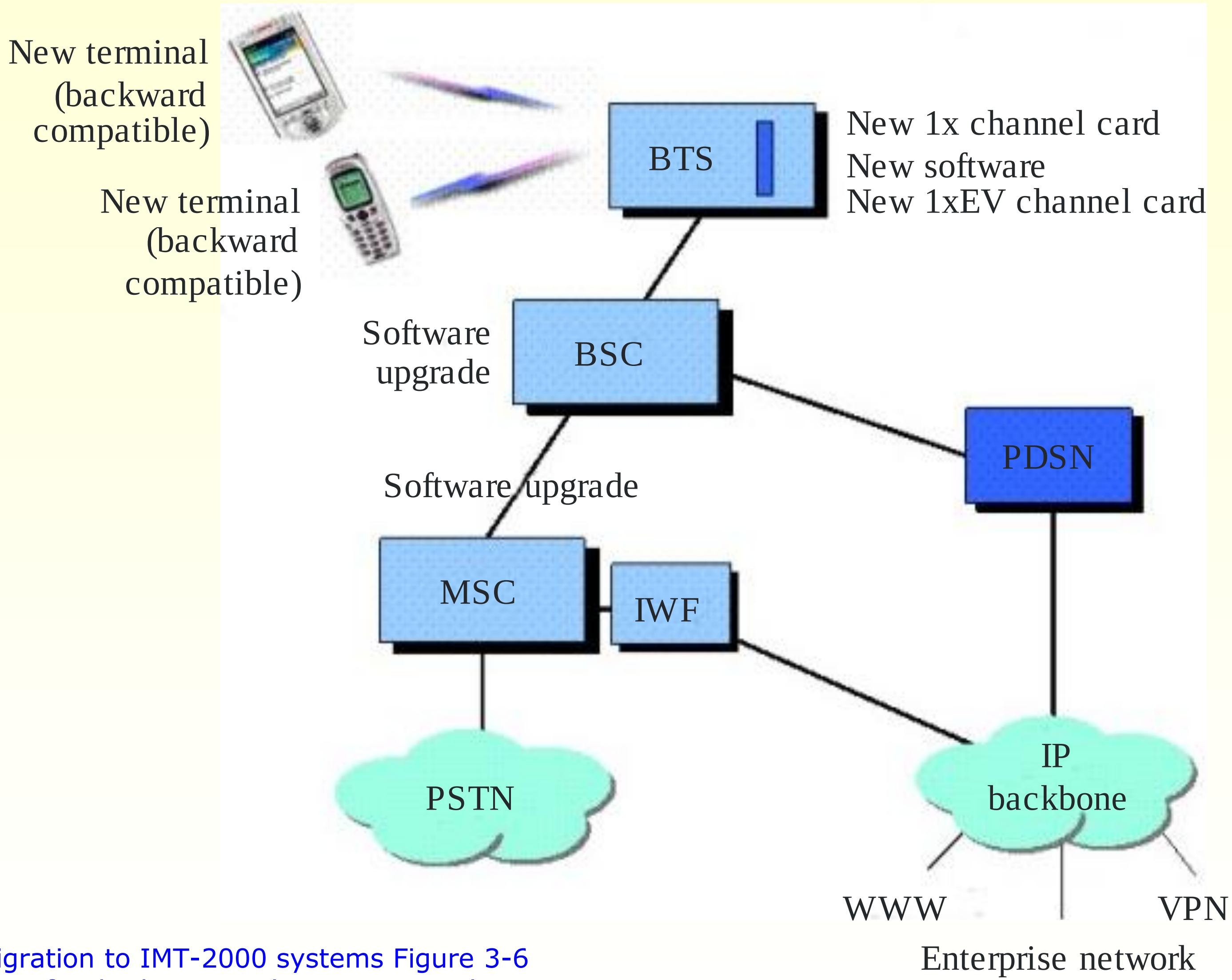
ITU HB 2011 Migration to IMT-2000 Table 3-1



http://www.4gamericas.org/index.cfm?fuseaction=page&sectionid=249

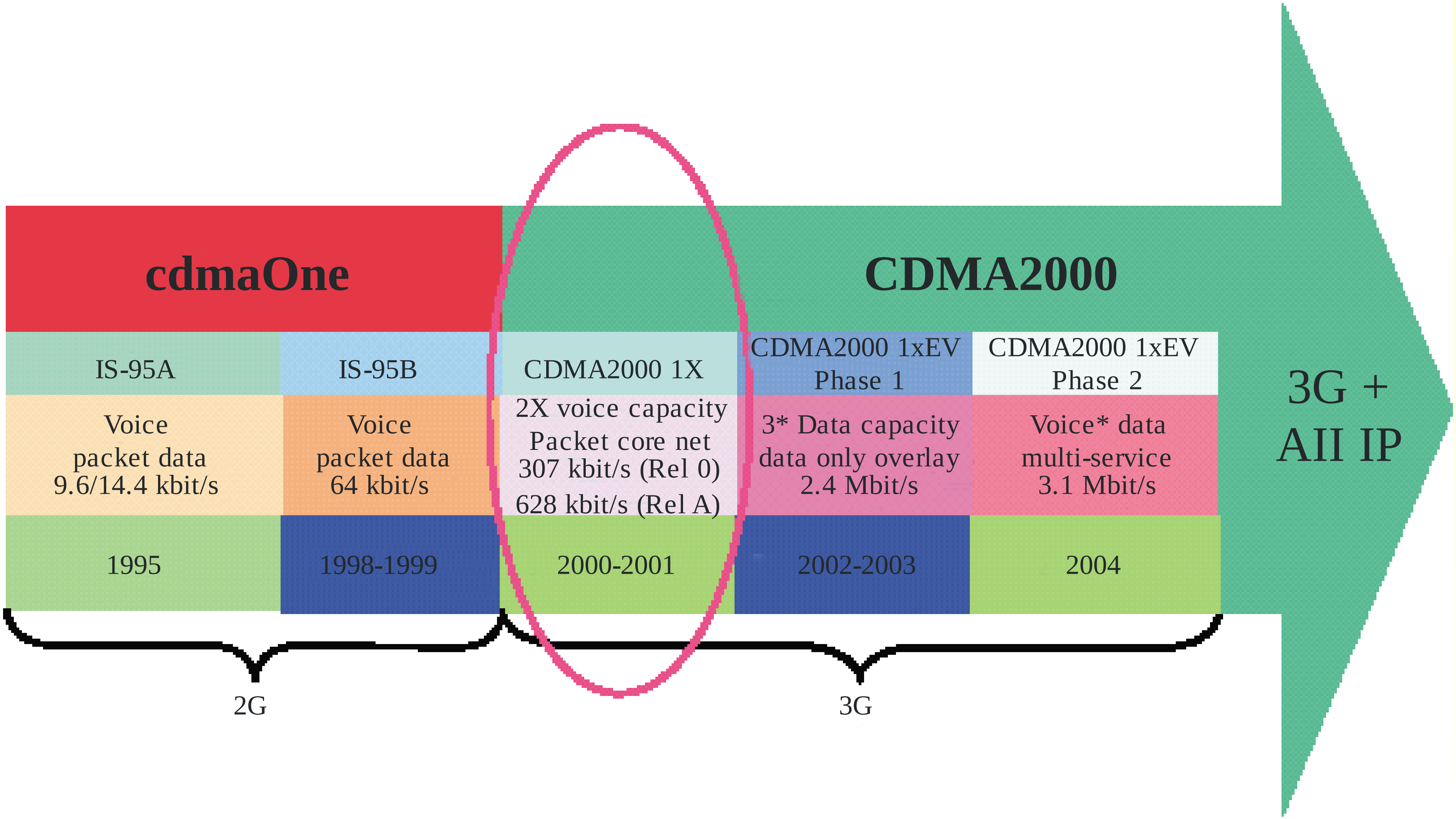
Evolution path from cdmaOne to CDMA2000

Adding CDMA2000 1xEV



ITU HB 2011 Migration to IMT-2000 systems Figure 3-6
This is the case of Pelephone evolution in Israel

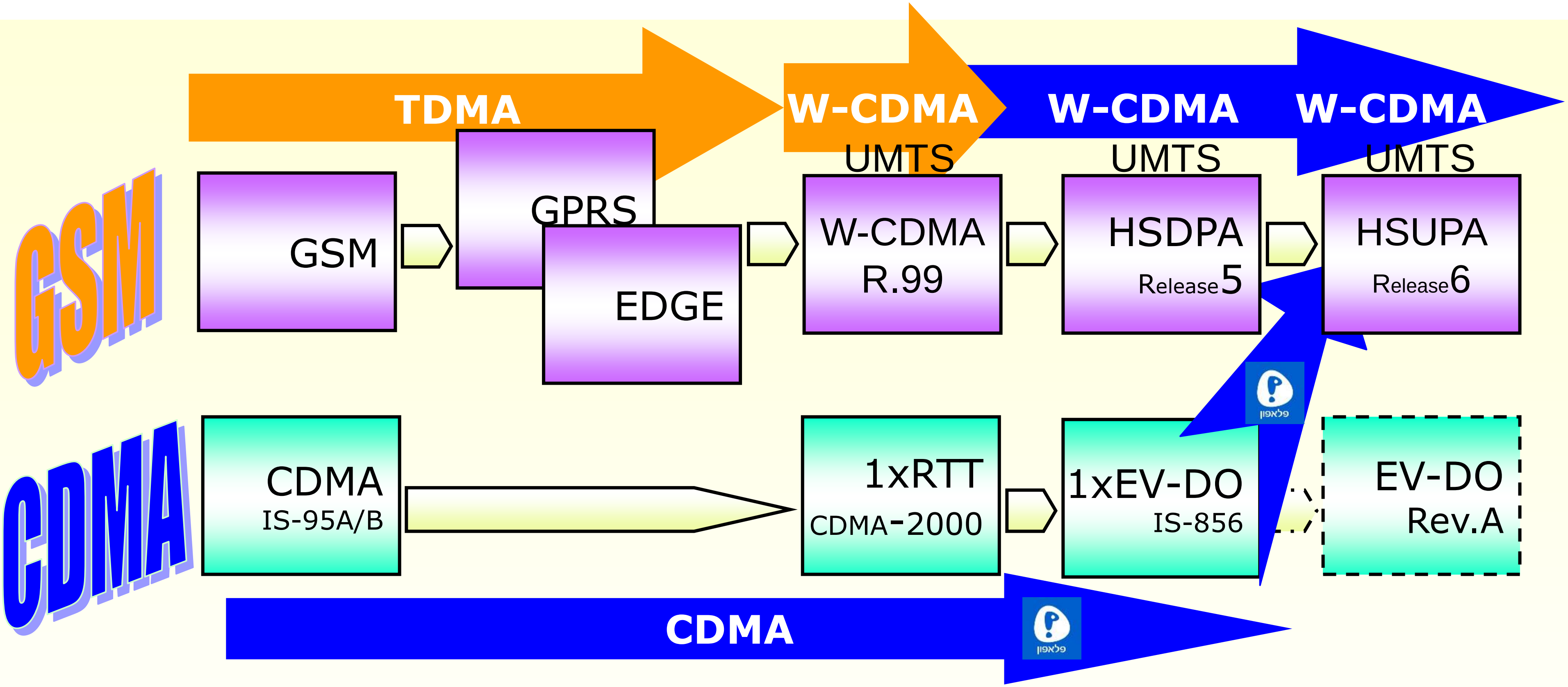
Deplo-IMT-03-6



Pelephone 824-835; 869-870
ITU HB 2011 Migration to IMT-2000 systems Figure 3-8

Deplo-IMT-03-8

An operator (Pelephone) evolution (Gidi)



GPRS: General Packet Radio Service

EVDO: EVolution - Data Optimized (Data Only)

EDGE: Enhanced Data rates for Global Evolution

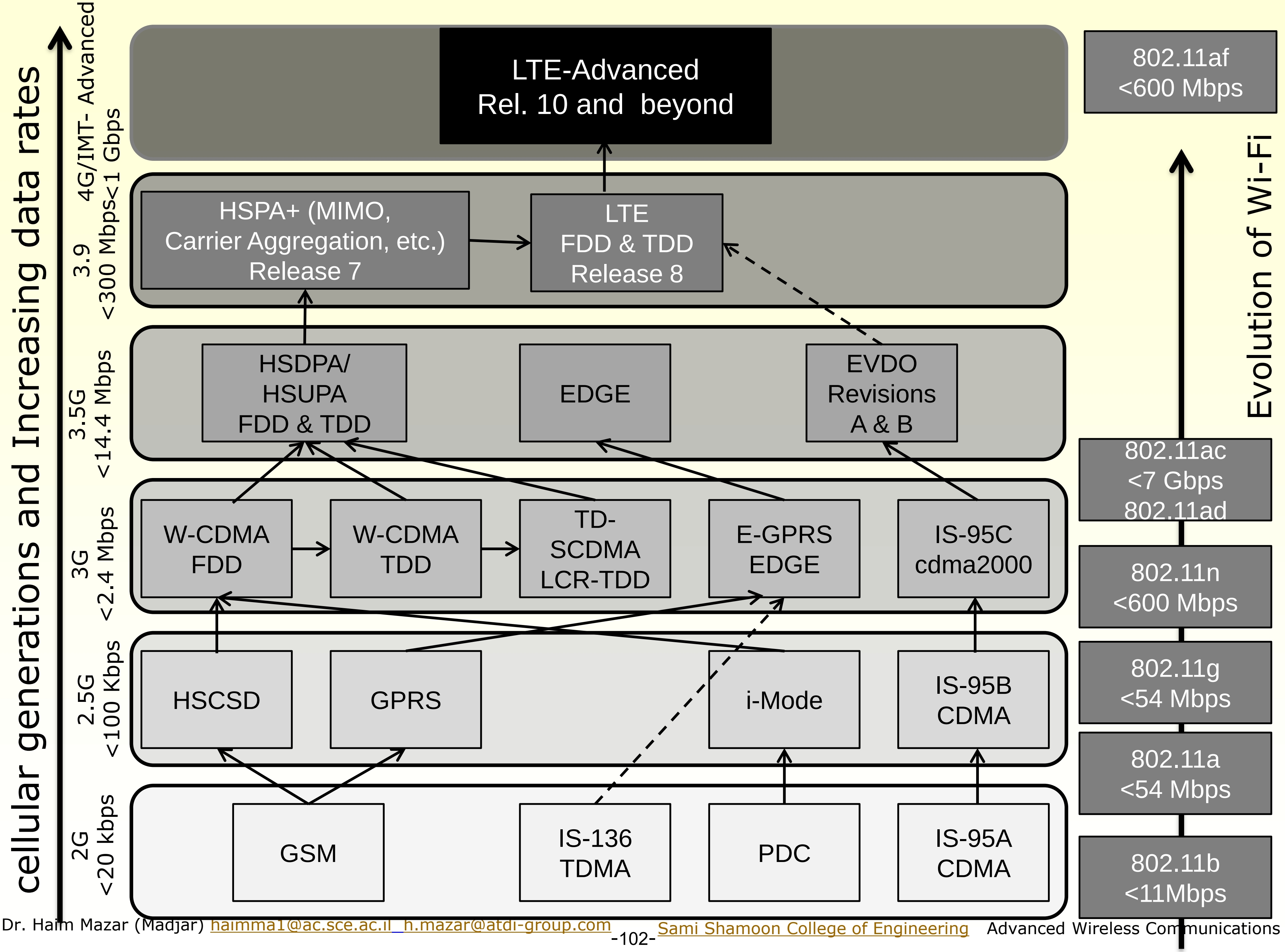
UMTS: Universal Mobile Telecommunications System

W-CDMA Wideband Code-Division Multiple Access

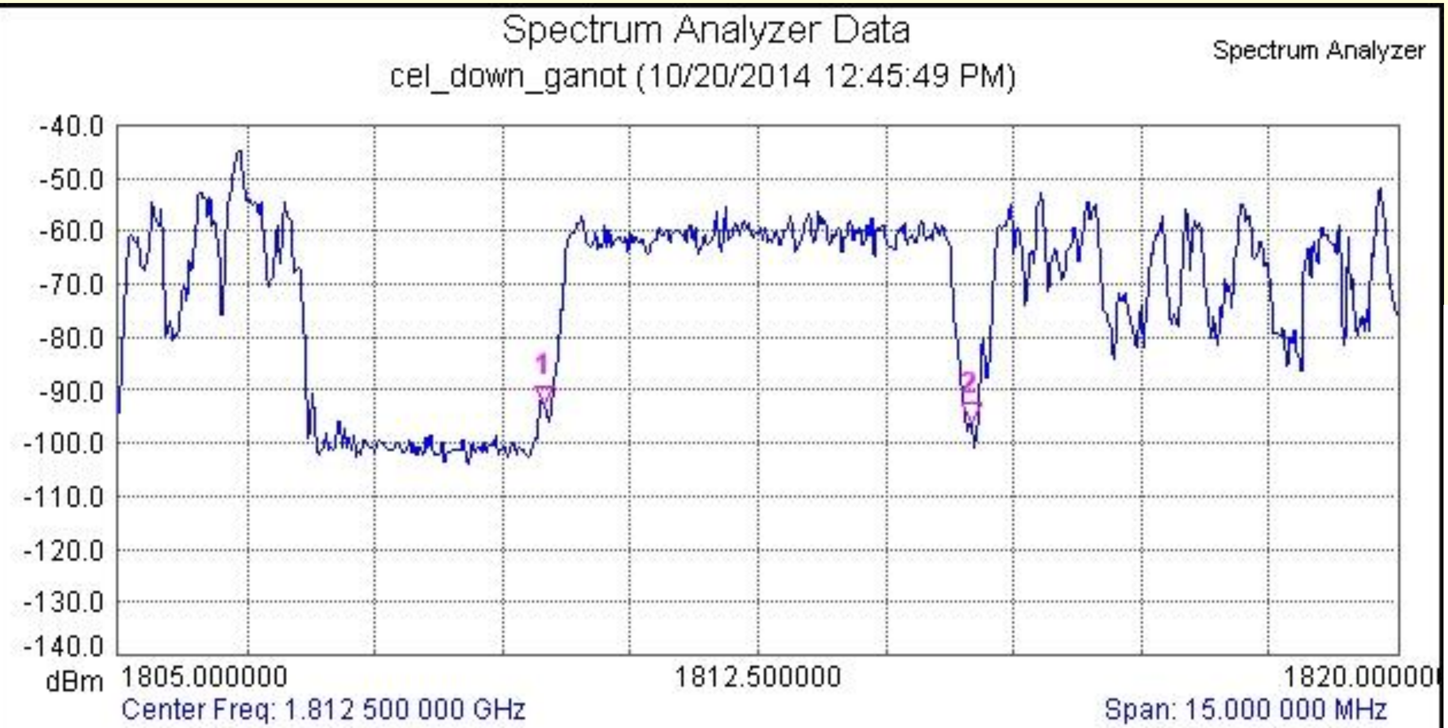
HSDPA: High-Speed Downlink Packet Access

HSUPA: High-Speed Uplink Packet Access

RTT: Radio Transmission Technology


cellular generations and Increasing data rates
2G <20 kbps
2.5G <100 Kbps
3G <2.4 Mbps
3.5G <14.4 Mbps
3.9 <300 Mbps
4G/IMT- Advanced <1 Gbps
LTE-Advanced Rel. 10 and beyond
HSPA+ (MIMO, Carrier Aggregation, etc.) Release 7
LTE FDD & TDD Release 8
HSDPA/ HSUPA FDD & TDD
EDGE
EVDO Revisions A & B
W-CDMA FDD
W-CDMA TDD
TD-SCDMA LCR-TDD
E-GPRS EDGE
IS-95C cdma2000
HSCSD
GPRS
i-Mode
IS-95B CDMA
GSM
IS-136 TDMA
PDC
IS-95A CDMA
802.11af <600 Mbps
Evolution of Wi-Fi
802.11ac <7 Gbps 802.11ad
802.11n <600 Mbps
802.11g <54 Mbps
802.11a <54 Mbps
802.11b <11Mbps

Real Measurements of GSM 1800 and LTE signals



Mkr	Ref	Delta	Ref Freq	Ref Amp	Delta Freq	Delta Amp
1	☐	☐	1.810 0 GHz	-92.71 dBm	- -	- -
2	☐	☐	1.815 0 GHz	-96.16 dBm	- -	- -

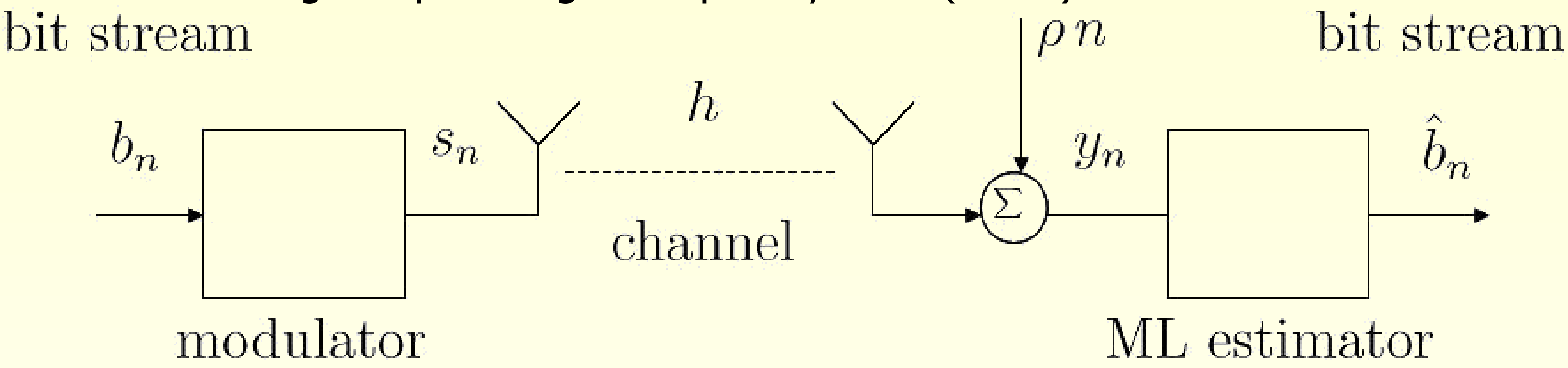
Measurement Parameters

		Reference Level	-40.000 dBm
Trace Mode	Max Hold	Scale	10.0 dB/div
Preamp	OFF	GPS Longitude	E 34 48 56
Min Sweep Time	0.001 S	GPS Latitude	N 32 0 45
Reference Level Offset	0 dB	GPS Fix Time	10 20 2014 11 02 44
Input Attenuation	0.0 dB	Serial Number	1005175
RBW	30.0 kHz	Base Ver.	V3.46
VBW	30.0 kHz	App Ver.	V4.40
Detection	Peak	Model	MS2724B
Center Frequency	1.812 500 000 GHz	Options	25, 27, 31
Start Frequency	1.805 000 000 GHz	Date	10/20/2014 12:45:49 PM
Stop Frequency	1.820 000 000 GHz	Device Name	
Frequency Span	15.000 000 MHz		

According to Rec. ITU-R M.1036, 1,805-1,880 MHz are the downlink of Band 2, and Band 3 of 3GPP TS 36.104. This band was most useful for GSM-1800 (DCS-1800) and nowadays for LTE. Real signals measured on 20 October 2014: the downlink adjacent GSM-1800, 200KHz channel separation; & LTE 1,810-1,815 MHz, 5 MHz bandwidth.

Cellular - Maximum Likelihood Comms

Single Input Single Output System (SISO) Dr. Doron Ezri



$$S_{Rx} = -174\,dBm/Hz + 10\cdot\log(\underbrace{\overbrace{15kHz\cdot 12}^{\text{Single RB bandwidth}}\cdot\#RB}_{\text{Receiver bandwidth}}) + NF + SINR$$

Single RB bandwidth

Receiver bandwidth

Noise power

RB- Resource Block

Nokia Siemens

Field measurement parameters

based on Nokia Siemens

- Terminals are measuring from serving cell:
  - RSRP (Reference Signal Received Power)
  - RSRQ (Reference Signal Received Quality)
- Scanners are measuring from all decoded cells:
  - RSRP
  - RSRQ
  - Wideband channel power, RSSI (Received Signal Strength Indicator) RSSI is common for all GSM family
  - Primary & Secondary Synchronization Channels: P-SCH, S-SCH power
  - Reference signal SINR $\frac{signal}{\text{int}\,erference + noise}$
- System and link level simulations gives SINR thresholds for a certain service level- MCS (Modulation and Coding Scheme) or throughput
- RSRP and RSRQ are more common measurements

⇒ **Mapping from SINR thresholds to RSRP/RSRQ threshold needed**

RSRP & RSRQ

RSRP (only for LTE/5G):

- RSRP is the power of a single resource element
- UE measures the power of multiple resource elements used to transfer the reference signal but then takes an average of them rather than summing them.
- Reporting range -44…-140 dBm

- **RSRQ:**
- RSRQ = RSRP / (RSSI/N)

N is the number of resource blocks over which the RSSI is measured

RSSI is wide band power, including intracell power, interference and noise.

- Reporting range -3…-19.5dB

3GPP RSRP Definition:
Reference signal received power (RSRP) is the linear average power over the power contributions of the resource elements that carry cell-specific reference signals within the considered measurement frequency bandwidth

3GPP RSRQ Definition:
Reference Signal Received Quality (RSRQ) is the ratio *N*×RSRP/(E-UTRA carrier RSSI), where *N* is the number of RBs of the E-UTRA carrier RSSI measurement bandwidth. The measurements in the numerator and denominator shall be made over the same set of resource blocks.
E-UTRA Carrier Received Signal Strength Indicator (RSSI) comprises the linear average power of the total received power observed only in OFDM symbols containing reference symbols for antenna port 0, in the measurement bandwidth, over *N* number of resource blocks by the UE from all sources, including co-channel serving and non-serving cells, adjacent channel interference, thermal noise etc

Mapping between RSRP, RSRQ & SINR (1/2)

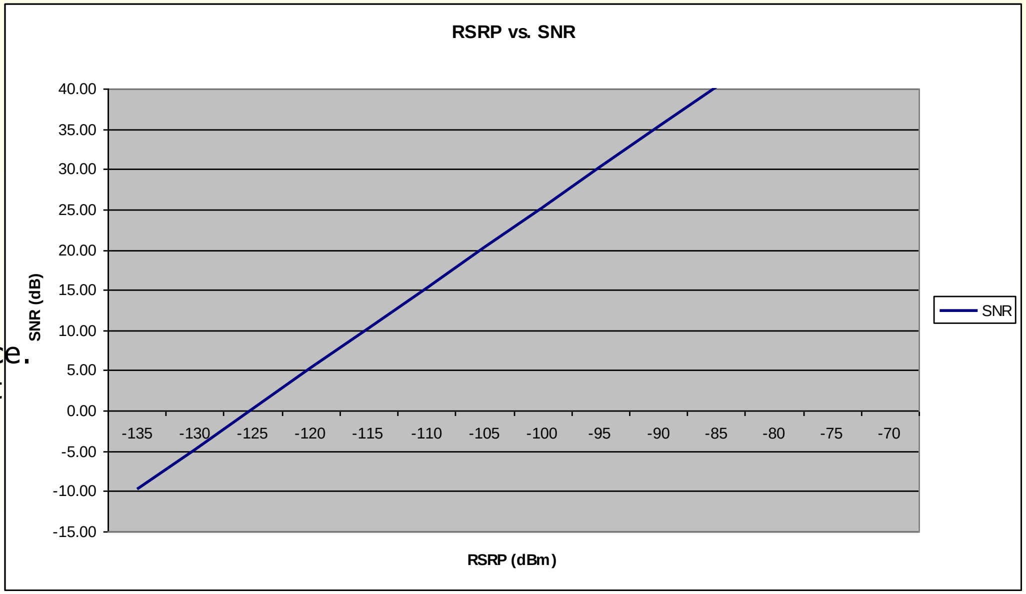
Based on Nokia Siemens

SNR vs RSRP has a linear relation

$$SNR = \frac{RSRP}{P_{n\_RE}}$$

$$P_{n\_RE} = 15KHz\_noise\_power$$

- RSRP is measured for a single subcarrier
  - noisepower_for_15KHz= -125.2dBm
    - Including Noise figure UE = 7 dB
- Assumption: RSRP doesn’t contain noise power



Curve gives upper limit to SINR with certain RSRP. SINR is always lower than SNR in in live network due to interference. If Interference considered the curve would move to the left
-174+10*log15k+NF

RSRQ values higher than −9dB guarantee the best subscriber experience; the range between −9 and −12dB can be seen as neutral with a slight degradation of QoS; starting with RSRQ values of −13dB and lower, significant declines of throughput and a high risk of call drop; see Kreher R. and Gaenger K. 2011: p. 231

Mapping between RSRP, RSRQ & SINR (2/2)

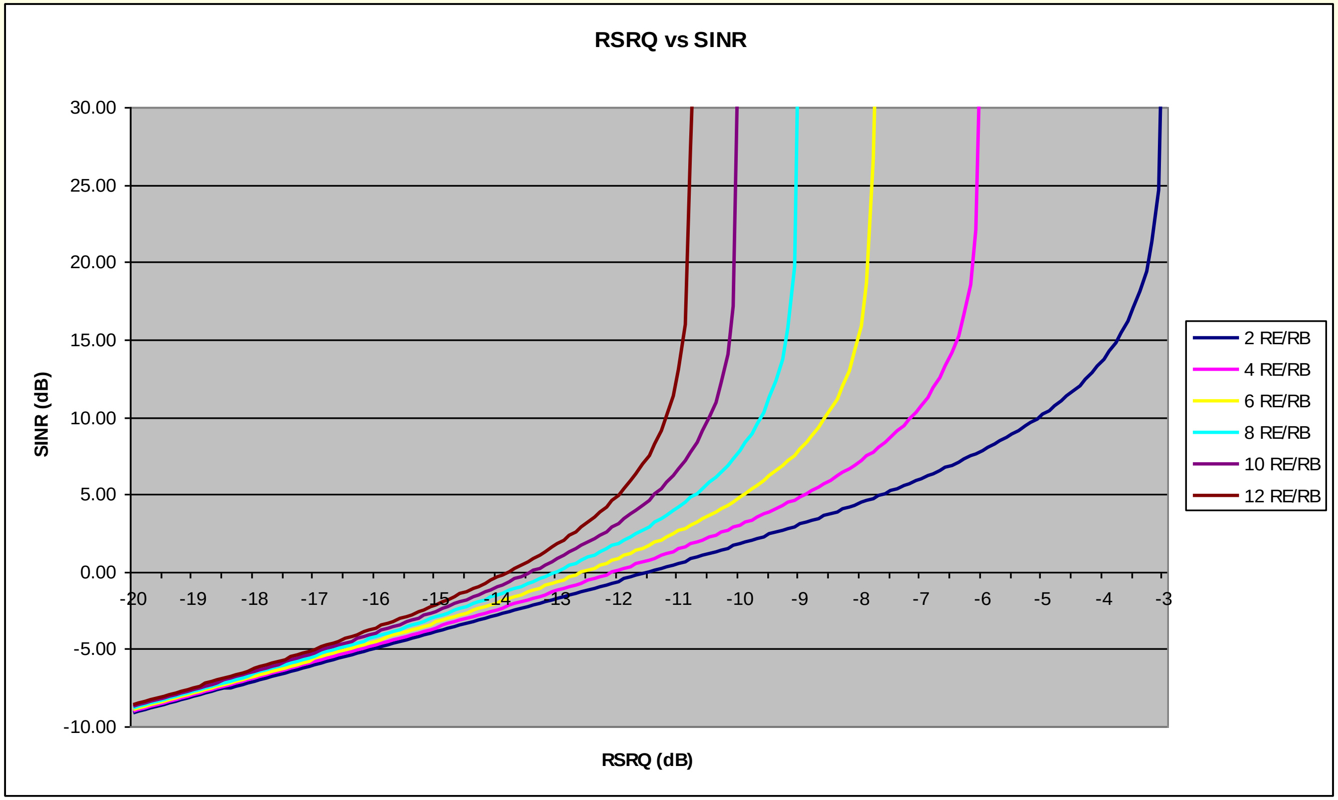
Based on Nokia Siemens

- RSRQ depends on own cell traffic load, but SINR doesn't depend on own cell load
  - Used Resource Elements per Resource Block (RE/RB) in serving cell is an input parameter for RSRQ -> SINR mapping
  - Assumption: RSRP doesn't contain noise power

- Equation used:

$$SINR = \frac{12}{\frac{1}{RSRQ} - RE/RB}$$

- 2, RE/RB equals to empty cell. Only Reference Signa power is considered from serving cell.
- 12, RE/RB equals to fully loaded serving cell. All resource elements are carrying data.



Link Budget , RSSI and RSRP

Based on Nokia Siemens

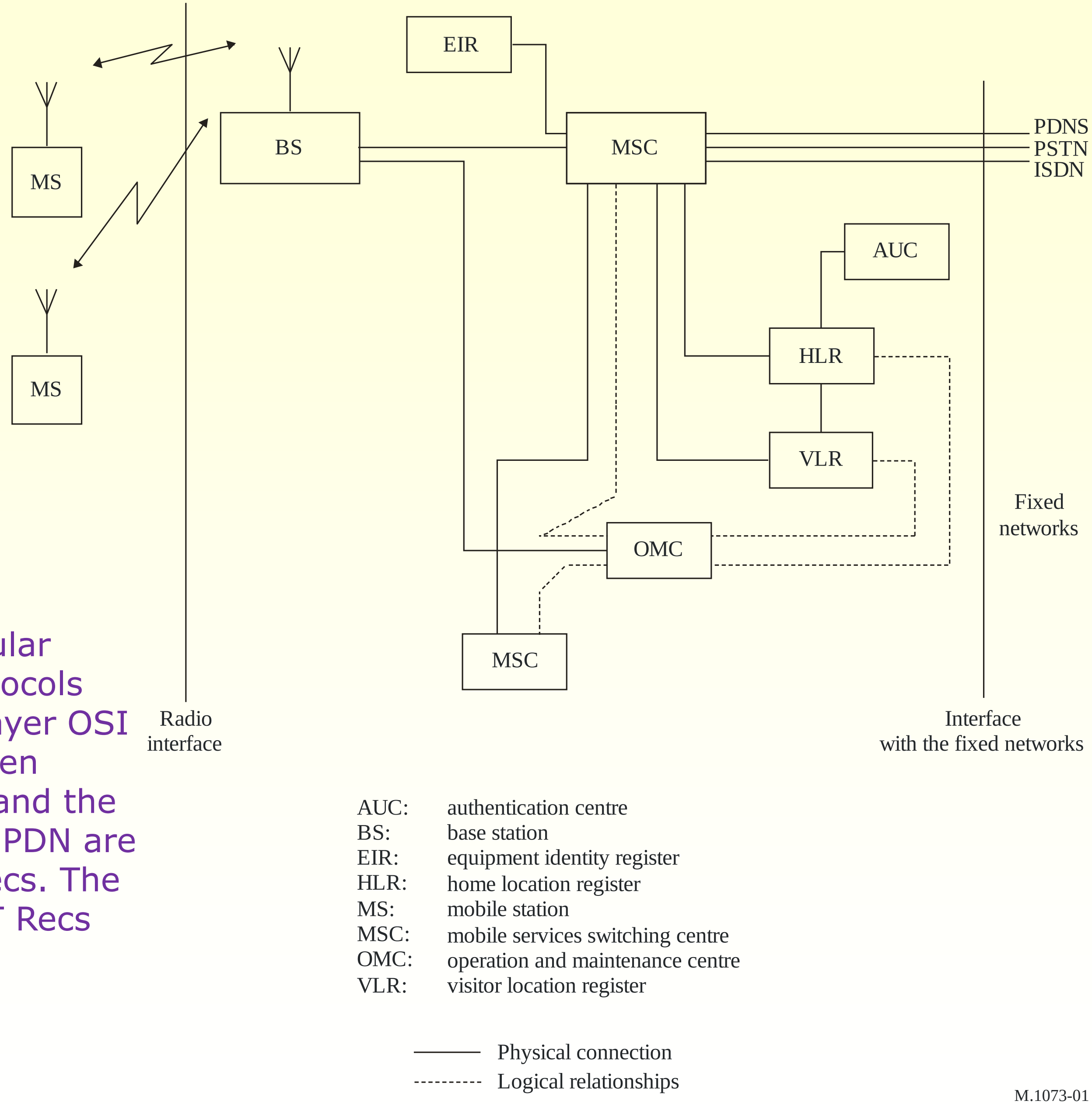
- LiBu provides the RSSI
  - RSSI = wideband power= noise + serving cell power + interference power
  - RSSI at the cell edge is the Rx Sensitivity
    - RSSI=12*N*RSRP
  - RSRP is the received power of 1 RE (3GPP definition) average of power levels received across all Reference Signal symbols within the considered measurement frequency bandwidth
  - RSSI per resource block is measured over 12 resource elements (100% of the power is considered i.e. 43dBm)
  - N: number of RBs across the RSSI is measured and depends on the BW
    - Based on the above under full load and high SNR (Note: In lab conditions it is possible to know the load not in real networks.):

If we keep these other factors equal: RF, the same data rate, penetration loss: maxi ranges of LTE and 3G are very similar

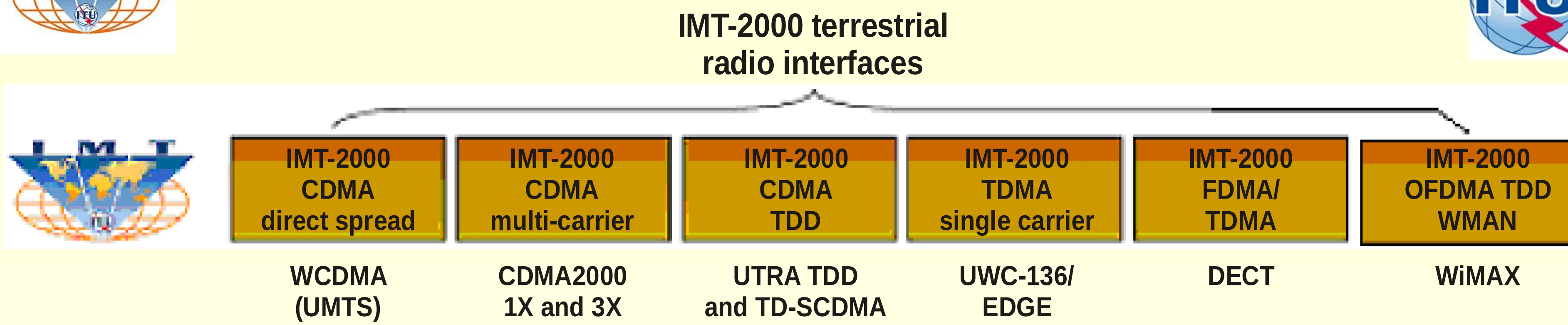
RSRP (dBm)= RSSI (dBm) -10*log (12*N)

BW	1.4MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
# RB	6	15	25	50	75	100
Scaling:[-10log (12N)]	-18.57	-22.55	-24.77	-27.78	-29.54	-30.79

Network architecture (Rec. ITU-R M.1073) (2012)



Basic system architecture for cellular systems. The communication protocols are specified according to the 7-layer OSI model, while the interfaces between mobile switching centres (MSCs) and the interfaces to the ISDN, PSTN and PDN are all specified according to ITU-T Recs. The numbering plan also follows ITU-T Recs



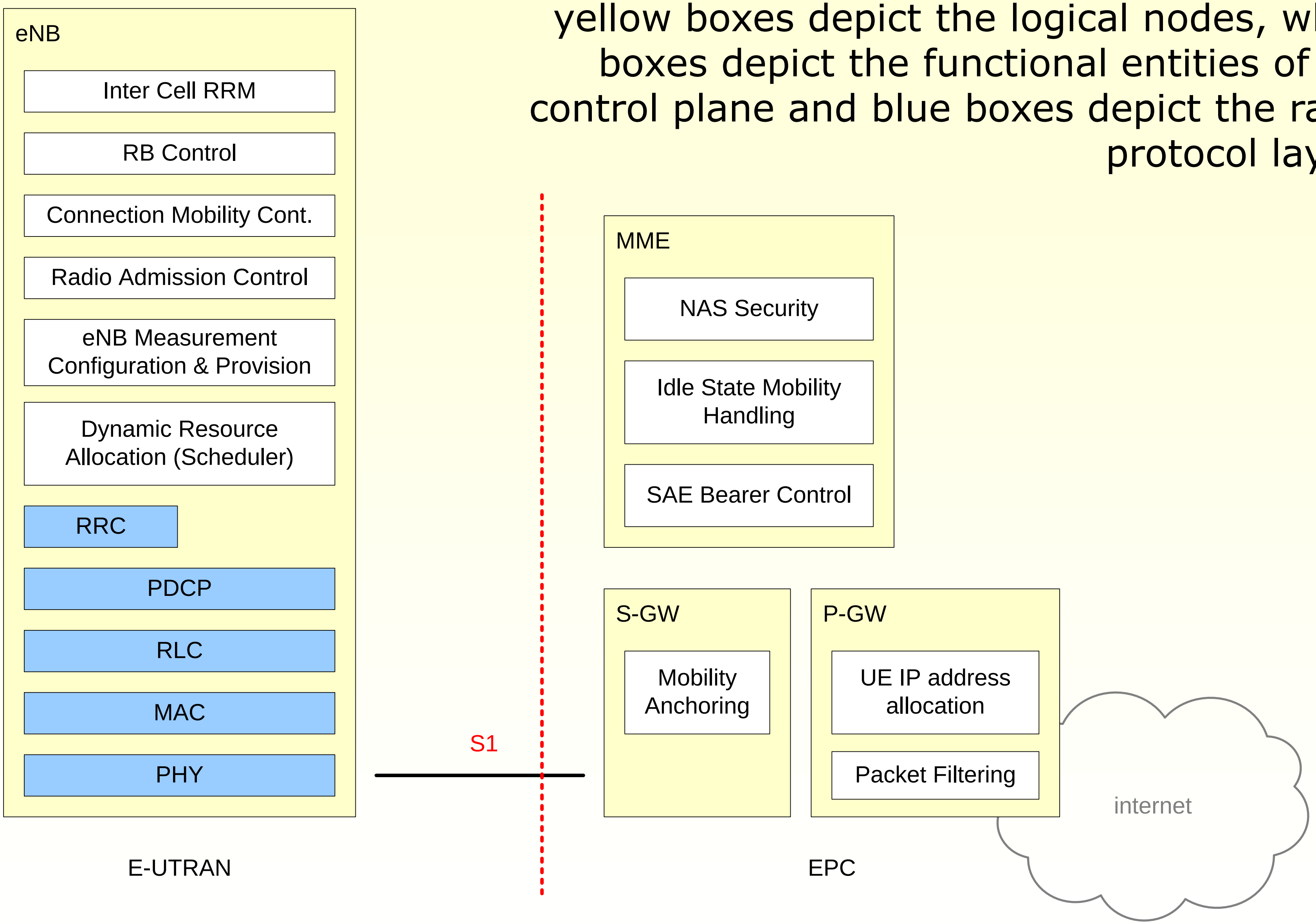
Deplo-IMT-05

Full Name	Common Names	External Organizations
IMT-2000 CDMA Direct Spread	UTRA FDD, WCDMA, UMTS	3GPP
IMT-2000 CDMA Multi-Carrier	CDMA2000 1x and 3x, CDMA2000 EV-DO	3GPP2
IMT-2000 CDMA TDD (time-code)	UTRA TDD 3.84 mchip/s high chip rate, UTRA TDD 1.28 mchip/s low chip rate, TD-SCDMA, UMTS	3GPP
IMT-2000 TDMA Single-Carrier	UWC-136, EDGE, GERAN	ATIS WTSC and TIA
IMT-2000 FDMA/TDMA (frequency-time)	DECT	ETSI
IMT-2000 OFDMA TDD WMAN	WiMAX, WirelessMAN-OFDMA	IEEE

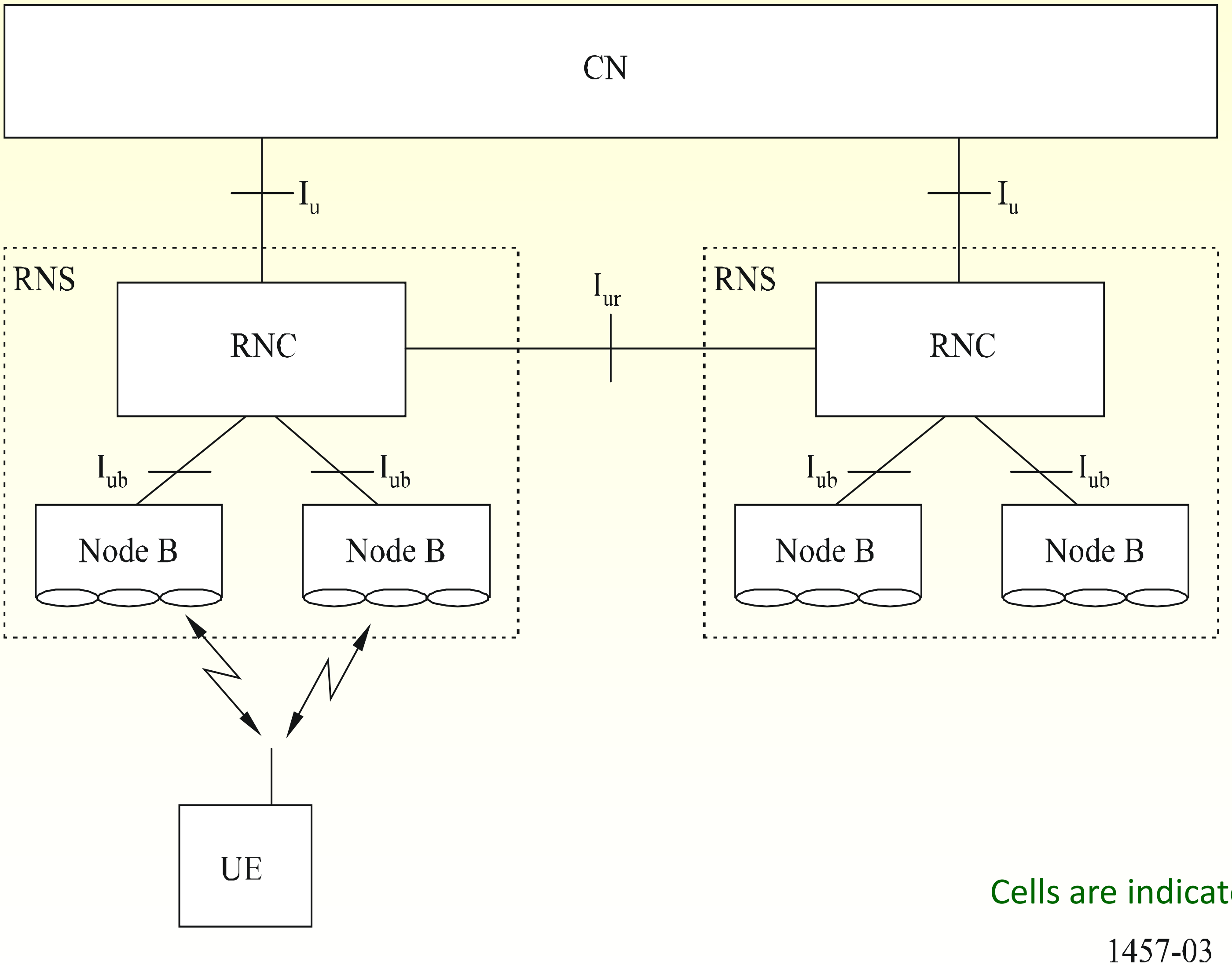
IMT-2000 Terrestrial Radio Interfaces: External Organizations

Overall architecture of the E-UTRAN radio access network (M.1457)

yellow boxes depict the logical nodes, white boxes depict the functional entities of the control plane and blue boxes depict the radio protocol layers

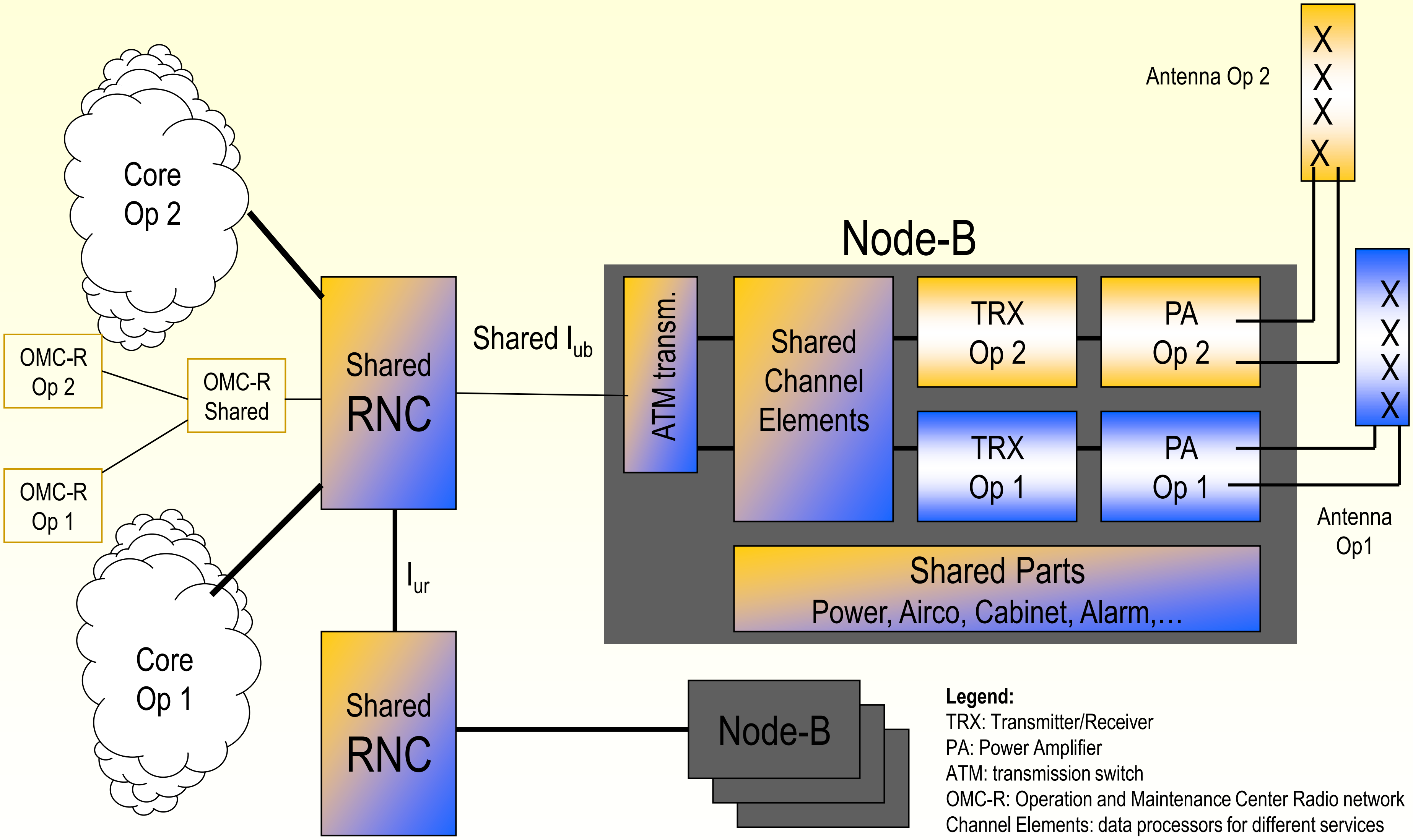


UMTS Radio Access Network architecture M.1457 2019



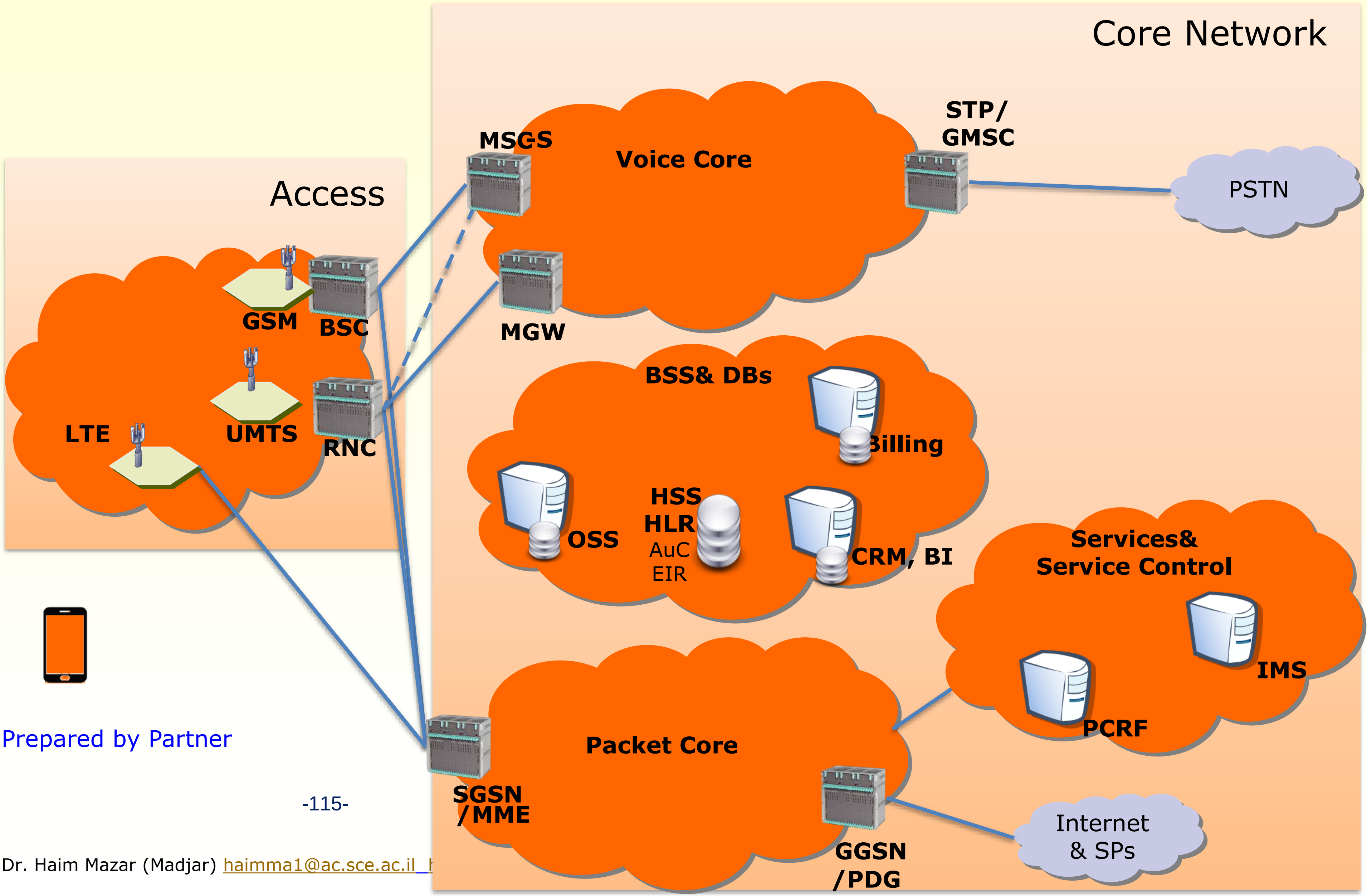
Cells are indicated by ellipses

UMTS RAN-Sharing: full RAN sharing



Legend:
TRX: Transmitter/Receiver
PA: Power Amplifier
ATM: transmission switch
OMC-R: Operation and Maintenance Center Radio network
Channel Elements: data processors for different services
RNC: Radio Network Controller
Iub: logical connection (or interface) between RNC and Node-B

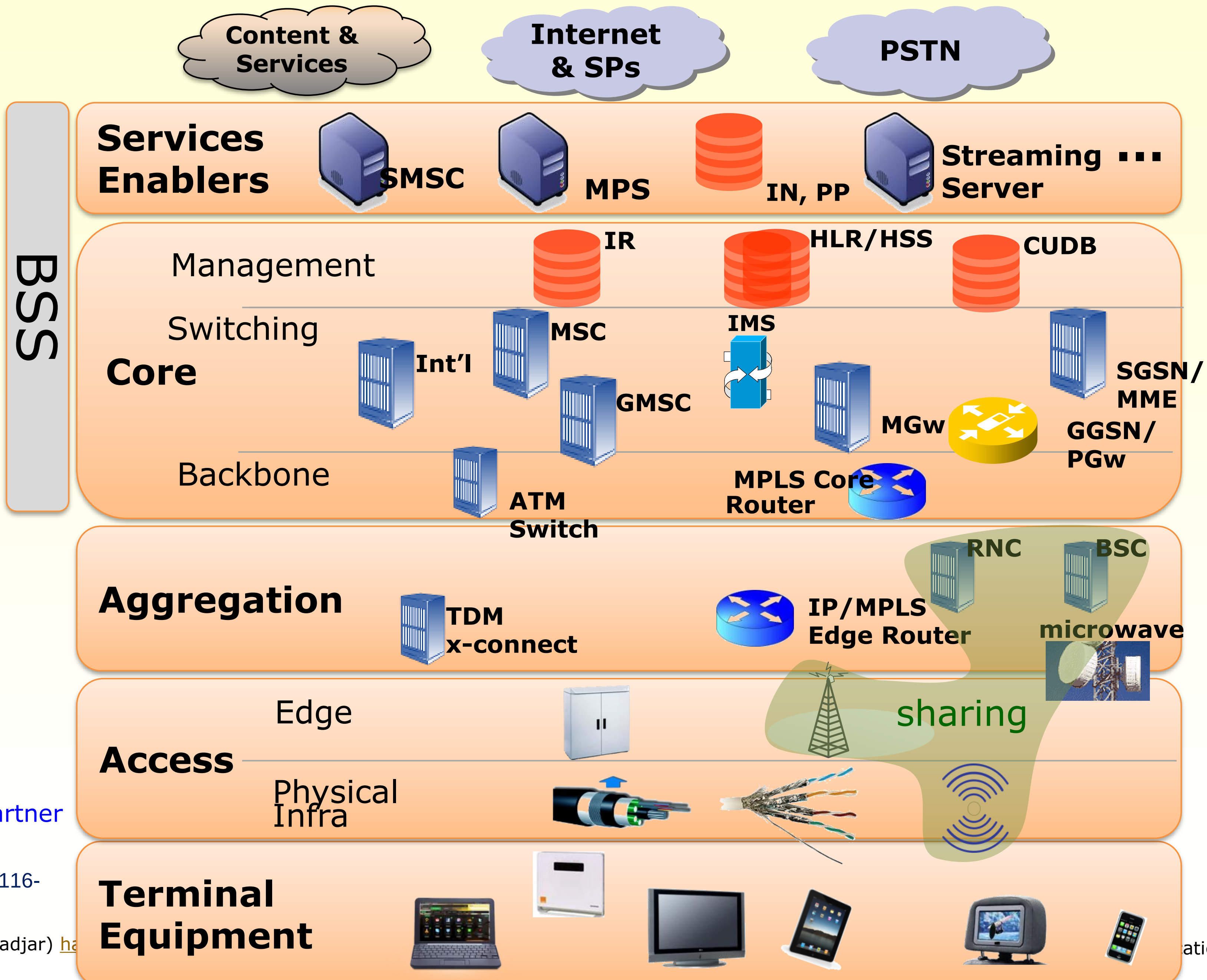
3G-4G Cellular Architecture



Prepared by Partner

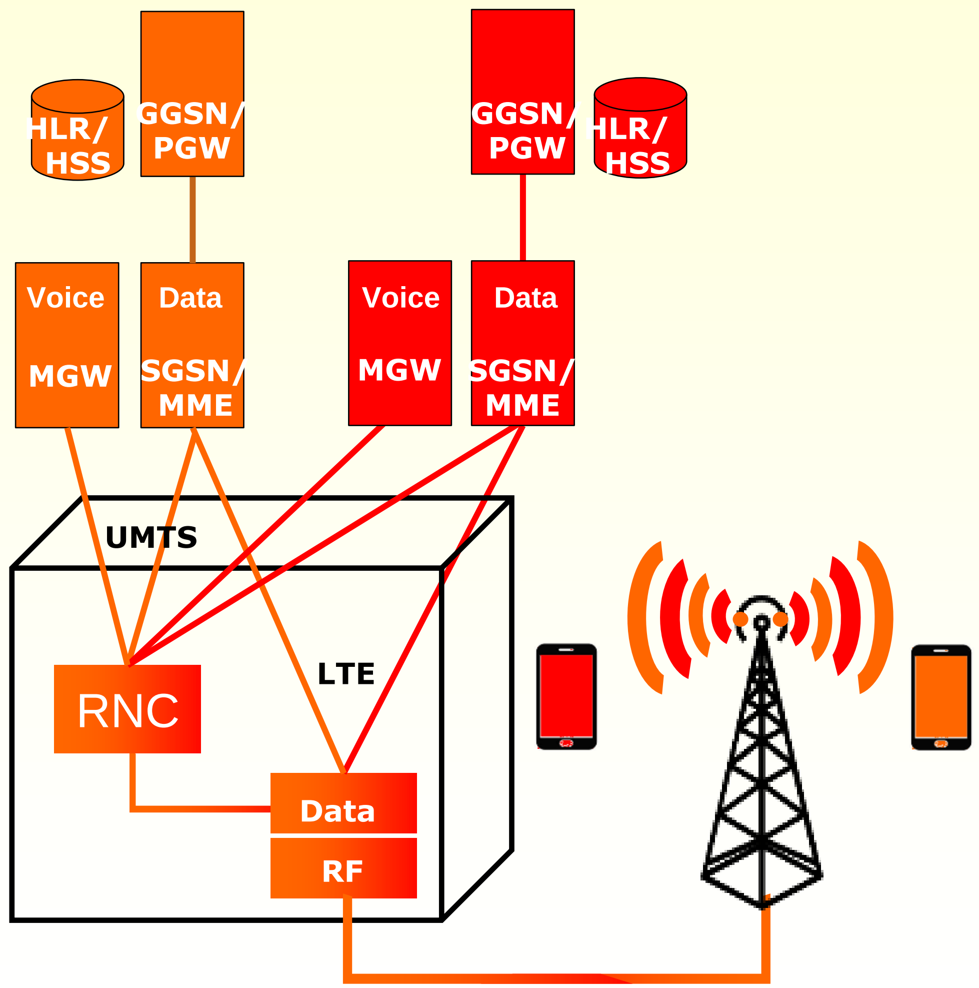
Dr. Haim Mazar (Madjar) haimma1@ac.sce.ac.il

Cellular subsystems

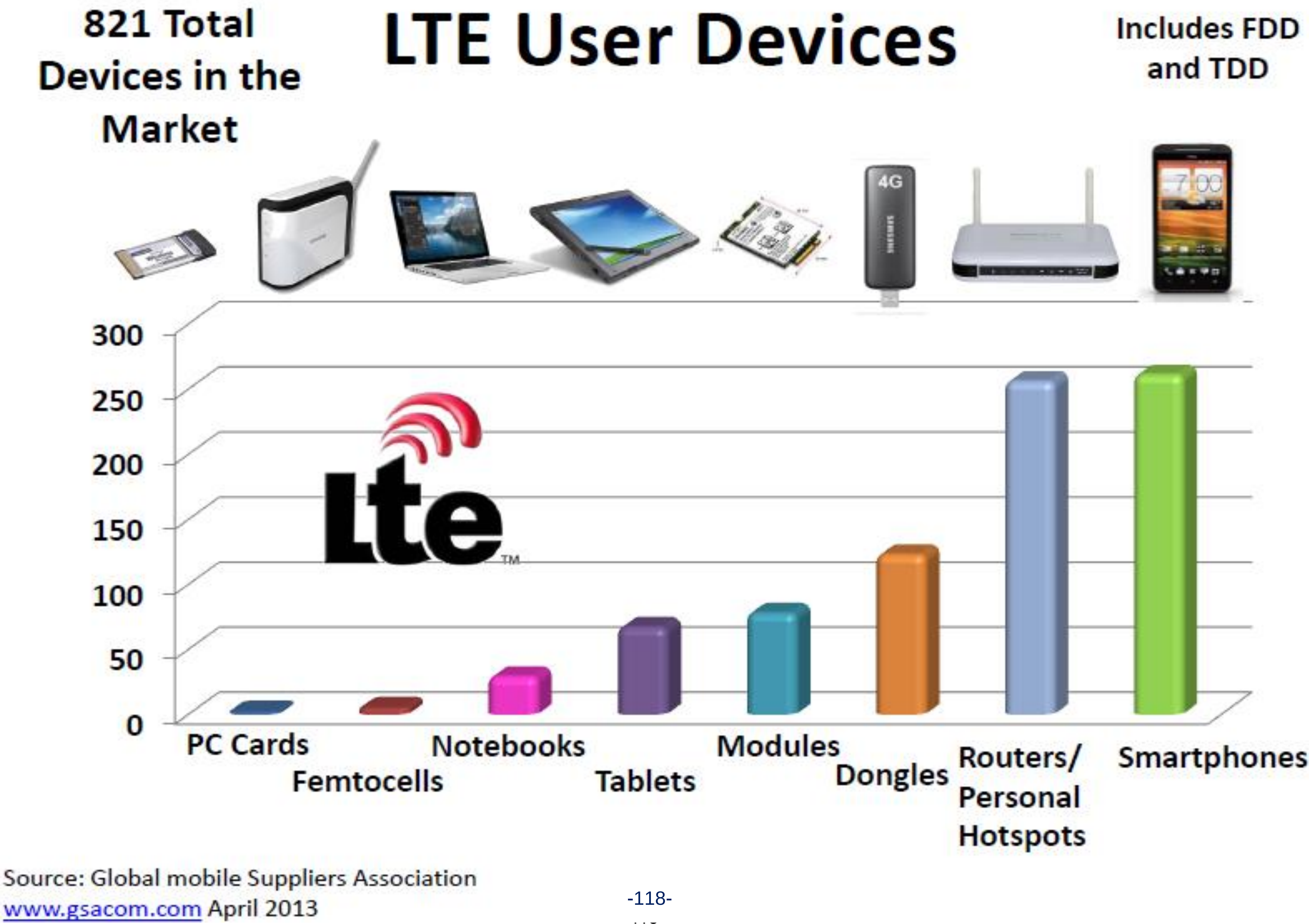


Prepared by Partner

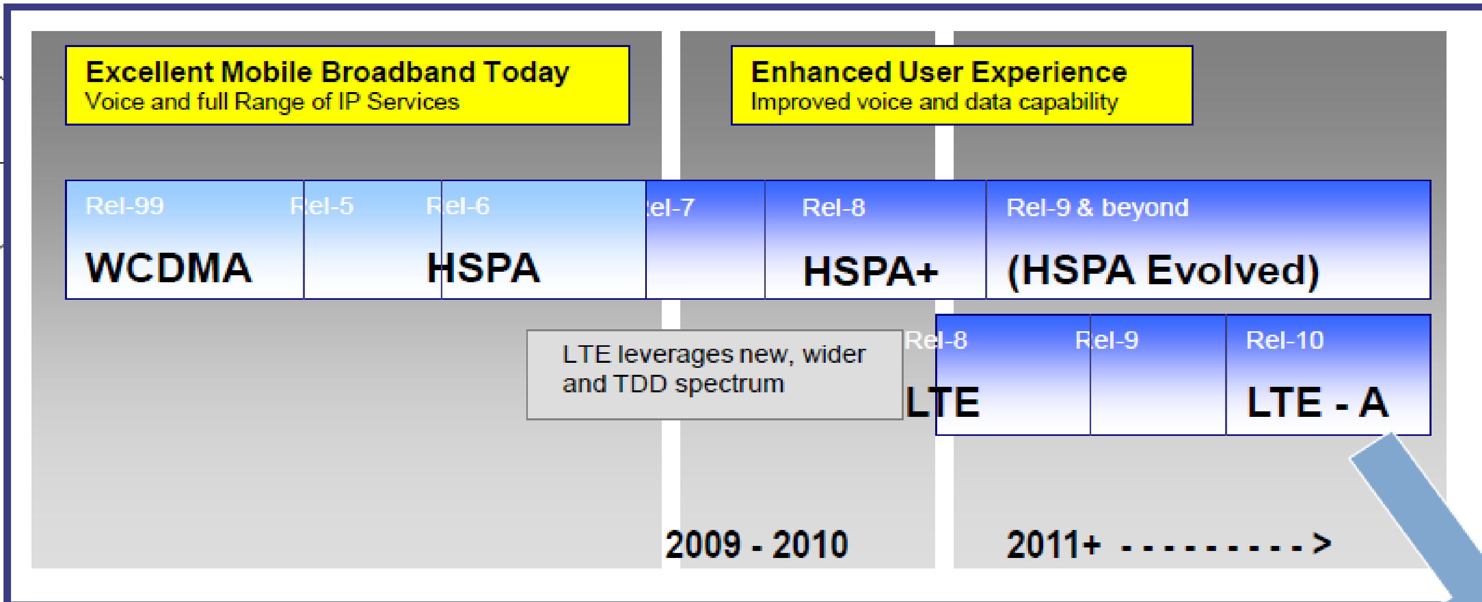
Active network Sharing,
MOCN (Multi-Operator Core Network)



Prepared by Partner


821 Total Devices in the Market
LTE User Devices
Includes FDD and TDD
4G
Lte
300
250
200
150
100
50
0
PC Cards
Femtocells
Notebooks
Tablets
Modules
Dongles
Routers/ Personal Hotspots
Smartphones
Source: Global mobile Suppliers Association
www.gsacom.com April 2013

Roadmap for LTE



LTE-Advanced will shortly be confirmed by the ITU as meeting the requirements for an IMT-Advanced system

Smooth transition from 3G to 4G

LTE-Advanced will be the main feature of 3GPP Release 10

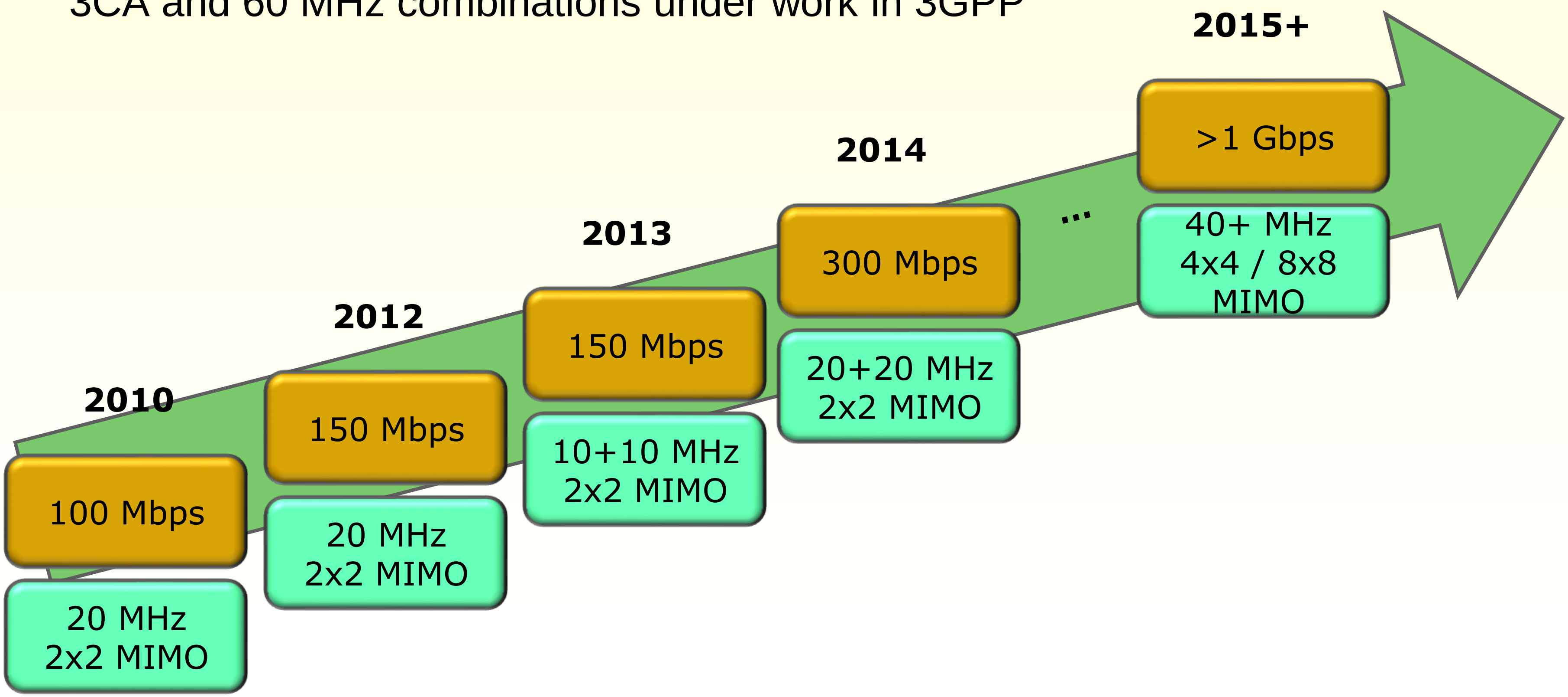
LTE-Advanced formally submitted on Oct 7, 2009 to the ITU for evaluation as a candidate for IMT-Advanced

- Improved spectrum efficiency
- Support for wider bandwidth: Up to 100 MHz
- Downlink transmission scheme
  - Improvements to LTE by using 8x8 MIMO
  - Data rates 100 Mbps high mobility, 1 Gbps low mobility
- Uplink transmission scheme
  - Improvements to LTE; data rates up to 500 Mbps
- Reduced latency
- Relay functionality
  - Improving cell edge coverage
  - More efficient coverage in rural areas
- Backward compatibility and interworking with LTE and other 3GPP legacy systems

LTE-Advanced Peak Data Rate Evolution

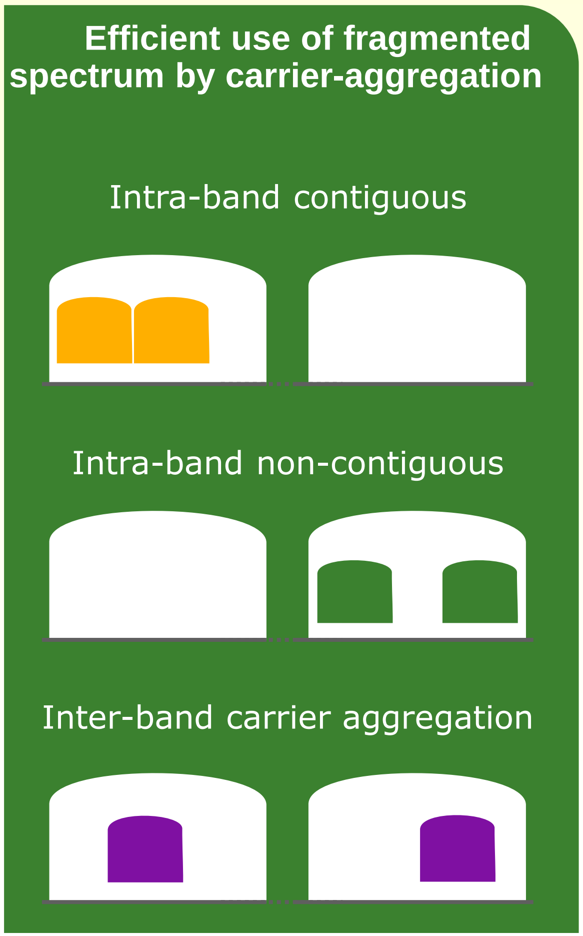
Source Shalev

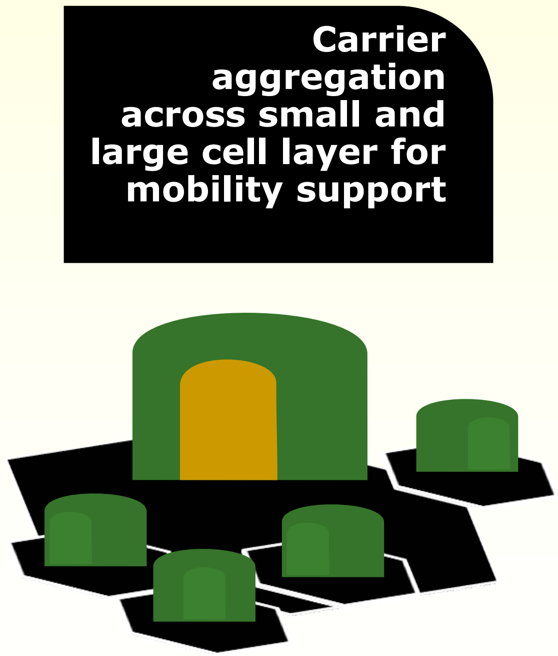
- Initial devices 100 Mbps (Cat 3) with contiguous 20 MHz
- Currently devices 150 Mbps (Cat 4) with contiguous 20 MHz
- 150 Mbps with 10 + 10 MHz carrier aggregation 2013
- 300 Mbps with 20 + 20 MHz starting 2014
- 3CA and 60 MHz combinations under work in 3GPP

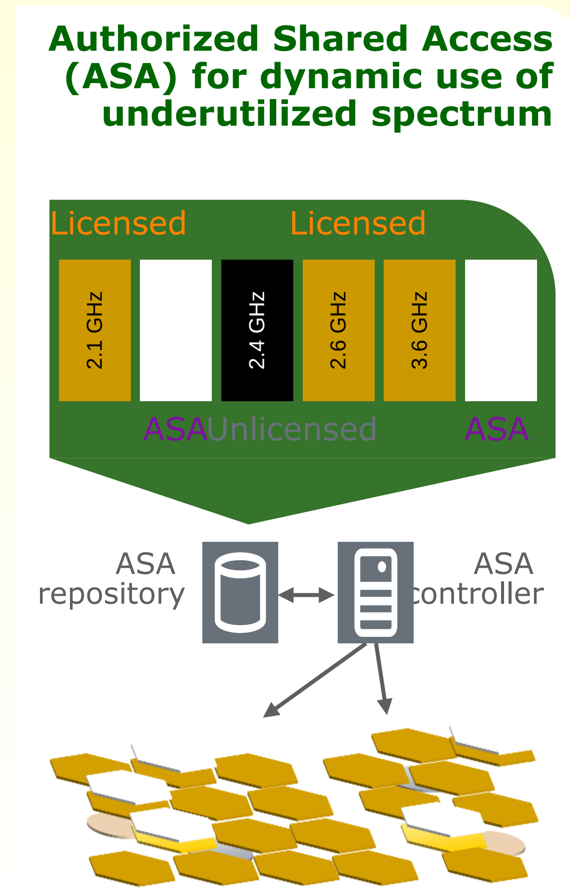


More Capacity - more spectrum needed

Source Shalev







LTE- advanced: Radio-access network interfaces

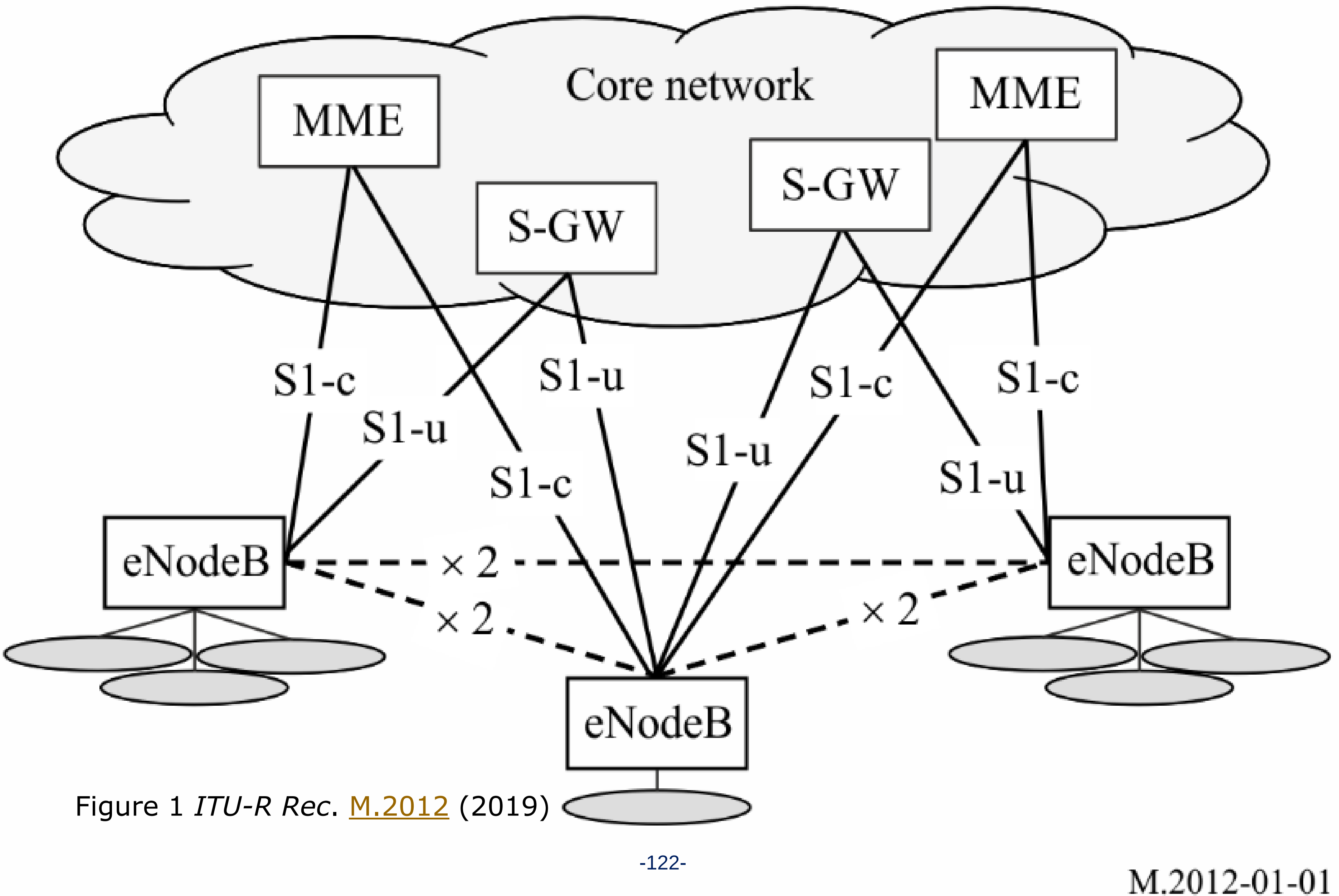
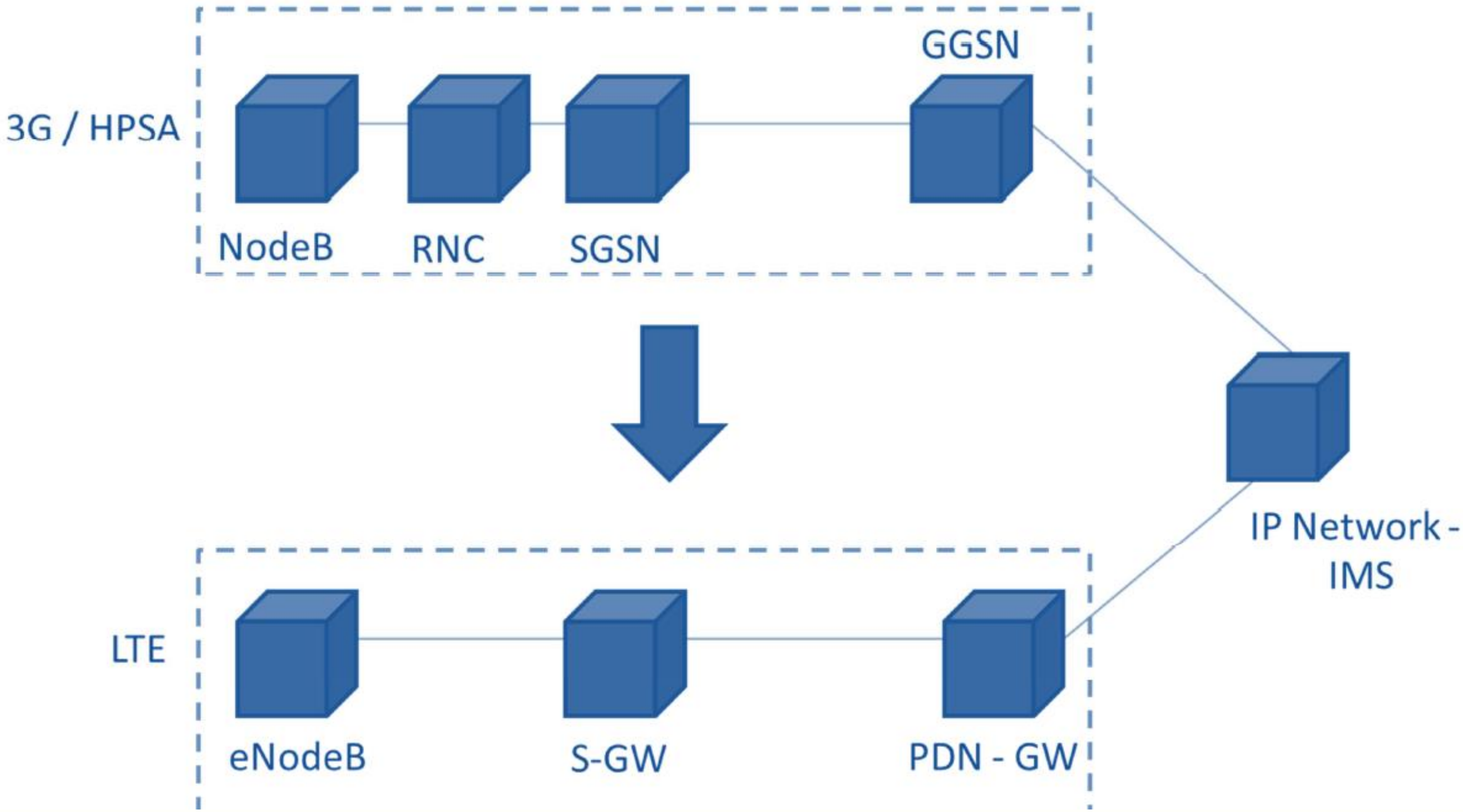


Figure 1 *ITU-R Rec.* M.2012 (2019)

LTE simplifies network architecture



LTE networks are simpler and work with fewer components compared to 3G. This removes interactivity and also results in lower latencies.

LTE brings a new capability to mobility: Ofcom report November 2013

Source: Ofcom

Headline speed by technology generation

Table 36 - Headline speed by technology generation

Generation	Headline rate	Phase and configurations
2G	470 kbps for both UL/DL	E-EDGE with single carrier, 4 PDCH timeslots
3G	DL : 84/336 Mbps, UL: 23 Mbps	HSPA+, DC DL: 2×2/4×4 MIMO, 2/4 carriers 64QAM UL: 2 carriers, 16QAM
4G	DL: 326 Mbps, UL: 86 Mbps	LTE, Channel Bandwidth 20MHz, DL: 4×4 MIMO UL: 64QAM
	DL: 600Mbps -3Gbps, UL: 512Mbps	LTE-Advanced, 8*8 MIMO, Carrier Aggregation of up to 100MHz

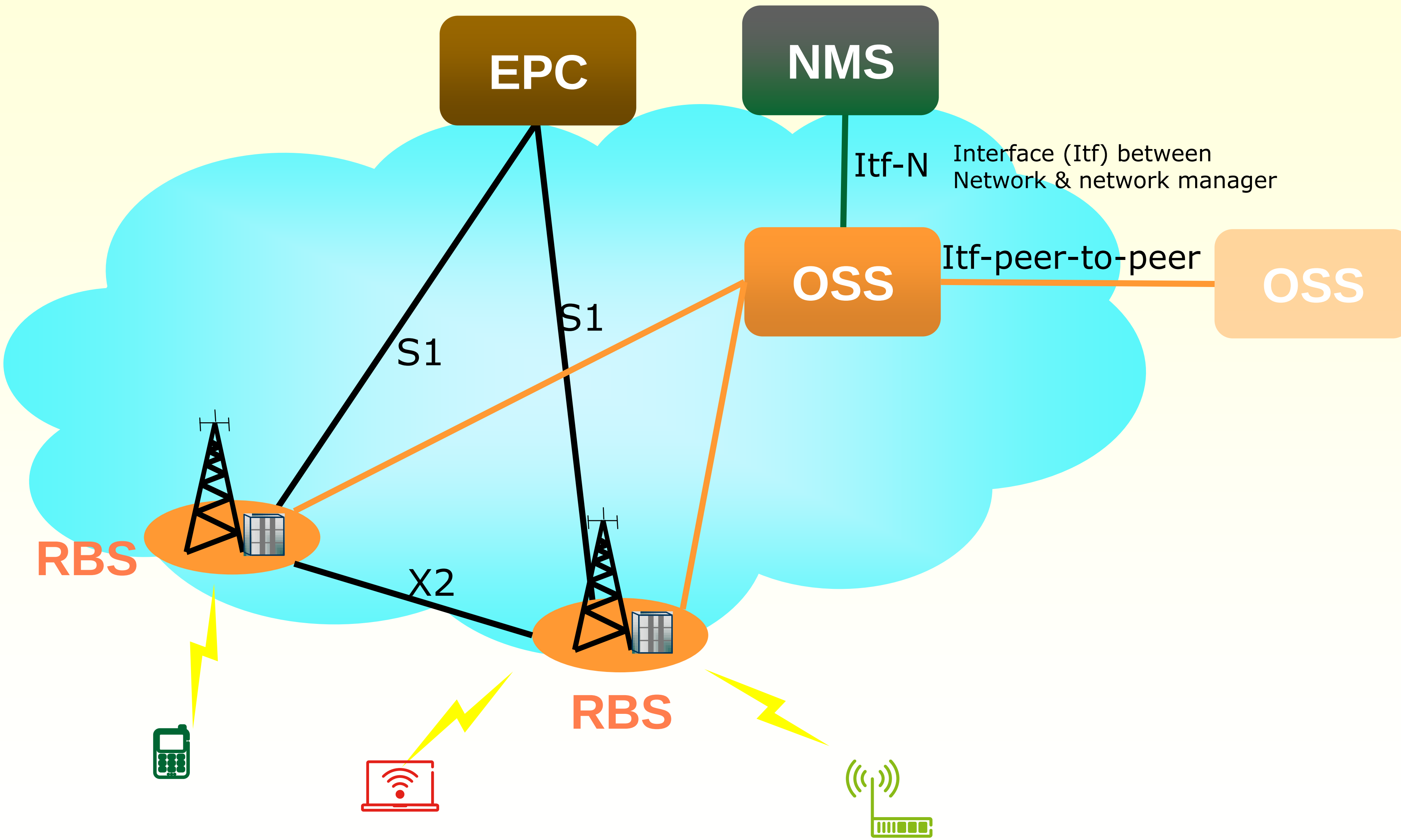
Source: Ofcom

LTE brings a new capability to mobility: Ofcom report November 2013

LTE- advanced: network architecture interfaces

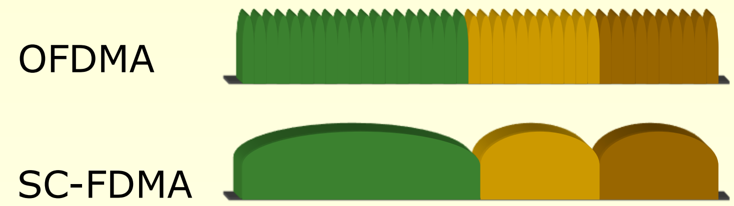
- Network is responsible for all radio-related functions in one or several cells
- LTE-Advanced radio-access network has a flat architecture with a single type of node
- eNodeB is a conventional BS wirelessly backhauled to the remaining part of the network
- eNodeB is connected to the serving gateway (S-GW) by means of the S1 interface: to the user by S1-u, and to the Mobility Management Entity (MME) by S1-c. To share load and for redundancy, one eNodeB can interface with multiple MMEs/S-GWs
- The X2 interface connects eNodeBs to each other, to support active-mode mobility and multi-cell Radio Resource Management (RRM) functions such as Inter-Cell Interference Coordination (ICIC)

LTE Radio Access Network (Ericsson)

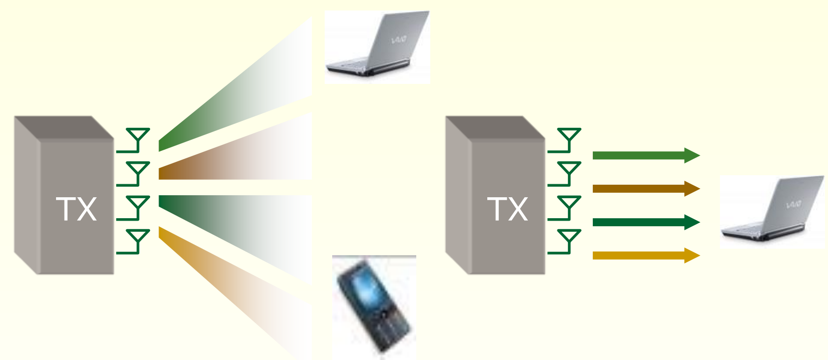


Key LTE radio access features (Ericsson, 2010)

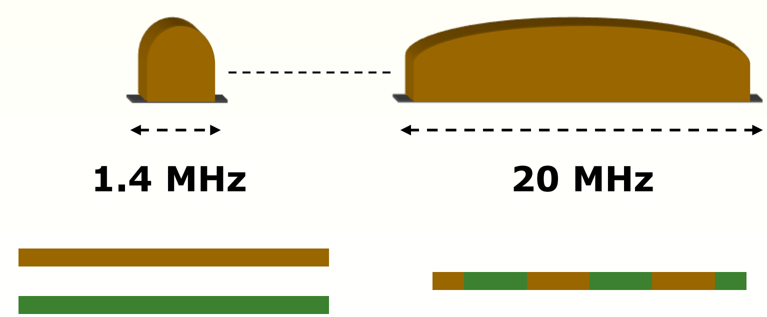
Radio Access
- Downlink: OFDM
- Uplink: SC-FDMA



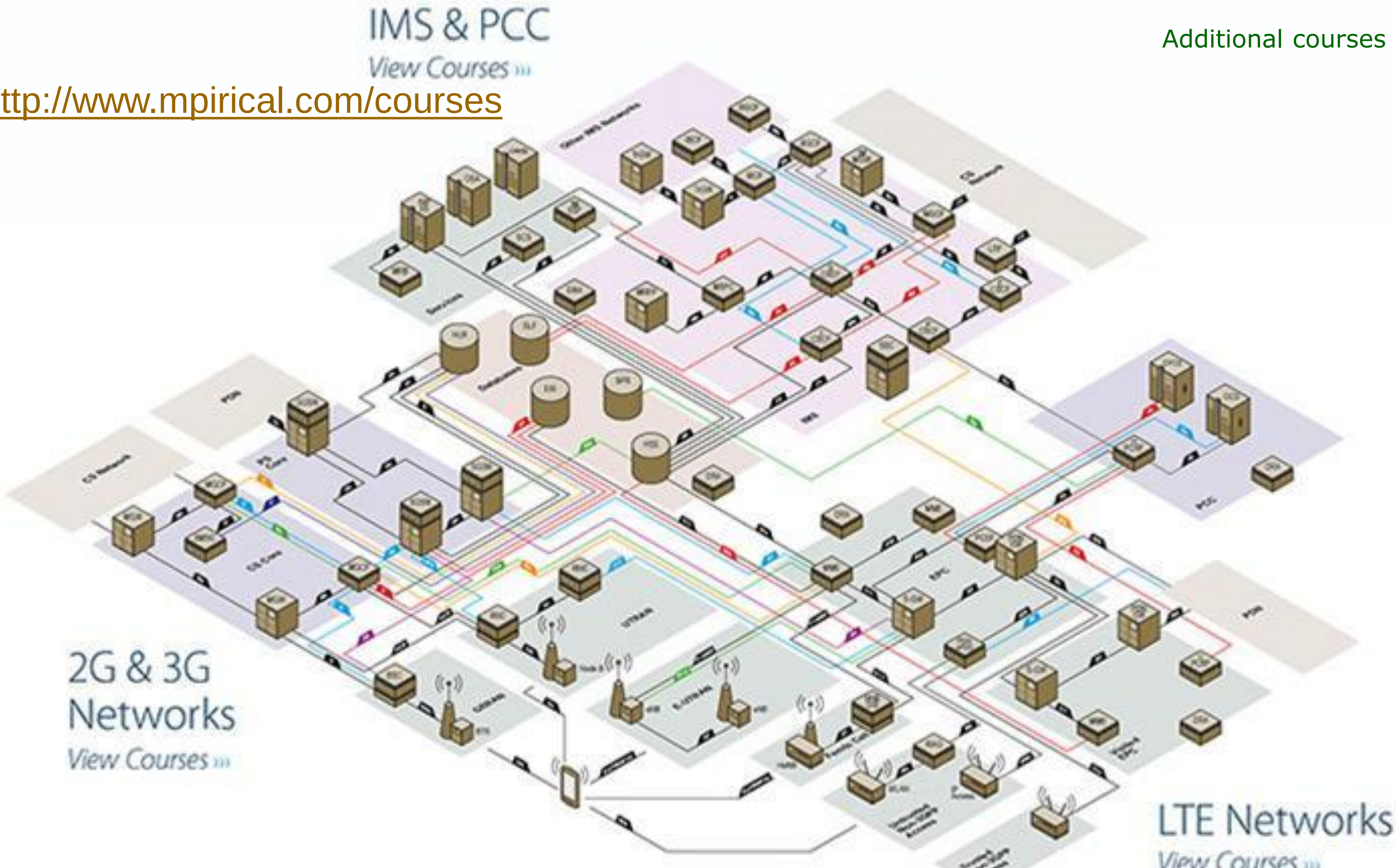
Advanced antenna solutions
- Diversity
- Multi-layer transmission (MIMO)
- Beam-forming



Spectrum flexibility
- Flexible bandwidth
- New and existing bands
- Duplex flexibility: FDD and TDD



http://www.mpirical.com/courses



- WEBINAR 5 - **PART :1**What LTE parameters need to be Dimensioned and Optimized
- WEBINAR 5 - **PART :2**What LTE parameters need to be Dimensioned and Optimized

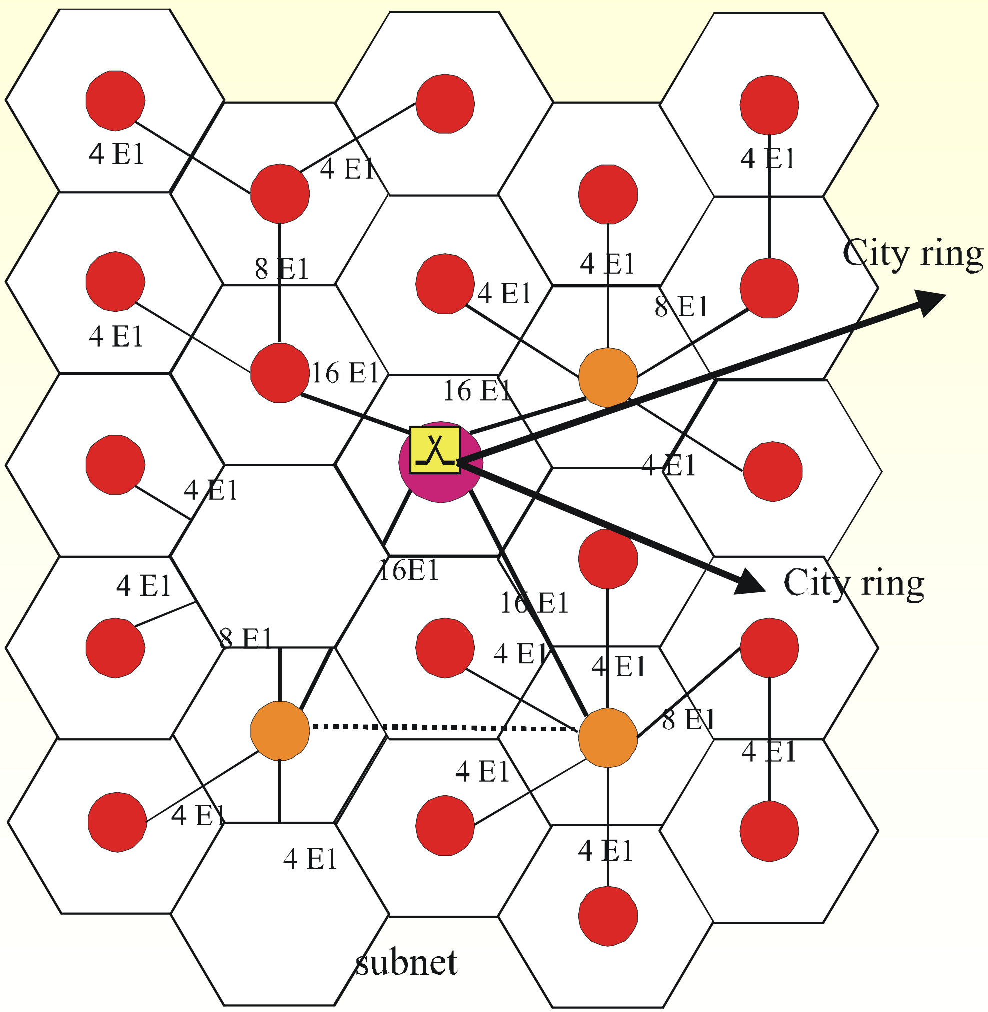
LTE parameters need to be dimensioned & optimized (CelPlan)

Wi-Fi offload to improve cellular capacity more on offload

(Source: NSN 2012)

1. By 2015 more than 90% of wireless traffic will be data; 60-70% of wireless traffic is estimated to be generated indoors; 40% of data traffic generated by mobile handsets and tablets was offloaded in 2011
2. Harmonized traffic steering across all 3GPP and Wi-Fi access technologies and frequency bands (including 2G, 3G and LTE).
3. Capacity for 3G and 4G networks to keep pace with the rate of growth in network traffic
4. Wi-Fi integration as seamless extension of the mobile network: faster data connections; hot zone for a superior mobile broadband experience, especially for public indoors
5. Real-time traffic off-loading between cellular and Wi-Fi is based on network load and business priorities
6. Off-loading per customer segments or commonly
7. Can be used with existing Wi-Fi capable mobile devices

Example of sub network structure for BS access using sub-star & chains of FS links



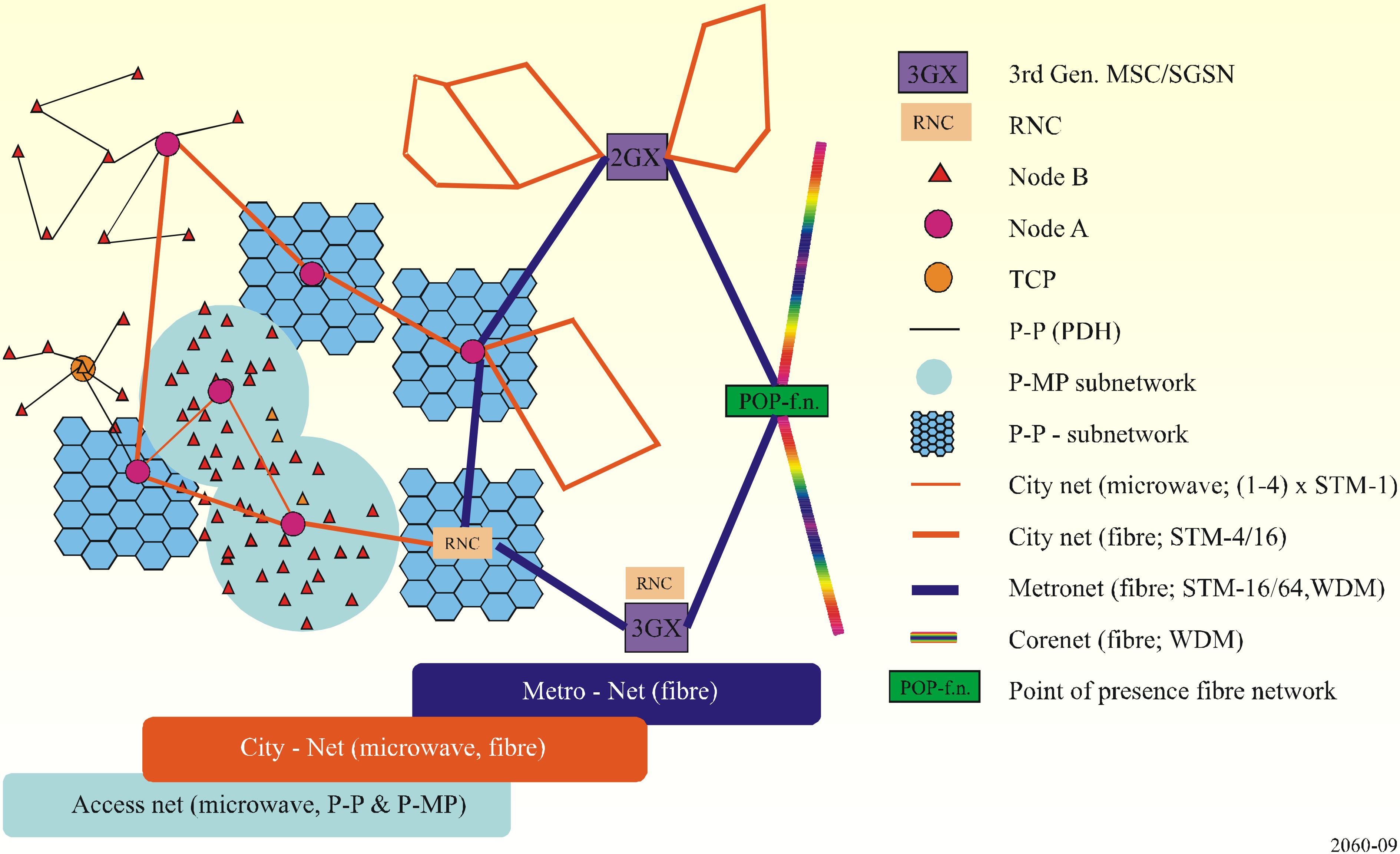
- Node B (3 Sector) and/or BS GSM
- Node B (3 Sector) and/or BS GSM serving as TCP
- Node A (possibly colocated with Node B)
- external ATM-Multiplexer

E1 - 2 Mbit/s transmission capacity

n E1 - *n* times E1 (*n* = 2, 4, 8, 16)

2060-04

General overview of an IMT-2000 network



Abbreviations

1G	first generation
2G	second generation
3G	third generation
3GPP	third Generation Partnership Project
3GPP2	third Generation Partnership Project 2
ANSI	American National Standard Institute
ARPU	average revenue per user
ATM	asynchronous transfer mode
CAPEX	capital expenditure
CDMA	code-division multiple access
CEPT	European Conference of Postal and Telecommunications Administrations
CITEL	Comision Interamericana de Telecomunicaciones
CN	core network
CS	circuit switching
CSCF	call session control function
DECT	digitally enhanced cordless telecommunications
EBIT	earnings before interest and taxes
EBITDA	earnings before interest and taxes, depreciation and amortization
EDGE	enhanced data rates for global evolution
EDGE DO	EDGE data only
ETSI	European Telecommunication Standards Institute
FDD	frequency division multiplexing
GERAN	GSM EDGE radio access network
GGSN	gateway GPRS support node
GPRS	general packet radio service
GSM	global system for mobile communications
HA	home agent
HLR	home location register
HSDPA	high speed downlink packet access
IMS	IP multimedia subsystem
IMT	International mobile telecommunication
IP	Internet protocol
ISDN	integrated services digital network
MAP	mobile application part
MGCF	media gateway control function
MMS	multimedia message service
MSC	mobile switching centre
MT	mobile terminal
MVNO	mobile virtual network operator
NPV	net present value
OPEX	operational expenditure
PCF	packet controller function
PDC	personal digital cellular
PDSN	packet data serving node
PDSN	public data switched network
PS	packet switching
PSTN	public switched telephone network
RAN	radio access network
RNS	radio network system
SDMA	space division multiple access
SDO	standard development organization
SGSN	serving GPRS support node
SIM	subscriber identification module
SCDMA	synchronous code-division multiple access
TD-CDMA	time division-code division multiple access
TDD	time division duplexing
TDMA	time-division multiple access
TD-SCDMA	time-division synchronous code-division multiple access
UIM	user identity module
UMTS	universal mobile telecommunication system
UTRA	UMTS terrestrial radio access
UTRAN	UMTS terrestrial radio access network
VNO	virtual network operator
VoIP	voice over IP
WCDMA	Wideband code division multiple access
WiMAX	worldwide interoperability for microwave access.

Advanced Wireless Communications, 2022

Academic course for 4th year engineering students

Fixed Service

Dr. Haim Mazar (Madjar), reelected vice-chair (VC) ITU-Radio Study Group 5 (terrestrial services). Vice Chair Working Party 5C (Fixed Service)

Representing Israel, ATDI and ITU-R Study Group 5; ITU headquarters; 5 Dec 2022
https://www.flickr.com/photos/itupictures/52544537443/in/album-72177720304216437/

Evolution & current state of Fixed Services technology: Basics (1)

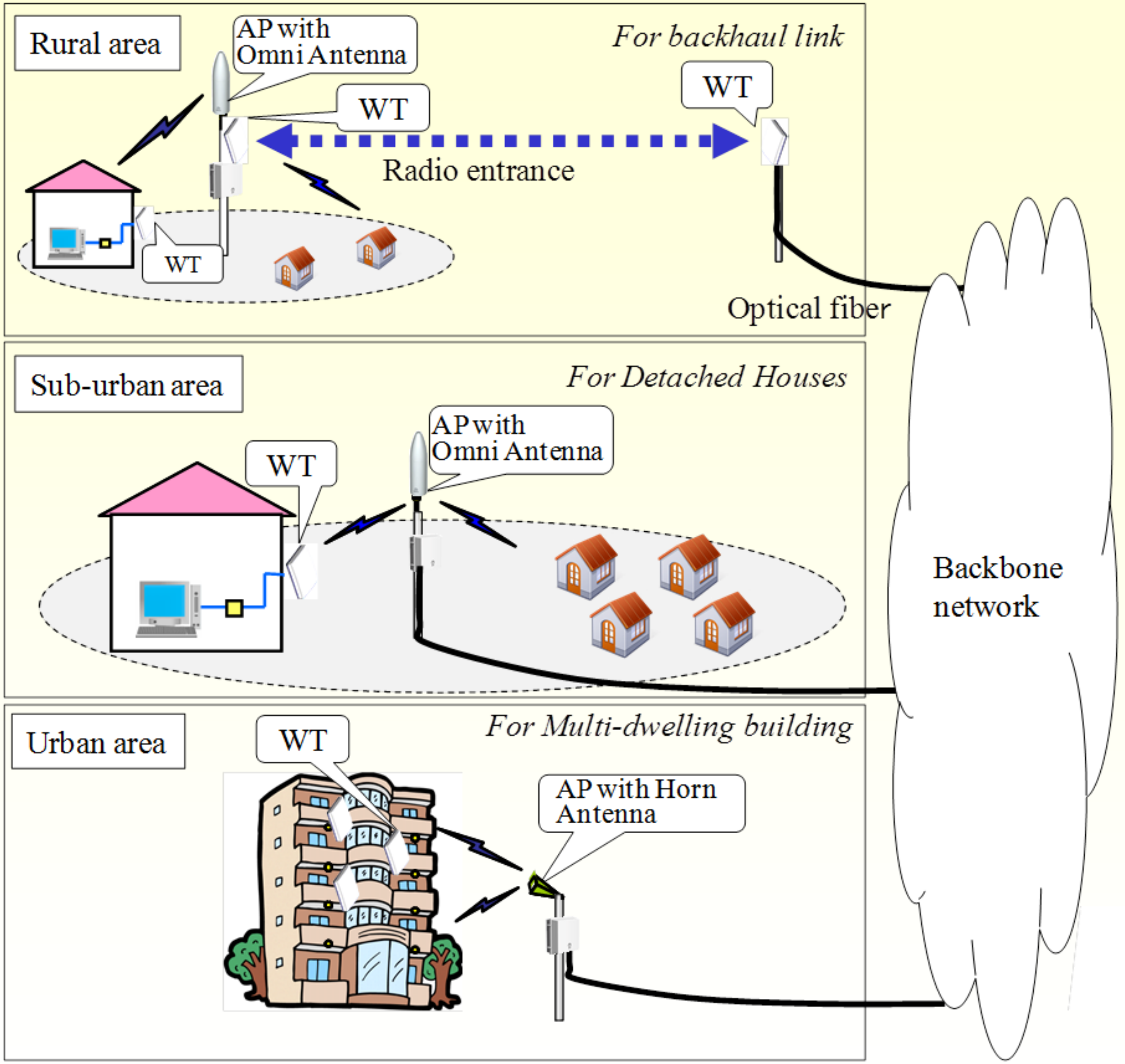
1. ITU Radio Regulations (RR 1.120) defines *fixed service* as: *"A radiocommunication service* between specified fixed points
2. Physical network supporting the end-to-end path is optical fibre, copper, radio relay or satellite
3. µwave remains (time to market, flexibility), fiber (capacity & distance) increases and copper (distance, availability) decreases
4. Nominal voice-grade bandwidth is limited to 4 kHz; sampled at 8 kHz (twice the highest frequency), quantization of 8 bits per sample, the fundamental standard for uncompressed digitized voice (narrow band channel) is **64 kbps** (8 kHz x 8 bits)
5. Data rate of E1 is 2.048 M bits/second: 32 ch. of 64 Kbps
6. Each byte of STM-1 (Synchronous Transport Module level-1) corresponds to a 64kbit/s channel. STM-1 frame is the basic transmission format for SDH (Synchronous Digital Hierarchy)

Evolution of Fixed Services technology (2)

1. Mobile Wireless Access implemented by IMT (LTE)
2. Time-division multiplexing (TDM) migrates to packet- mode
3. Increased capacity due to higher RF bandwidth and higher modulation schemes with retained availability
4. Adaptive and Agile: Modulation 4–1024QAM, Capacity, Transport technology
5. Multiple radios technique; 4X4 MIMO (Multiple-Input and Multiple-Output)
6. Today reuse of channels 80; tomorrow up to 150 (using narrow beam class 4 antennas)
7. Higher RF: 6L, 6U, 7, 8, 10, 11, 13, 15, 18, 23, 26, 28, 32, 38, 42, 60, 70/80 GHz (E band)
8. Today: 7, 14, 28MHz, 56MHz channels; tomorrow 112, 224…MHz bandwidth channels
9. Increases capacity: today Bandwidth: up to 10 Gbps @ 70/80 GHz band; tomorrow Bandwidth: up to 40 Gbps

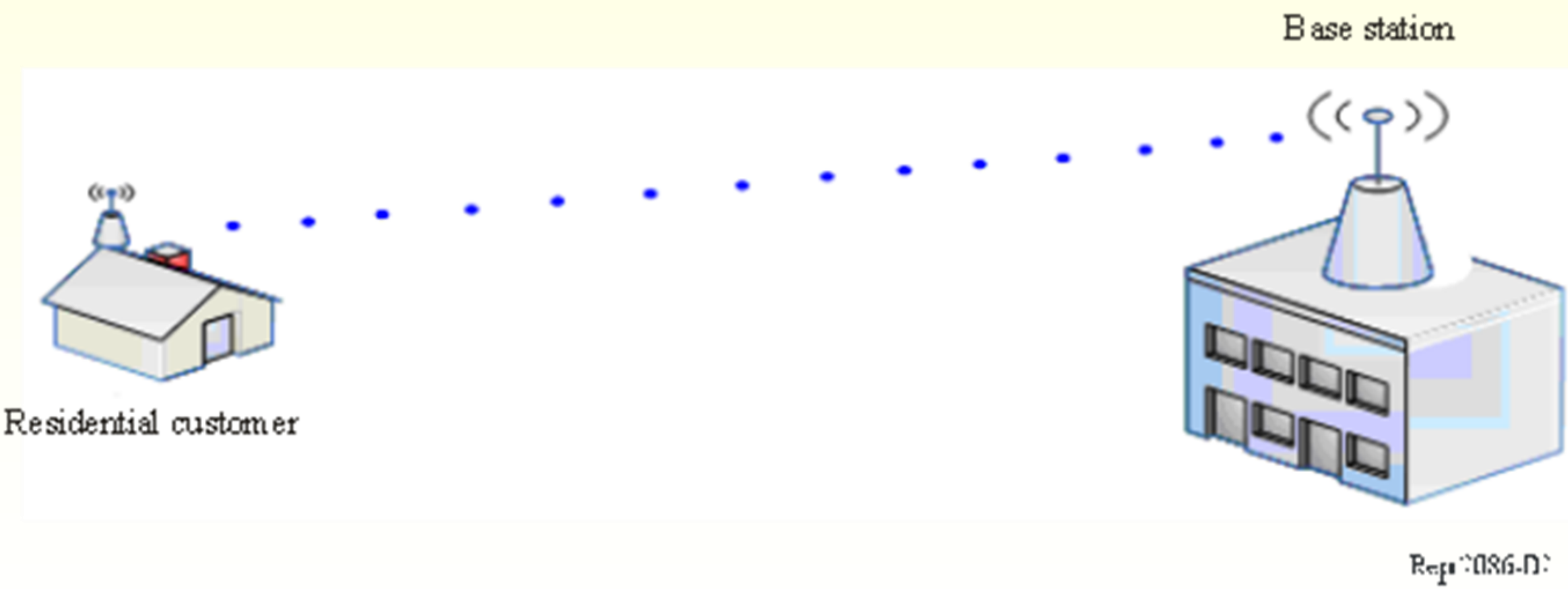
Rural, Urban and Suburban FS macro cells and small cells

Report ITU F.2086 (2010) P-MP system with an omnidirectional Access Point (AP) antenna is mainly deployed for detached houses scattering in a service area. The service area (last mile or first mile) radius is approximately 1 km, which depends on service availability objective and regional rain conditions. A P-MP system is also applied to a multi-dwelling building which is not equipped with available wiring ducts in urban areas. A horn antenna is implemented in such multi-dwelling buildings. Multiple IP-based user terminals, such as PCs, can be accommodated by Wireless Terminal (WT)

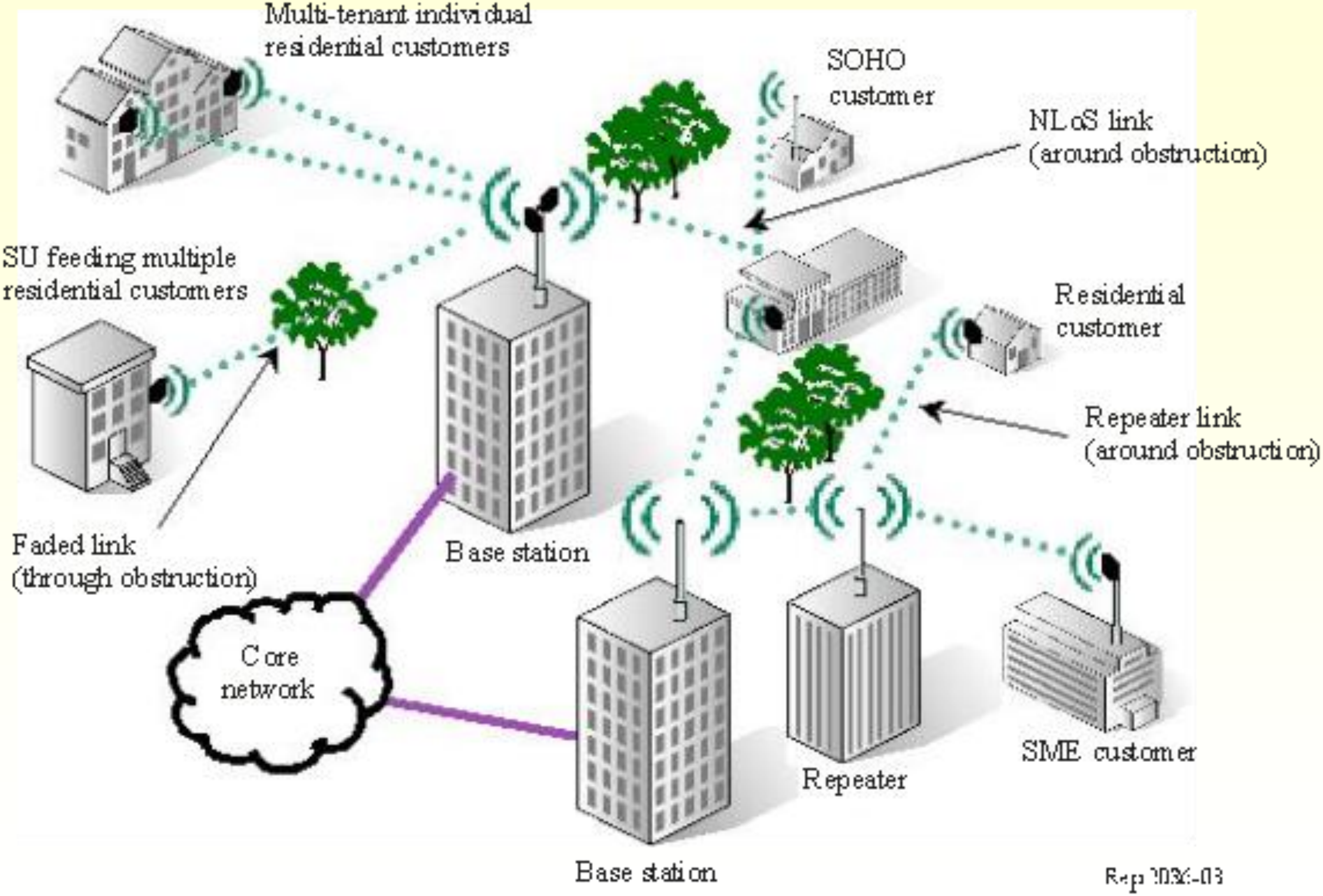


Rep F.2086: Point to Point deployment topology

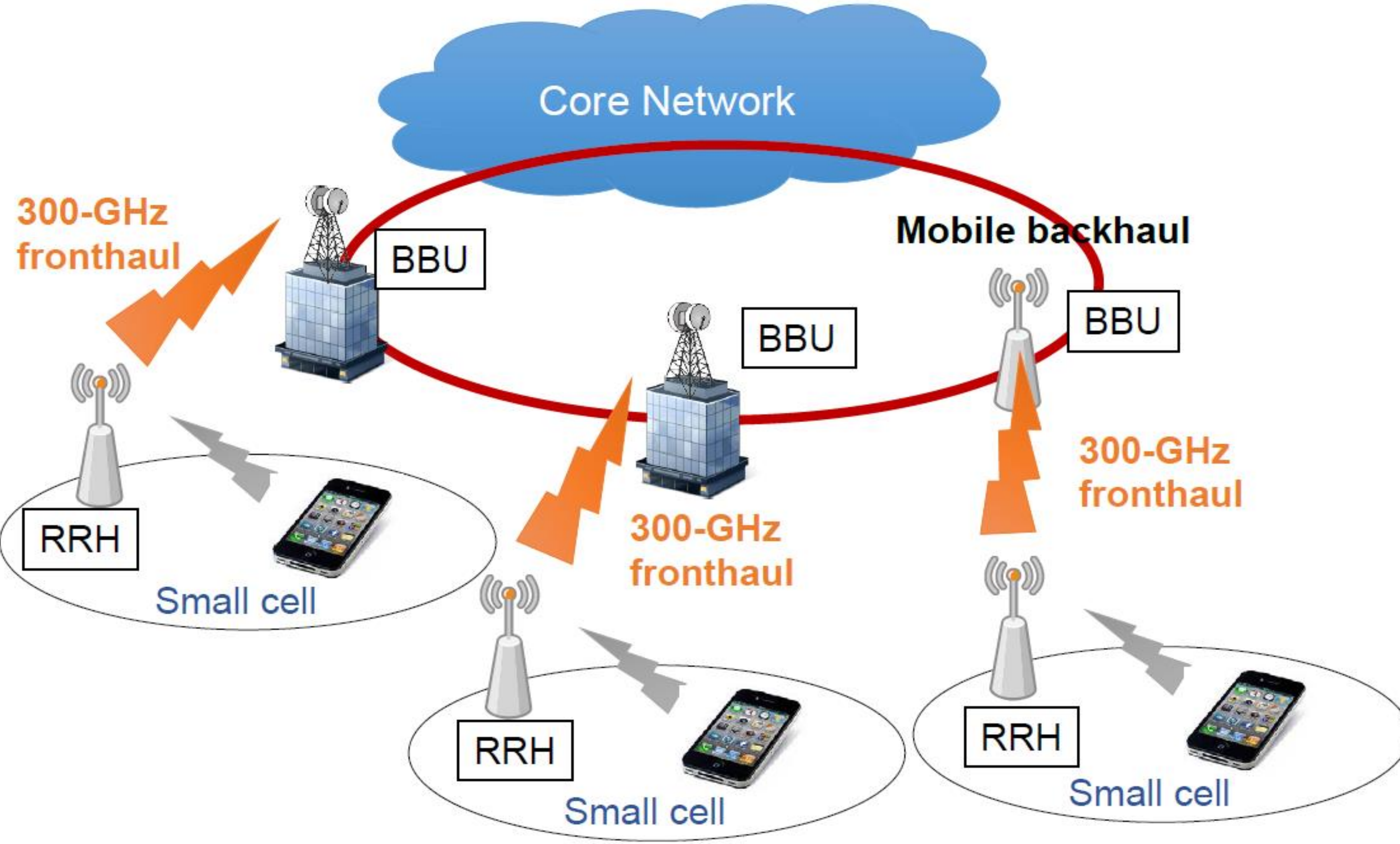
In P-P systems, traffic is transmitted directly from one station to another. Uses for P-P systems also include backhaul links for Local Area Network (LAN), Metropolitan Area Network (MAN), and cellular mobile networks



Illustrating network deployment configuration based on P-MP configuration



Fronthaul and backhaul operation to be used for mobile system network
Rep. ITU-R F.2416 (2018) Fig. 3

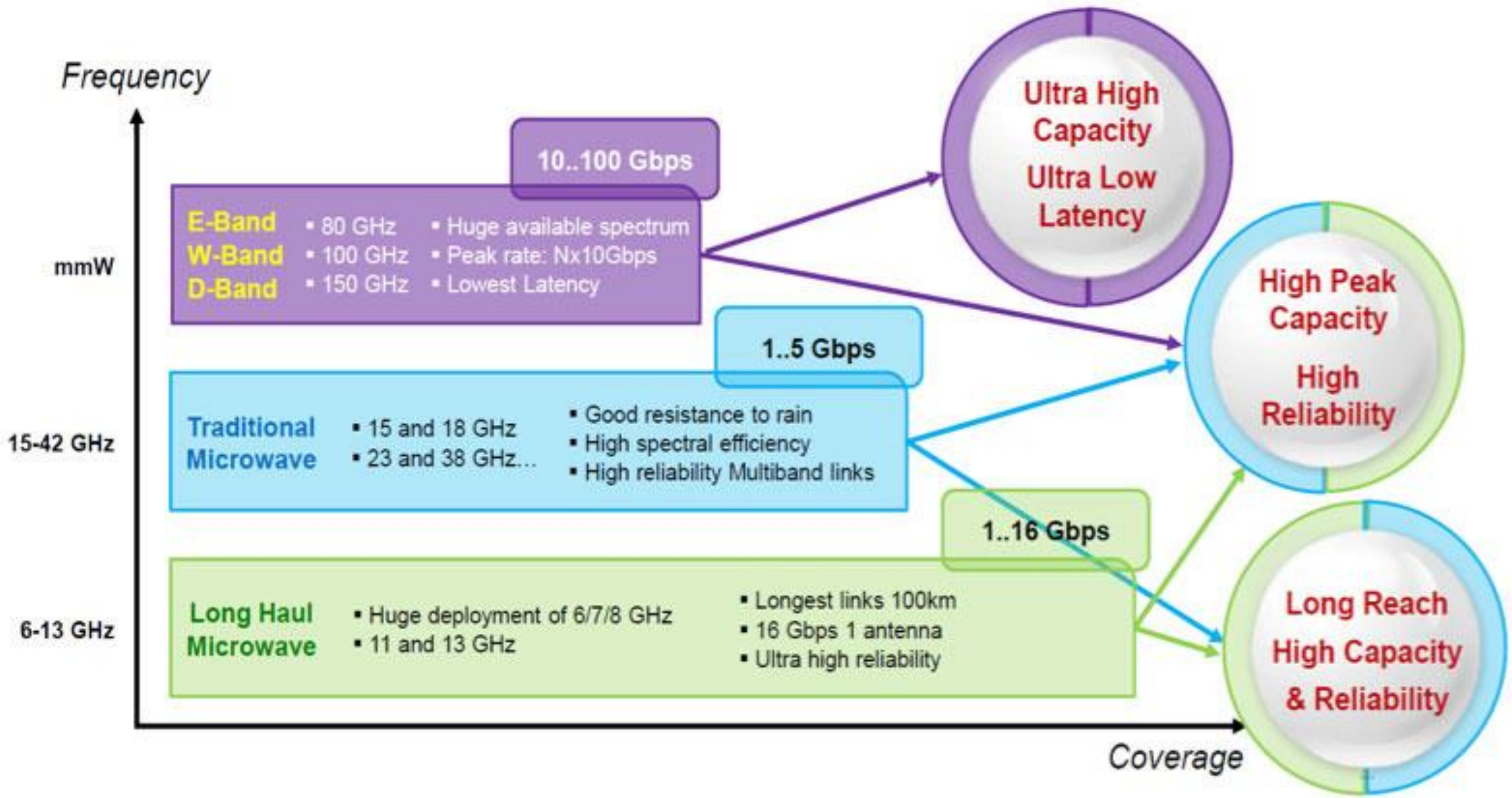


FS frequency bands for harmonised channel arrangement

Source: ECC Newsletter May 2020 Fig 2 Quo Vadis?

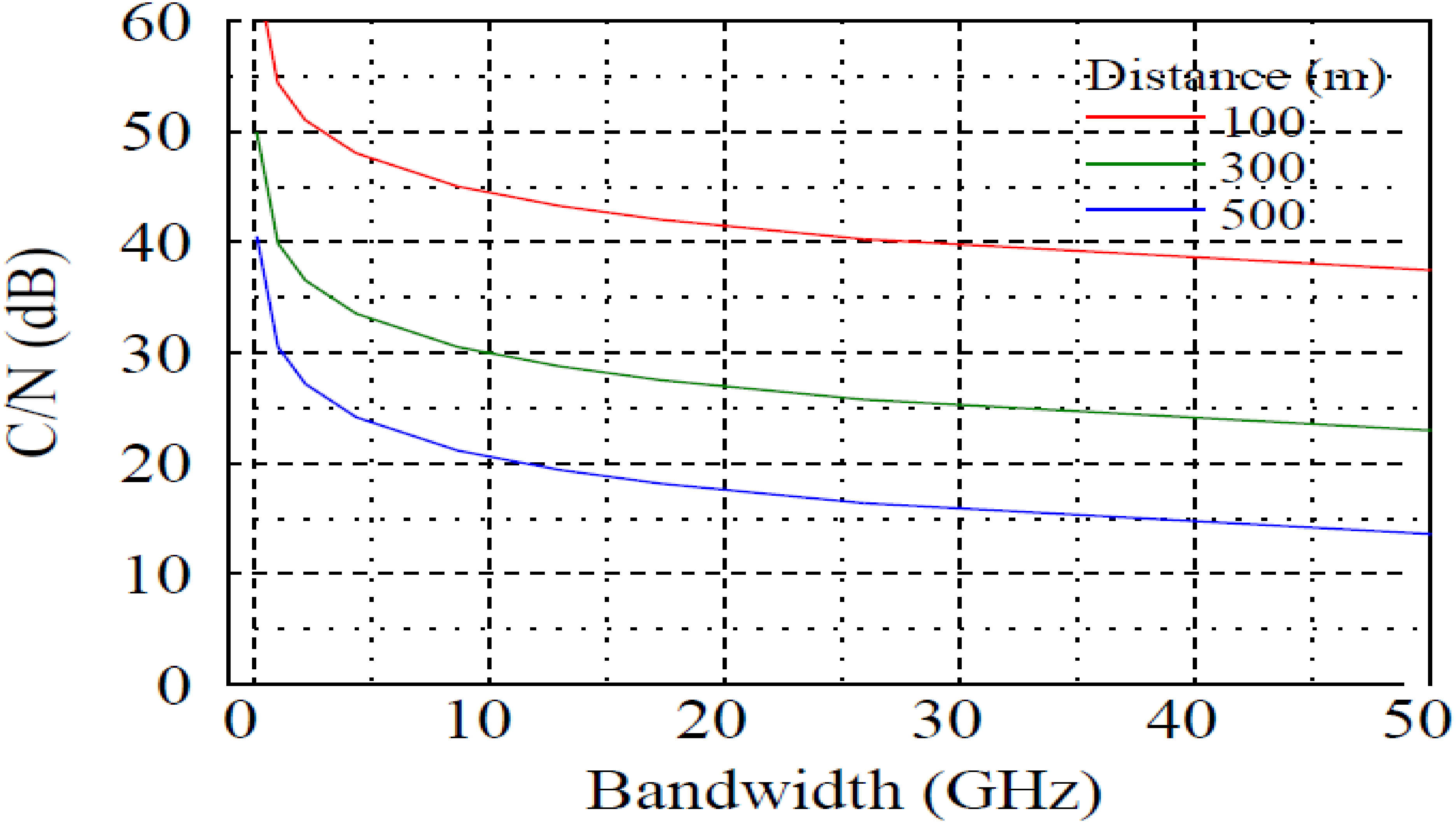
Fixed Service evolves towards more efficient spectrum use

Trends for the use of FS in the E-band (Source: ETSI White Paper No. 25, Microwave and Millimetre-wave for 5G Transport; (Fig 5 Quo Vadis? Fixed Service evolves towards more efficient spectrum use)



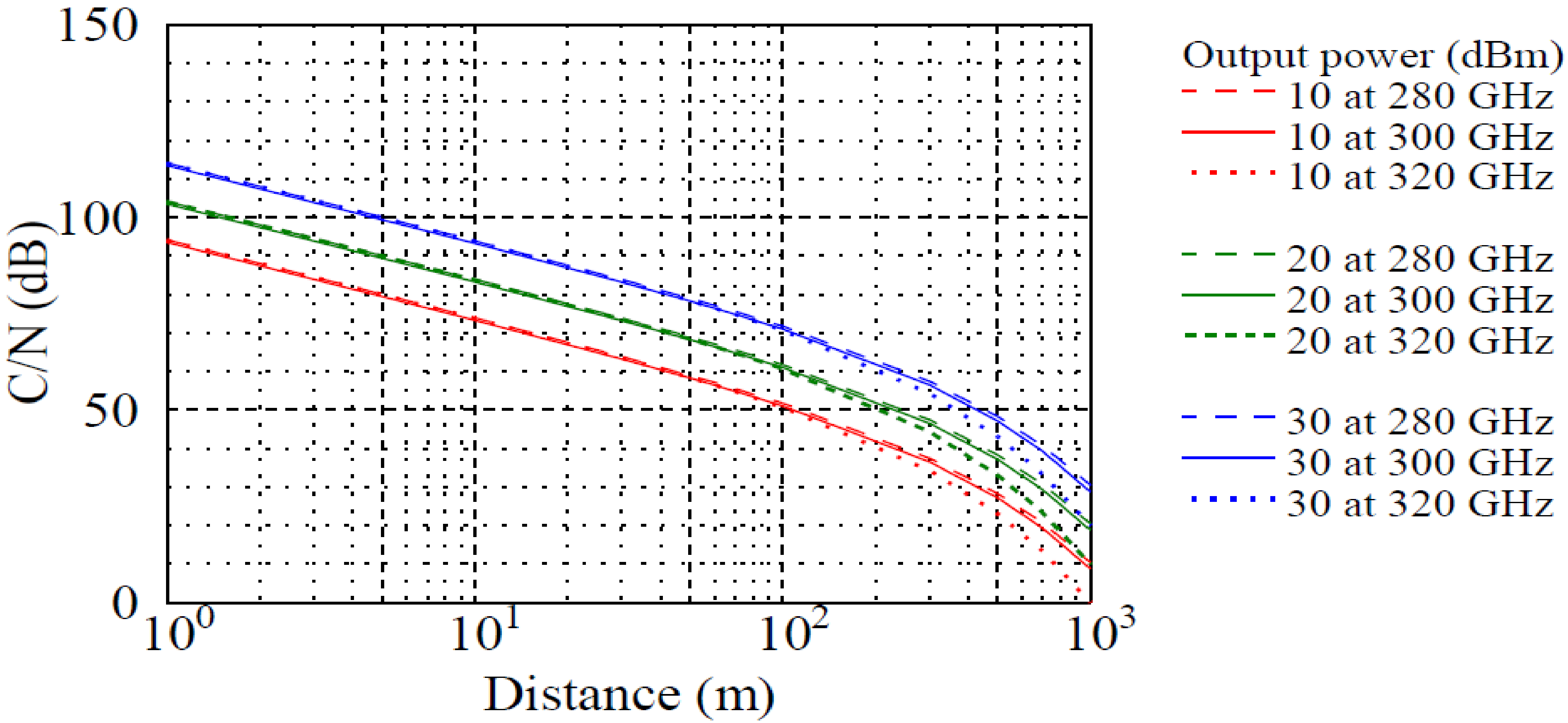
C/N versus bandwidth for signal transmission

Rep. F.2416 (2018) Fig. 8



C/N versus distance of 300-GHz wireless link

Rep. F.2416 (2018) Fig. 9



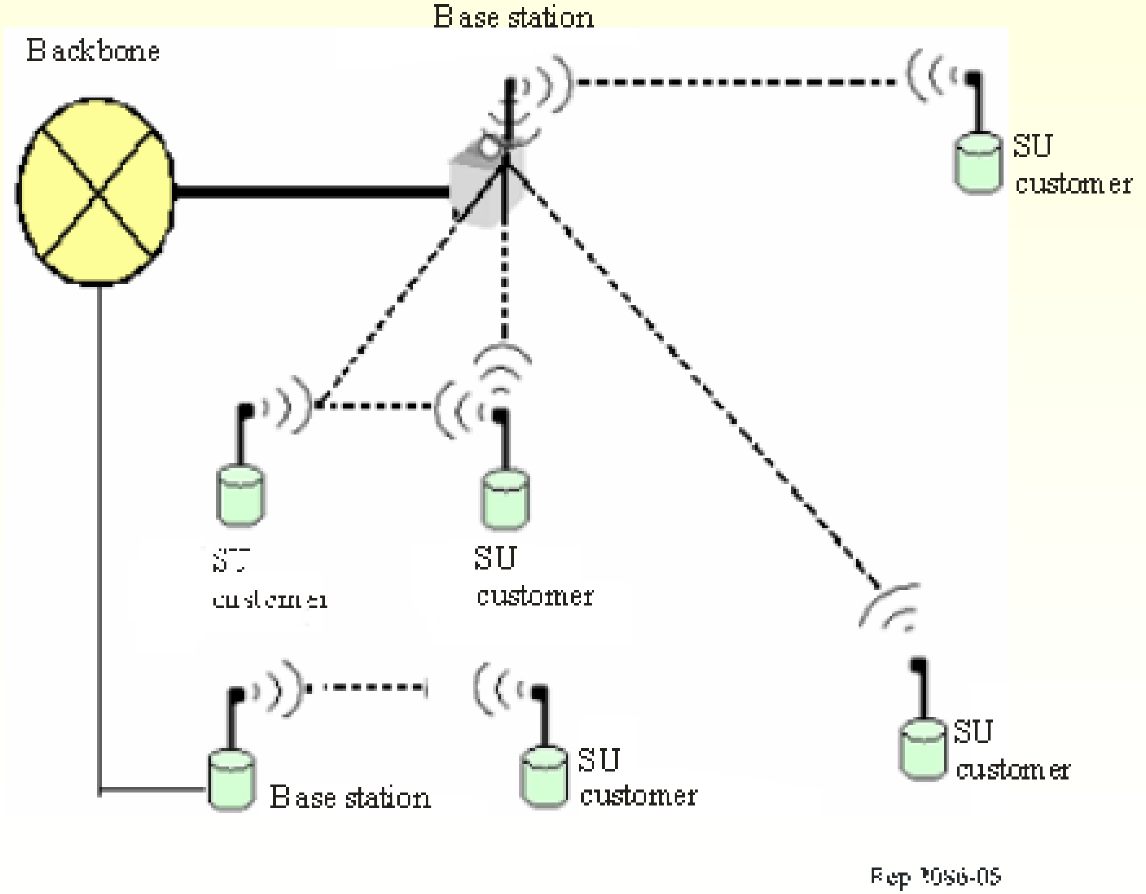
Acronyms and Abbreviations

BRAN	Broadband radio access network (ETSI)
BBU	Base Band Unit
BS	Base station
BWA	Broadband wireless access
FDD	Frequency division duplex
FWA	Fixed wireless access
ISP	Internet service providers
LAN	Local area network
LoS	Line-of-sight
MIMO	Multiple input multiple output
MPEG4	Moving Picture Experts Group 4
MP-MP	Multipoint-to-multipoint
NLOS	Non-line-of-sight
P-P	Point-to-point
P-MP	Point-to-multipoint
QoS	Quality of service
RLAN	Radio local area network
RRH	Remote radio head
SDH	Synchronous digital hierarchy
SME	Small medium enterprise
SOHO	Small office home office
ST	Subscriber terminal
SU	Subscriber unit
TCP/IP	Transmission control protocol/Internet protocol
TDD	Time division duplex
VoIP	Voice over Internet protocol
WAN	Wide area network
WAS	Wireless access systems

Rep F.2086: Combination P-P, P-MP & MP-MP deployment topology

Enclosed a mix topology: the wireless network may have both P-MP and MP-MP links and the BS supporting its Subscriber Unit may be connected to the other networks via backbone network

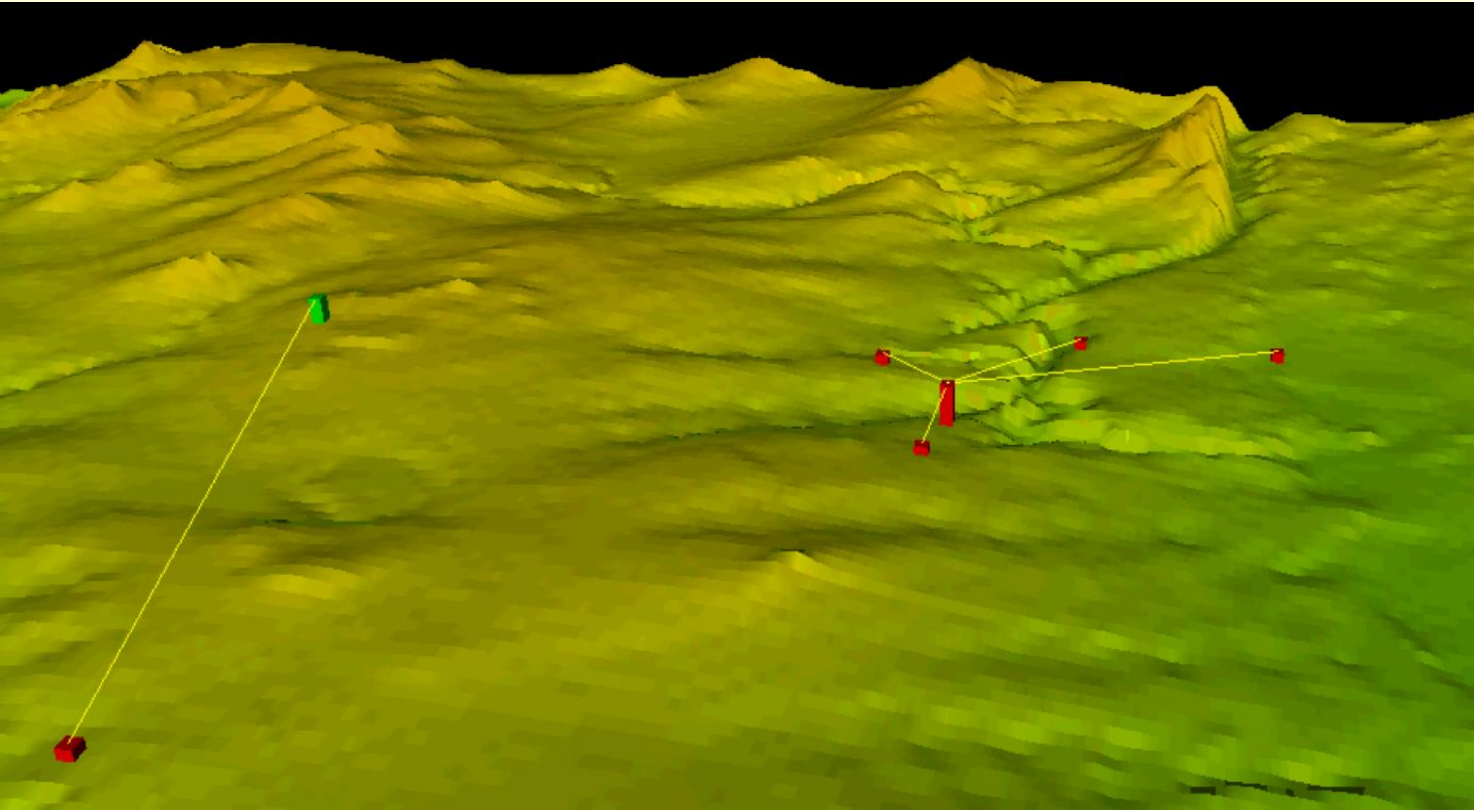
Figure 5: Illustration of network deployment based on combination P-P, P-MP & MP-MP configuration



Rep 2086-05

3D terrain: left 1-way P2P, right P2MP

Source: FMS program, 2013

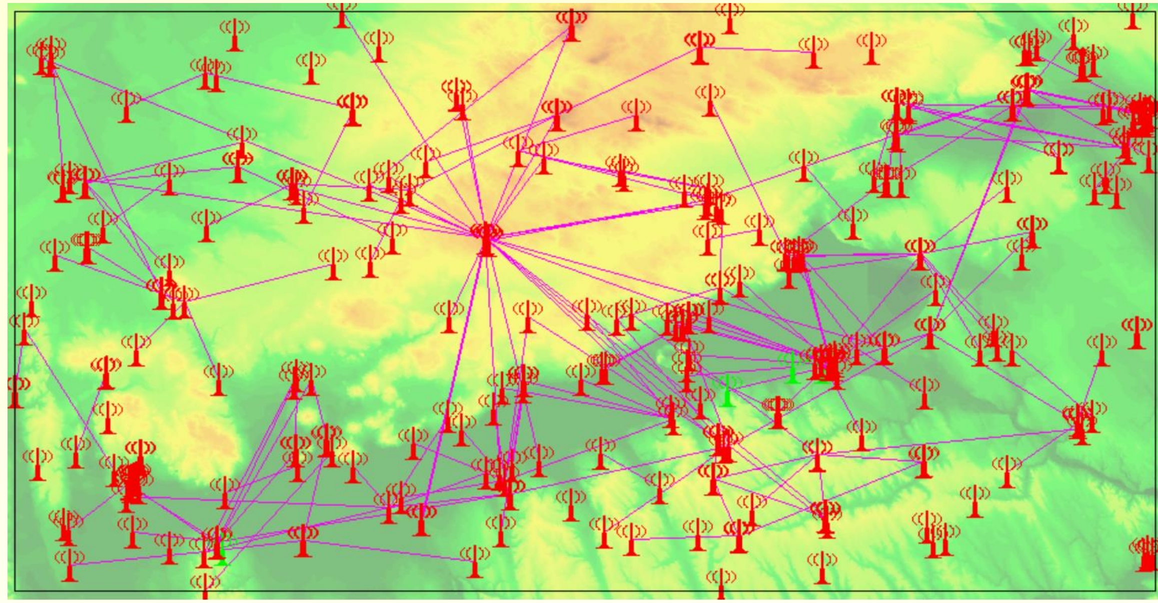


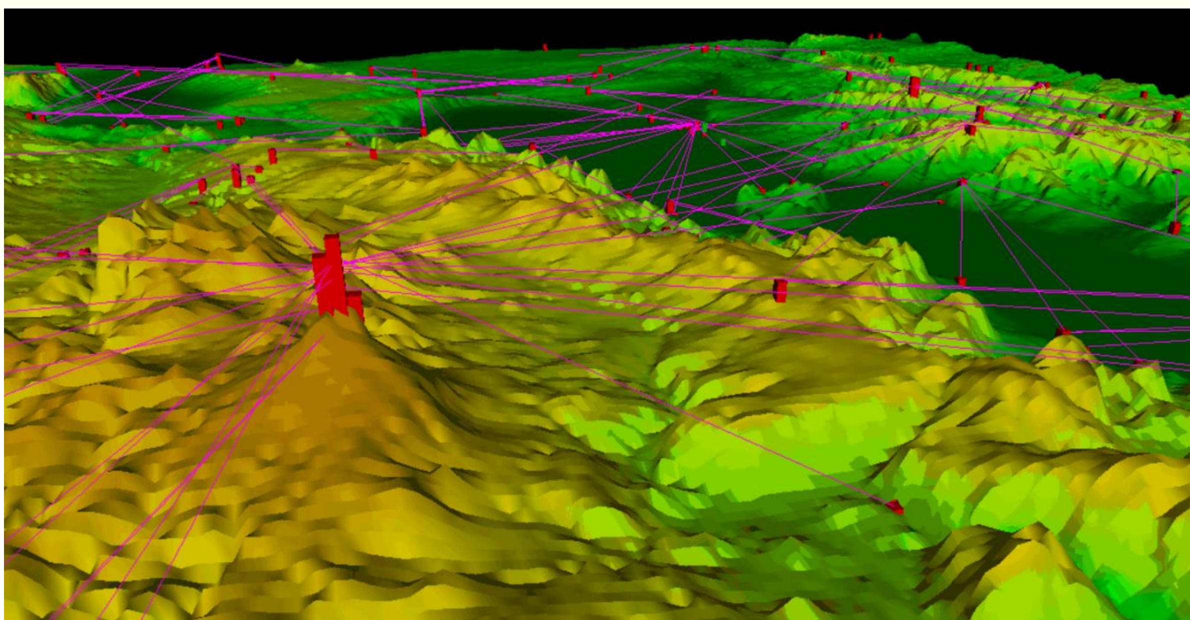
Microwave links 2-15 GHz around one Hungarian lake

Source: FMS program, 2013

Central station is at top of the mountain

2-D





3-D

3D: the central station is the biggest red column

LoS and NLoS FS links: RF, obstacles, attenuation by atmospheric gases; distances

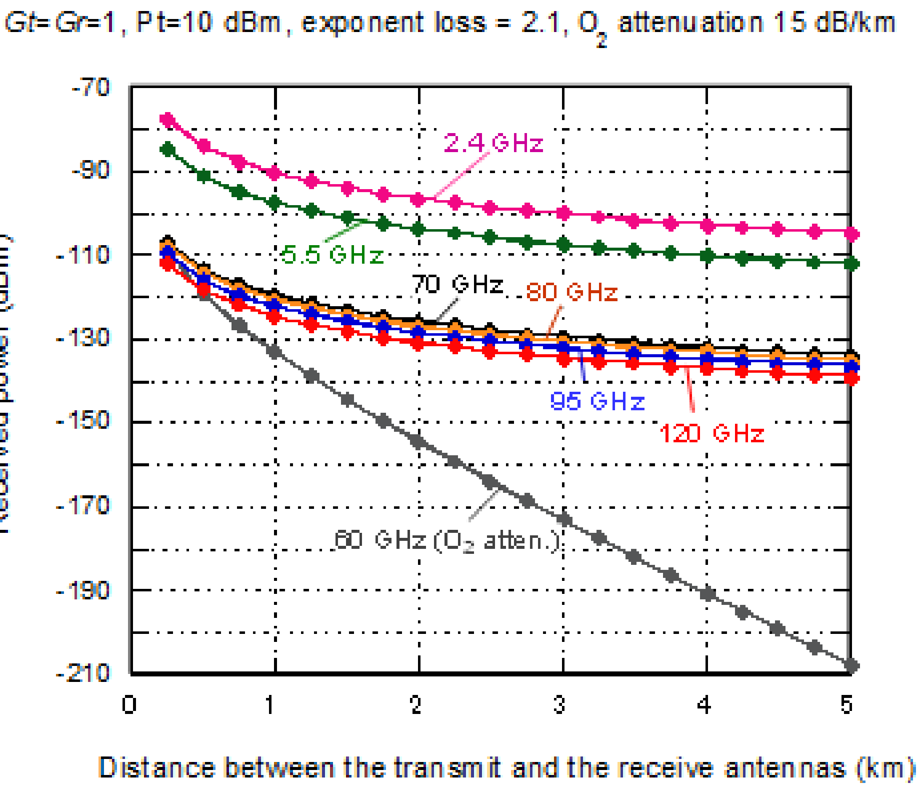
- Ionosphere, tropospheric, trans-horizon, diffraction and Line-of –Sight paths
- If no topographical or man made obstacles (smooth earth), the earth curvature is the limit of LoS links
- Fixed Wireless Systems (FWS) operating in lower RF profit from the enhanced propagation range, relative to higher frequencies deployment
- RF: below 6 GHz for NLoS; above 6 GHz for LoS
- Distance, obscuring buildings, attenuation by atmospheric gases

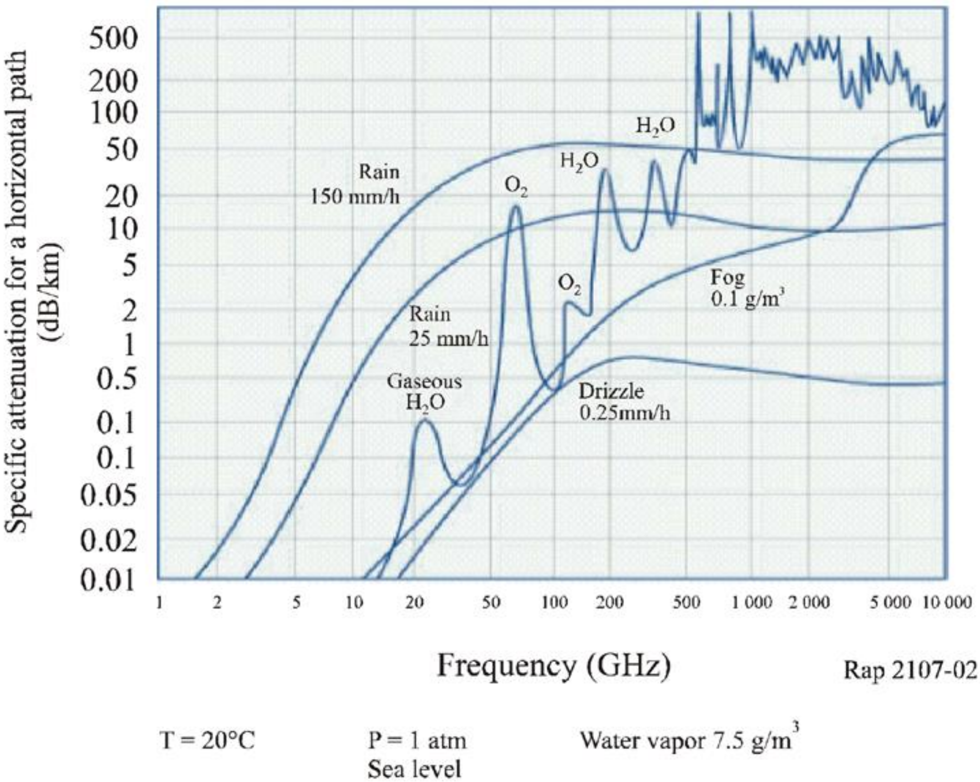
Rep. F.2107 (2011): Characteristics and applications of fixed wireless systems operating in frequency ranges between 57 GHz and 134 GHz

The simulated results are provided for the 2.4/5.5/60/70/80/95/120 GHz bands. It is assumed the transmit power P_t is 10 dBm, the transmit and receive antenna gains (G_t and G_r) are unity, n is 2.1, and the oxygen absorption is 15 dB/km for the 60 GHz band and zero otherwise.

Fig. 1 Received power (dBm) vs. distance (km). For the 70/80/95/120 GHz bands, the gaseous absorption is negligible

Fig. 2 shows the attenuation (dB/km) vs the frequency (GHz) due to the gases & hydrometeors through the atmosphere. Rain has the greatest impact in the 60/70/80/95/120 GHz bands





Lower RF→ higher range, less attenuation by obstacles & gases

PL=Propagation Loss; *d*=distance, λ=wavelength

$$PL = 20 \log (4\pi d / \lambda) \; ; \; f\,(MHz) = 300/\lambda\,(m)$$

Attenuation by obstacles depends on λ, relative to obstacle

Lower RF offers lower PL at free-space and non free-space prop.

The ability to cross obstacles is better at lower RF

In general, above 6 GHz, if there is no optical Line of Sight, there is no electromagnetic propagation

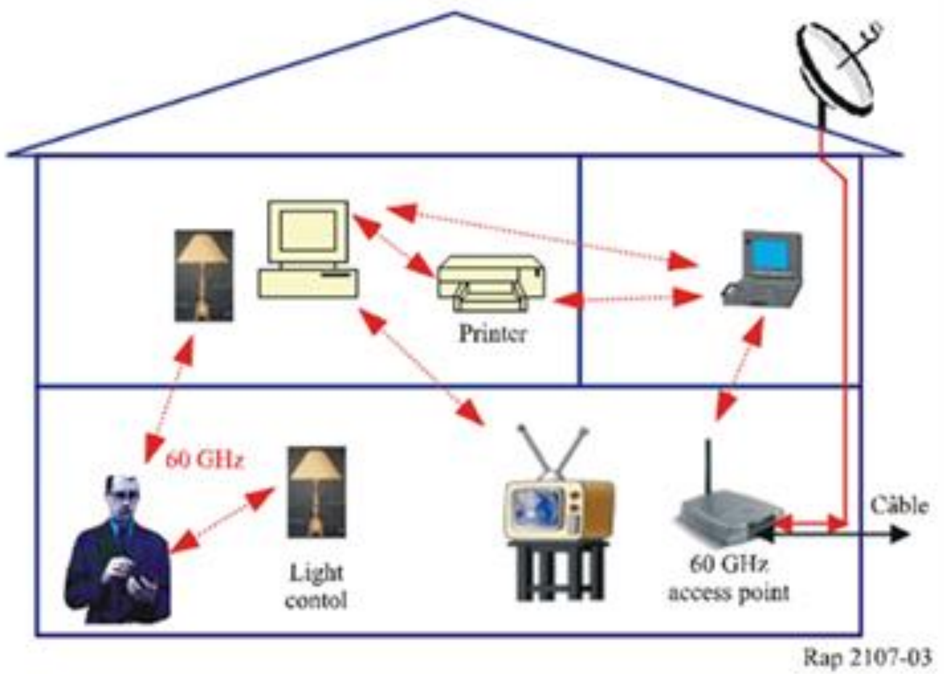
At f > 15 GHz   λ <2 cm rain drops, dust & vapor attenuate the wireless signal

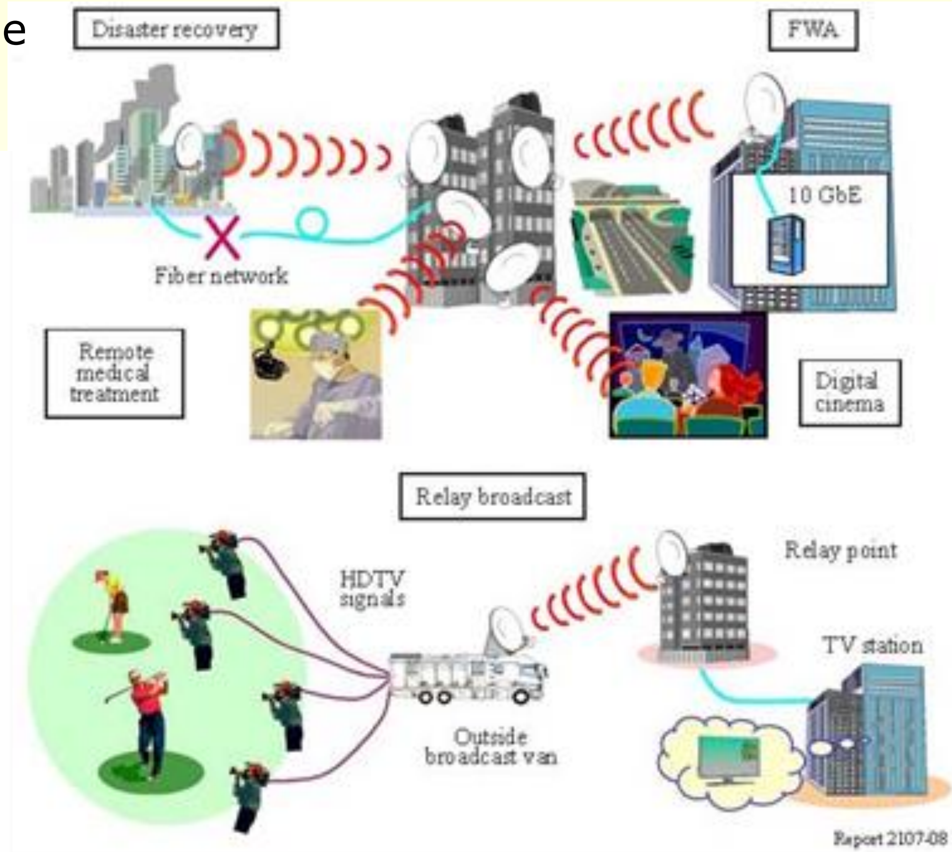
Relevant meteorological information concerning the propagation mechanisms is given Recs ITU-R P.676 and P.834

Rep F.2107 (2011): Examples of FWS operating between 57 GHz & 134 GHz

Fig 8: Application examples of 10 Gbit/s wireless link

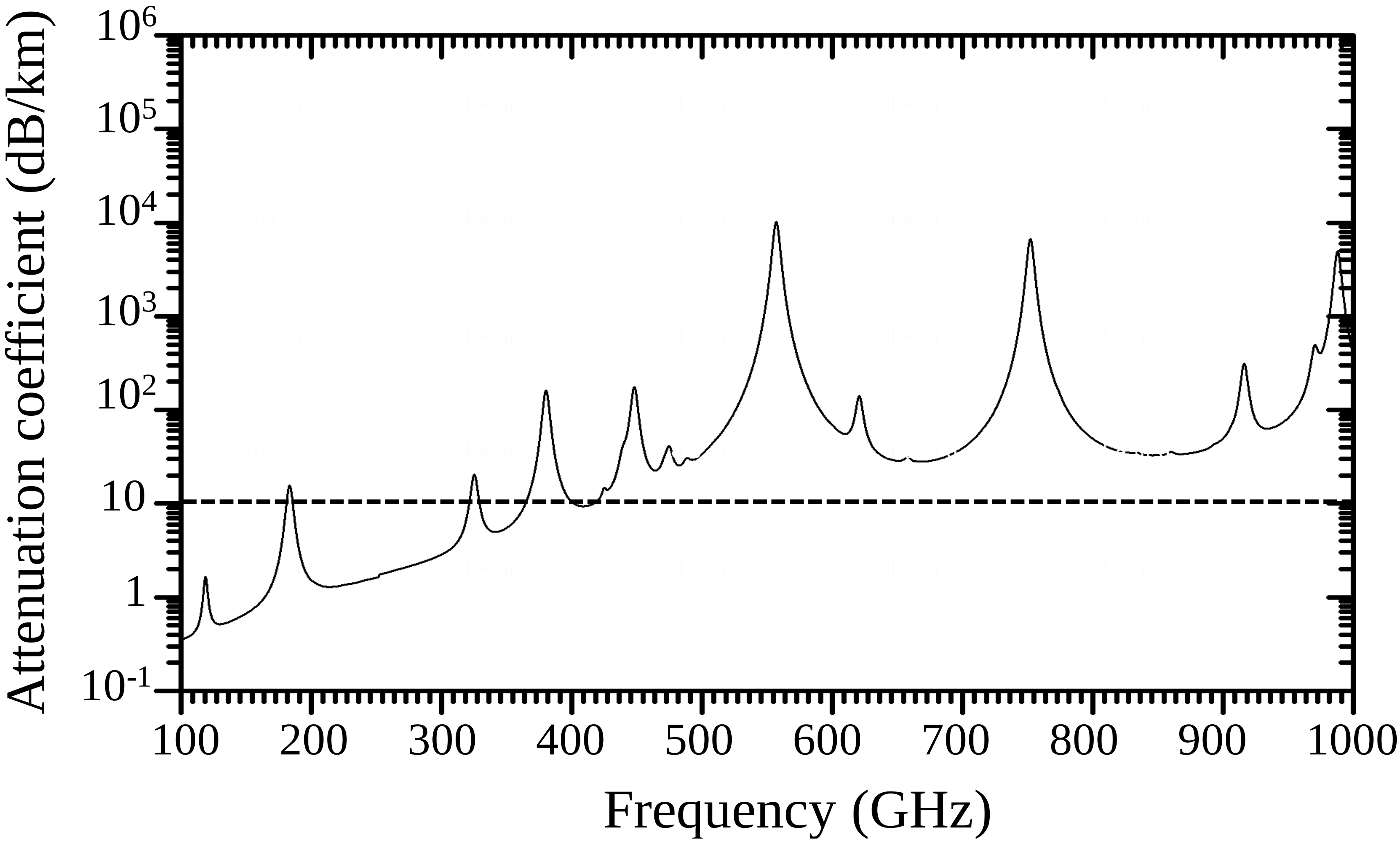
Fig 3: Example of a 60 GHz system for home environment, application where consumer electronics are controlled and operated



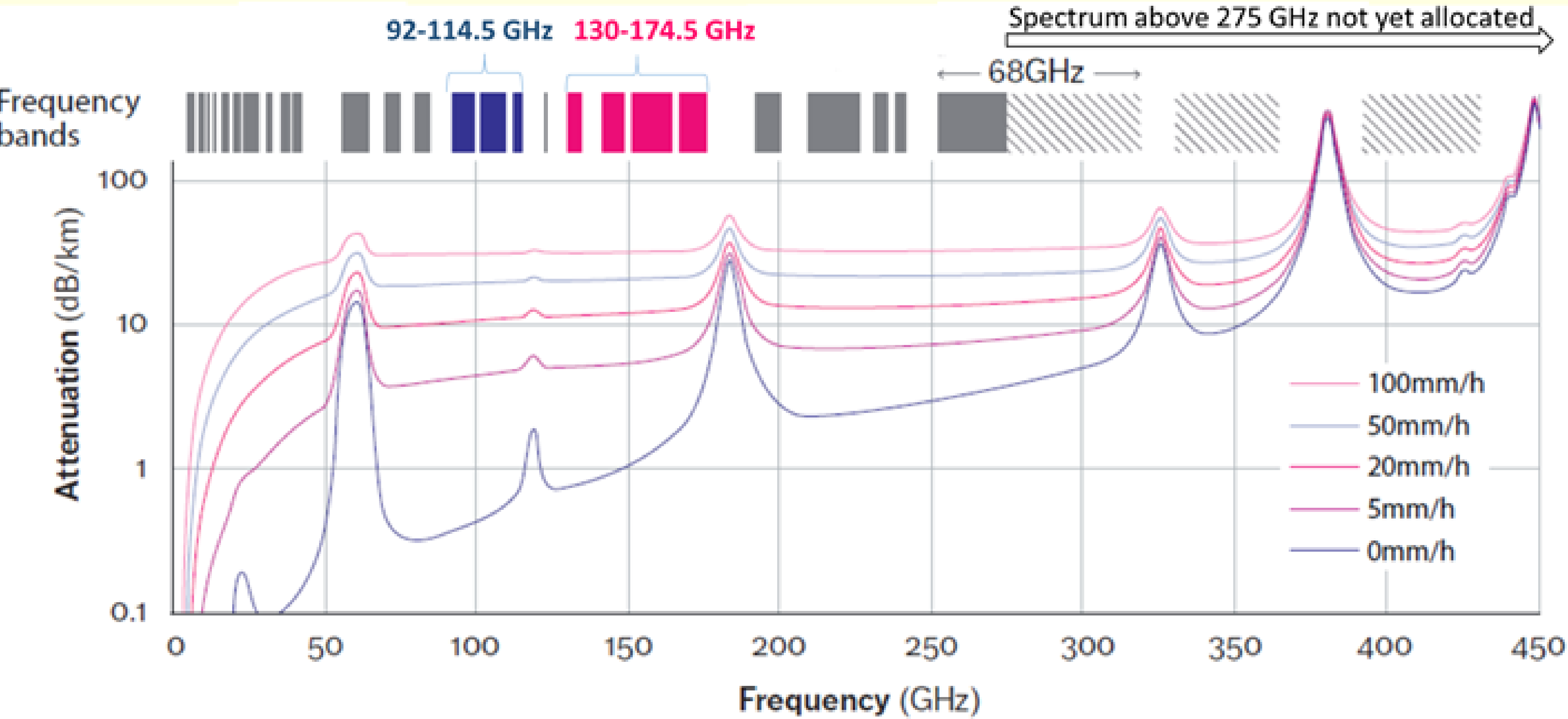


ITU Report F.2416: Technical and operational characteristics and applications of the point-to-point fixed service applications operating in the frequency band 275-450 GHz (2018)

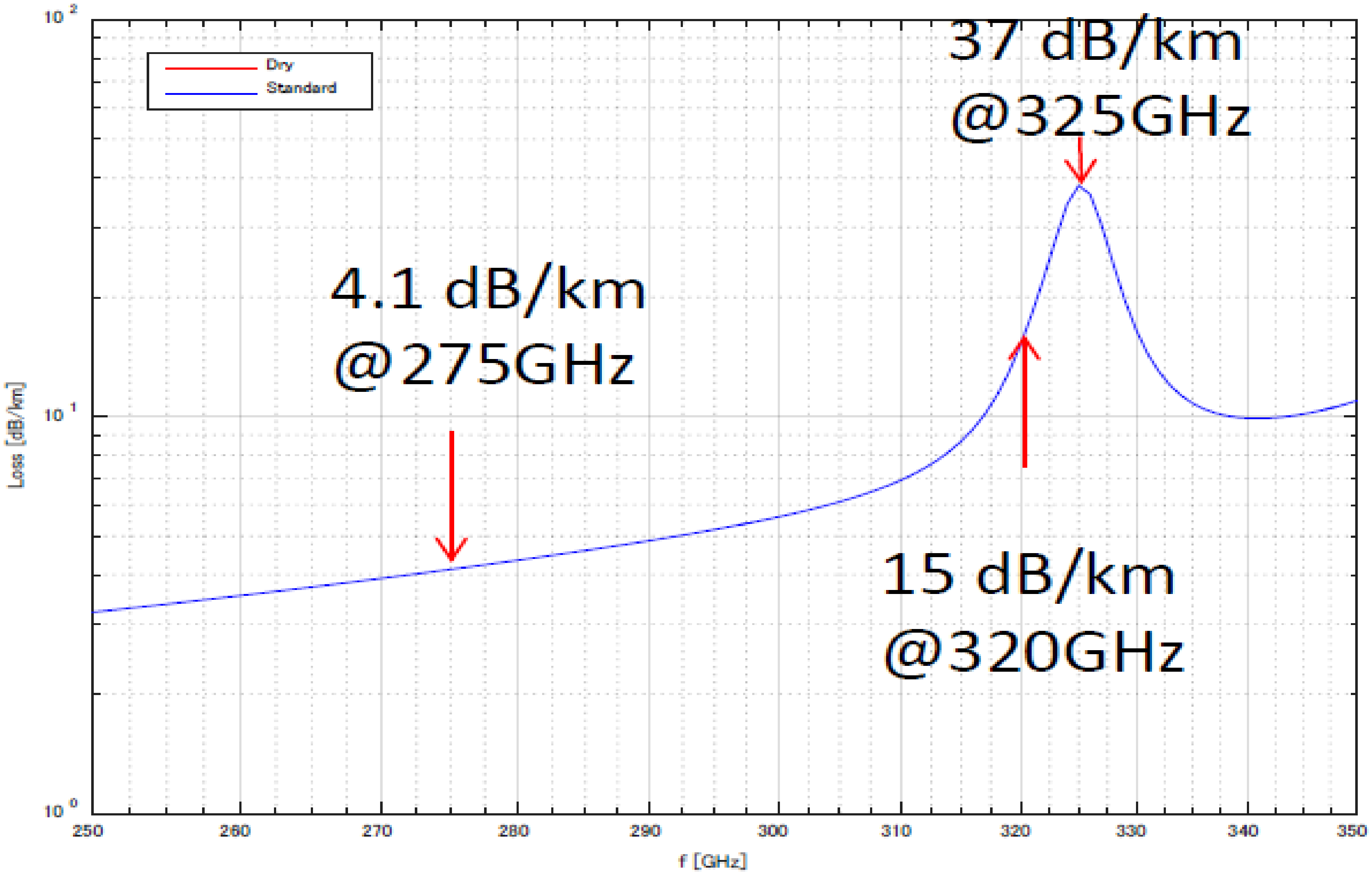
Attenuation coefficient in the frequency range 100-1 000 GHz (dashed line indicates attenuation coefficient highest peak of 60 GHz band)



ITU Report F.2416: Attenuation from atmospheric gases and rain



ITU Report F.2416: Attenuation characteristics by atmospheric gases



Rep F.2107 (2011) : Specifications at 120 GHz; Table 9 Example specifications of the 120 GHz band wireless link

Bandwidth	3 GHz (123.5-126.5 GHz: HD-SDI transmission) 17 GHz (116.5-133.5 GHz:10 Gbit/s data transmission)
Modulation	ASK
Output power	40 mW
Detection	Envelope detection
Receiver sensitivity (BER< 10^{-12})	−40 dBm (without FEC) −46 dBm (with FEC)
Power consumption	100 W
Weight	7.3 kg
Size	W190 × D380 × H130 mm
Antenna	Cassegrain antenna (450 mm diameter)
Antenna gain	48.6 dBi
Antenna beamwidth	0.4º (@ 3 dB)
Input signal interface	Electrical signal: 1 to 11.1 Gbit/s; Optical signal: 9.95～11.1 Gbit/s; (OC-192, 10GbE with and w/o FEC); HD-SDI signal: 1.5 Gbit/s, 50i/60i (NTSC/PAL)

Applications & examples; distance & bandwidth

1. Ethernet capacities, up to 1 Gbps per Ethernet connection
2. TDM capacities: E1's and STM-1
3. Up to 56MHz channels
4. Modulation agile 4QAM- 1024QAM
5. Link quality
   1) Up to 50 km hop length with 99.999% availability
   2) Actual deployments of up to 80 km

Report 2107-13

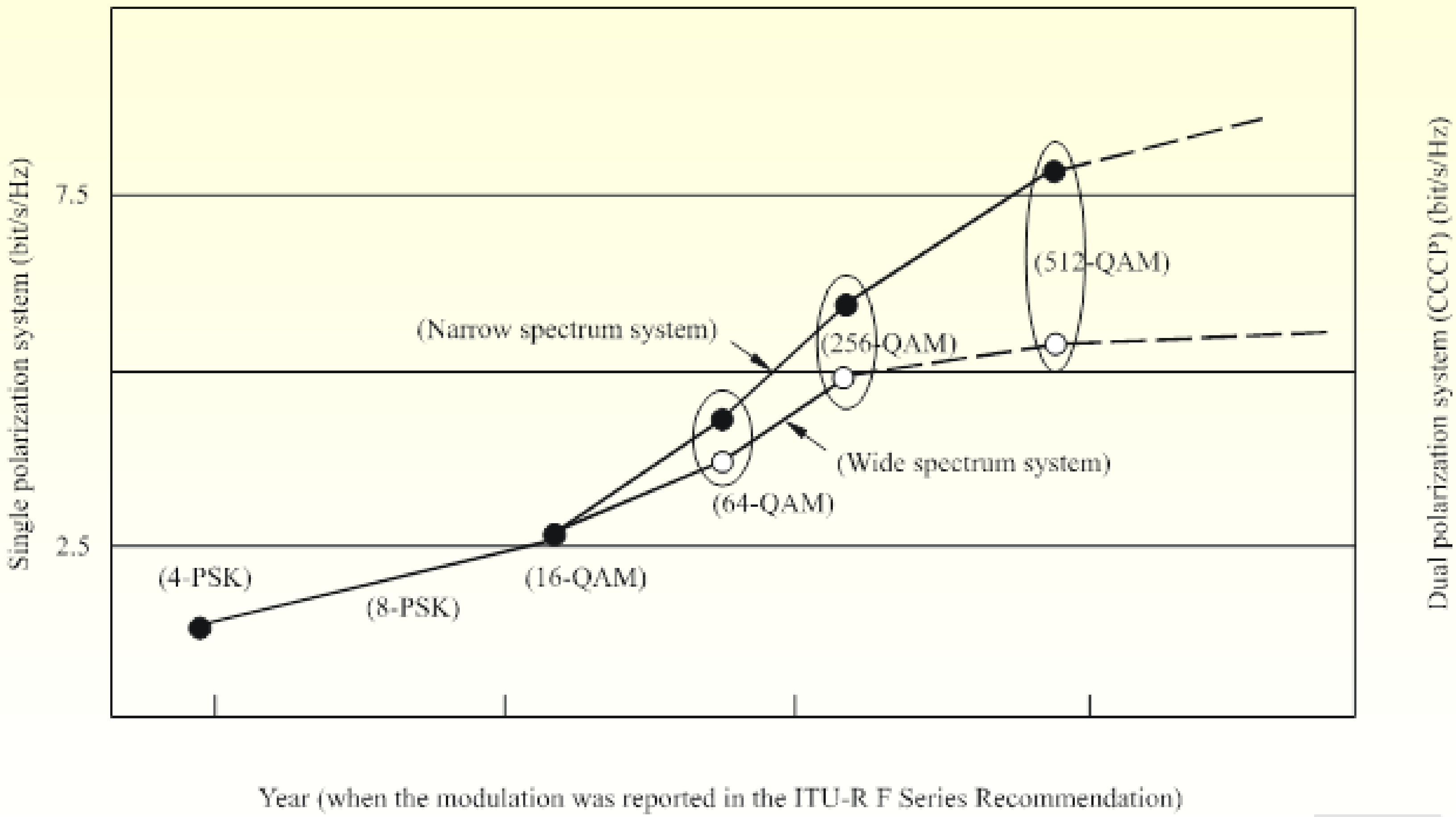
Report F.2060(2006) T.4: Capacity of fixed wireless links according to bandwidth & modulation

Bandwidth (MHz)	Capacity (Mbit/s)						
	2 × 2	8	2 × 8	34	51	155	2 x 155
3.5	4 states	16 states					
7		4 states	16 states				
13.75, 14			4 states	16 states	32 states		
27.5, 28, 29.65				4 states	16 states	128 states	128 states (CCDP)
40						64 states	64 states (CCDP)
55, 56						16 states	16 states (CCDP)

CCDP: co-channel dual polarized

FIGURE 2

Increase of frequency utilization efficiency (bit/s/Hz) in the FS



Rap 2047-02

Table 2: Desired take-off angles and best heights for layer 1F2

Distance (km)	Take-off angle (degrees)	Height above ground (wavelengths)
200	60-75	0.28
400	45-65	0.33
800	30-45	0.42
1 200	20-35	0.55
1 600	15-25	0.72

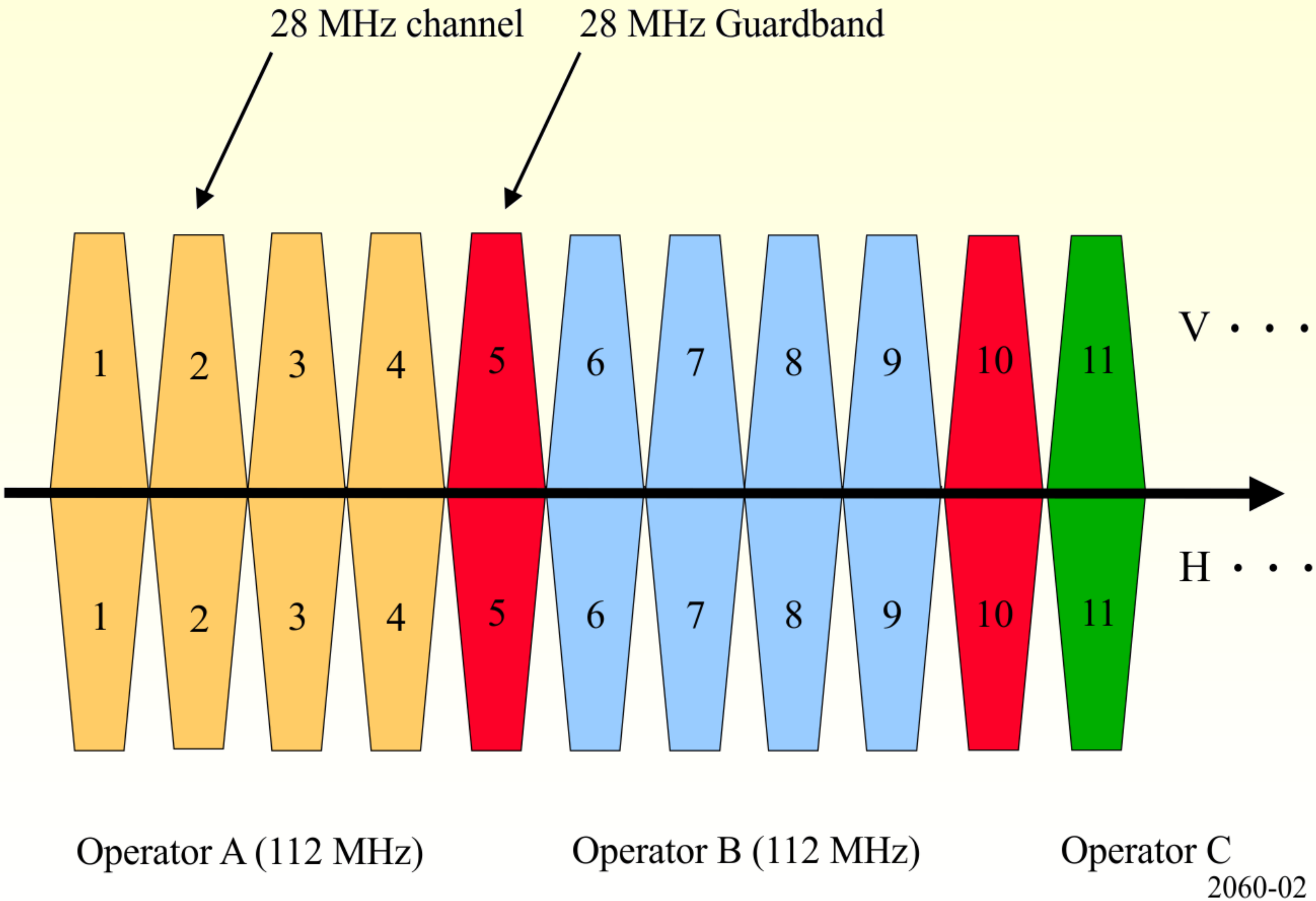
The height (in wavelengths) of the antenna above the ground generally determines the elevation angle of radiation. The optimum angle depends on the effective height of the ionosphere and the distance to the other station Height above ground (wavelengths) is related in some way reciprocally to the 'antenna factor'

Channel Arrangements (CA) and Blocks

	RF Band	Rec ITU-R		RF Band	Rec ITU-R
1	406.1-450 MHz	F.1567	14	10.0-10.68 GHz	F.747
2	1 350 -1 530 MHz	F.1242	15	blocks at 10.15-10.3/10.5-10.65 GHz	F.1568
3	1 350-2 690 MHz	F.701	16	10.7-11.7 GHz	F.387
4	1 900-2 300 MHz	F.1098	17	14.4-15.35 GHz	F.636
5	2 290-2 670 MHz	F.1243	18	17.7-19.7 GHz	F.595
6	2 and 4 GHz	F.382	19	21.2-23.6 GHz	F.637
7	blocks @ 3 400-3 800 MHz	F.1488	20	25, 26 & 28 GHz	F.748
8	3 400-4 200 MHz	F.635	21	31.8-33.4 GHz	F.1520
9	4 400-5 000 MHz	F.1099	22	36-40.5 GHz	F.749
10	5 925 - 6 425 MHz	F.383	23	CA & blocks at 40.5-43.5 GHz	F.2005
11	6 425-7 125 MHz	F.384	24	51.4-52.6 GHz	F.1496
12	7 110-7 900 MHz	F.385	25	CA & blocks @ 71-76 & 81-86 GHz	F.2006
13	7 725-8 500 MHz	F.386	26	92-95 GHz	F.2004

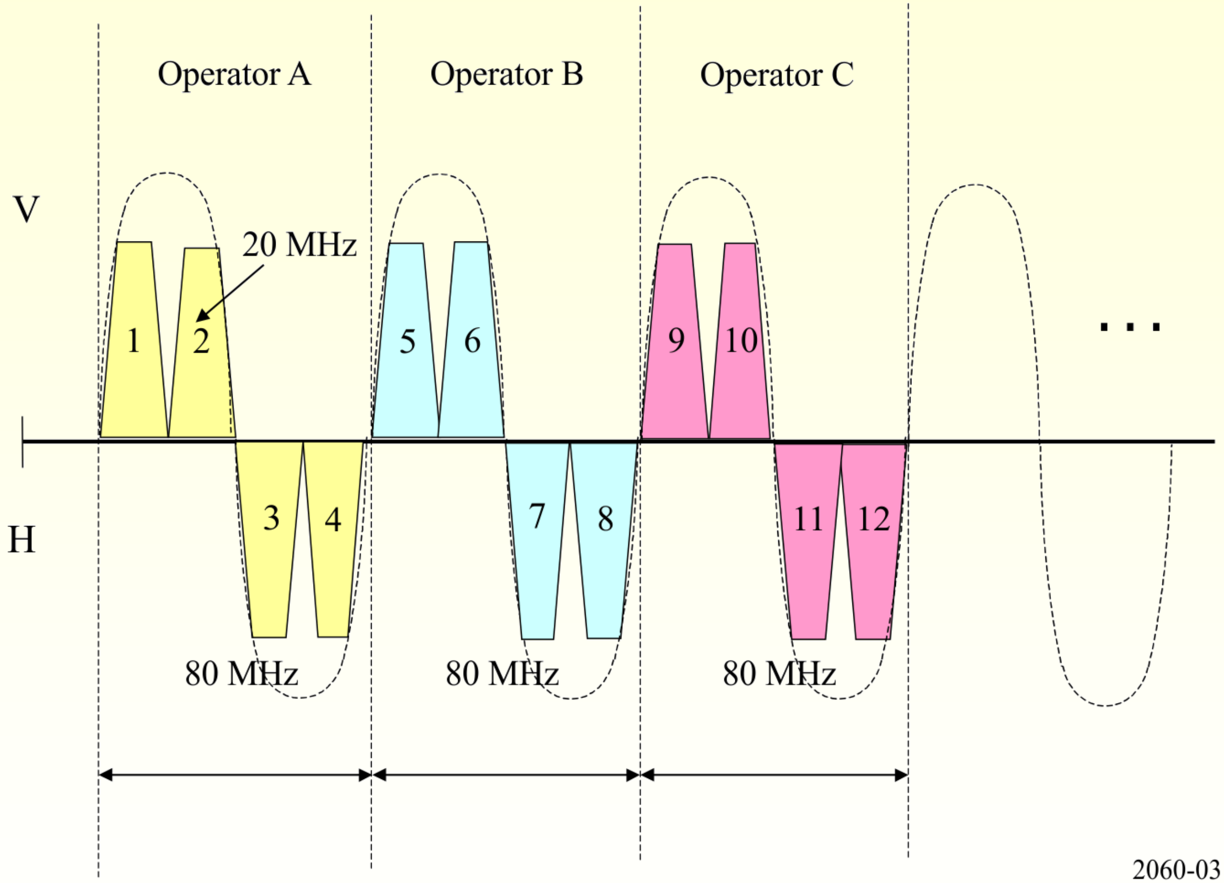
Report F.2060 (2006): Block Assignment Scenarios, with and without Guard Band

With guard band



Report F.2060 (2006): Block Assignment Scenarios, with and without guard band

Interleaved assignment without guard band (cont.)



Link budget point-to-point logarithmically and numerically

Inserting the free-space propagation loss *d* (km) and *f* (GHz) to the received signal:

$Pr = P_t + G_t - L_t - P_l + G_r - L_r = P_t + G_t - L_t + G_r - L_r - 92.45 - 20 \log d\,(\text{km}) - 20 \log f\,(\text{GHz})$

e.g., for a **point-to-point** system, distanced *d* 40 km, operating at 7,500 MHz (λ wavelength 0.04 m), transmitting 2 Watts (33 dBm), 44.5 dBi (28,000) gains for transmitting and receiving antennas, 1 dB (1.25) cable losses at transmitter and receiver, assuming free-space loss $(4\pi d/\lambda)^2$, equivalent to $20 \log (4\pi d/\lambda)$:

$$p_r = \frac{2 \times 28,000 \times 28,000}{(4 \times \pi \times 40,000 \div 0.04)^2 \times 1.25 \times 1.25} = 6.35\ 10^{-6}\ \text{Watts}$$

In logarithmic expressions, for free-space loss:

$P_r = 22 + 20\log(40,000/0.04) = 22 + 120 = 142$ dB and $P_r = 33 + 44.5 - 1 - 142 + 44.5 - 1 = -22$ dBm

Multipath fading is taken into account to guarantee performance of fixed wireless systems

Fading countermeasure is usually expressed in terms of an improvement factor (IF). IF is the ratio of the outage time observed for a system without the countermeasure, to that observed when the countermeasure is operative Outage time indicates the time duration over which the system exceeds a chosen bit-error ratio (BER) threshold

Fade Margin

$$FM = P_r - P_{r,min}$$

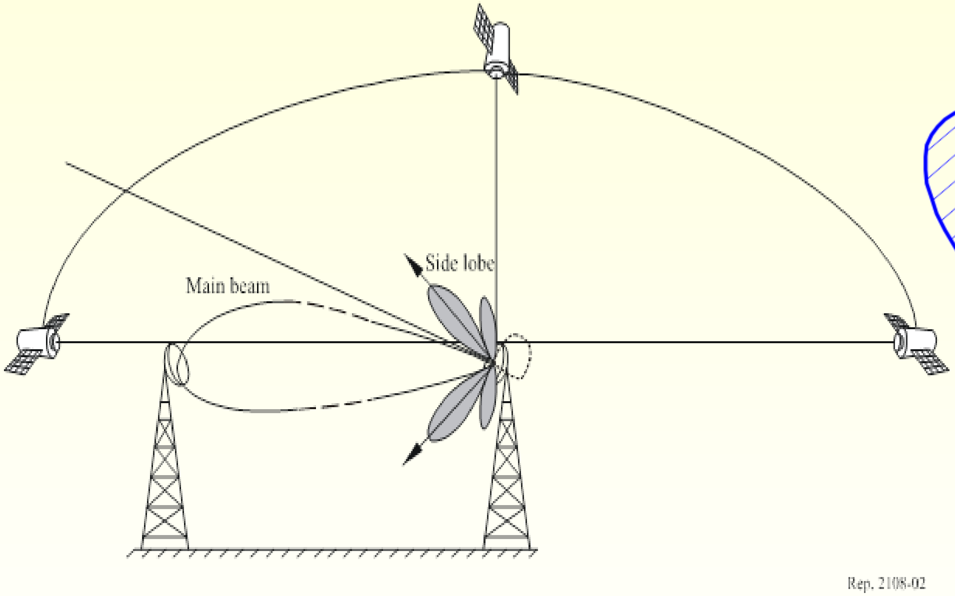
or:

- $$FM = G_e + G_r + P_e - L_T(p) - FL - P_{r,min}$$
- FM: fade margin
- P_e: input power at the emission (transmitter power) (dBm)
- $L_T(p)$: total loss (rain at p%, gas, diffraction) (dB)
- FL: feeder loss (total: at the emission and reception) (dB)
- $P_{r,min}$: min. level at the reception (usually for BER of 10^{-6}) (dBm)
- G_e: antenna gain at the emission (transmitter) (dBi)
- G_r: antenna gain at the reception (receiver) (dBi).

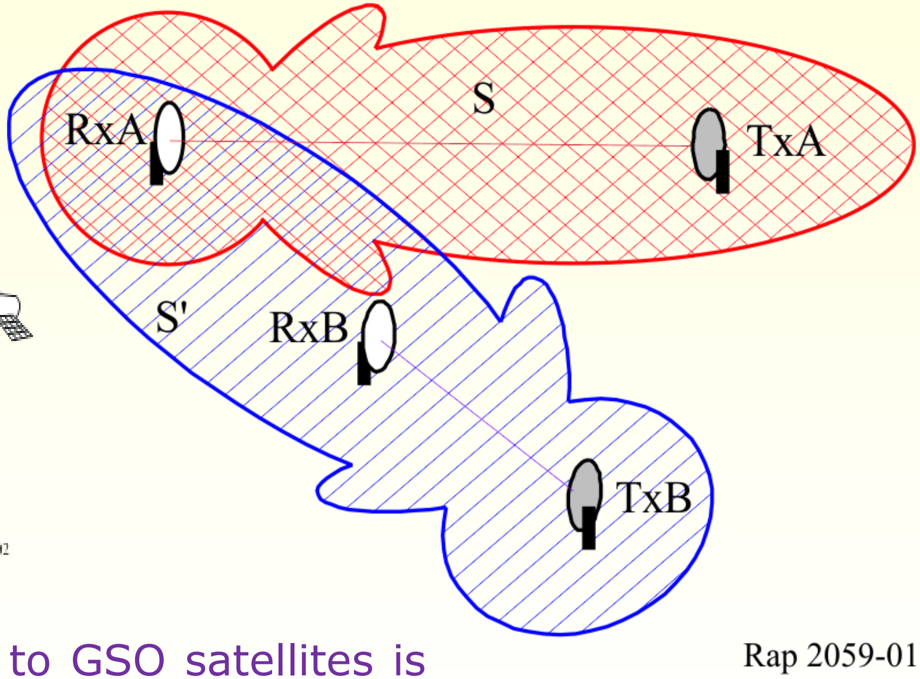
If only P-P FS systems are considered, in the following calculation usually $G_e = G_r = G$.

Sharing Scenarios: ITU-R Reports F. 2059 (2005) & F.2108 (2007)

F.2108 Fig. 2: FS system parameters for different freq. bands



F. 2059 Fig. 1: Spectrum denial area "S"



In most cases the interference from and to GSO satellites is transmitted and recieved through the antennas side lobes

Satellite Communications

- Designations of Satellites RF bands & main RF bands
- Orbits and Services
  - GEO: FSS , BSS
  - MSS & LEO (incl. GPS); MEO; HEO
- Satellites' Equipment

http://mazar.atwebpages.com/

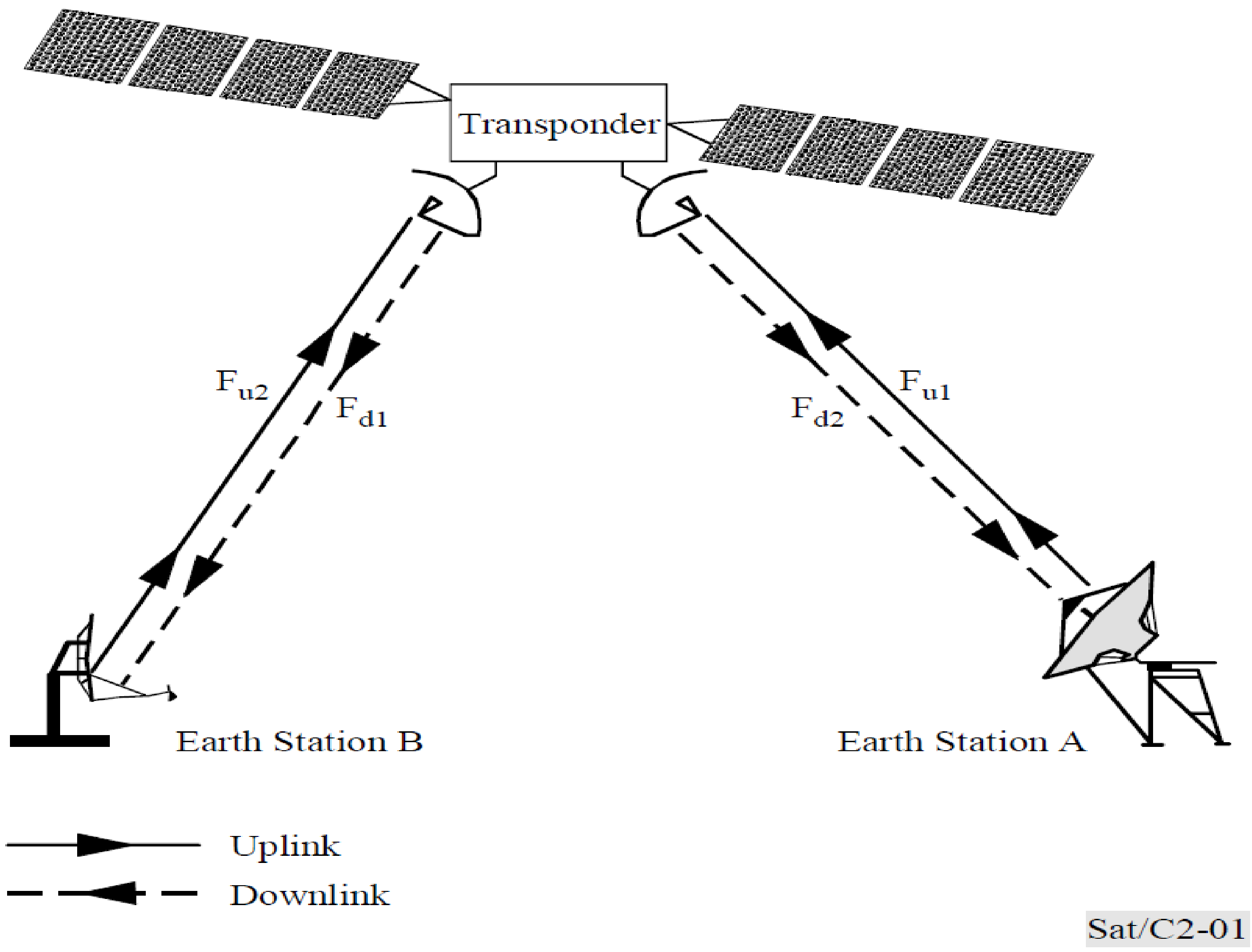
Designations of Satellites RF bands

	RF (GHz)			RF (GHz)
S Band	2 - 4		Ku Band	12 – 18
C Band	4 - 8		K Band	18 - 27
X Band	8 - 12			

Main Frequency bands used for GSO

Frequency bands (GHz)		
Current denomination	Up path/uplink (bandwidth)	Down path/downlink (bandwidth)
6/4 (C Band) (Unplanned FSS)	5.725-6. 725 (1,000 MHz)	3.4-4.2 (800 MHz)
6/4 (C Band) (Planned FSS)	6.725-7.025 (300 MHz)	4.5-4.8 (300 MHz)
8/7 (X-Band) (Unplanned FSS)	7.925-8.425 (500 MHz)	7.25-7.75 (500 MHz)
13/11 (Ku Band) Planned FSS	12.75-13.25 (500 MHz)	10.7-10.95;11.2-11.45 (500 MHz)
13-14/11-12 (Ku Band) Unplanned FSS	13.75-14.5 (750 MHz)	10.95-11.2;11.45-11.7; 12.5-12.75 (750 MHz)
18/12 (Ku Band) Planned BSS	17.3-18.1 (800 MHz)	11.7-12.5 (800 MHz)
30/20 (Ka Band)*	27.5-31.0 (3,500 MHz)	17.7-21.2 (3,500 MHz)
40/20 (Ka Band)	42.5-45.5 (3,000 MHz)	18.2-21.2 (3,000 MHz)

The basic satellite link



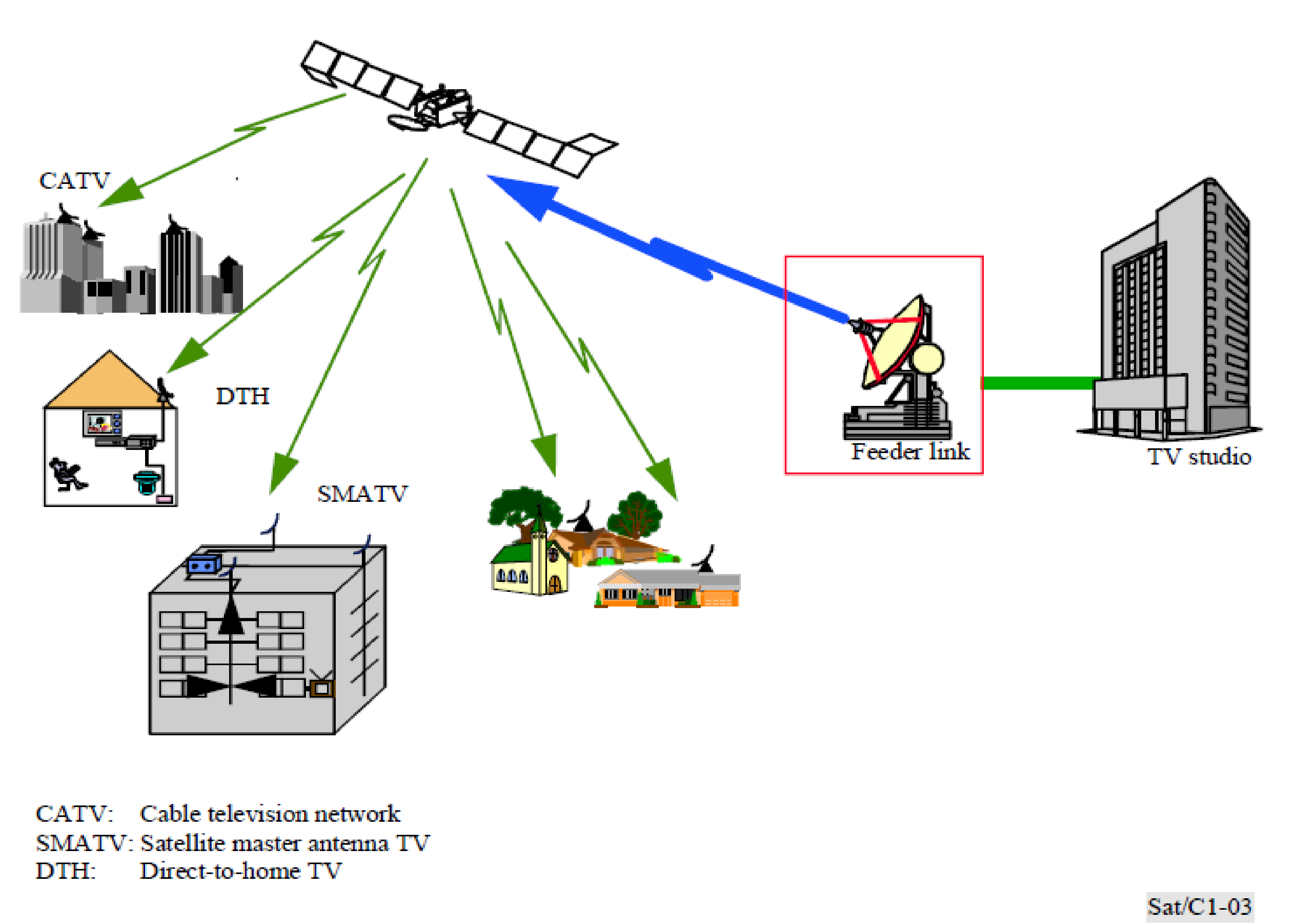
Handbook on Satellite Communications ITU SAT HB 2002

Satellites Orbits ITU Satellites Handbook

ORBITS	LEO	MEO	HEO	GEO
Environment constraints	Currently low (space debris: growing concern)	Low/medium	Medium/high	Low; short number of orbital slots; station keeping
	Van Allen belts: 4 crossings/day			
Typical orbital period	1.5-2 h	5-10 h	12 h	24 h
Altitude range	500-1,500 km	8,000-18,000 km	Up to 40,000 km apogee (perigee ~ 1,000 km)	35,700 km
Visibility duration	15-20 mn/pass	2-8 h/pass	8-11 h/pass (apogee)	Permanent
Elevation	Rapid variations; high and low angles	Slow variations; high angles	No variations (apogee); high angles near Equator	No variation; low angles at high latitudes
Propagation delay	Several milliseconds	Tens of milliseconds	Hundreds of milliseconds (apogee)	> 250 milliseconds
Link budget (distance)	Favorable; compatible with small satellites and handheld user terminals	Less favorable	Not favorable for handheld or small terminals; requires large and powerful satellites	Not favorable for handheld or small terminals
Instantaneous ground coverage (diameter at 10° elevation)	≈ 6,000 km	≈ 12,000-15,000 km	16,000 km (apogee)	16,000 km (~ 0.4 of earth circumference at Equator)
Examples of systems	Iridium, Globalstar, Skybridge, Orbcomm…	Odyssey, ICO-P ; O3B	Molnya, Archimedes…	Intelsat, Inmarsat, Meteosat, Milcom; Eutelsat, Amos…
	Scientific missions			

LEO: low-Earth orbits; MEO: medium-Earth orbits; HEO: highly-eccentric orbits; GEO: geostationary

Generic illustration of BSS (ITU SAT Handbook)



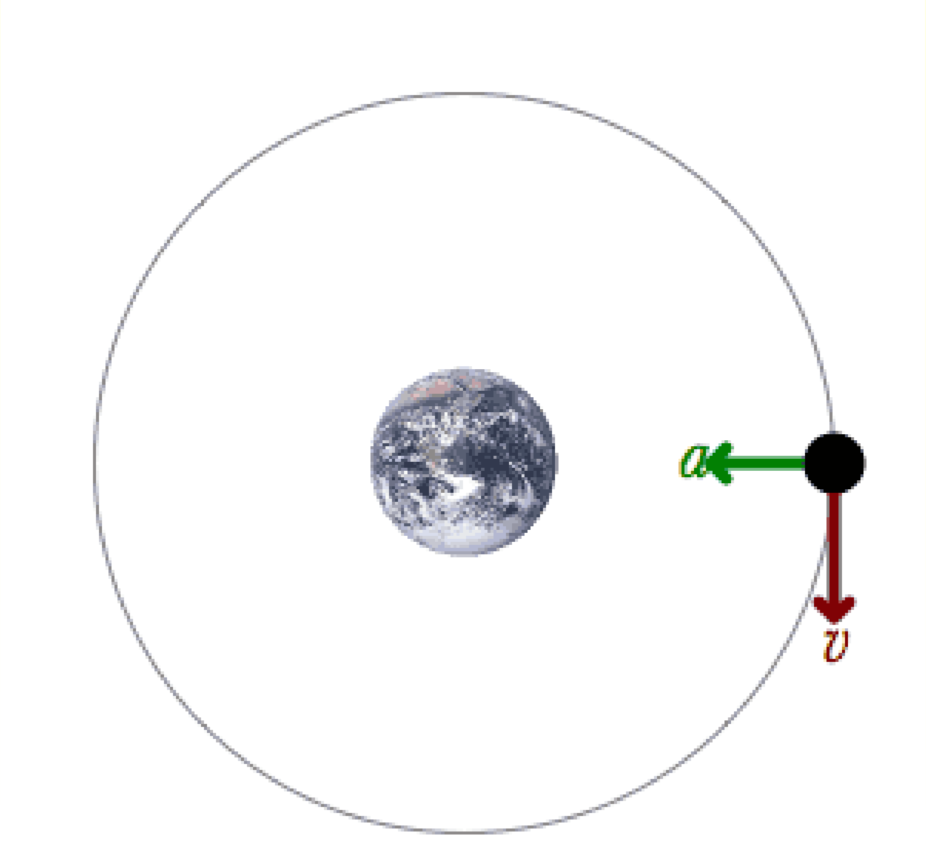
Geostationary Satellite

1. Circular orbits above the equator
2. Angular separation less than 1^0 allows more than 360 satellites
3. Orbital height above the earth, about 23,000 miles/ 35,000km
4. Round trip time to satellite about 0.24 seconds $\frac{36,000 \times 2}{300,000}$
5. GEO satellites require more power for communications
6. Signal to noise ratio for GEOs is worse due to distances
7. 1 GEO covers about 40% of the world
8. Polar regions cannot be “seen” or covered by GEOs
9. As stationary, GEOs don’t require dynamic tracking
10. GEOs are good for broadcasting to wide areas and FSS

Computing the altitude above sea level of Geo-Satellites

see https://youtu.be/fSrbJ8efv40 and https://www.youtube.com/watch?v=hoRYiVDIcpg

https://en.wikipedia.org/wiki/Newton%27s_law_of_universal_gravitation



Geostationary satellite altitude above sea level

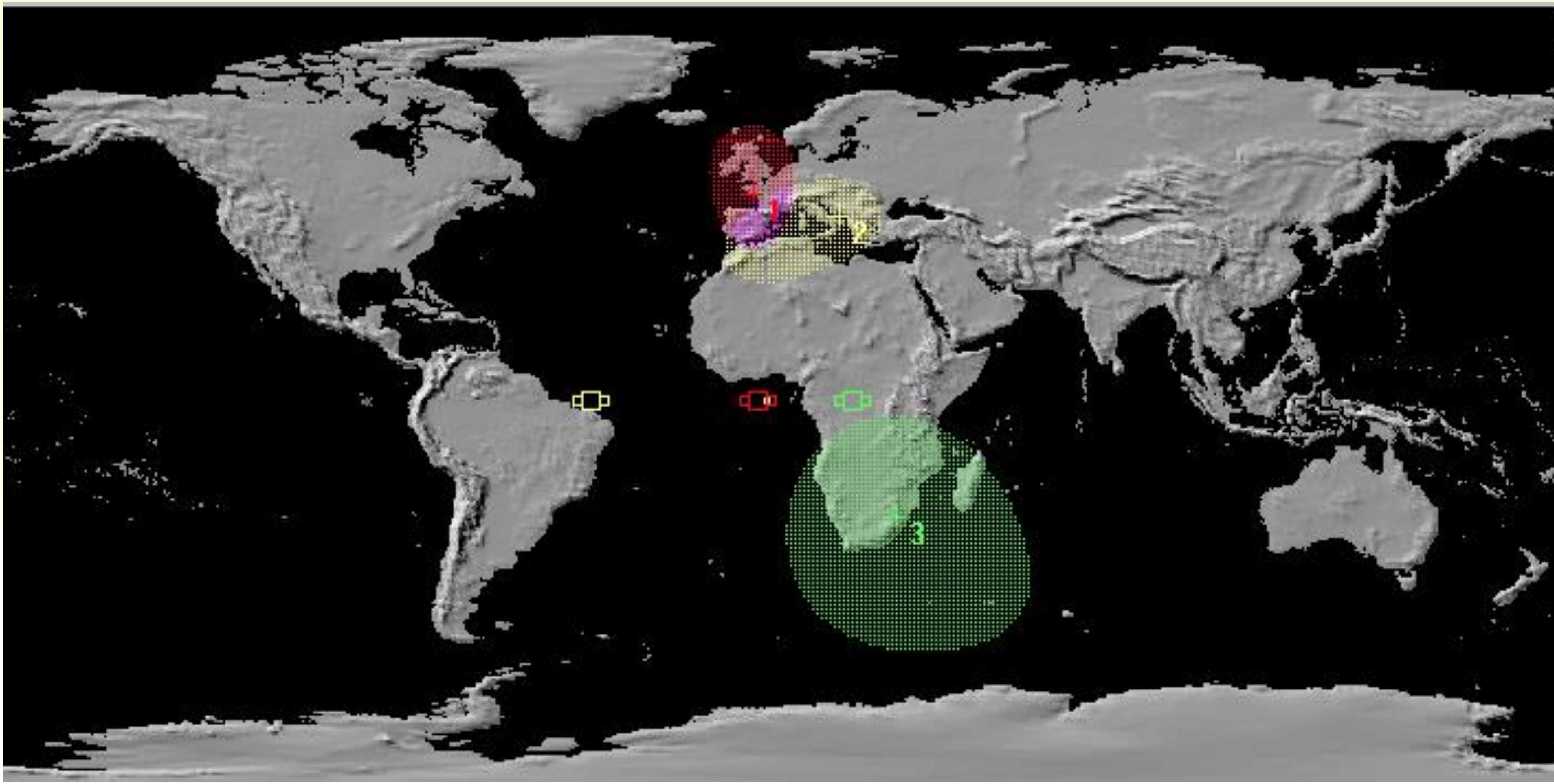
G the gravitational constant 6.674×10^{-11} ($m^3\cdot kg^{-1}\cdot s^{-2}$); $mass_{EARTH}$= 5.9723 10^{24} (kg), R_e= earth- radius= $6.378*10^6$ (m). Equating the centrifugal (satellite circular motion) and centripetal (gravity) forces, when *r* is the distance between the centers of the masses. Thus gravity-force $\frac{Gm_s m_E}{r^2}$ equals centrifuge $m_s r\omega^2 = mS\frac{v_t^2}{r}$; $\omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi\ (rad))}{24\ (hr)} * \frac{1\ (hr)}{3600\ (s)} = 7.27222 * 10^{-5}$ ($rad\cdot s^{-1}$); $\frac{Gm_s m_E}{r^2} = m_s r\omega^2 \rightarrow \frac{Gm_E}{r^2} = r\omega^2 \rightarrow \frac{Gm_E}{r^3} = \omega^2$; $r^3 = \frac{Gm_E}{\omega^2} \rightarrow r = \sqrt[3]{\frac{Gm_E}{\omega^2}} = \sqrt[3]{\frac{(6.67*10^{-11})(5.9723*10^{24})}{(7.27221*10^{-5})^2}}$;

$r = 4.22323 * 10^7 m = R_E + Altitude \rightarrow Altitude = r - R_E$;

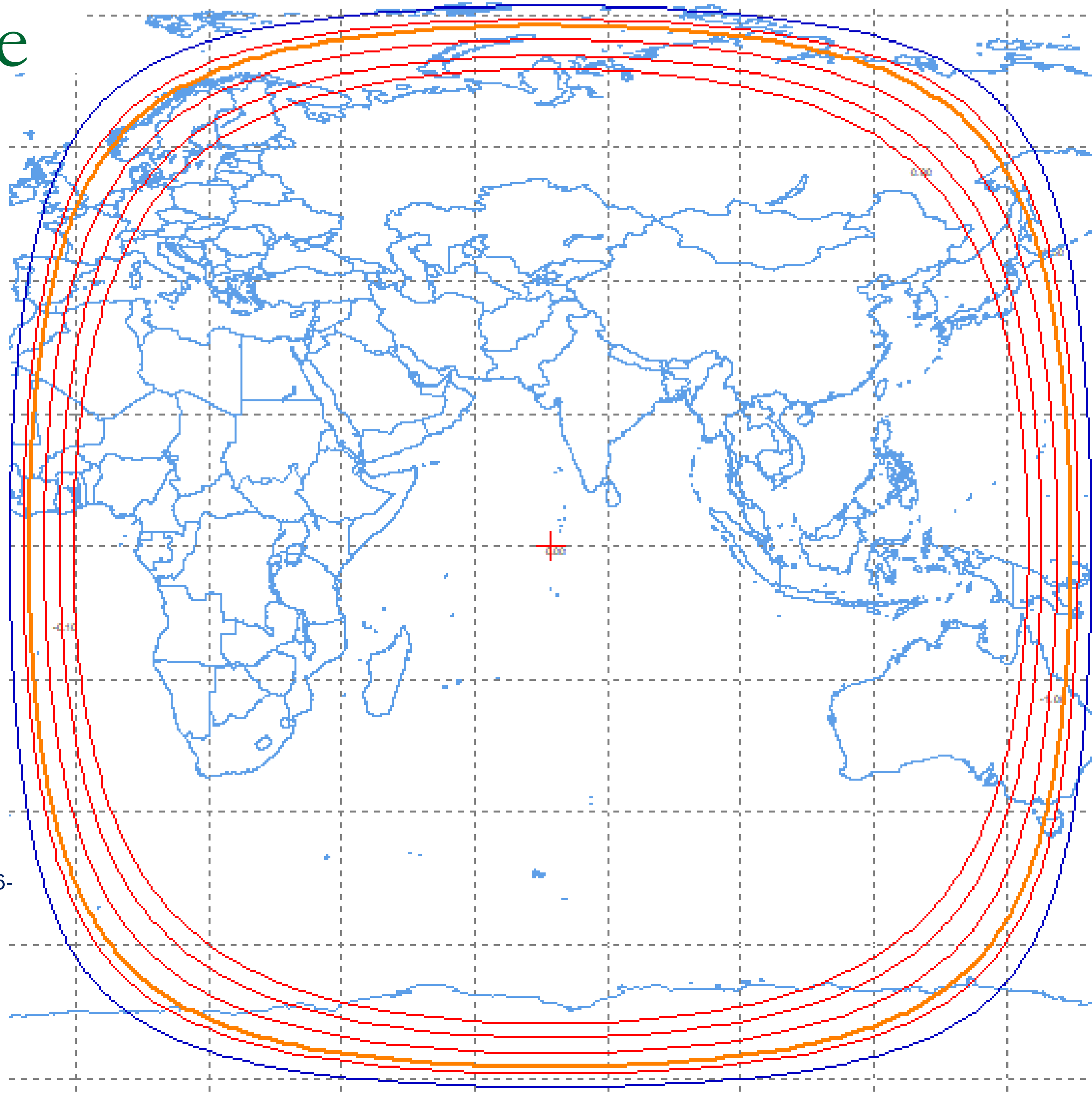
$Altitude = 4.22323 * 10^7 - 6.378 * 10^6 = 3.58543 * 10^7 \approx 3.59 * 10^7 [m]$

$$\boldsymbol{Altitude \approx 3.59 * 10^7 \approx 35,900\ (km)}$$

Example- geostationary satellite high-quality coverage



FSS coverage

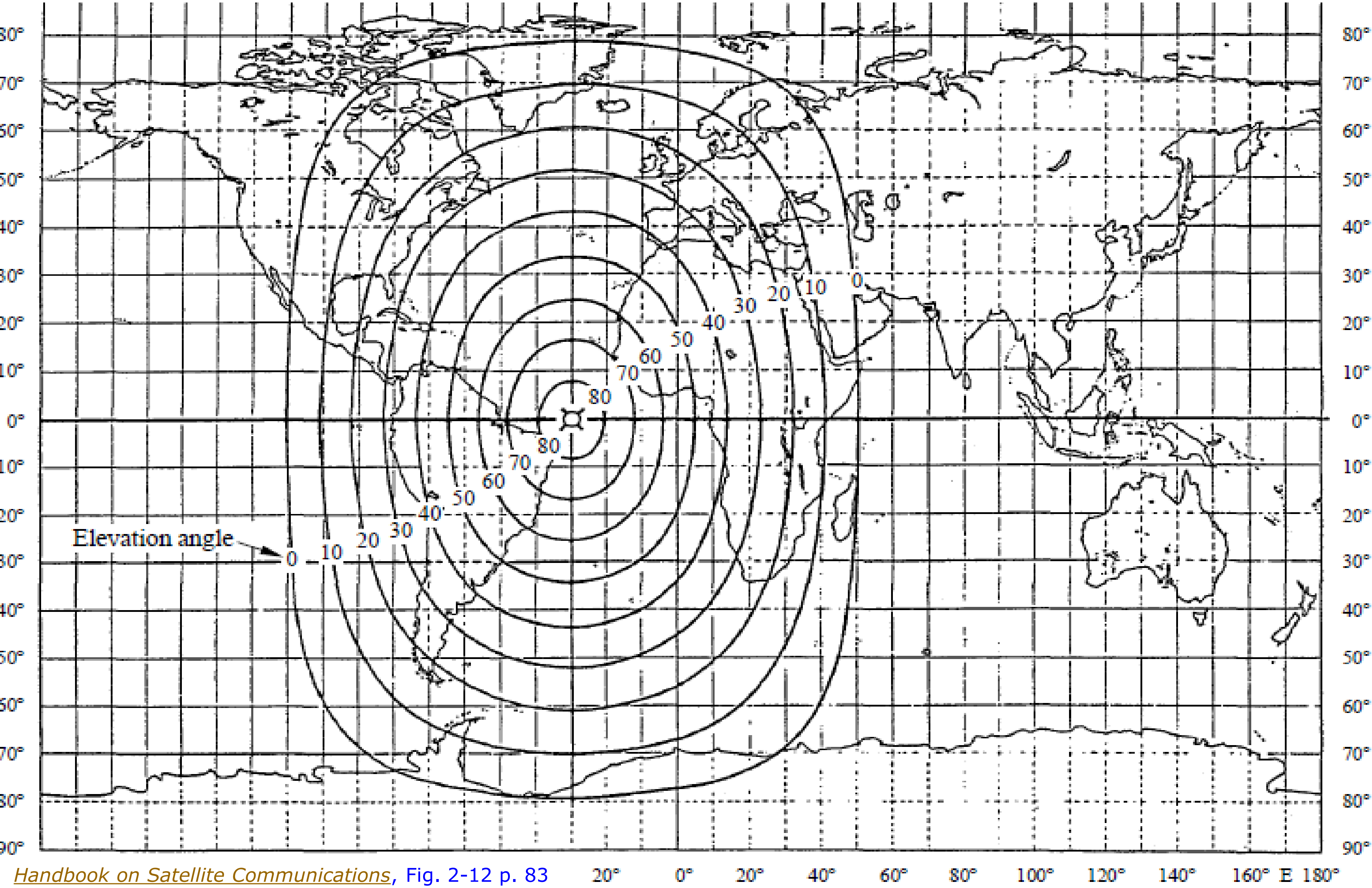


Dr. Haim Mazar (Madjar) haimma1@

Calculating Elevation and Azimuth to the Geostationary Satellite

1. The principal limitation in coverage is the area above 75 degrees North or South Latitude
2. At the same longitude as the GEO sat, the elevation angle to the geostationary satellite equals approximately 90 minus the absolute latitude; the latitude of the Earth-Station (ES) defines the elevation angle to the satellite and thus limits the edge of coverage
3. The geographical latitude determines the elevation angle towards broadcasting satellites; the longitude determines which of those satellites can be received
4. Calculator1 **or Calculator2** can be used to calculate the elevation ***ϑ*** and azimuth ***Φ*** toward the geostationary satellite, given the, based on the longitude of the Geo Satellite, and the coordinates (longitude and latitude) of the ES
5. Pay attention: use decimal coordinates, e.g., latitude 33.725^0 E, and not dd.mm.ss latitude $33^0$42’30’’ E for the ES

Elevation angle, LoS from an earth surface towards a GSO satellite

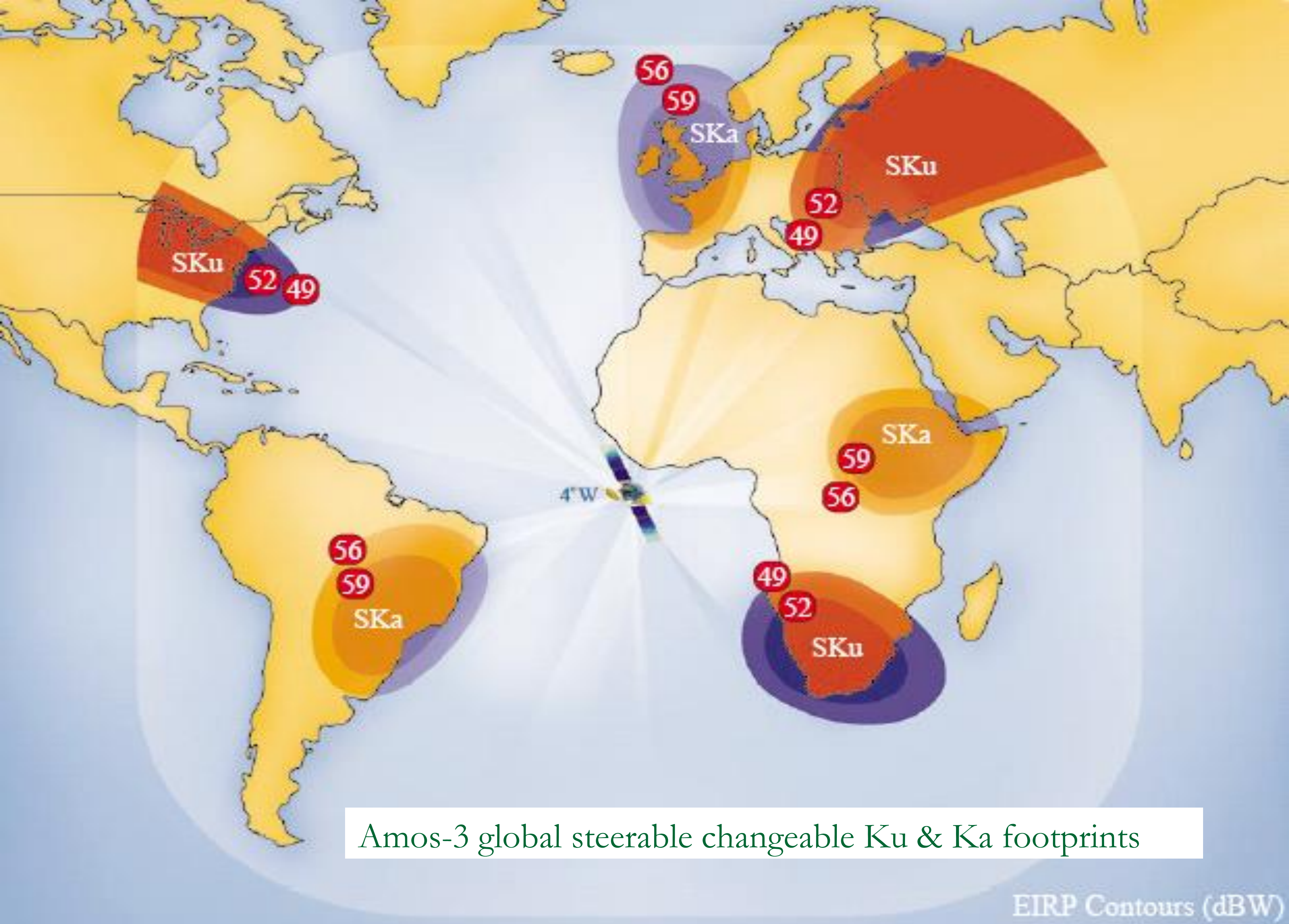


Handbook on Satellite Communications, Fig. 2-12 p. 83

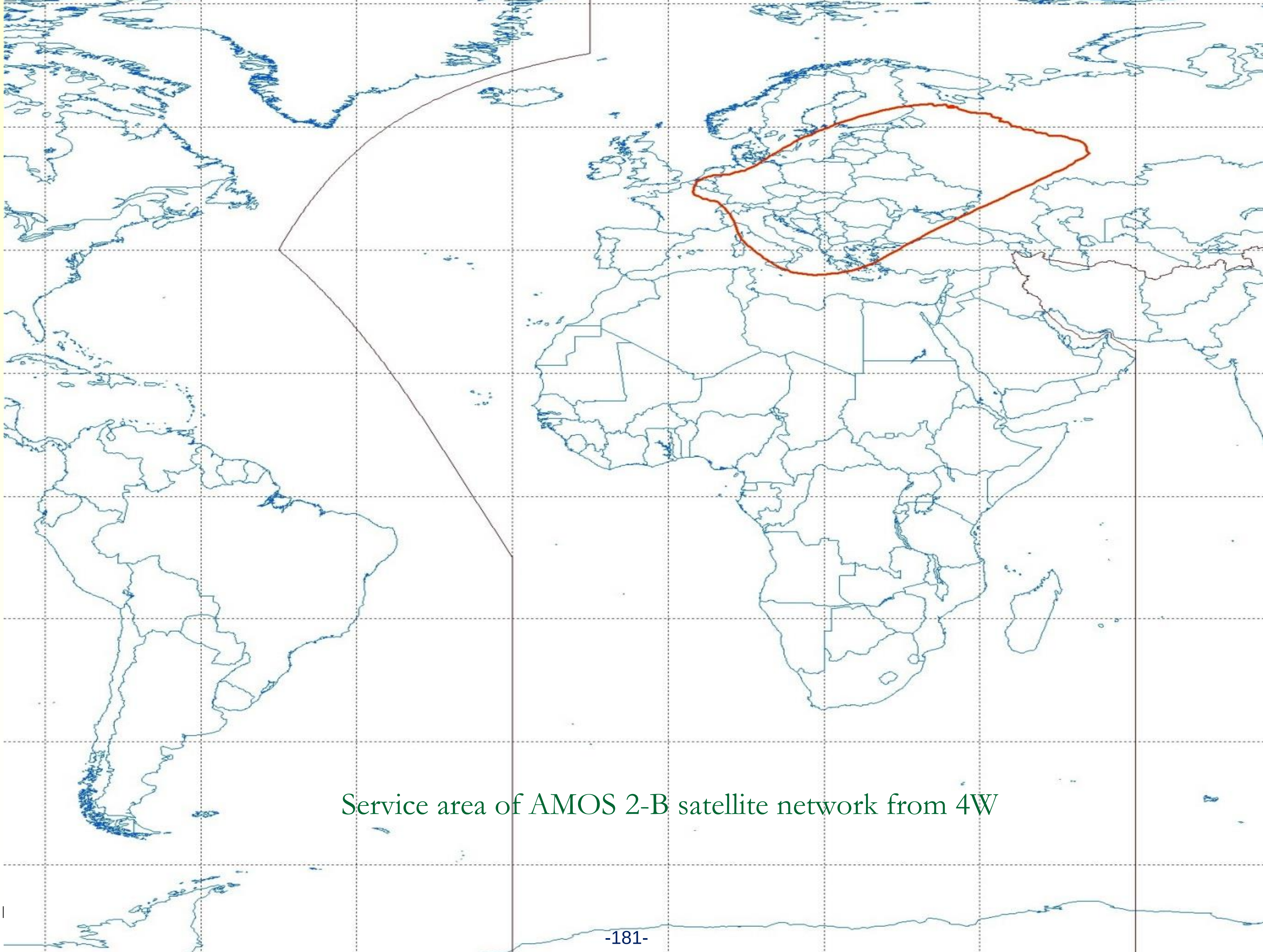
Sat/C2-12

GEO Main Problems, Rami Neudorfer

- Positioning in orbit: small rockets; fuel up to 10-15 years
- Stability: solar panels and antennas
- Power: solar power is used to generate electricity Batteries are needed as about half the time the LEOs are behind the earth
- Communications: satellite to satellite communication microwave or by optical laser
- Harsh environment: components need to be specially “hardened”, not only for temperature

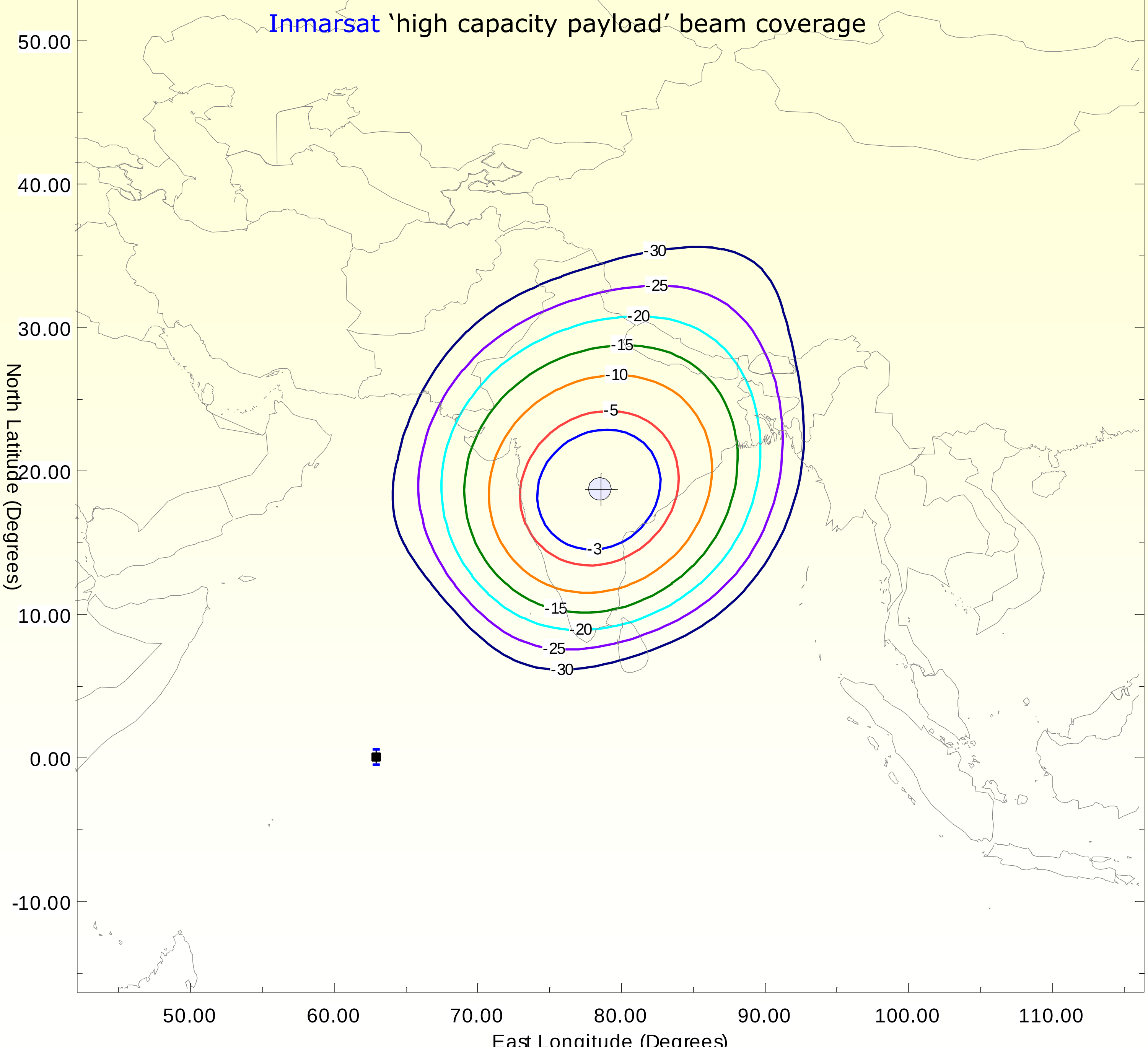


Amos-3 global steerable changeable Ku & Ka footprints

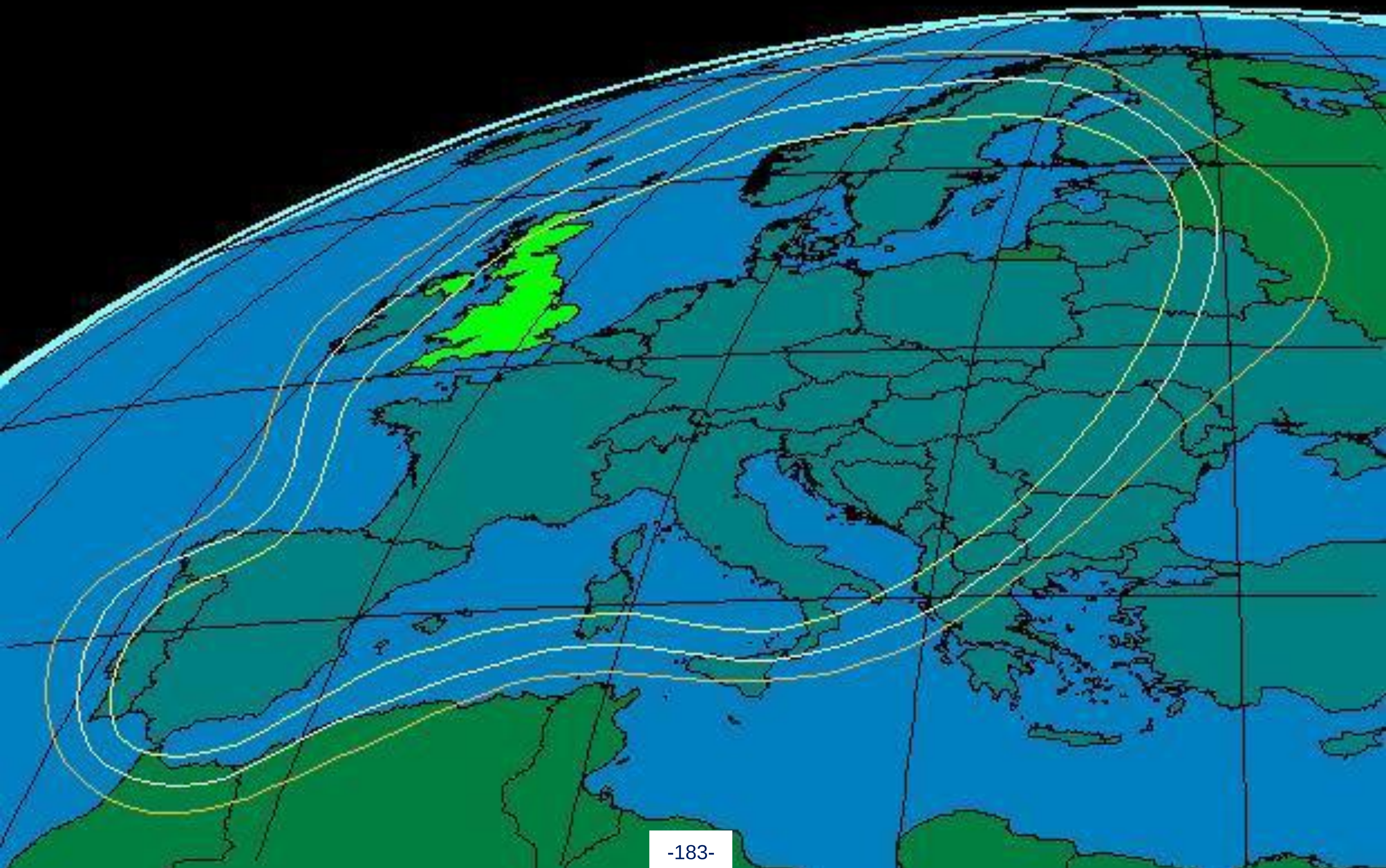


Service area of AMOS 2-B satellite network from 4W

Inmarsat 'high capacity payload' beam coverage



ASTRA Coverage, Transfinite Visualise 7



Typical Earth Station, Rami Neuderfer

GEO Satellite, Rami Neuderfer

Amos Satellite, Rami Neuderfer

Typical GEO Ku Band Link Budget & *G/T*

Parameter	Downlink (DL) Values	Uplink (UL) Values	Units
E.I.R.P. space to earth	52		dBW
E.I.R.P. earth to space		71	dBW
PL path loss	205	207	dB
G earth station	37.4	60	dBi
G space station		42	dBi
T earth station	10 log 100= 20		dB/K
T space station		10 log 500 = 27	dB/K
G/T earth station	37.4- 20= 17.4		dB/K
G/T space station		42-27= 15	dB/K
Normalised DL Thermal *C/N*	93		dB
Normalised UL Thermal *C/N*		107.6	dB
Signal Bandwidth	$36x10^6$ Hz; 10 log 36 $x10^6$=75.6		dB Hz
C/N	17.4	32	dB

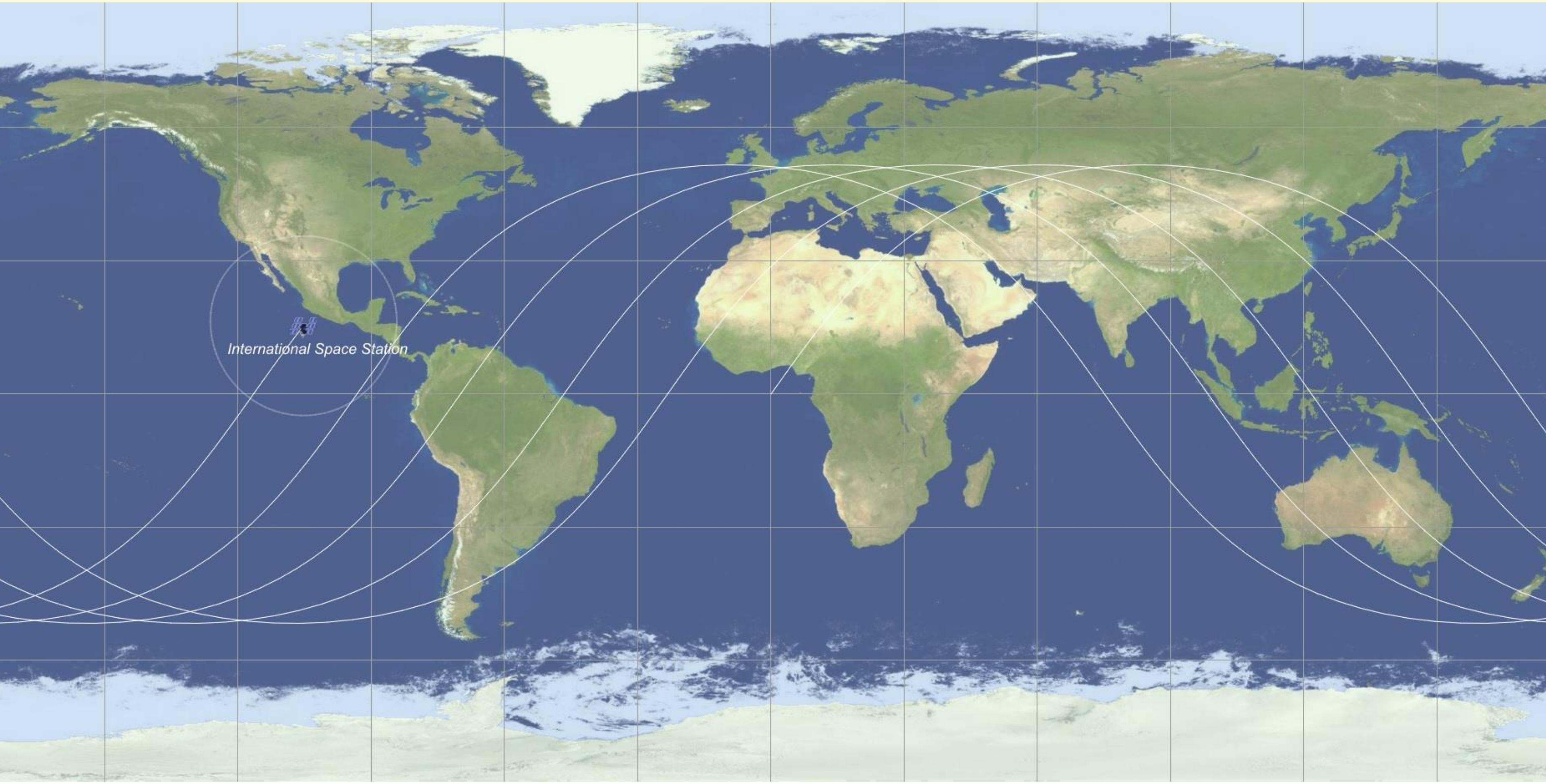
Orbit comparison- main coverage performances & link constraints SAT HB Table 6.1, revised

ORBITS	LEO	MEO	HEO	GEO
Environment constraints	Currently low (space debris: growing concern)	Low/medium	Medium/high	Low; short number of orbital slots; station keeping
	Van Allen belts: 4 crossings/day			
Typical orbital period	1.5-2 h	5-10 h	12 h	24 h
Altitude range	500-1,500 km	8,000-25,000 km	Up to 40,000 km apogee (perigee ~ 1,000 km)	35,700 km
Visibility duration	15-20 mn/pass	2-8 h/pass	8-11 h/pass (apogee)	Permanent
Elevation	Rapid variations; high and low angles	Slow variations; high angles	No variations (apogee); high angles near Equator	No variation; low angles at high latitudes
Propagation delay	Several milliseconds	Tens of milliseconds	Hundreds of milliseconds (apogee)	> 250 milliseconds
Link budget (distance)	Favorable; compatible with small satellites and handheld user terminals	Less favorable	Not favorable for handheld or small terminals; requires large and powerful satellites	Not favorable for handheld or small terminals
Instantaneous ground overage (diameter at 10° elevation)	≈ 6,000 km	≈ 12,000-15,000 km	16,000 km (apogee)	16,000 km (~ 0.4 of earth circumference at Equator)
Examples of systems	Iridium,Globalstar, Skybridge, ORBCOMM, International Space Station (ISS)	Odyssey; O3B, GPS, GLONASS, Galileo, BeiDou	Molniya, Archimedes	Intelsat, Inmarsat, Meteosat, MILCOM; Eutelsat, AMOS
	Scientific missions			
LEO: low-Earth orbits; MEO: medium-Earth orbits; HEO: highly-eccentric orbits; GEO: geostationary orbits				

LEO vs GEO Orbits, Rami Neuderfer

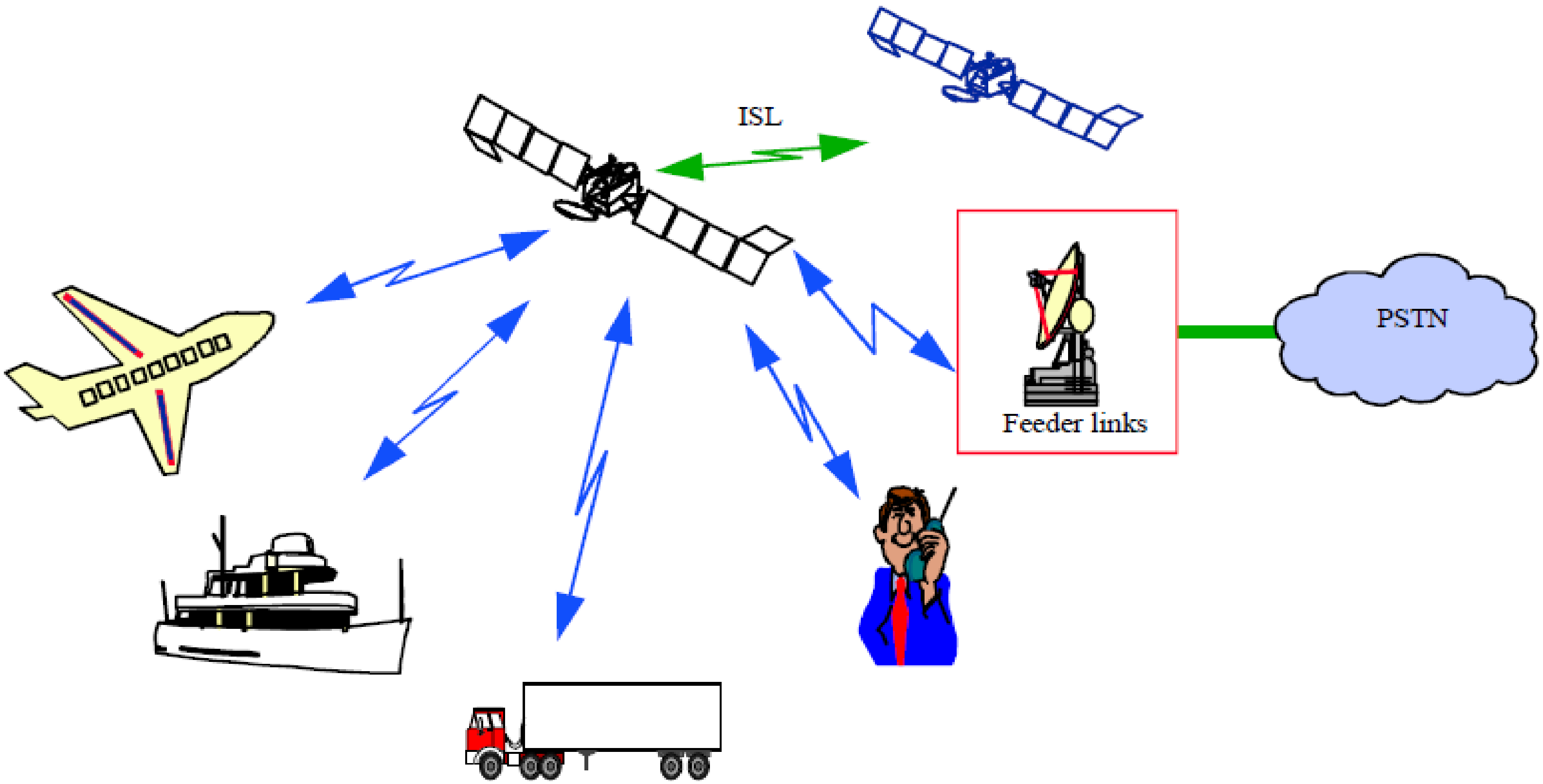
- Low earth orbit satellites - between 100 - 1500 miles
- Signal to noise should be better with LEOs
- Shorter delays, between 1 - 10 ms typical
- LEOs move relative to the earth; they require dynamic tracking or non directive antennas (my addition)
- Circular orbits are simplest
- Inclined orbits are useful for coverage of equatorial regions
- Elliptical orbits can be used to give quasi stationary behaviour viewed from earth using 3 or 4 satellites
- Orbit-changes extend the life of satellites

Low Earth Orbit; Transfinite



SEE also shaded topo http://visibleearth.nasa.gov/view.php?id=57752

Generic illustration of MSS



(A possible inter-satellite link (ISL) with another satellite is represented)

PSTN: public switched telephone network

Handbook on Satellite Communications

Sat/C1-02

FIGURE 1.2

Generic illustration of mobile-satellite services

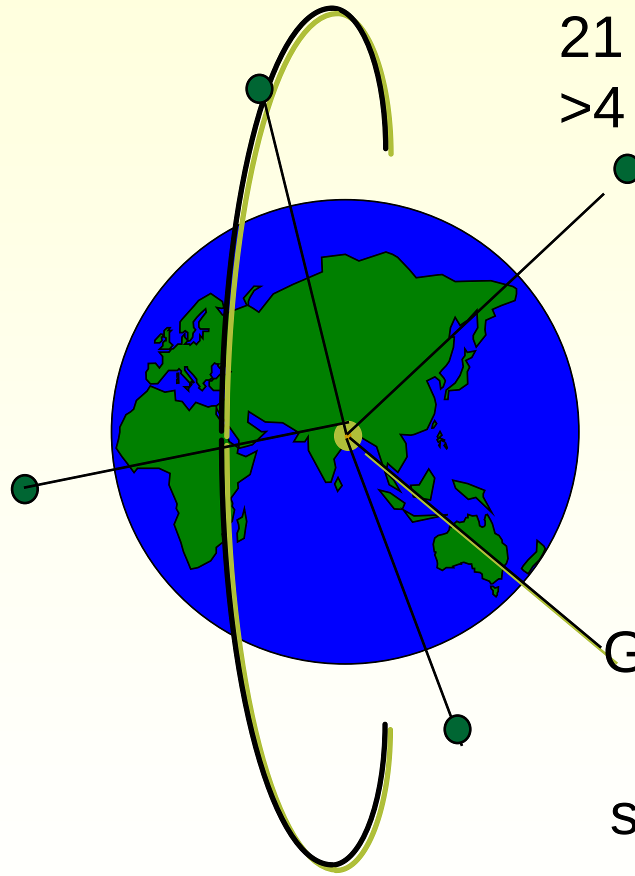
GPS: Global Positioning System, Struzak

6 inclined orbit planes, 20.000km

X,Y,Z coordinates (100m - 15m accuracy)

Time & frequency transfer

21 satellites
>4 visible



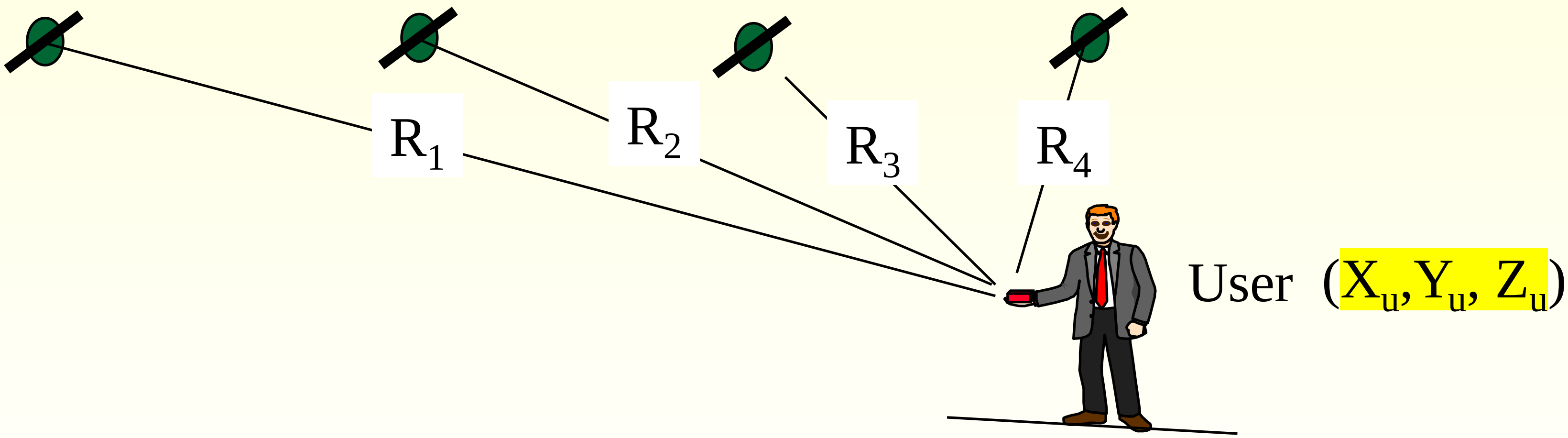
GPS receiver

strong signal

GPS Principle, Ryszard Struzak

The locus of points having a constant difference in distance to two points (here, two satellites) is a **hyperboloid**. Thus, from 4 or more measured reception times, the receiver can be placed at the intersection of the surfaces of three or more hyperboloids.

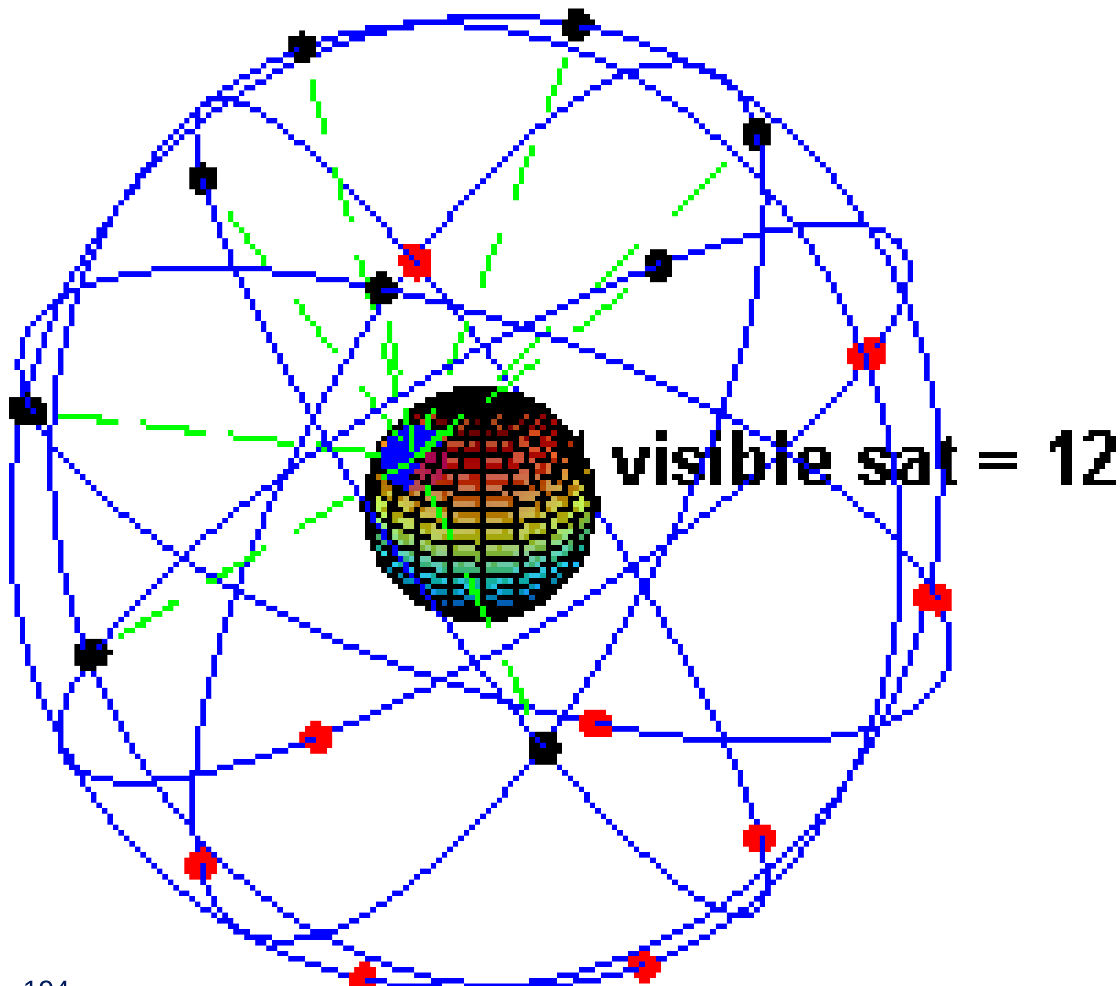
i-th satellite message: ”*my time is T_i; my position is (X_i, Y_i, Z_i)*”



Pseudo-ranges:	$R_i = c(dT_i)$.
Position:	$(X_i-X_u)^2 + (Y_i-Y_u)^2 + (Z_i-Z_u)^2 = (R_i - C_b)^2$
	c = light velocity C_b = clock bias i = 1...4.

Orbiting at an altitude of approximately 20,200 km (12,600 mi)

A simulation of the original design of the GPS space segment, with 24 GPS satellites (4 satellites in each of 6 orbits), showing the evolution of the number of visible satellites from a fixed point (45°N) on earth (considering "visibility" as having direct line of sight). The parameters used to simulate the orbits are: eccentricity (e) 0.05, inclination (i) 55° and a separation between orbits of 60° in the right ascension of the ascending node. Within each orbit, the four satellites are evenly spaced (the instant of pass through perihelion being arbitrary for the first satellite in each orbit). The orbital period of the satellites was taken to be 12 hours. The earth was considered a perfect sphere with a radius of 6400 km.
http://en.wikipedia.org/wiki/File:ConstellationGPS.gif 14 Dec 2022

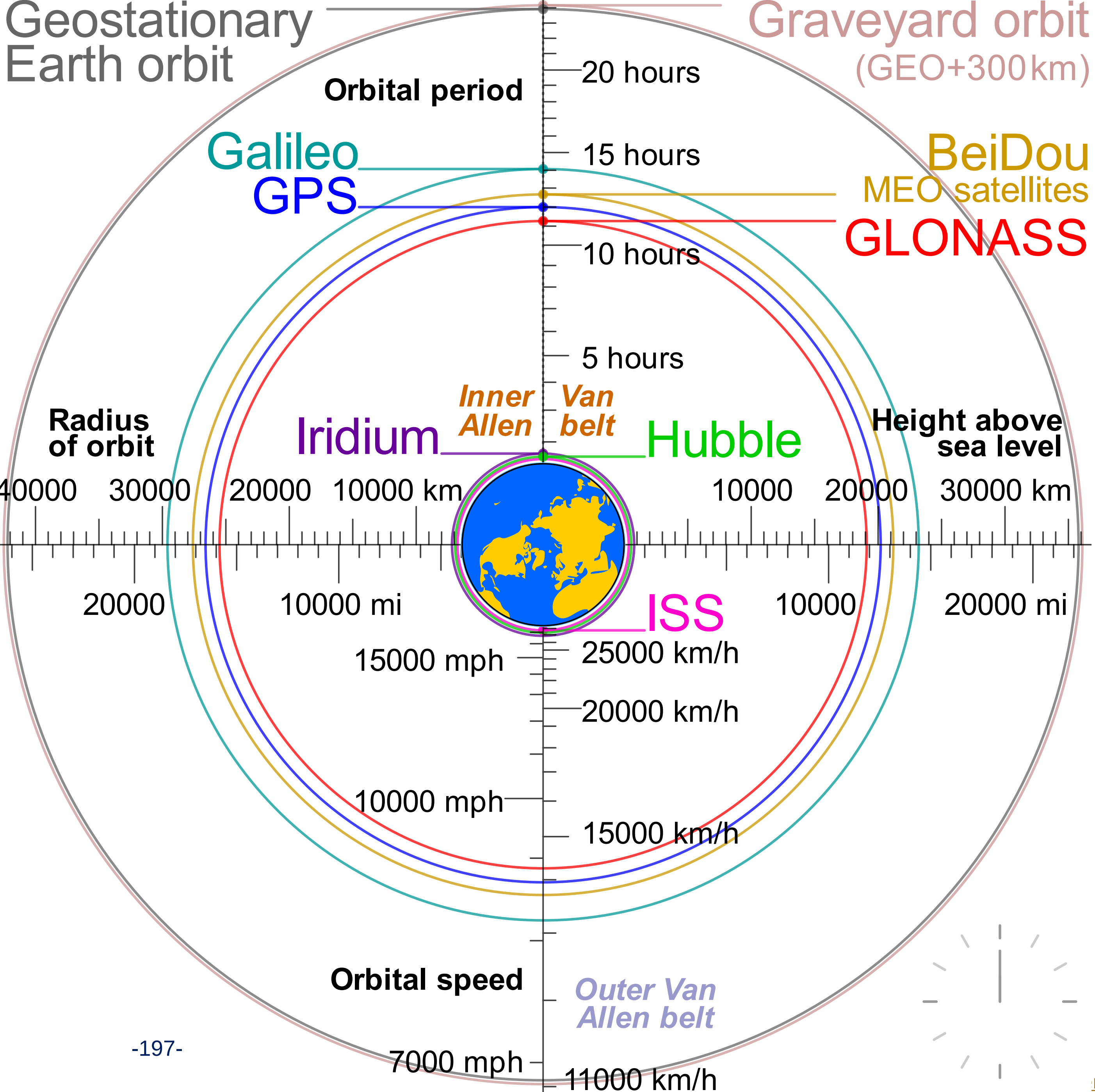


Comparison of Russian GLONASS and American GPS

Parameter	GLONASS	GPS
Ephemeris information presentation method	Earth centred fixed coordinates + its derivatives of first and second order	Modified Kepler elements of orbit
Geodesic coordinate system	Parametry Zemli 1990; PZ-90.11	Geodetic Datum; WGS-84
Time corrections relative to the Universal Time Coordinated (UTC)	UTC (SU) SU is the Russian UTC	UTC (USNO); US Naval Observatory master clock
Number of satellites (fully operational)	GLONASS-M: 24 + 2 spares, + 2 GLONASS-K test	30 + 1 spare + 1 test
Number of orbital planes	3	6
Orbital inclination	64.8°	55°
Orbit altitude	19,100 km	20,180 km
Orbital period	11 h 15 min	12 h
Satellite signal division method	FDMA	CDMA
Frequency band L1 (MHz) (civilian)	1,597.5 515-1,605.886; center 1,602	1,575.42 ±1.023
Frequency band L2 (MHz) (+military)	1,242.4265-1,249.136; center 1,246	1,227.6 ±1.023
Duration of almanac transmission	2.5 min	12.5 min
Super frame capacity	7,500 bits (5 frames)	37,500 bits (25 frames)
Frame length	30 seconds	
Synchro-code repetition period	2 s	6 s
Cross-talk between neighboring channels	–48 dB	–21 dB
Coarse/Acquisition (C/A); chips per sec	511 kHz	1,023 kHz
C/A-code length (symbols)	511	1,023
C/A-code type; pseudorandom noise (PRN)	pseudo-random ranging code	binary sequence: gold code
Modulation	BPSK	
Navigational message data rate	50 bit/s	

Galileo (satellite navigation)

Wiki	
Country/ies of origin	European Union
Operator(s)	GSA, ESA
Type	Civilian, commercial
Status	Initial services
Coverage	Global
Accuracy	1 metre (public) 1 cm (encrypted)
Constellation size	
Total satellites	30
Satellites in orbit	24 usable, 2 unavailable, and 2 retired (12/2020)
First launch	2011
Total launches	28
Orbital characteristics	
Regime(s)	3 × MEO planes
Orbital height	23,222 kilometres (14,429 mi)
Other details	
Cost	€10 billion



Wiki Orbit size comparison of GPS, GLONASS, Galileo, BeiDou-2 & Iridium constellations, the International Space Station, the Hubble Space Telescope, & geo orbit (& its graveyard orbit), with the Van Allen radiation belts & the Earth to scale. The Moon's orbit is around 9 times as large as geos orbit. Click

Satellites' Equipment: Space Segment

- Solar arrays collect energy from the sun & stored in batteries or used real-time;
- Thermal subsystem which controls & manages heat creating and transfer in the satellite;
- Propulsion sub-system for the station keeping of the satellite; and
- Radiocommunication payload which collects signals from the Earth & retransmits these back down, or uses some of them to control & monitor the spacecraft:
  - Active repeaters- 1 demodulates the signal received & re-modulates it before its transmission back to Earth; or
  - Passive reflectors- one that acts as a pure bend-pipe system, where the signal spectral components are reflected back to Earth at a different carrier frequency.

Satellites' Equipment: Earth Stations

- Earth station is the transmission, reception, relay & control terminal of a telecommunication link via satellite;
- General configuration of GEO earth station is not substantially different from that of a radio-relay terminal, but the very large free-space attenuation (about 200 dB) undergone by the carrier radio waves, on their path between the station and satellite (approximately 36,000 km) usually requires the main subsystems of an earth station to have a much higher performance level, than those of a radio relay terminal:
  - High-gain (i.e. large diameter, high performance) antenna. Due to its narrow beam, the receiver is less susceptible to noise and to interference;
  - High-sensitivity receiver (i.e. with a very low internal noise); & powerful transmitter.
  - The antenna of the earth station is used for both Rx & Tx transmission
- GEO & MSS Earth stations consists of the following main subsystems:
  - Antenna, Rx amplifiers (low-noise), Tx amplifiers (power);
  - Telecommunication equipment- RF converters & modems;
  - Multiplexers and demultiplexers;
  - Connection with the terrestrial network; and
  - Auxiliary equipment, power-supply & general infrastructure.

Small Earth Stations

- Small stations serve as remote area communications systems (rural telecommunications & services to isolated sites such as off-shore platforms, pipelines, mines, etc.) & business communications (corporate networks), generally in the framework of closed users communities;
- Some important applications are telephony & data transmission; TV reception for local distribution (e.g. cable TV, CATV) or re-broadcasting etc.
- TVRO is television receive-only: antenna & associated equipment for reception from a broadcasting-satellite. TVROs needed for BSS are smaller than the ones needed for reception n in the FSS; for example, 0.6 m to 0.8 m diameter ant are used to receive digital TV bouquets at 11 GHz.
- VSATs are very small aperture terminals, serving business communications. VSAT earth stations operate on the FSS bands: 14/11-12 GHz and 6/4 GHz bands; see Recommendation ITU-R S.725.
- At higher frequencies, the ant diameter is smaller for a given ant gain & bandwidth. The sizes of typical antennas are for the:
  - C Band (4 GHz to 6 GHz) 1.4m to 2.4m;
  - Ku Band (11 to 14 GHz) 0.45m to 1.2m;
  - Ka Band (20 to 40 GHz) 0.2m to 0.6m.

Advanced Wireless Communications, 2022

Academic course for 4th year engineering students

Radar Systems

http://mazar.atwebpages.com/

Radar (Radio Detection And Ranging) Applications

1. **Radar** is an object-detection system which uses mainly radio waves to determine the range, altitude, direction, or speed of both moving and fixed objects
2. **Civil Applications**: Air Traffic Control (including altimetry and flight-control); Nautical Radars (landmarks and other ships); a/c and cars anti-collision; ocean-surveillance; outer-space surveillance and rendezvous; meteorology; ground-penetrating radar (geological observations, coins), astronomy
3. **Military Applications**: air-defense and fire control - Acquisition (bistatic, monostatic) (phased array antennas), tracking (conical scan, monopulse), illumination, detonation; antimissile; protection (a/c, tanks, fence)

Radar Frequency Bands $c=\lambda f$

From M.A. Richards, Georgia Tech

Band	Frequencies	Wavelengths
HF	3 - 30 MHz	100 m - 10 m
VHF	30 - 300 MHz	10 m - 1 m
UHF	300 MHz - 1 GHz	1 m - 30 cm
L	1 - 2 GHz	30 cm - 15 cm
S	2 - 4 GHz	15 cm - 7.5 cm
C	4 - 8 GHz	7.5 cm - 3.75 cm
X	8 - 12 GHz	3.75 cm - 2.5 cm
K_u	12 - 18 GHz	2.5 cm - 1.67 cm
K	18 - 27 GHz	1.67 cm - 1.11 cm
K_a	27 - 40 GHz	1.11 cm - 7.5 mm
mm	40 - 300 GHz	7.5 mm - 1 mm

Range ⇔ Delay: radar range is measured by the time delay between pulse transmission & reception

$$r = \frac{1}{2} c_p \tau$$

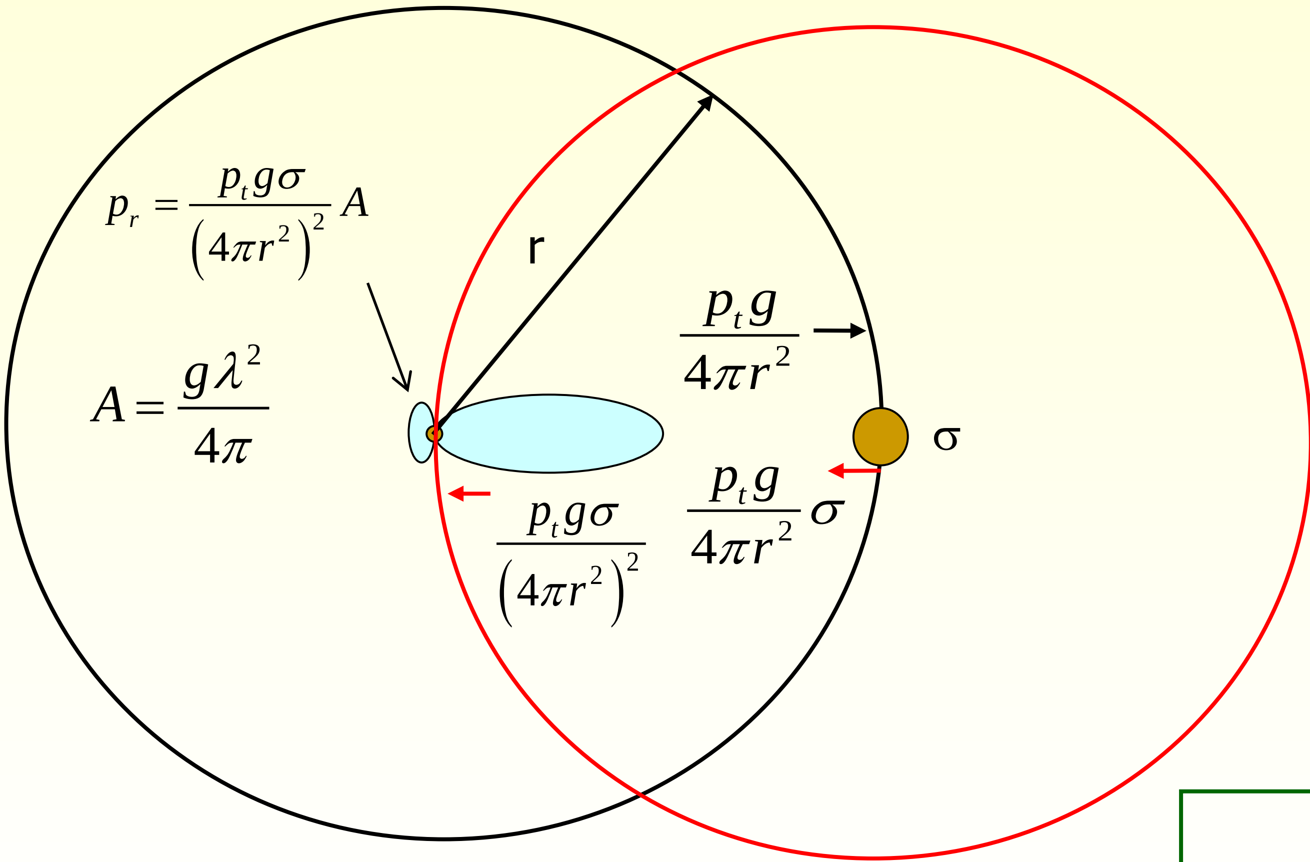
range

2-way

velocity of propagation

delay

The Radar equation



$$p_r = \frac{p_t g^2 \lambda^2}{(4\pi)^3 r^4}\sigma$$

Radar Friis equation, Basic Transmission Loss

σ: radar target cross-section *d*: distance from the radar to the target λ: wave length

$$P_{TARGET} = pfd \cdot a_e = \left(\frac{g_T p_T}{4\pi r^2}\right) \times \sigma$$

$$P_{received} = \left(\frac{g_T p_T}{4\pi r^2}\right) \times \sigma \times \left(\frac{1}{4\pi r^2}\right) \times \left(\frac{g_T \lambda^2}{4\pi}\right) = P_{Transmit} g^2 \times \sigma \times \left(\frac{\lambda}{4\pi r^2}\right)^2 \frac{1}{4\pi}$$

$$p_{received} = p_{transmit} \times g^2 \times \sigma \times \frac{\lambda^2}{(4\pi)^3 r^4}$$

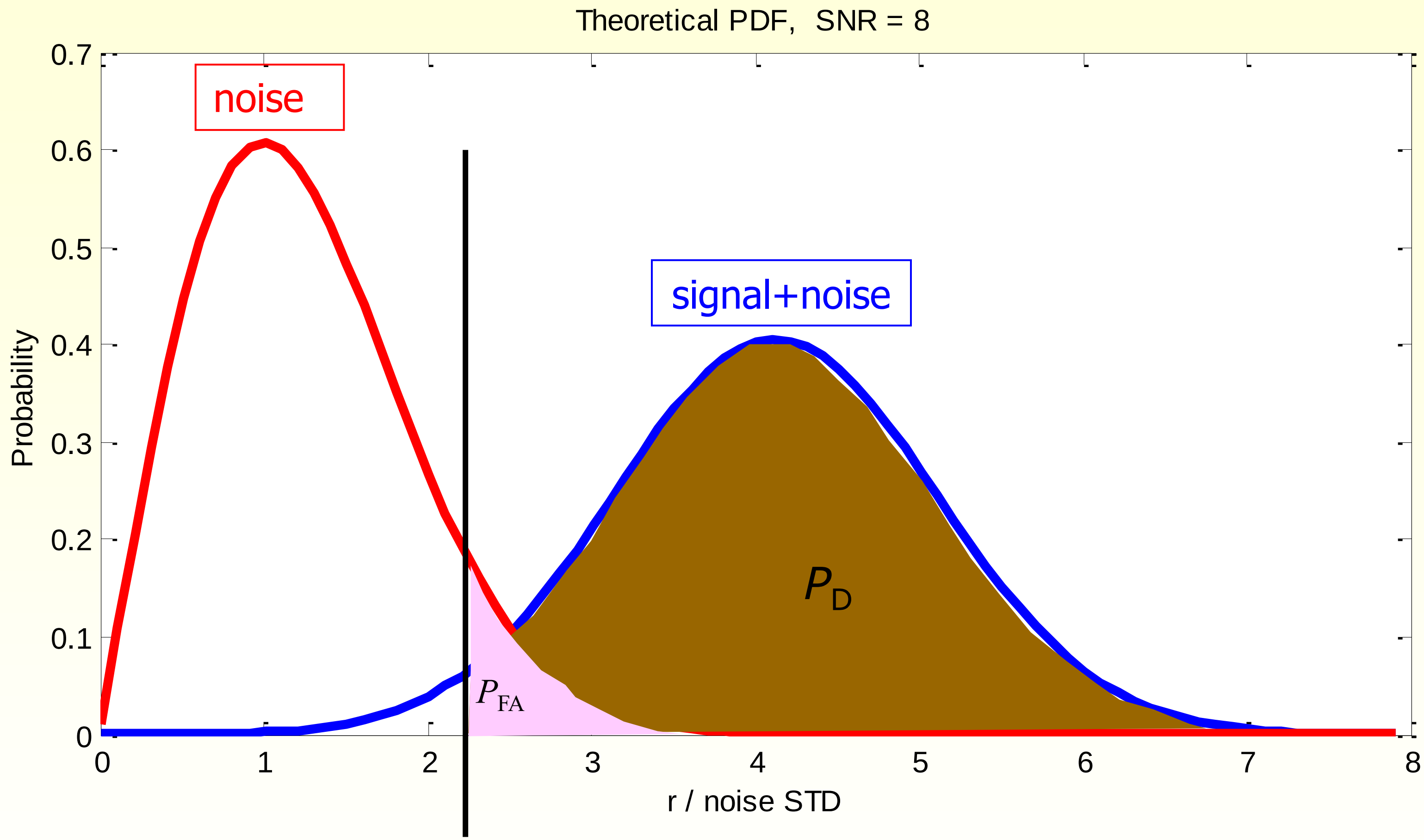
P minimal discernable signal= kTbfs/n. For pulse radar b≈ $\frac{1}{\tau}$

Exercise*: prove that for* pulse width t_o and *b= 1/* t_o the max detection range depends on transmitted energy and not only transmitted power

$$d_{\max}{}^4 = P_{Transmit} \times g^2 \times \sigma \times \frac{\lambda^2}{(4\pi)^3 P_{\min}} = P_{Transmit} g^2 \sigma \frac{\lambda^2 \tau}{(4\pi)^3 kTf} = Energy_{Transmit} g^2 \sigma \frac{\lambda^2}{(4\pi)^3 Ktf}$$

Pulse Detection Probability; for single pulse, non-fluctuating

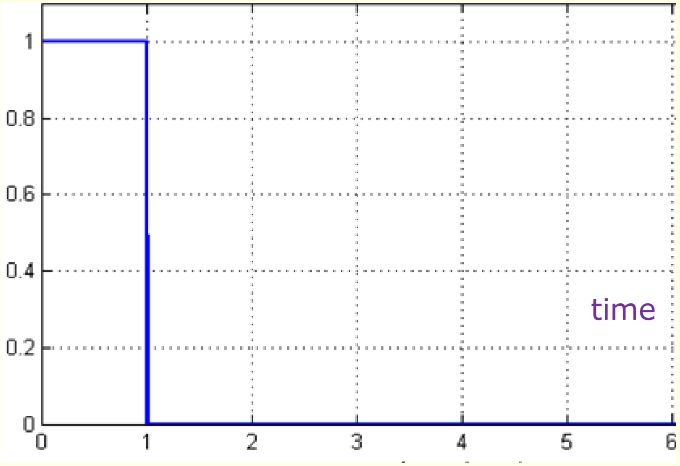
The PDP is the aggregate surface below the **red** or **blue** curves; total **red** surface equals 1, as the area below the **blue** graph

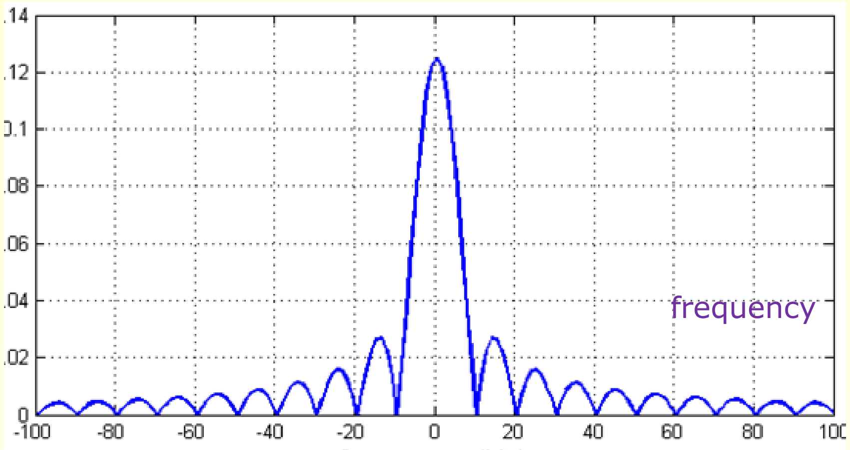


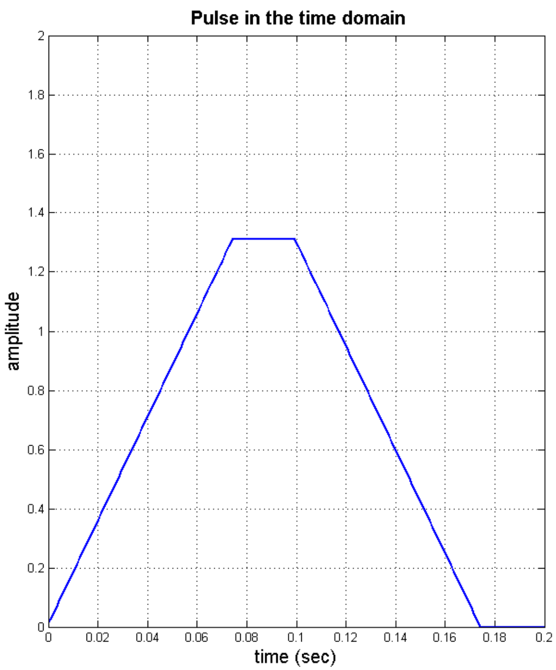
threshold
determining
signal or noise

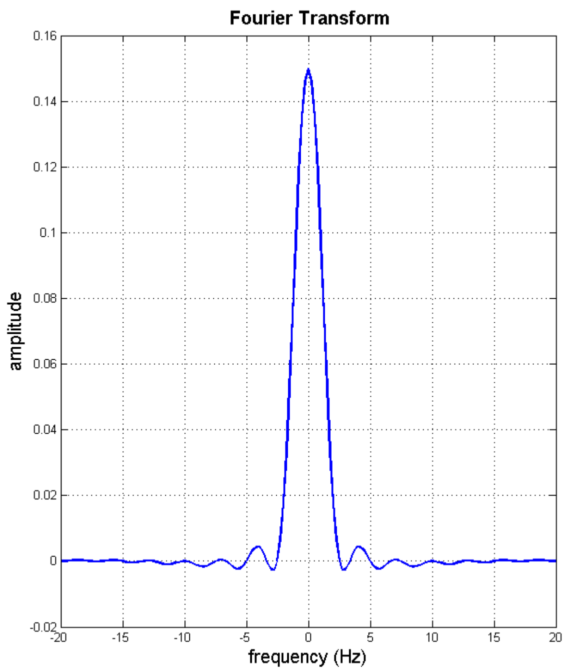
All values are numeric
'*r*': wanted received power; '*n*': noise
PFA: Probability False Alarm

Search Pulse Radar: time versus frequency domain

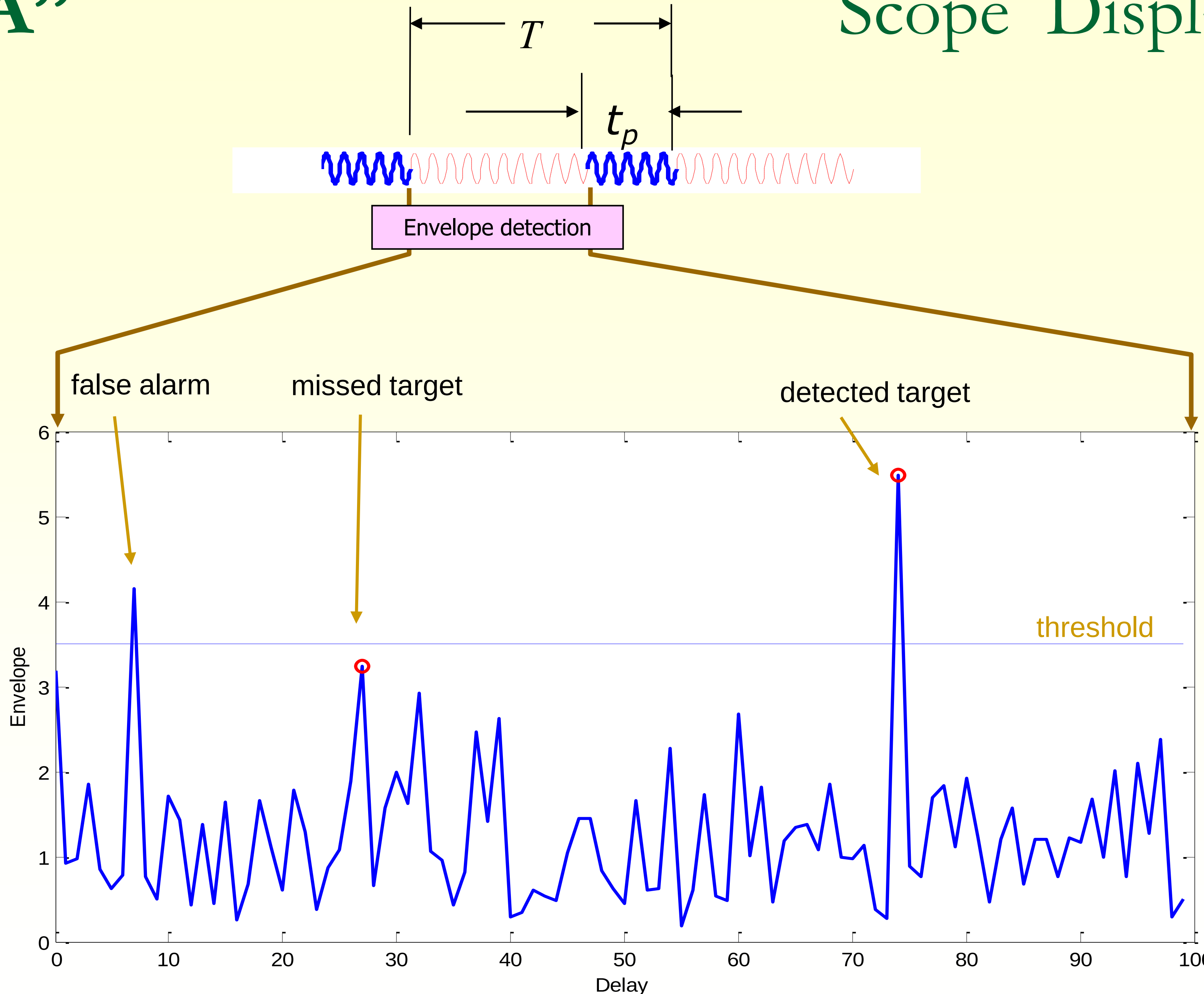


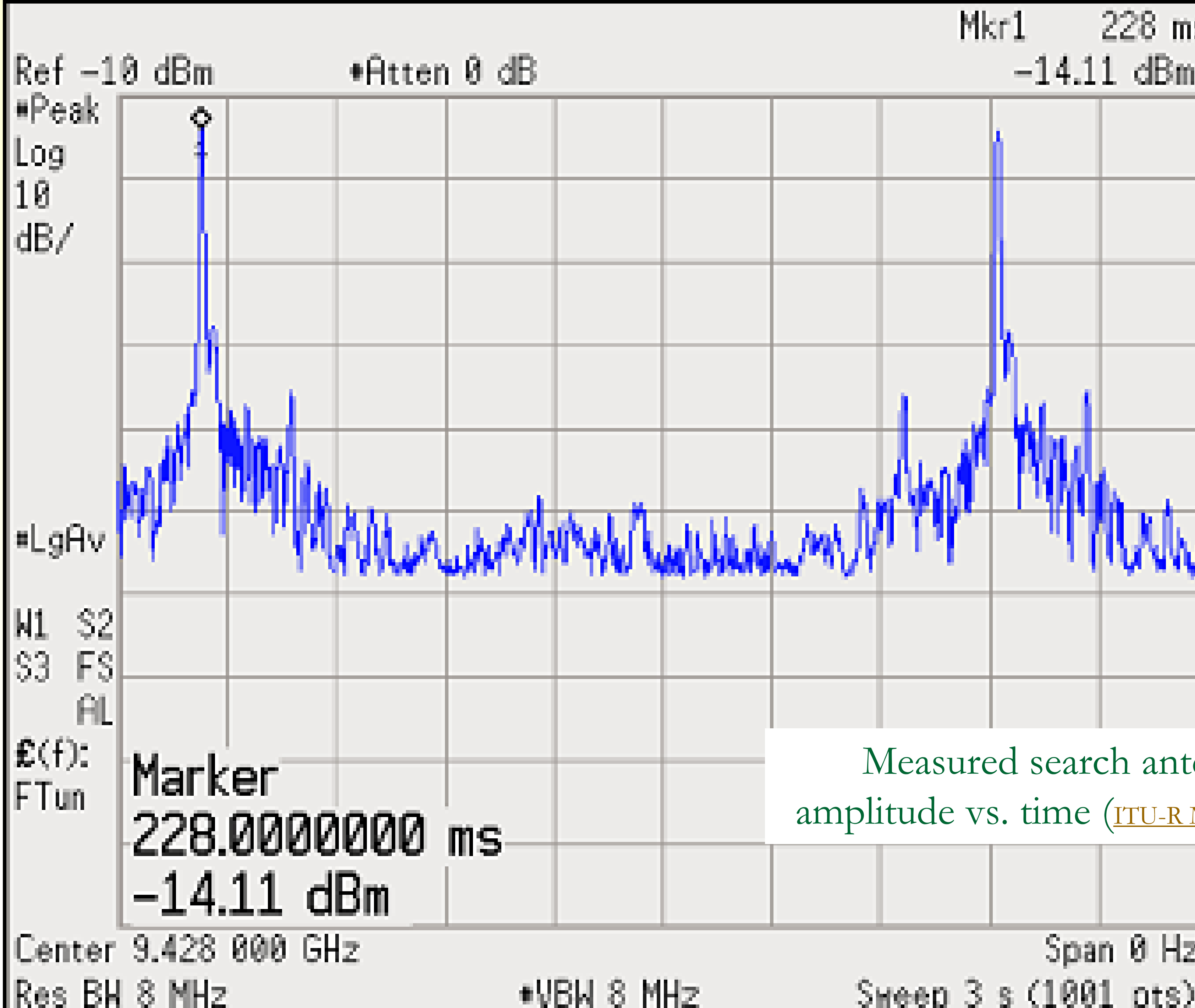






"A" Scope Display

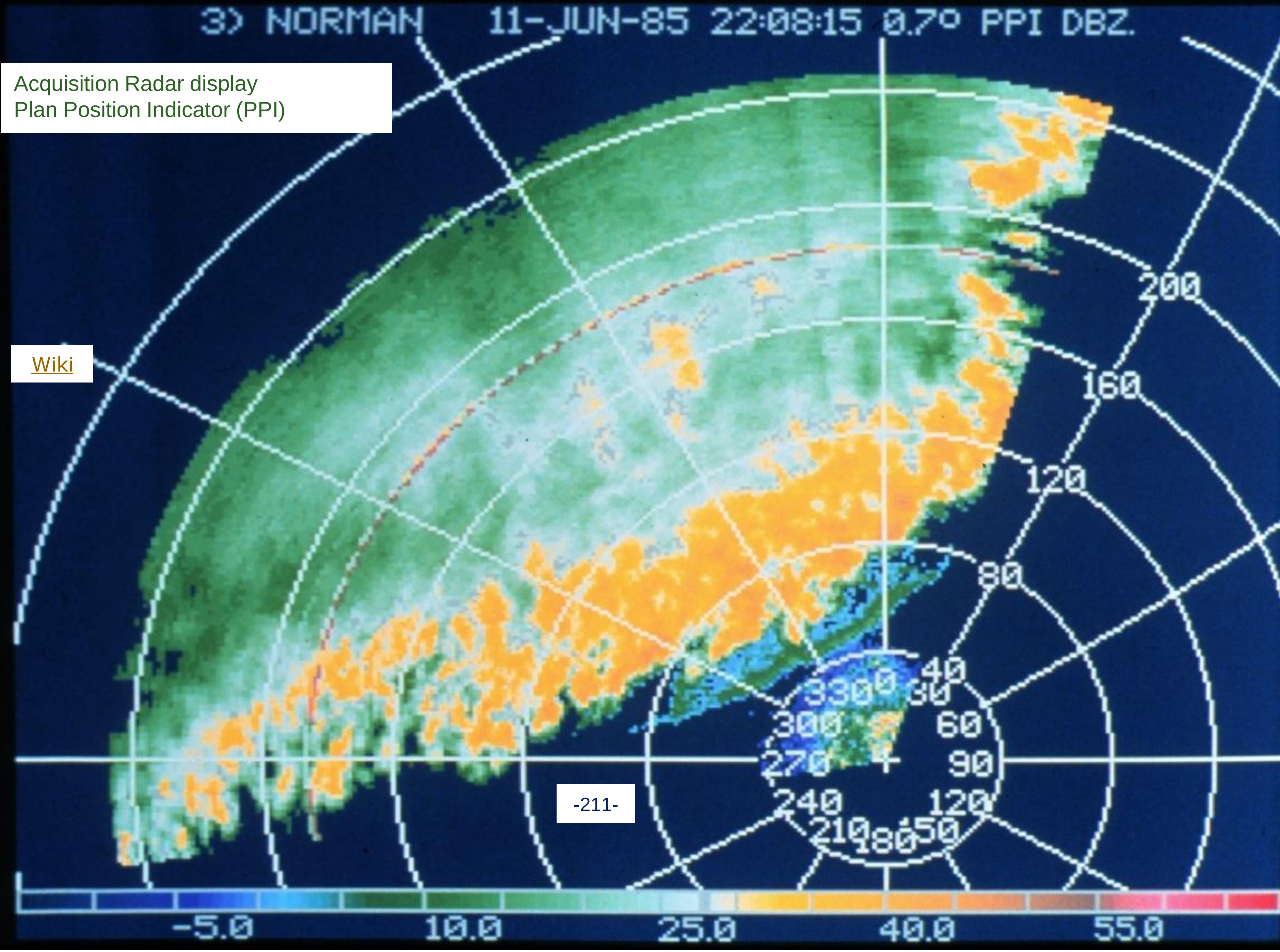


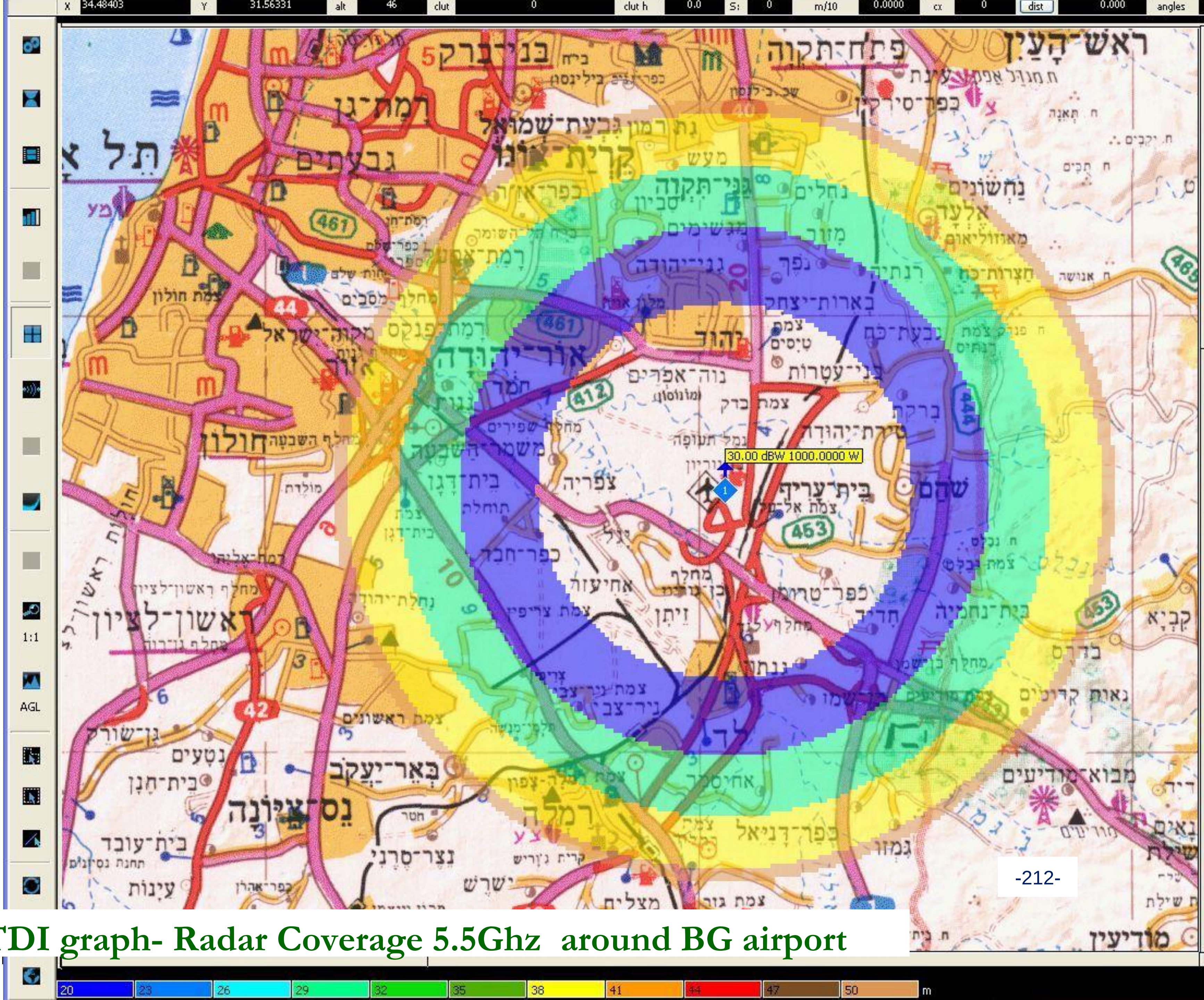


Measured search antenna plot; amplitude vs. time (ITU-R M.1851 Fig. 29)

Acquisition Radar display
Plan Position Indicator (PPI)

Wiki



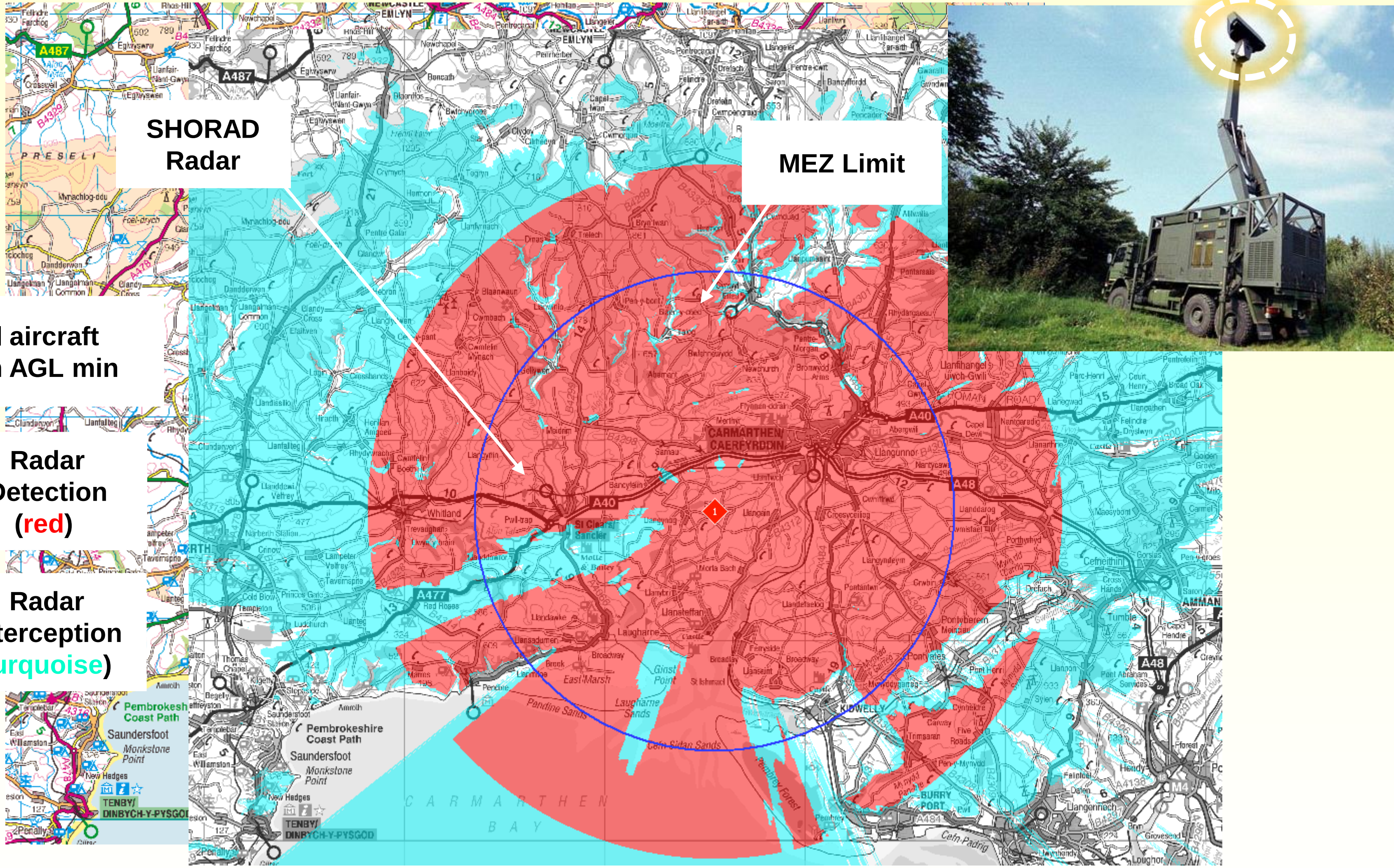


ATDI graph- Radar Coverage 5.5Ghz around BG airport

Line of Sight & detecting low flying A/C

Giraffe, surveillance radar

Radars



SHORAD Radar
MEZ Limit
Tactical aircraft At 100 m AGL min
Radar Detection (red)
Radar Interception (turquoise)
CARMARTHEN/ CAERFYRDDIN
CARMARTHEN BAY

Typical Pulse Search Radar Parameters

- transmitter power ……………………….... 1 MW
- pulse width ……………………….... 1 μsec
- mainbeam antenna gain…………... 43 dBi
- scan all directions (all sectors)
- frequency range ………………. 3300-3500 MHz
- first sidelobe antenna gain ………. 20 dBi
- backlobe antenna gain……………... 0 dBi
- 2nd harmonic output ……………. 73 dB down
- 3rd and higher harmonics ………... >80 dB down
- receiver sensitivity ………………. -90 dBm

Radar Unambiguous Range (see also Boonton, 4 Jan.2023)

The range R_u corresponds to the ***maximum range*** *that a target* can have such that its echo is received before the transmission of the next pulse.

$$R_u = \frac{cT_p}{2} = \frac{c}{2f_p}$$

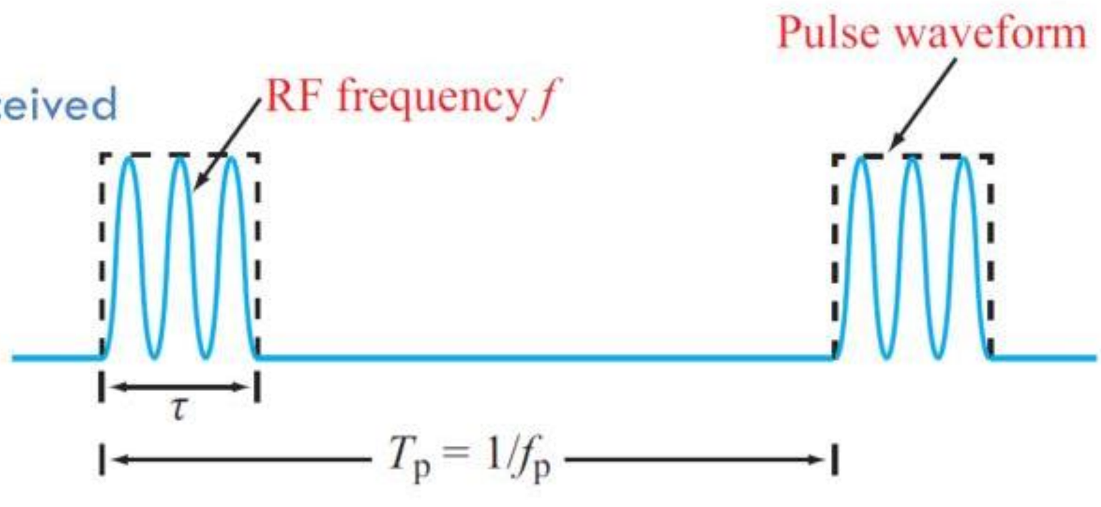
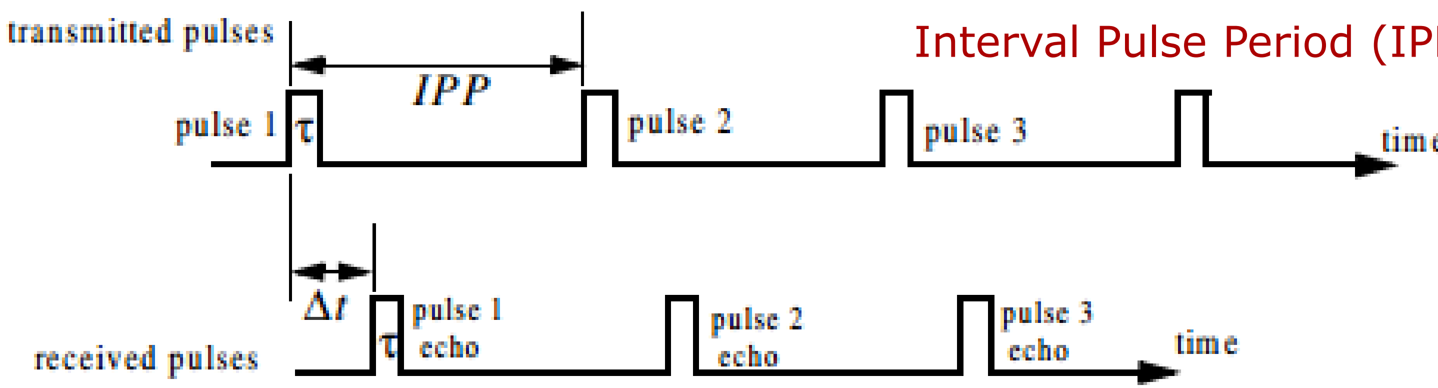
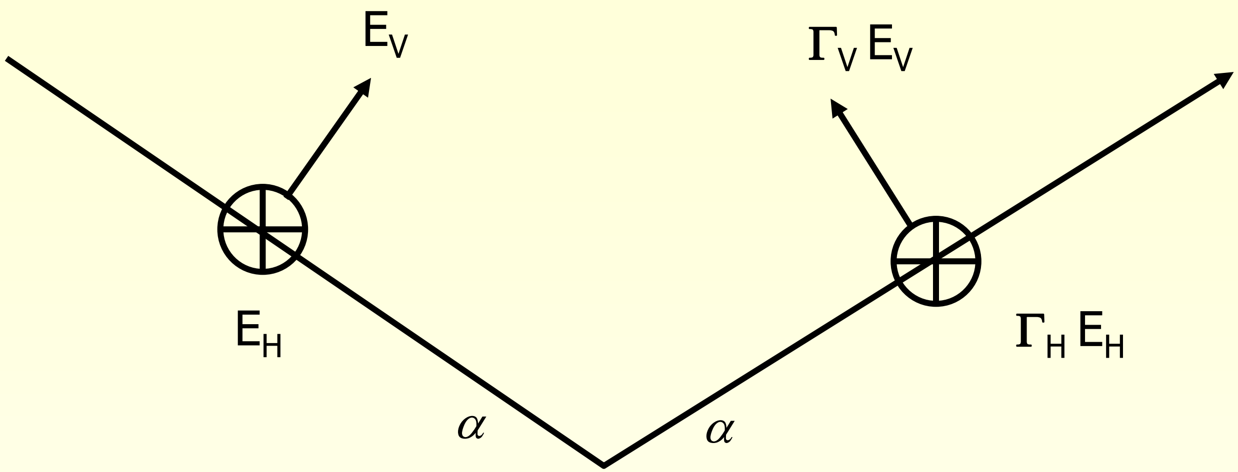


Figure 10-10: A pulse radar transmits a continuous train of RF pulses at a repetition frequency f_p.



Interval Pulse Period (IPP)

Reflectance to analyse polarity influence



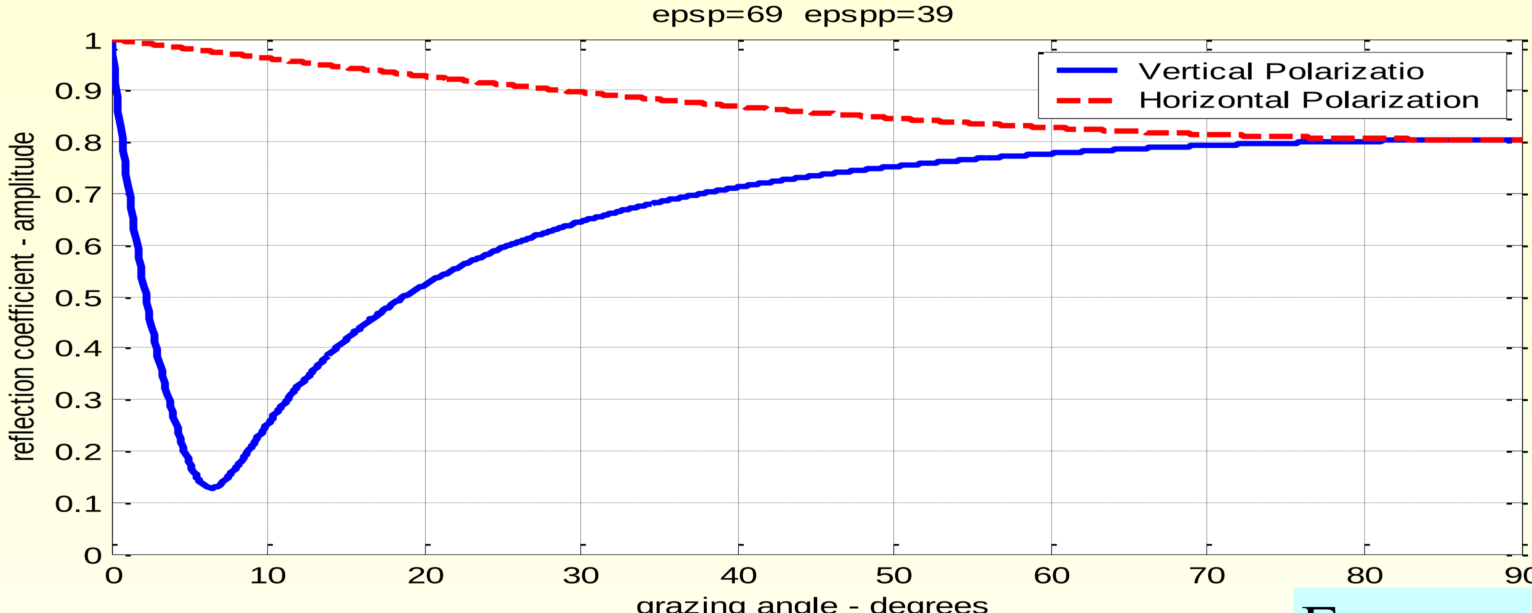
$$\varepsilon = \varepsilon' + j\varepsilon'' \approx k/\varepsilon_0 - j60\lambda\sigma$$

ε - complex dielectric constant of the surface
k - permittivity
σ - conductivity
ε_0 - dielectric constant of free space
λ - signal wavelength

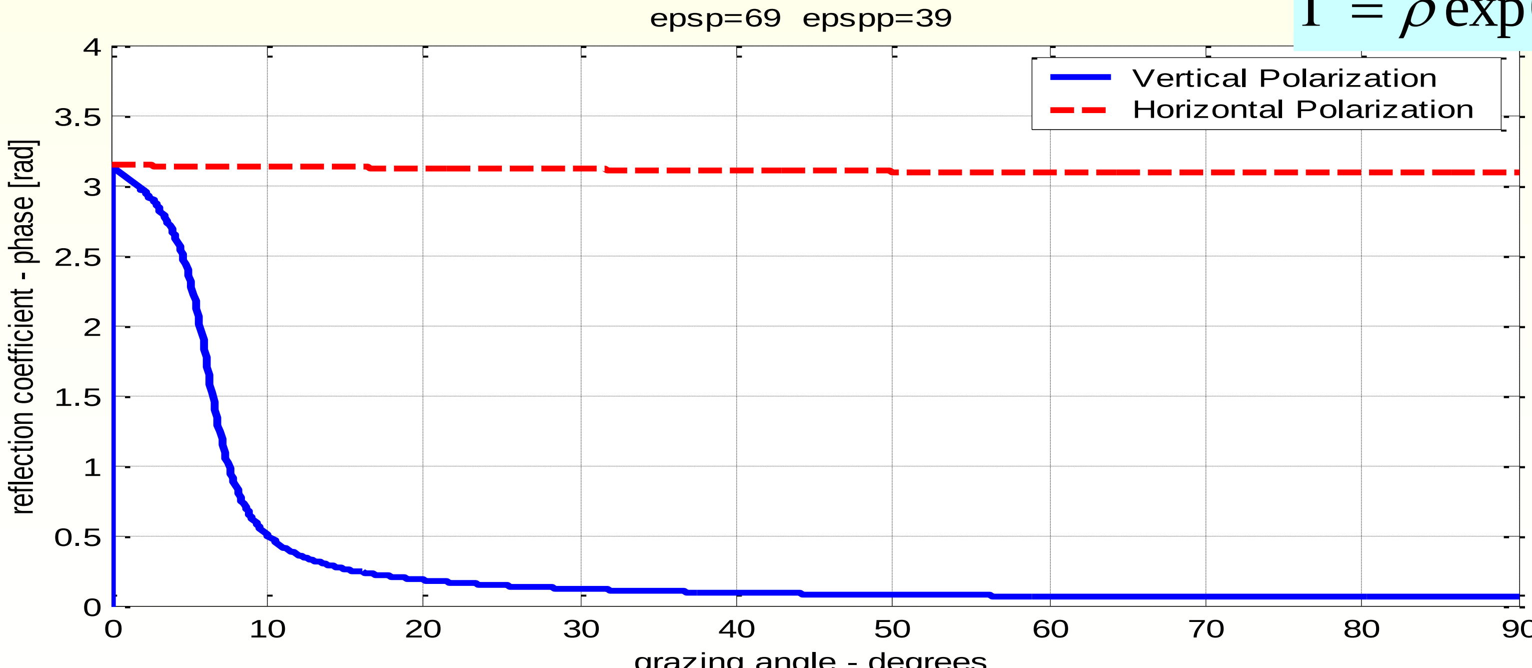
$$\Gamma_H = \frac{\sin\alpha - \sqrt{\varepsilon - \cos^2\alpha}}{\sin\alpha + \sqrt{\varepsilon - \cos^2\alpha}}$$

$$\Gamma_V = \frac{\varepsilon\sin\alpha - \sqrt{\varepsilon - \cos^2\alpha}}{\varepsilon\sin\alpha + \sqrt{\varepsilon - \cos^2\alpha}}$$

Vertical vs Horizontal Polarity

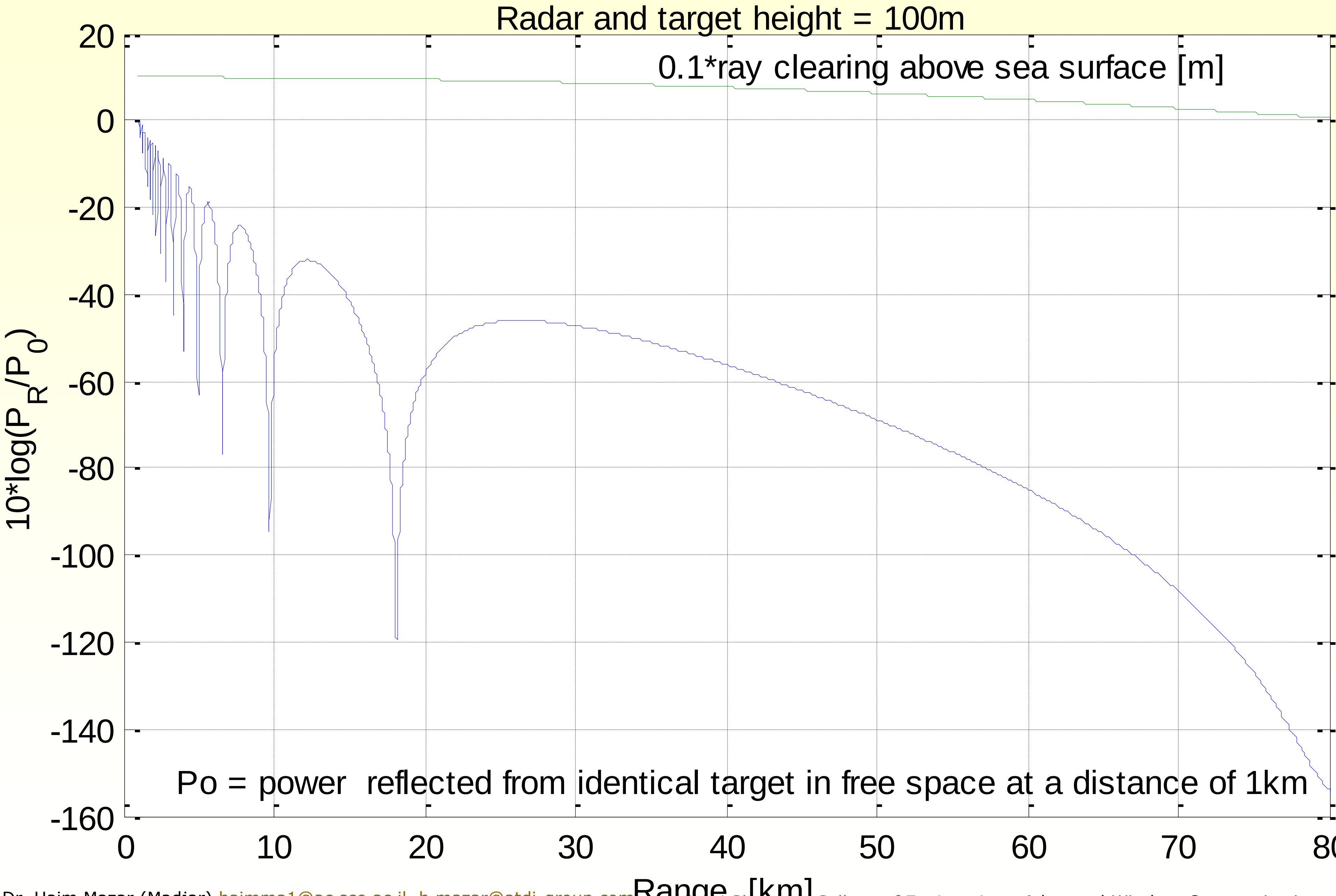


$$\Gamma = \rho \exp(-j\phi)$$

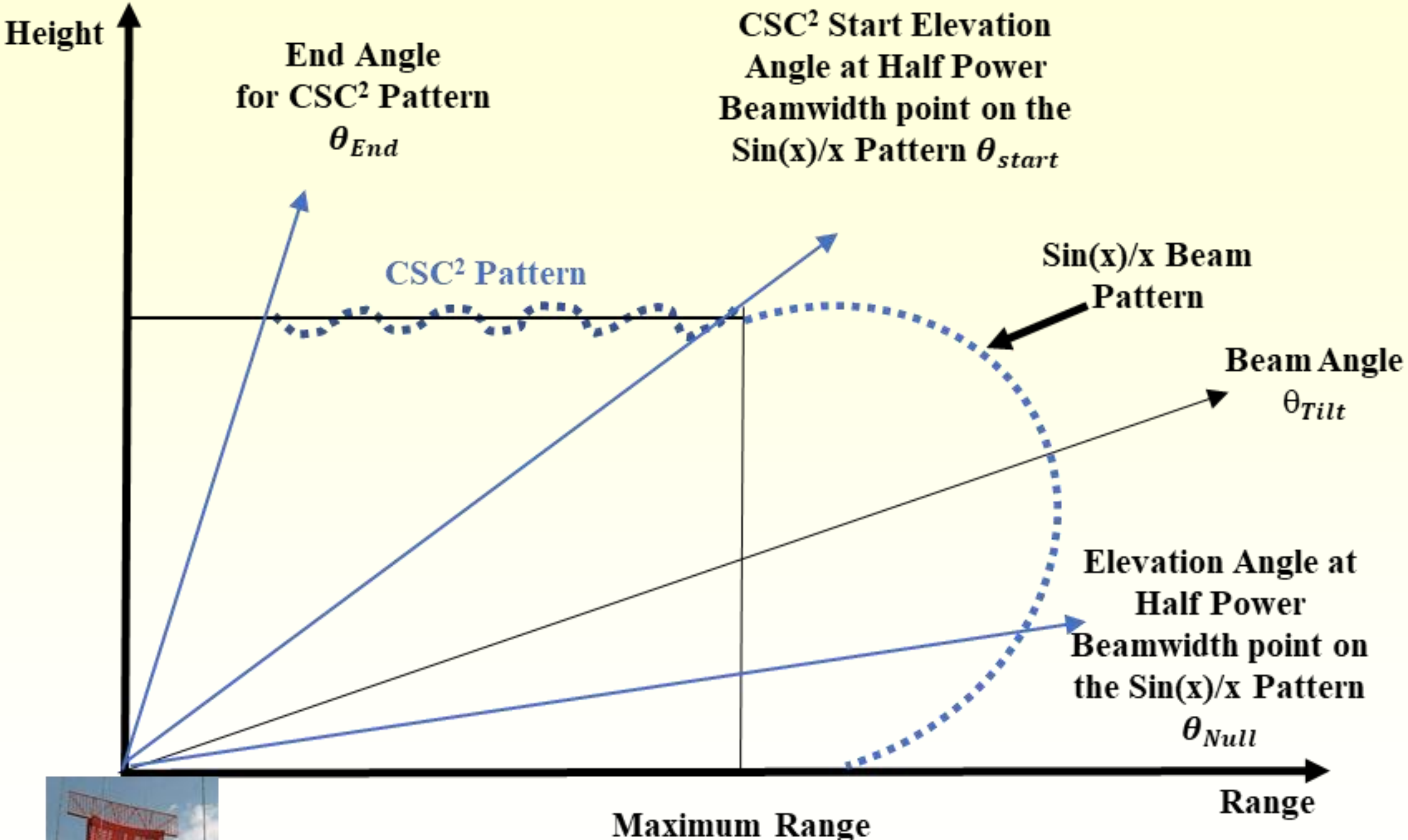


ref_coef

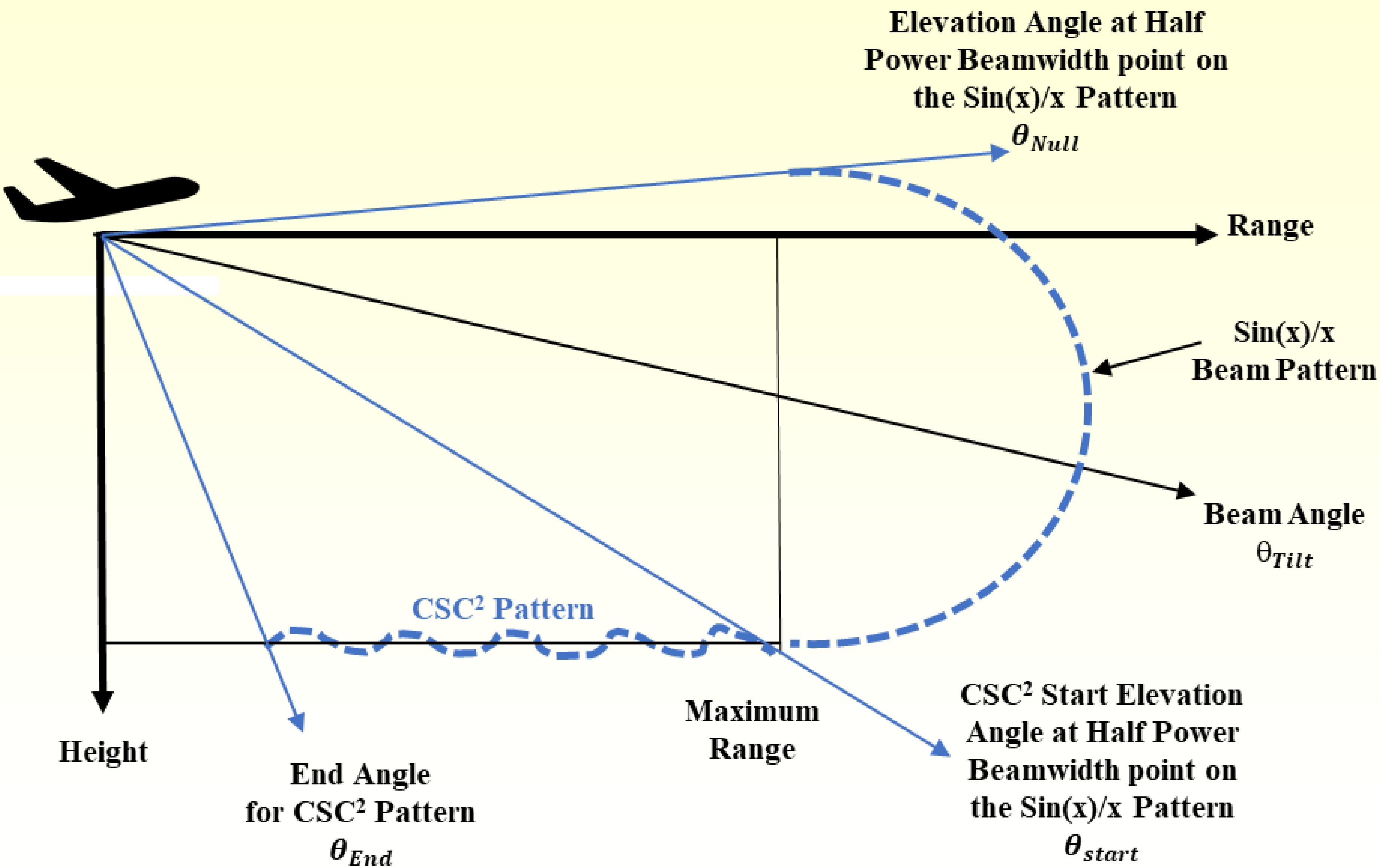
Relative received power from a target approaching at a fixed height



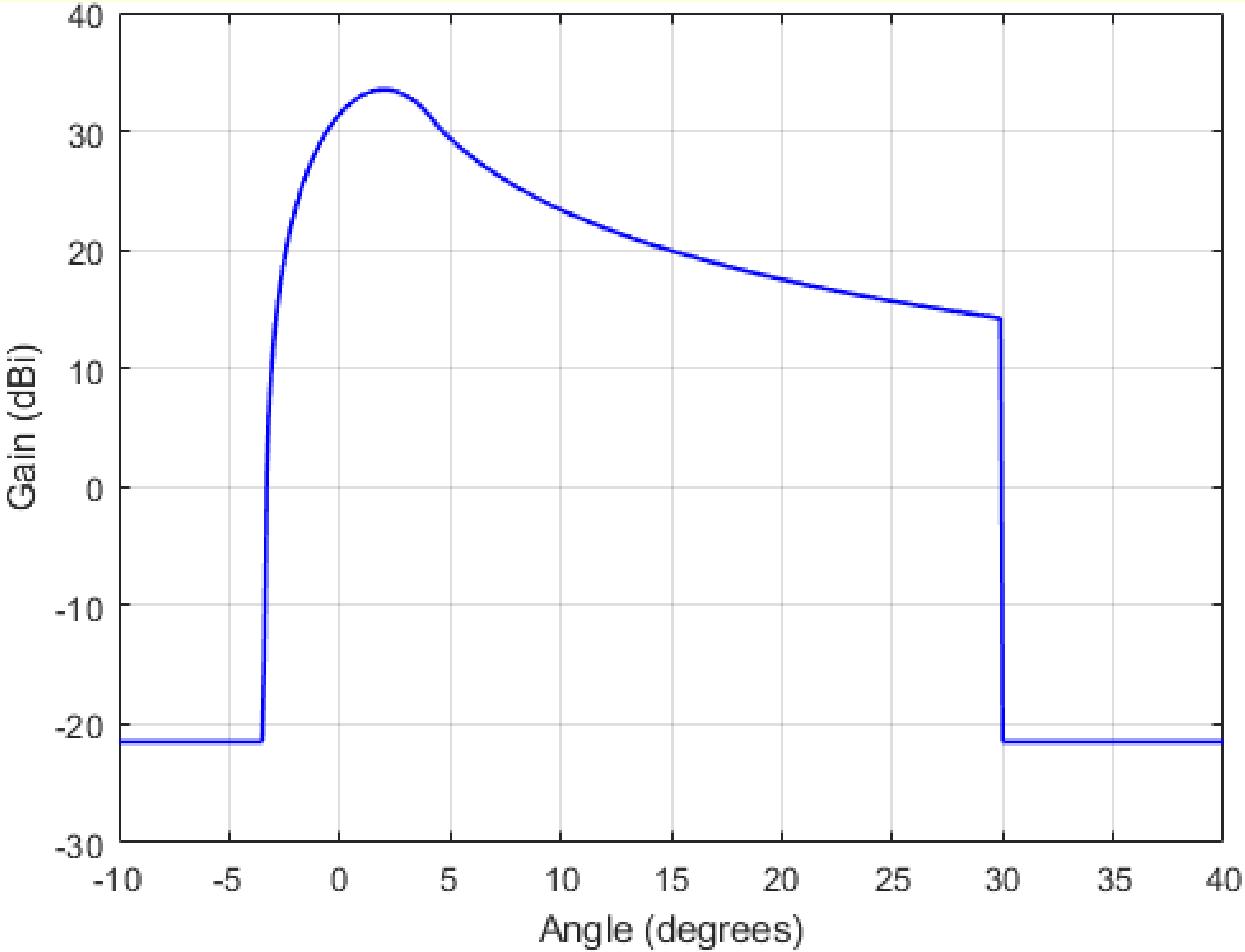
Cosecant squared beam coverage for search radar (M.1851 Fig. 5)



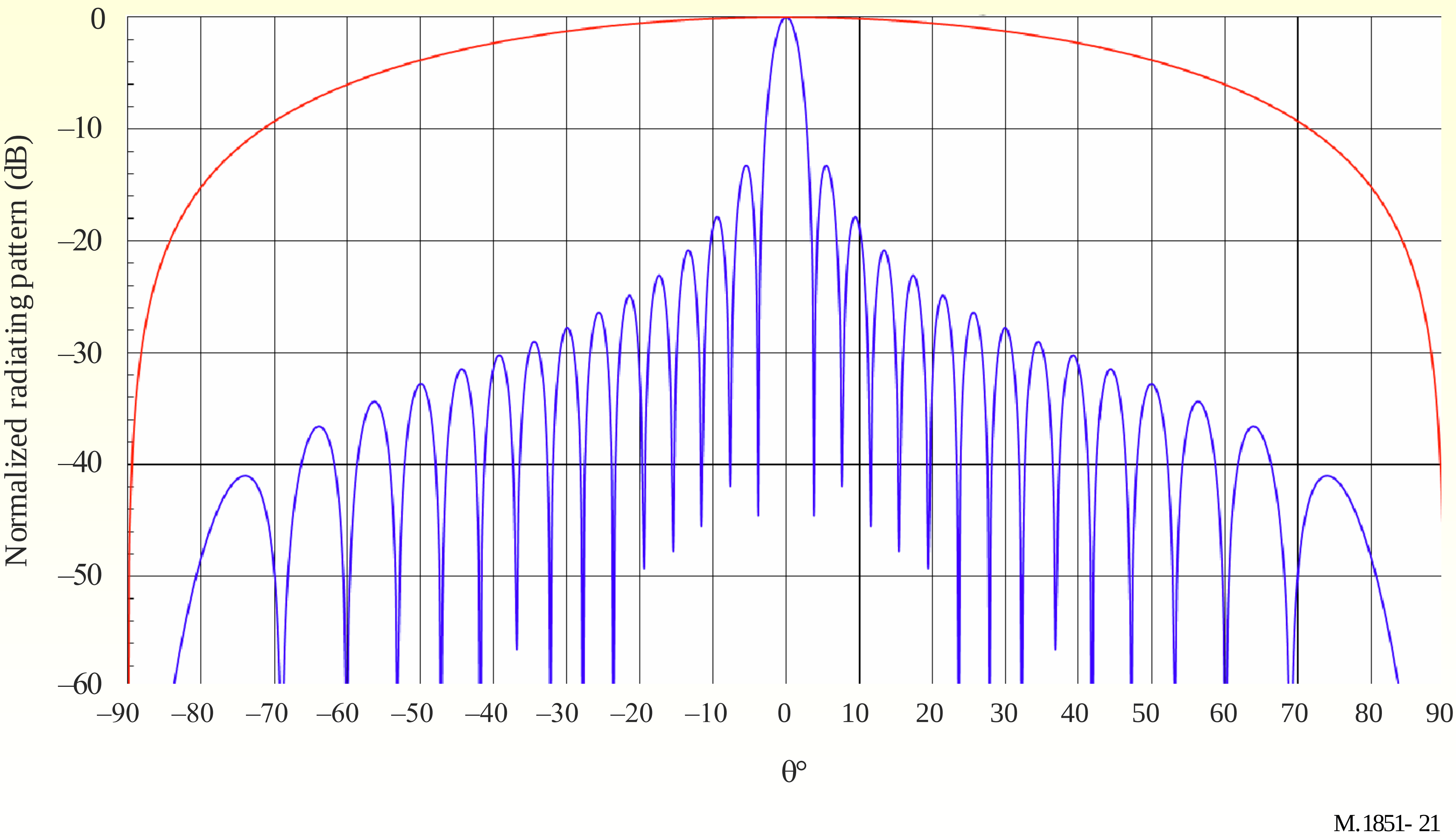
Cosecant squared beam coverage for search radar (M.1851 Fig. 6)



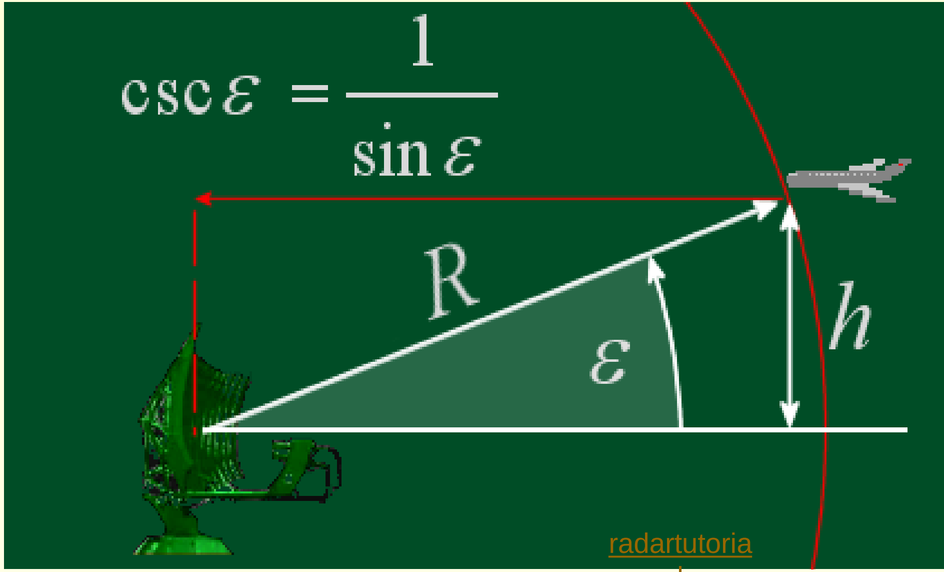
Ground Radar – Cosecant squared theoretical antenna directivity. Gain=33.5 dBi, θ_3dB=4.8°, θ_Start=4.4°, θ_End=30.0°, θ_Null=-3.5°, θ_Tilt=2.0°(M.1851 Fig. 8)



Theoretical normalised radiating pattern of an uniform linear array of 30 radiating elements with a λ/2 lattice (blue curve) steered at boresight with a cosine^2 element radiating pattern (red curve) M.1851 Fig. 23/21)



Cosecant squared beam equation



radartutorial

To get constant signal for a target flying at fixed altitude

$$p_{received} = p_{transmit} \times g^2 \times \sigma \times \frac{\lambda^2}{(4\pi)^3 r^4}$$

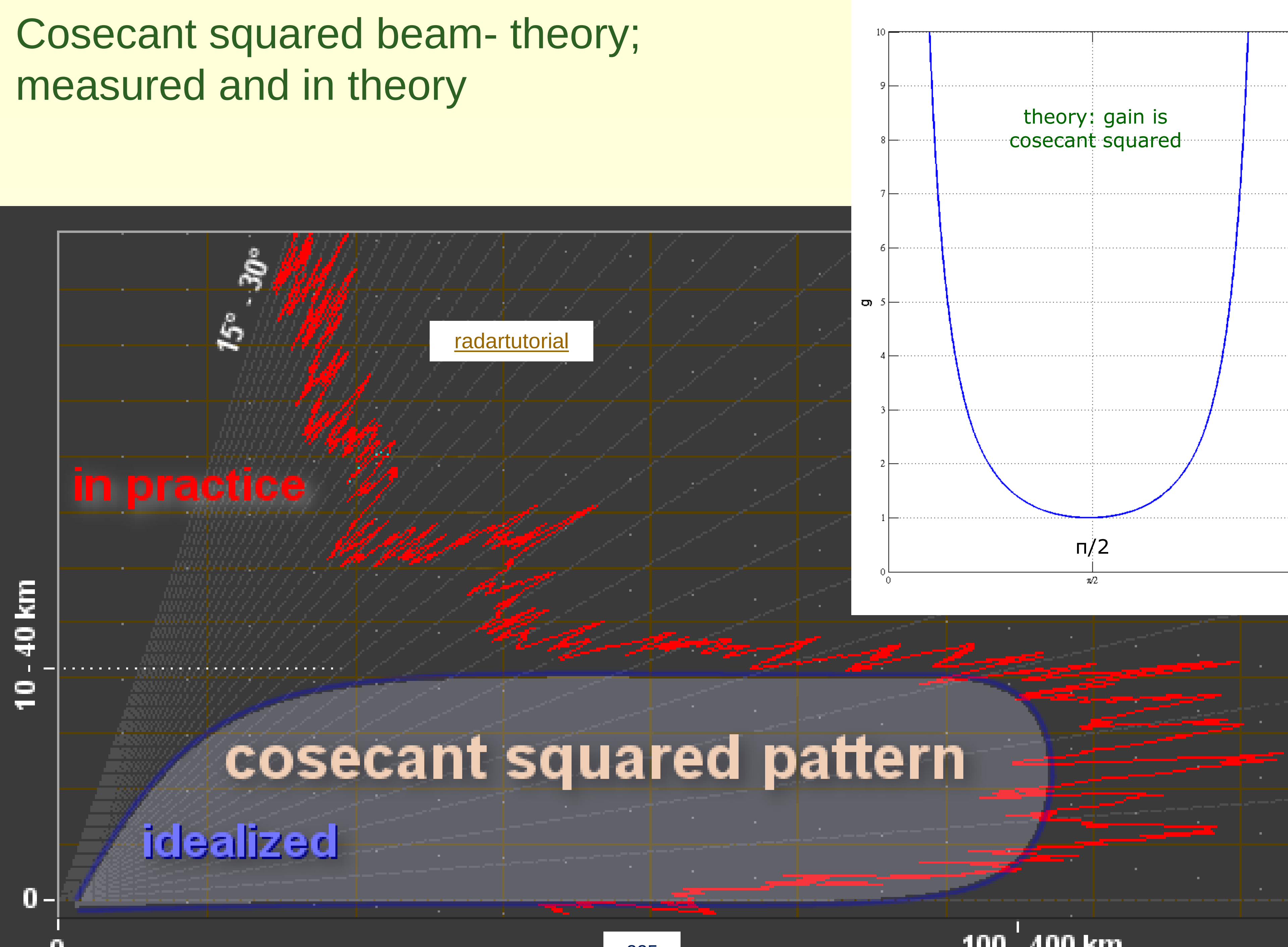
$$P_{received} = \frac{k_1 \times g^2}{r^4} = \frac{k_1 \times g^2 \sin^4\theta}{h^4} = \frac{k_1 \times (k_2)^2}{h^4}$$

$$k_1 = p_{transmit} \times \sigma \times \frac{\lambda^2}{(4\pi)^3}$$

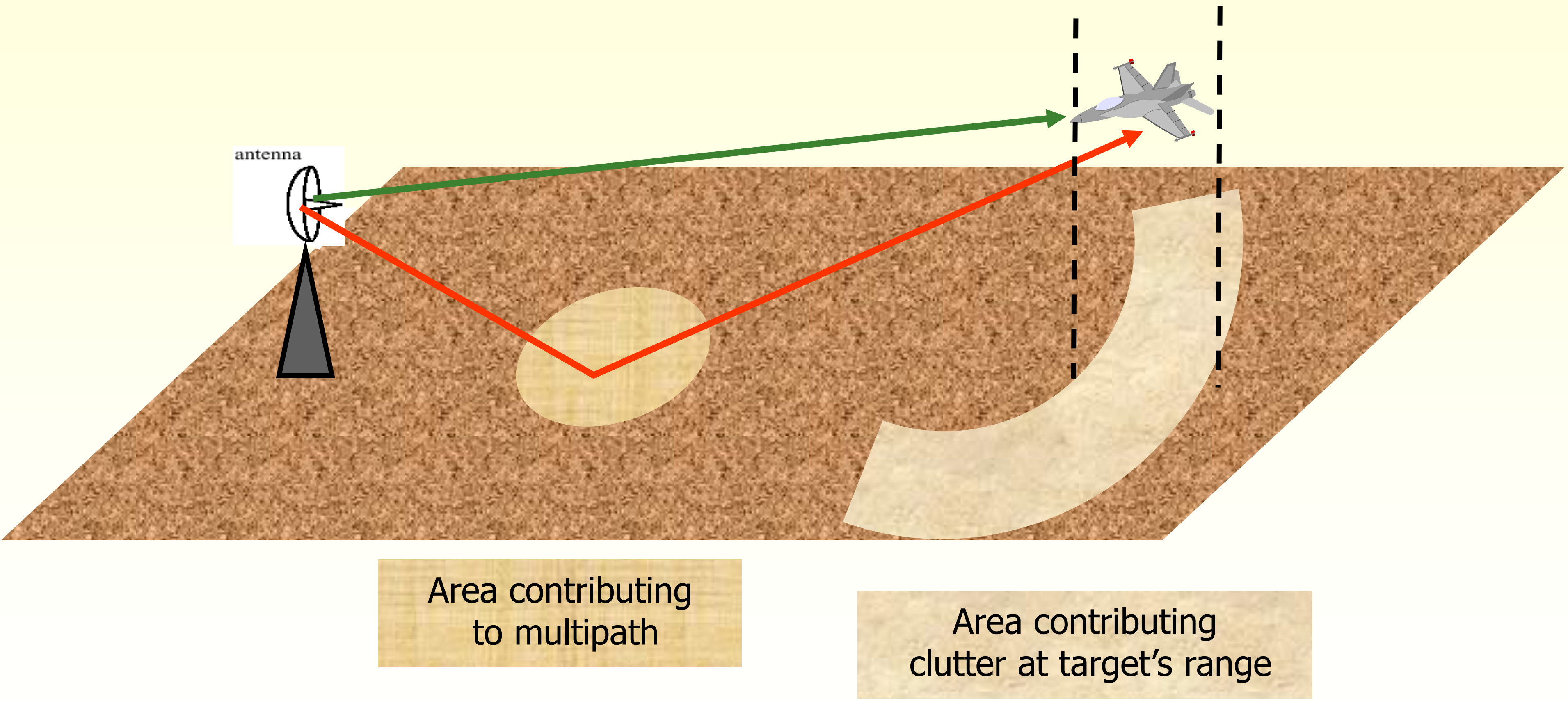
$$(k_2)^2 = g^2 \sin^4\theta \qquad g^2 = \frac{(k_2)^2}{\sin^4\theta}$$

$$g = \frac{k_2}{\sin^2\theta} = k_2 \csc^2\theta$$

Cosecant squared beam- theory; measured and in theory

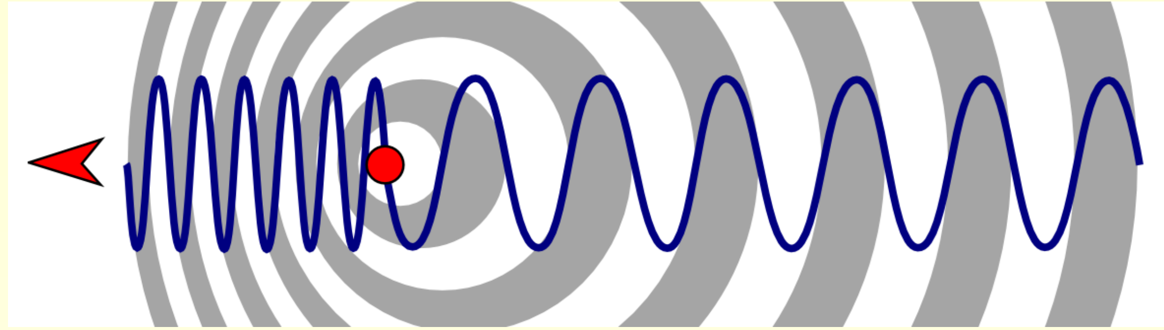


Ground Effects - multipath and clutter



Closing Velocity ⇔ Doppler Shift

the change in frequency of a wave in relation to an observer who is moving relative to the wave source



$$f_D \approx -2\frac{\dot{r}}{\lambda}$$

range rate

wavelength

2-way

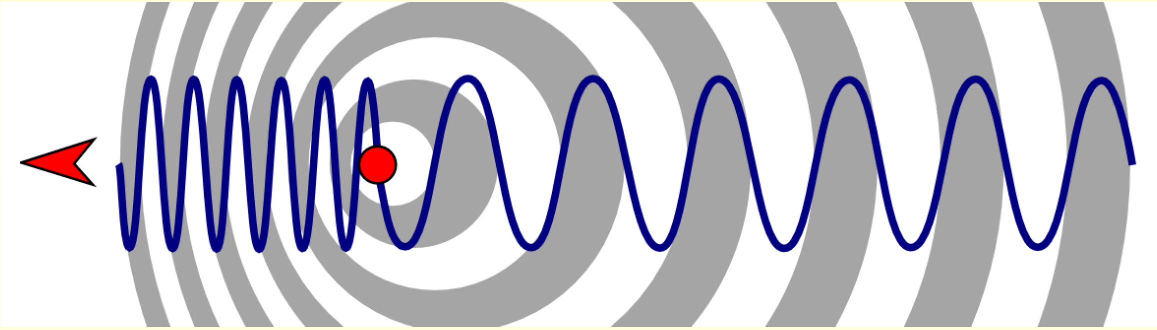
Doppler shift

Propagation-velocity

$$\lambda = \frac{c_p}{f_0}$$

Carrier frequency

The Doppler effect is used to measure the velocity of detected objects. A radar beam is fired at a moving target as it approaches or recedes from the radar source. Each successive radar wave has to travel farther to reach the car, before being reflected and re-detected near the source. As each wave has to move farther, the gap between each wave increases, increasing the wavelength. Vice versa, if the radar beam is fired at the moving car as it approaches. In either situation, calculations from the Doppler effect accurately determine the target's velocity. Because the doppler shift affects the wave incident upon the target as well as the wave reflected back to the radar, the change in frequency observed by a radar due to a target moving at relative velocity is twice that from the same target emitting a wave.



From Wiki

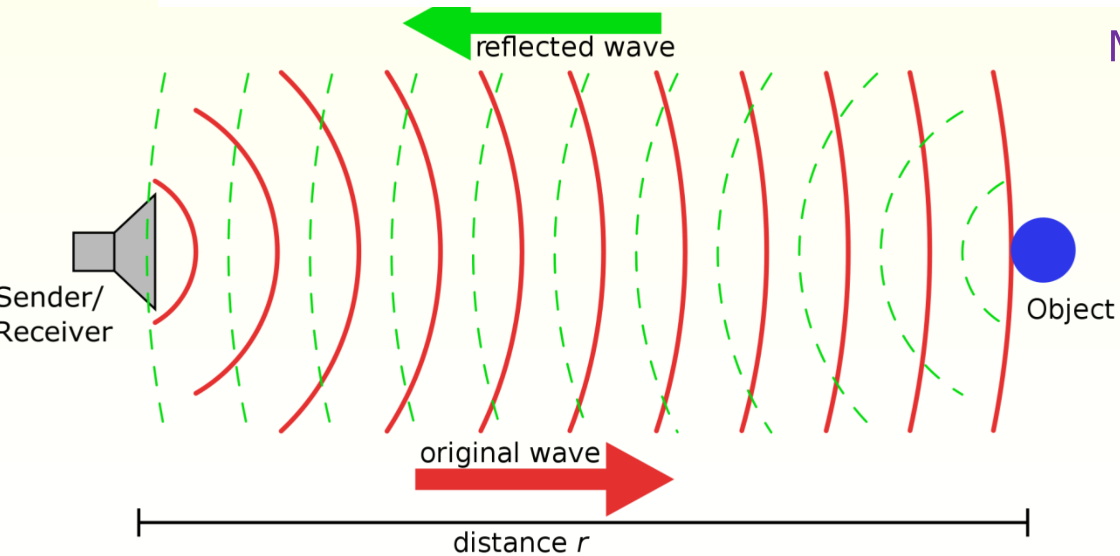
Because the doppler shift affects the wave incident upon the target as well as the wave reflected back to the radar, the change in frequency observed by a radar due to a target moving at relative velocity is **twice** that from the same target emitting a wave

Values of Doppler Shift

From M.A. Richards, Georgia Tech

Band	Frequency (GHz)	Doppler shift (Hz) for v = 1 m/s
L	1	6.67
C	6	40.0
X	10	66.7
K_a	35	233
W	95	633

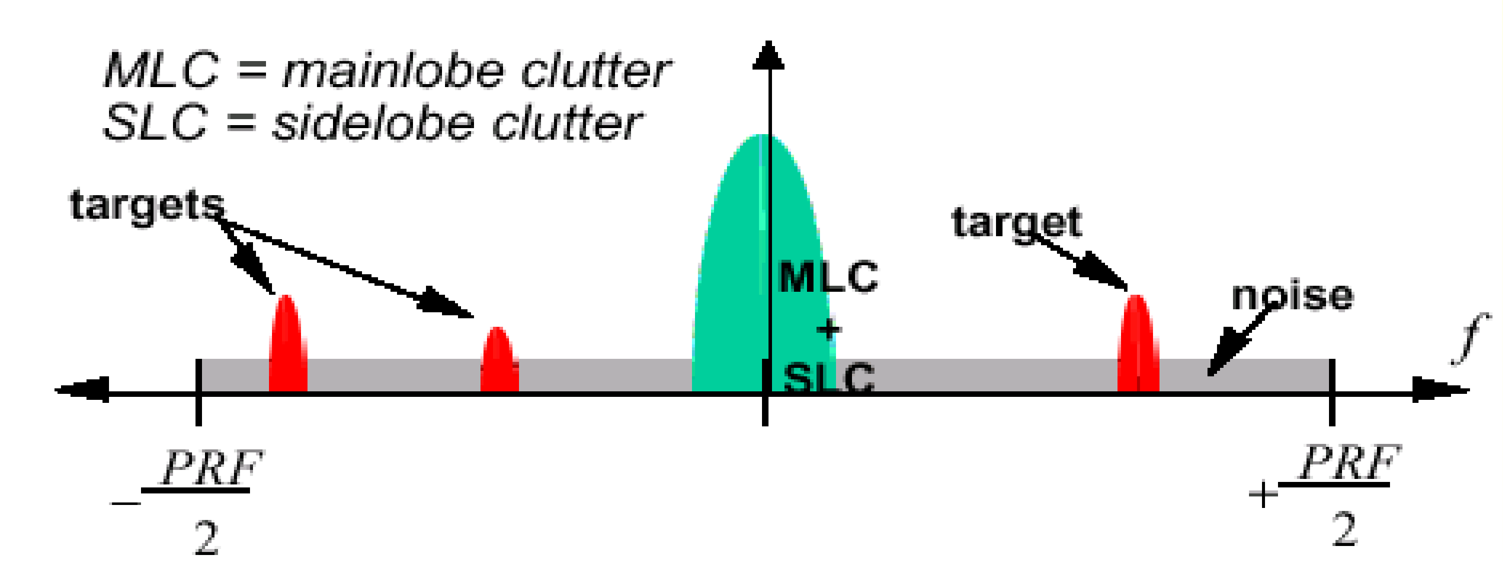
Mach 2 a/c causes 4.4 kHz shift at L band



Moving Target Indicator (MTI) or Doppler processing

From M.A. Richards, Georgia Tech

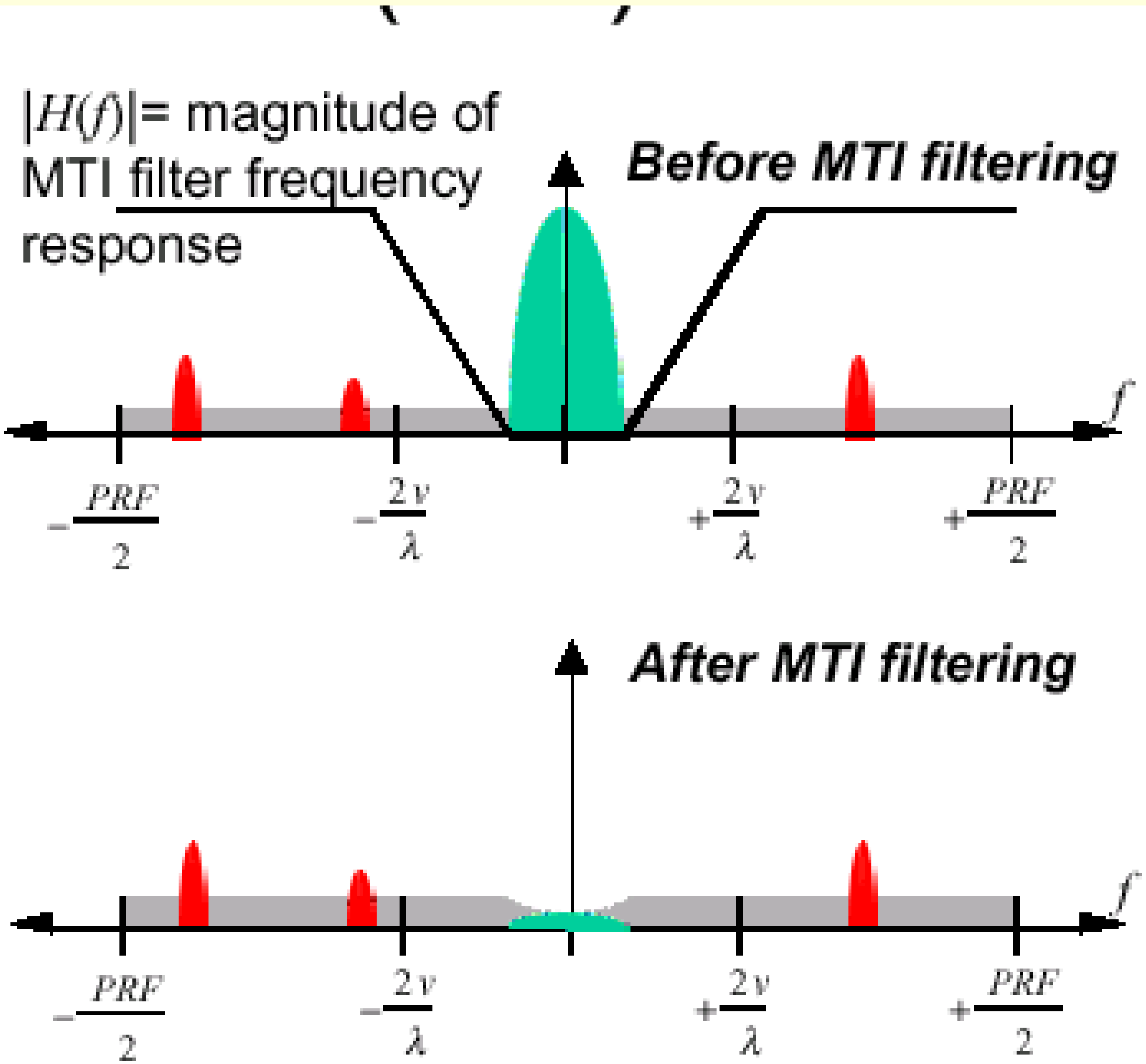
- Involves coherent processing of a pulse train (plain or compressed)
- Purposes: separate weak returns of moving targets from large clutter returns
- Two basic approaches:
  - Bank of filters (usually DFT)
  - Pulse cancelers



The concept of Moving Target Indication (MTI)

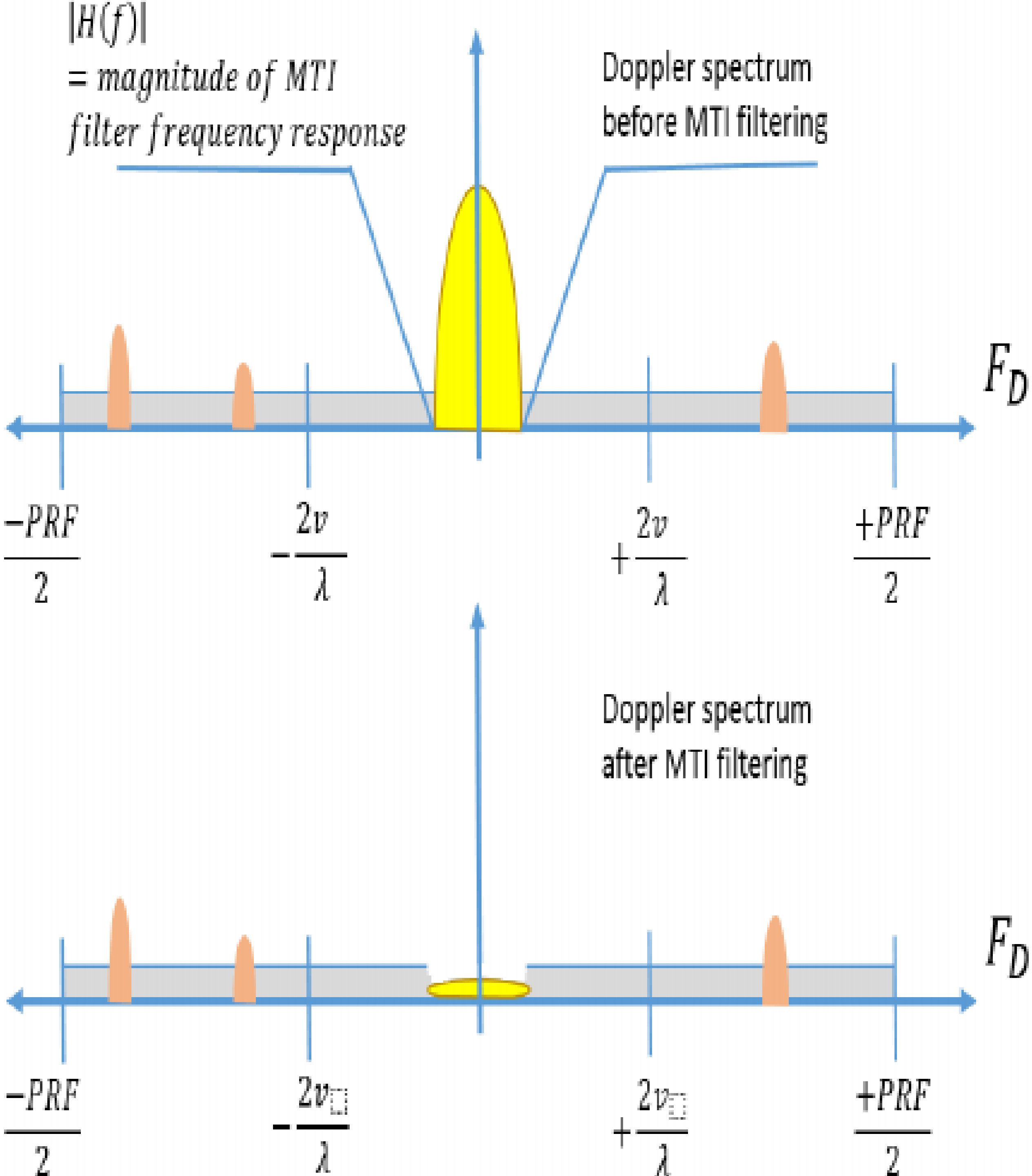
From M.A. Richards, Georgia Tech

- MTI filtering applies a high-pass filter to the data in each slow-time row
- Filter output retains noise, moving target(s), but has reduced clutter
  - goes to detector next



The concept of Moving Target Indication (MTI)

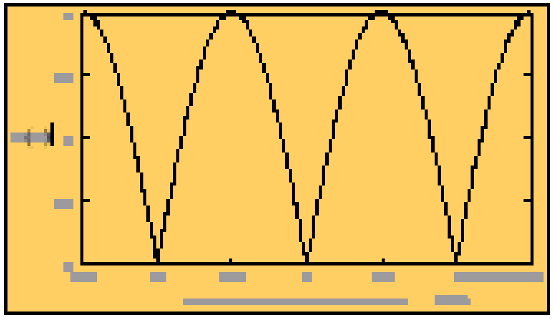
From M.A. Richards, Georgia Tech



Dr. Haim Mazar (Madjar) haimma1@ac.sce.

Blind speeds

From M.A. Richards, Georgia Tech



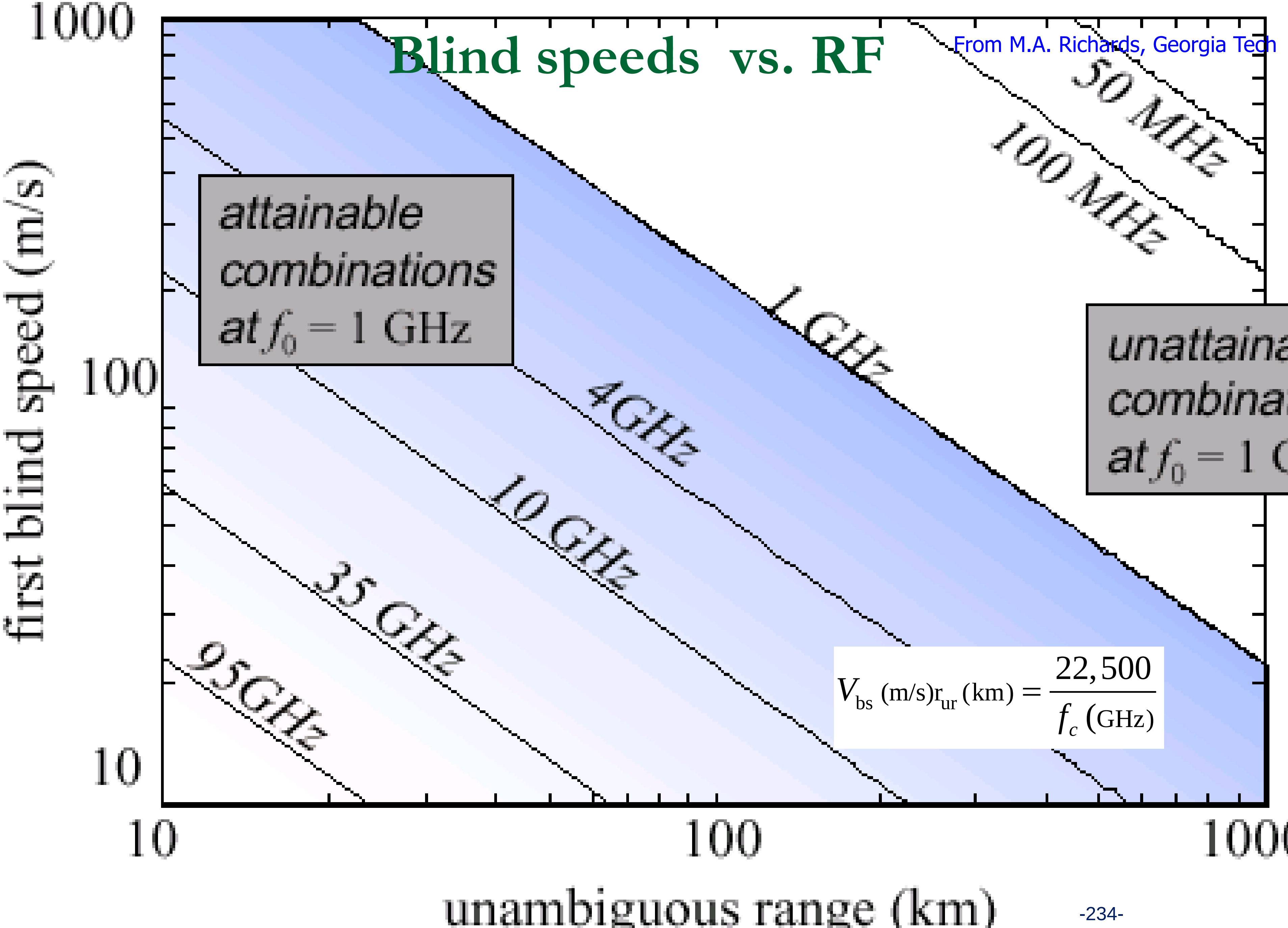
- MTI filters are digital filters, so frequency response is periodic
  - Nulls at multiples of PRF Hz
  - "Blind" to targets at corresponding radial velocity:
  - Could fix by raising PRF
- Unambiguous range is inversely proportional to PRF:
- Tradeoff in PRF choice required

$$v_{blind} = \frac{\lambda\, PRF}{2} = \frac{c\, PRF}{2 f_0}$$

$$R_{ua} = \frac{c}{2\, PRF}$$

Blind speeds vs. RF

From M.A. Richards, Georgia Tech



$$V_{bs}\,(\text{m/s})\,r_{ur}\,(\text{km}) = \frac{22{,}500}{f_c\,(\text{GHz})}$$

Staggered PRFs

Semantic Scholar

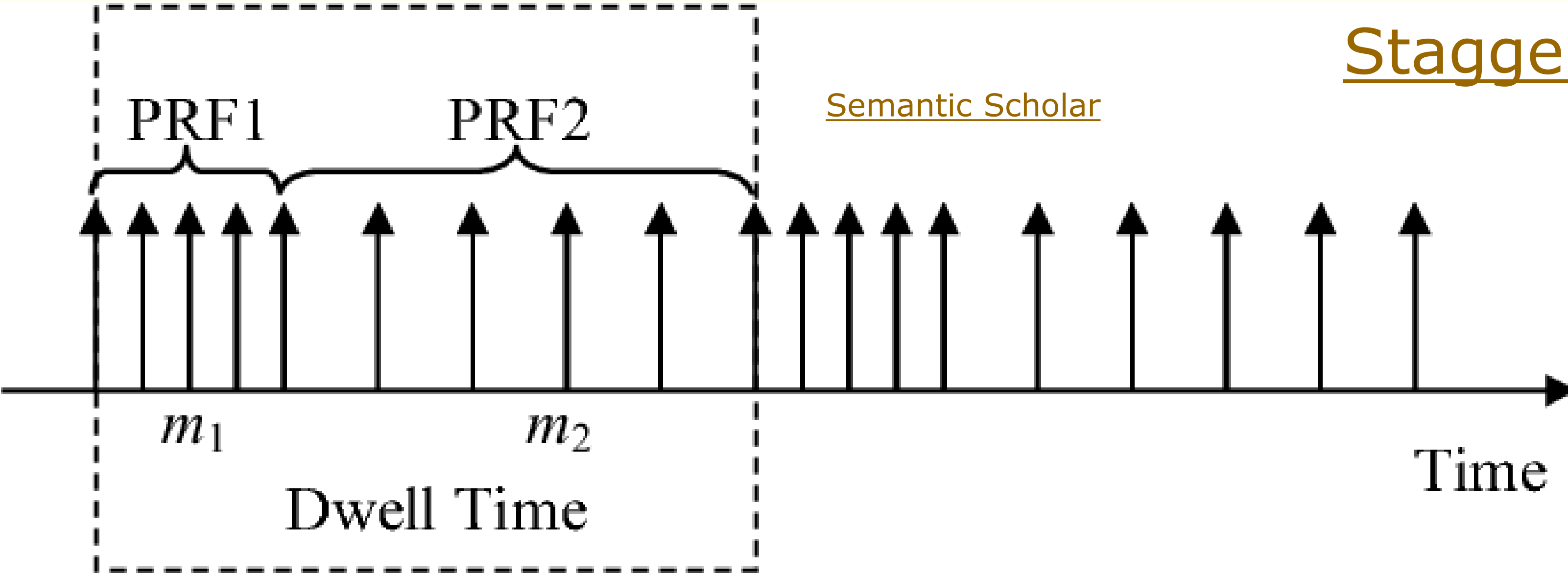
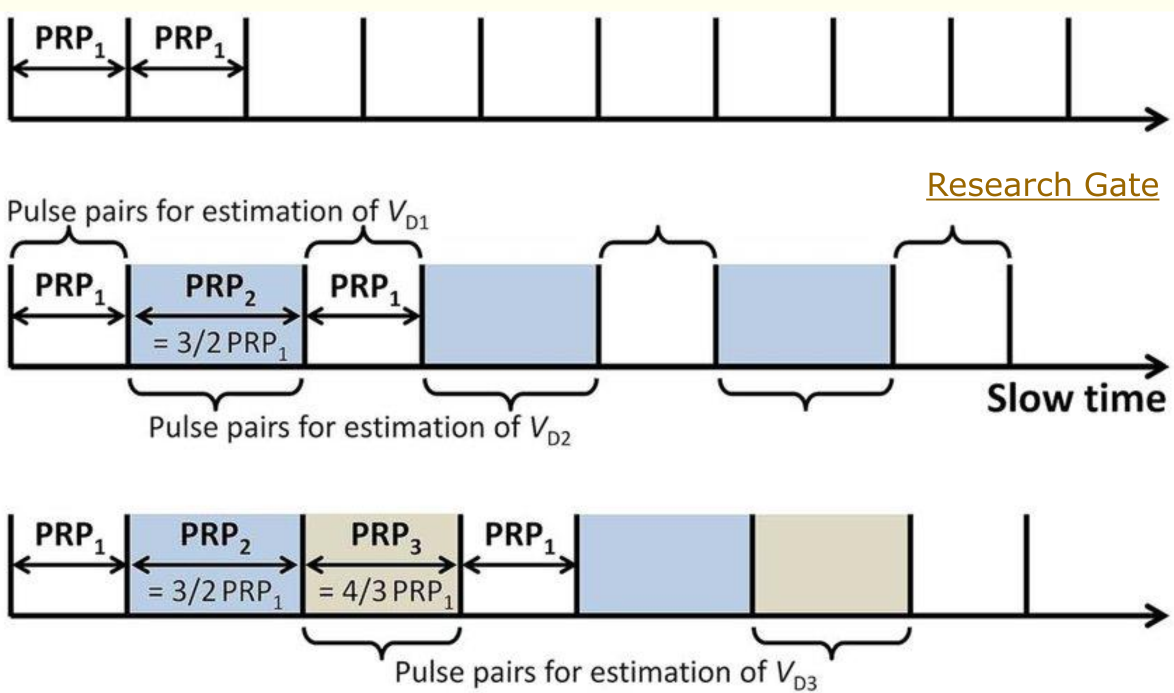


Figure 2. Dual PRF sampling technique.

Pulse Repetition Period (PRF)

Research Gate



When MTI (Moving Target Indicators) and AMTI (Adaptive MTI) are used in pulse radar to search: staggered trigger, pulses may be transmitted at nonequal intervals, to reduce the blind speed region

Unambiguous range (ur) vs. blind speeds (bs)

From M.A. Richards, Georgia Tech

Pulse Repetition Frequency (PRF) Pulse Repetition Interval (PRI)

$$r_{ur} = \frac{c}{2} PRI = \frac{c}{2\,PRF}$$

$$PRF = \frac{c}{2r_{ur}}$$

$$Doppler_{bs} = \frac{c}{2r_{ur}} = \frac{2v_{bs} f_c}{c}$$

$$PRF = \frac{2v_{bs}}{\lambda} = \frac{2v_{bs} f_c}{c}$$

$$v_{bs} r_{ur} = \frac{c^2}{4 f_c}$$

The quantum-mechanics **Heisenberg Uncertainty Principle** of electromagnetic wave relates the energy of a photon and its frequency. We cannot know both the position and speed of a particle, such as a photon or electron, with perfect accuracy; there is inherent uncertainty in the act of measuring a variable of a particle. The uncertainty also applies to **energy** and **time**: one cannot measure the precise energy of a system in a finite amount of time. To precisely measure a wave's energy would take an infinite amount of time, while measuring a wave's exact instance in space would require to be collapsed onto a single moment, which would have indefinite energy $\Delta t x \Delta E \geq (h/4\pi)$. Where Δt refers to the uncertainty in time (second or Hertz^{-1}) and ΔE in Energy (Joule or eV), and h is **Planck's** constant; see Libre Texts 13 Jan. 23.

$h = 6.62607015\times10^{-34}$ J·Hz^{-1} or stating Energy by the eV unit and Hz $4.135667696...\times10^{-15}$ eV·Hz^{-1} see Wiki 13 Jan. 23

Short Range Devices (SRDs)

You may look at my presentation international, regional & national regulation at ITU Workshop on SRDs, Geneva 3 June 14

http://mazar.atwebpages.com/

Definitions

- The regulatory framework for SRDs, such as the decision on frequency bands for use by SRDs, is a national matter
- ITU RR **1.19** *radiocommunication service:* A service as defined in this Section involving the transmission, *emission* and/or reception of *radio waves* for specific *telecommunication* purposes
- SRDs are not a “Radio Service” under ITU Radio Regulations RR; thus they cannot get primary or secondary allocation
- SRDs are emissions without a corresponding frequency allocation in the RR
- SRDs are not ISM applications, as defined in No. 1.15 of RR
- SRD covers radio transmitters, providing either unidirectional or bi-directional communication, with low capability of causing interference to other radio equipment
- For SRDs individual licenses are normally not required
- SRDs are permitted to operate on a *non-interference* and non-protected basis
- In general SRDs cannot claim protection from radio services, intentional or unintentional radiator, by ISM equipment, or by an incidental radiator
- SRDs are deployed in both bands designated for ISM applications and bands not designated for ISM applications

ISM Bands: RR

6 765-6 795 kHz	(centre frequency 6 780 kHz)	FN 5.138
13 553-13 567 kHz	(centre frequency 13 560 kHz),	FN 5.150
26 957-27 283 kHz	(centre frequency 27 120 kHz),	FN 5.150
40.66-40.70 MHz	(centre frequency 40.68 MHz),	FN 5.150
433.05-434.79 MHz	(centre frequency 433.92 MHz) in Region 1*	FN 5.138
902-928 MHz in Region 2	(centre frequency 915 MHz),	FN 5.150
2 400-2 500 MHz	(centre frequency 2 450 MHz),	FN 5.150
5 725-5 875 MHz	(centre frequency 5 800 MHz),	FN 5.150
24-24.25 GHz	(centre frequency 24.125 GHz)	FN 5.150
61-61.5 GHz	(centre frequency 61.25 GHz)	FN 5.138
122-123 GHz	(centre frequency 122.5 GHz)	FN 5.138
244-246 GHz	(centre frequency 245 GHz) `	FN 5.138

Note: 6.780 MHz x2= 13.560 MHz ; 6.780 MHz x4= 27.120 MHz; 6.780x6= 40.680 MHz; 6.780 MHz x32=433.920 MHz.
61.25 GHz x2= 122.5 GHz; 61.25 GHz x4=234 GHz

SRDs are deployed in both bands designated for **ISM** applications and bands not designated for ISM applications. ISM band is **sufficient** condition **but not obligatory**; SRD band is different than ISM band

15.13§ 9 Administrations shall take all practicable and necessary steps to ensure that radiation from equipment used for industrial, scientific and medical applications is minimal and that, outside the bands designated for use by this equipment, radiation from such equipment is at a level that does not cause harmful interference to a radiocommunication service and, in particular, to a radionavigation or any other safety service operating in accordance with the provisions of these Regulations.

Frequency Bands for SRDs

Global
Only in Europe
Only in Americas

ISM bands

6,780 kHz; 13,560 kHz
27,120 kHz; 40.68 MHz
433.92 MHz
915 MHz
2,450 MHz; 5,800 MHz
24.125 GHz;61.25 GHz
122.5 GHz ;245 GHz

9-148.5 kHz; 3,155-3,400 kHz
9 kHz- 47 MHz (specific SRDs)
7,400-8,800 kHz
138.20-138.45 MHz
169.4-216 MHz
312-315MHz (non Europe)
402-405 MHz medical devices
470-489 MHz (normally individually licensed)
823-832 MHz and 1,785-1,805 MHz
862-875 MHz in some Asian counties
862-876MHz Non-Specific SRDs
915-921 MHz
5,150-5,350 & 5,470-5,725 MHz
57-64GHz, 76-77GHz, 77-81GHz

non-ISM candidate bands for SRDs

Applications of ISM equipment, in and outside ISM bands

Frequency	Applications
Below 1,000 kHz	Induction heating; ultrasonic cleaning and medical diagnostics; Domestic induction cookers; metal melting; billet heating; tube welding; soldering and brazing; component heating; spot welding; selective surface heat; treating of metal parts; semiconductor crystal growing and refining; seam bonding of autobody surfaces; package sealing; heating strip steel for galvanizing, annealing and paint drying; electrical surgical units (ESU); hyperthermia equipment
1-10 MHz	Surgical diathermy (dampened wave oscillator); wood gluing and wood curing (3.2 and 6.5 MHz); valve induction generators production of semi-conductor material; RF arc stabilized welding; ESU
10-100 MHz	Dielectric heating and material preheating. The majority operate in the ISM RF bands at 13.56, 27.12 and 40.68 MHz, but many also operate on frequencies outside the ISM bands): drying (textile, fiberglass, paper and paper coating, veneer and lumber, foundry core, glue, film, solvent, food), ceramics, business products (books, paper, gluing and drying), food (post baking, meat and fish thawing), wood gluing, plastic heating (welding and moulding, die sealing and plastic embossing), adhesive curing. Medical applications: medical diathermy and hyperthermia equipment (27 MHz), MRI (10-100 MHz in large shielded rooms)
100-915 MHz	Medical applications (433 MHz), hyperthermia equipment (433 MHz and 915); food processing (915 MHz); RF plasma generators; Rubber vulcanization (915 MHz); MRI
Above 915 MHz	**Microwave ovens** domestic and commercial (915 MHz and 2,450 MHz), food tempering, thawing and cooking; RF excited ultra-violet paint and coating curing; pharmaceutical processing; RF plasma generators; rubber vulcanization (magnetrons at 915 and 2450 MHz)

SRDs: new multiplexing, spreading & modulation techniques for enhanced data-rate & to avoid interference

- Orthogonal frequency-division multiplexing (OFDM) is the modulation and multiplexing of Wi-Fi 802.11a and g
- Coded Orthogonal Frequency-Division Multiple Access (COFDM) is used in Wi-Fi 5GHz (IEEE802.11.a) as signal modulation technique; COFDM sends a stream of data symbols in a parallel, with multiple subcarriers (i.e. small slices of spectrum within the designated carrier RF band)
- Spread-spectrum techniques:
  - Direct-sequence spread spectrum (DSSS) is used at Wi-Fi IEEE 802.11b and ZigBee IEEE 802.15.4; ZigBee is basically a 10-meter range with transfer rate of 250 kbit/s
  - Frequency-hopping spread spectrum (FHSS) is used also for Bluetooth IEEE 802.15.1: a wireless technology for low-power low-cost and low-complexity SRD. Bluetooth exchanges data over short distances from fixed and mobile devices
- Complementary Code Keying (CCK) is the modulation scheme used with wireless networks (WLANs) that employ the IEEE 802.11b operating at either 5.5 or 11 Mbit/s

Typical Applications

1. Wideband data transmission: RLAN/Wi-Fi, UWB, White Space Devices (in the USA, white space devices are to operate on a non-protected, non-interference basis), Wideband Low Activity Mode (WLAM), short range video
2. RF IDentification (RFID), active medical implants, health monitoring, personal identification, inductive systems, proximity sensors
3. Car door openers, Transport and Traffic Telematics (TTT), road tolling, Automatic Meter Reading (AMR), Street Lamp Monitoring and Control, railway applications, car immobilisers
4. Logistics, livestock, Electronic Article Surveillance (EAS),
5. Radiodetermination: Automotive Short Range Radar (SRR), RF level gauges, radar sensor, Level Probing Radar (LPR)
6. Near Field Communication (NFC) & voice like: walkie-talkie, baby monitoring, remote control, radio microphone, cordless loudspeakers and telephones, aids for the hearing impaired, voice enabled data collection
7. Telemetry, tracking, tracing and data acquisition, model control, home automation, automotive industry, sensor monitoring
8. Alarm, social alarms, anti-theft

RFID technology, as a typical SRD

1. RFID was developed by the British Air Force during World War II to identify enemy aircrafts: identification, friend or foe (IFF)
2. RFID systems consist of transponders or tags, in objects to be identified
3. Many kinds of RFID systems, depending on power source , operating frequency and functionality
4. 3 types: passive, semi active and active
   1) Passive: no internal power source, inductive coupling or backscattering short range, unlimited life
   2) Semi-passive: like passive but uses battery for electronic components
   3) Active: battery powered incl. active transmitter; larger size, longer range, shorter life
5. Technological advances in RFID in recent years:
   1. RTLS (Real Time Location Systems): addition of location functionality to identification and data transfer, utilizing triangulation and other techniques
   2. 5.9GHz DSRC : “Wi-Fi for cars” for high data rate low latency V2V (vehicle to vehicle) and V2I (vehicle to infrastructure) communication

Wireless Power Transfer (WPT) as SRD

- ITU RR No. 1.15 *ISM applications :* operation of equipment or appliances designed to generate and use locally radio frequency energy for industrial, scientific, medical, domestic or similar purposes, **excluding applications in the field of *telecommunications***
- WPT with no data communication (e.g. Blue Tooth or ZigBee) is ISM, and may operate in all ISM bands
- ‘equipment with a WPT function may be regarded as another type of SRD’ (CISPR/1302/INF; 2015-03-20)
- WPT is SRD only if there are telecommunications
- USA separates between FCC Part 15 for ‘Radio Frequency Devices’ and FCC Part 18 for ISM.

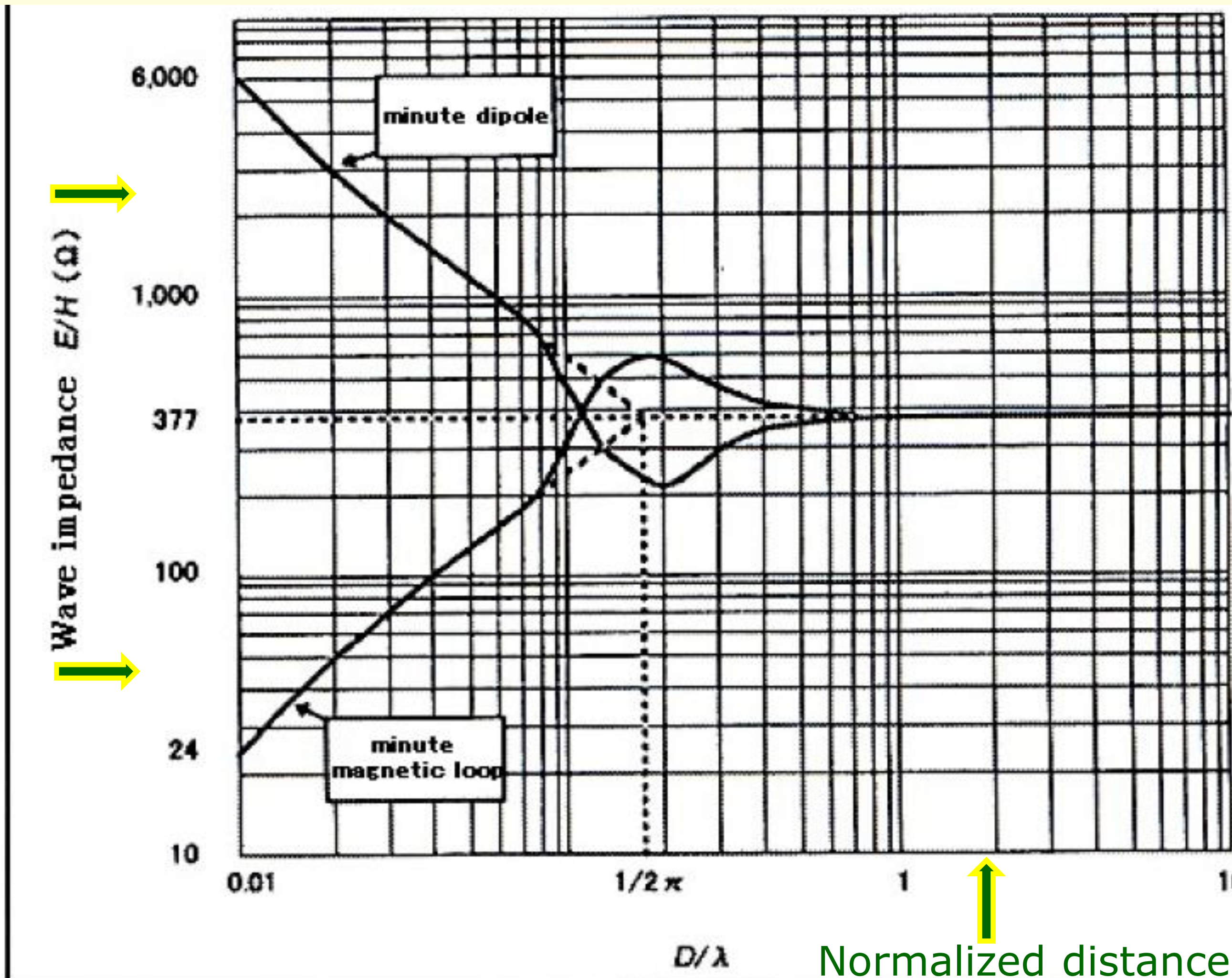
Wave Impedance (z)of minute dipole & minute magnetic dipole

$$PoyntingVector = \frac{p_t g_t}{4\pi d^2} = (\vec{e} \times \vec{h}) = \frac{e_o^2}{z} = h^2 z$$ relevant for far & near field

Source, Dipole Antenna - electric field is dominant

Source, Loop Dipole- magnetic field is dominant

See also next slide

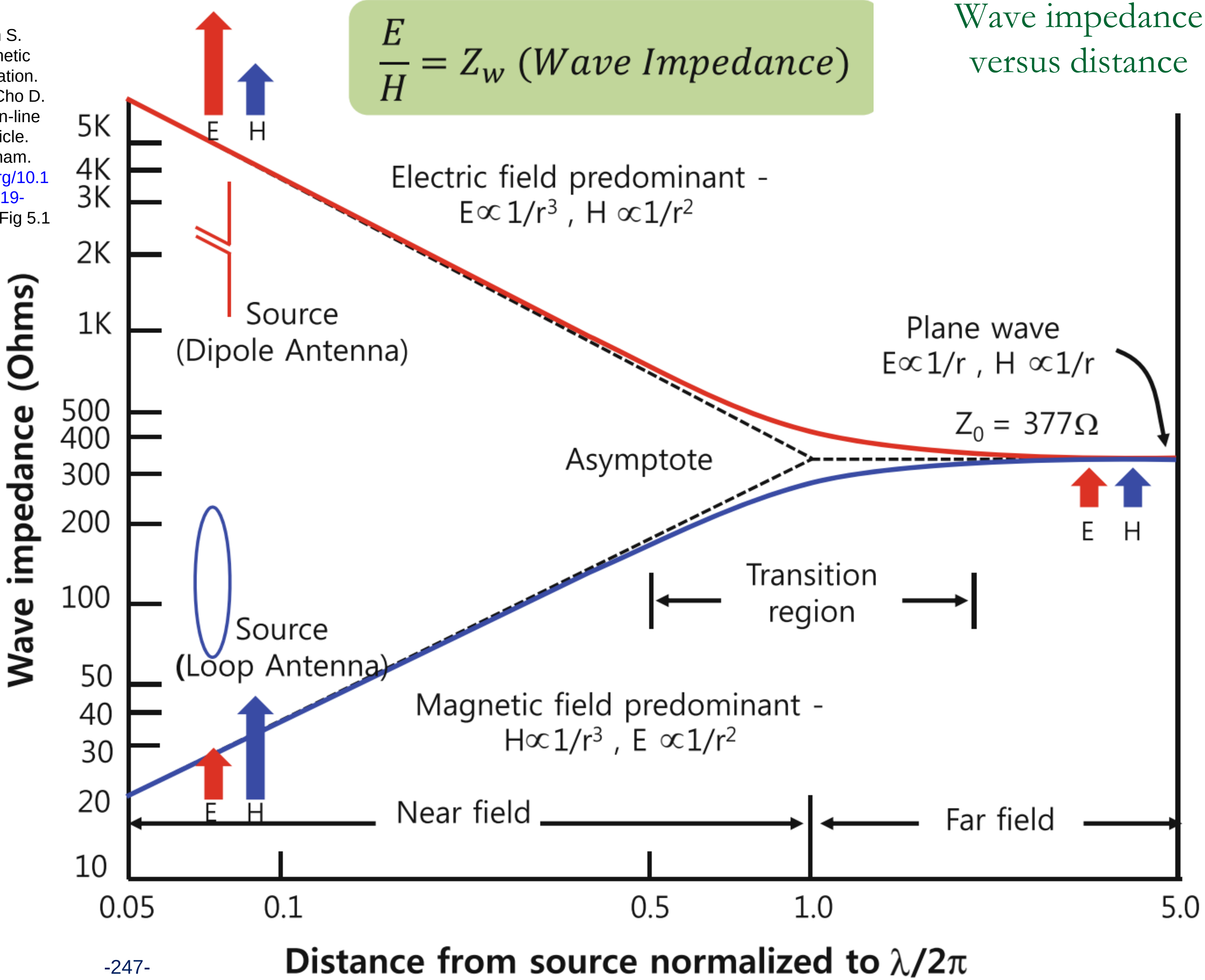


Normalized distance

Source: Ahn S. (2017) Magnetic Field Generation. In: Suh N., Cho D. (eds) The On-line Electric Vehicle. Springer, Cham. https://doi.org/10.1007/978-3-319-51183-2_5; Fig 5.1

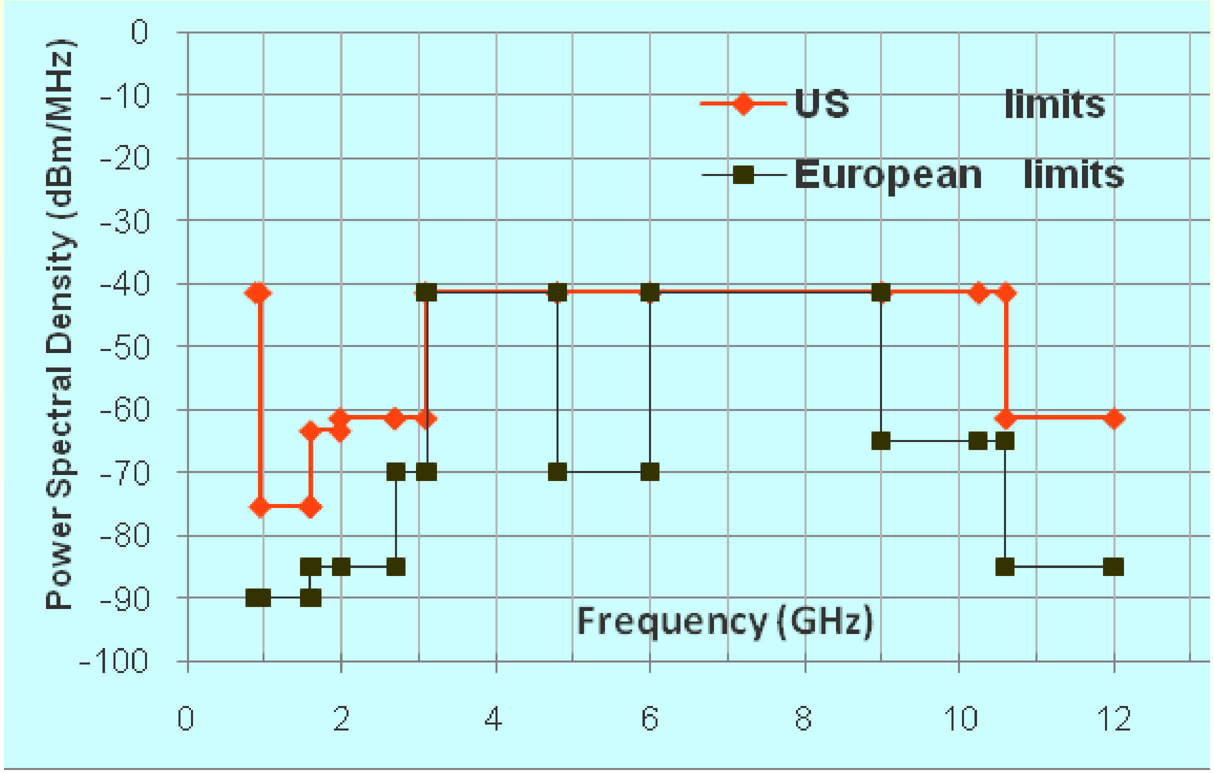
Wave impedance versus distance

$$\frac{E}{H} = Z_w \text{ (Wave Impedance)}$$



UHF RFID: Americas versus Europe

	RF band (MHz)	Max e.i.r.p. power (Watts)	Channels (kHz)	Total RF BW (MHz)	Approval process
Europe	865-868	up to 2 (e.r.p.) x 1.64=3.28	15 x 200	3	Radio Equipment Directive (RED)
Americas	902-928	4*	52 x 500	26	US tests every RFID



UWB emission masks in Europe and the US

Europe allowed UWB in 2005, US in 2001

Differences up to 49 dB@900-960MHz

SRDs & smart sustainable world, cities, houses, cars; Internet of Things

Wireless networks provide vital infrastructure and connection of ICT's that underpin the Smart Sustainable Cities

Source: ITU-T Report 2014 *EMF Considerations in Smart Sustainable Cities*

Typical Emerging technology: Z-Wave, *smart house*

current sub-1GHz RF

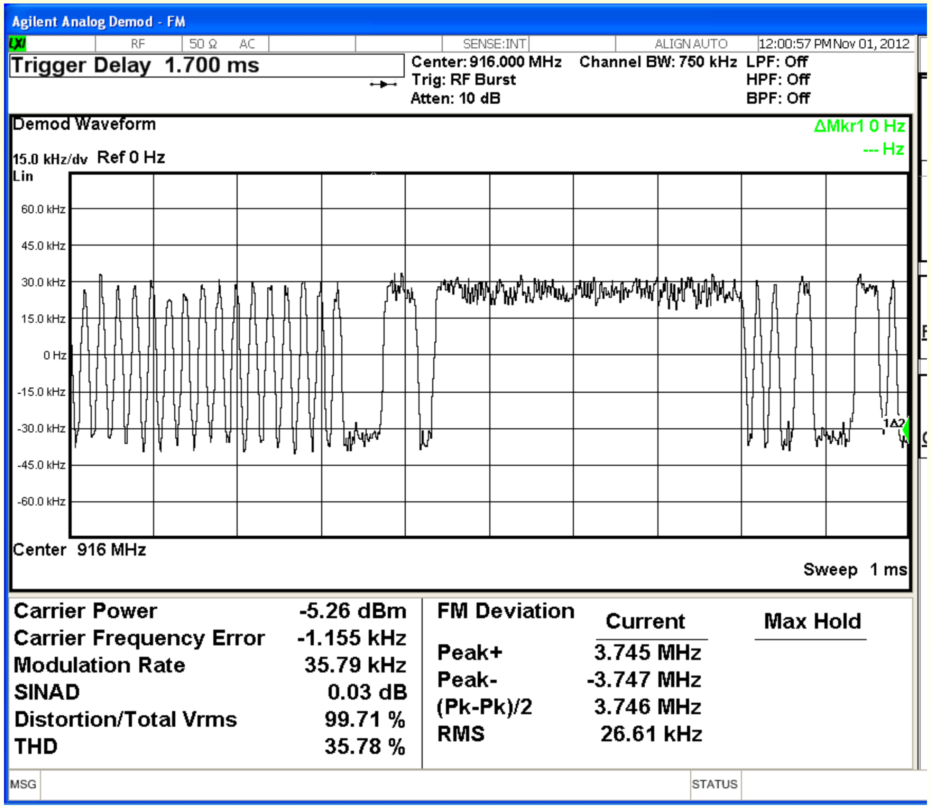
Z-Wave is designed mainly for remote controls, smoke alarms and security sensors

- Z-Wave uses a single frequency FSK
- Data rate up to 100 Kbps; unlike IEEE 802.11, designed primarily for high-bandwidth data flow
- Range between controllers & slave devices up to 100 ft

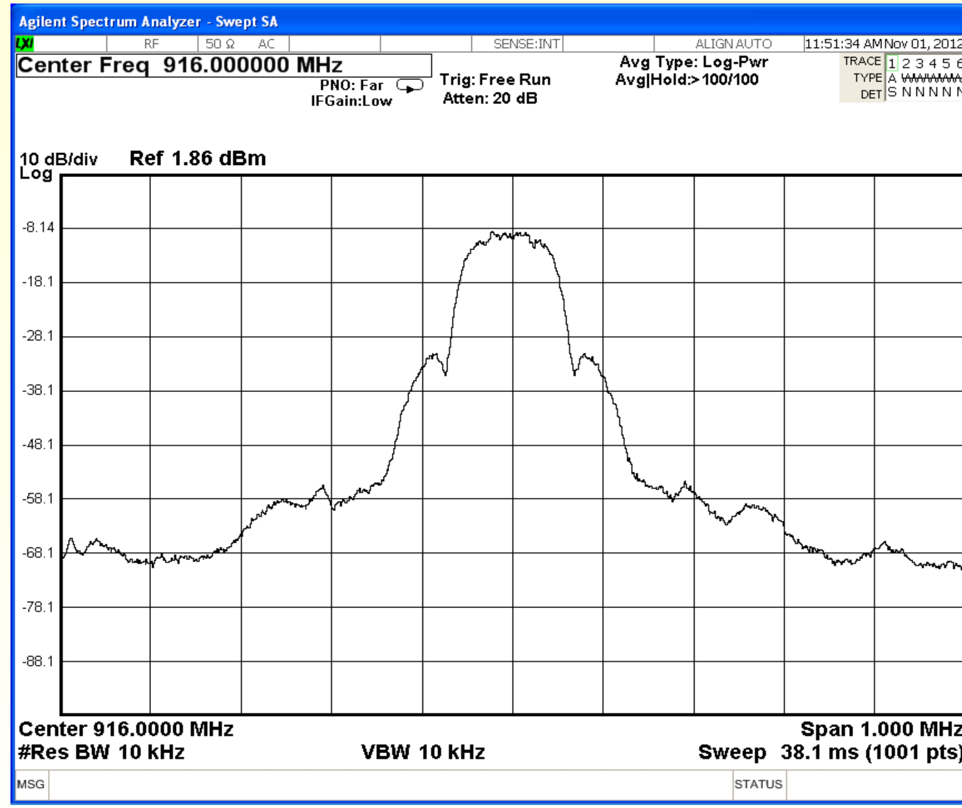
Country/Region	Standard	Z-Wave RF
Australia	AS/NZS 4268	921.4 MHz
Brazil	ANATEL Resolution 506	921.4 MHz
CEPT	EN 300 220	868.4 MHz
Chile	FCC CFR47 Part 15.249	908.4 MHz
China	CNAS/EN 300 220	868.4 MHz
Hong Kong	HKTA 1035	919.8 MHz
India	CSR 564 (E)	865.2 MHz
Japan 950 (obsolete by end of 2015)	ARIB T96	951-956 MHz
Japan 920 (since Feb 2012)	ARIB STD-T108	922-926 MHz
Malaysia	SKMM WTS SRD/EN 300 220	868.1 MHz
Mexico	FCC CFR47 Part 15.249	908.4 MHz
New Zealand	AS/NZS 4268	921.4 MHz
Russia	GKRCh/EN 300 220	869.0 MHz
Singapore	TS SRD/EN 300 220	868.4 MHz
South Africa	ICASA/EN 300 220	868.4 MHz
Taiwan	NCC/LP0002	922-926 MHz
UAE	EN 300 220	868.4 MHz
USA/Canada	FCC CFR47 Part 15.249	908.4 MHz

Dr. Haim Mazar (Madjar) haimma1@ac.sce.ac.il h.mazar@atdi-grou

New Technologies, more immune to interference
Z-Wave



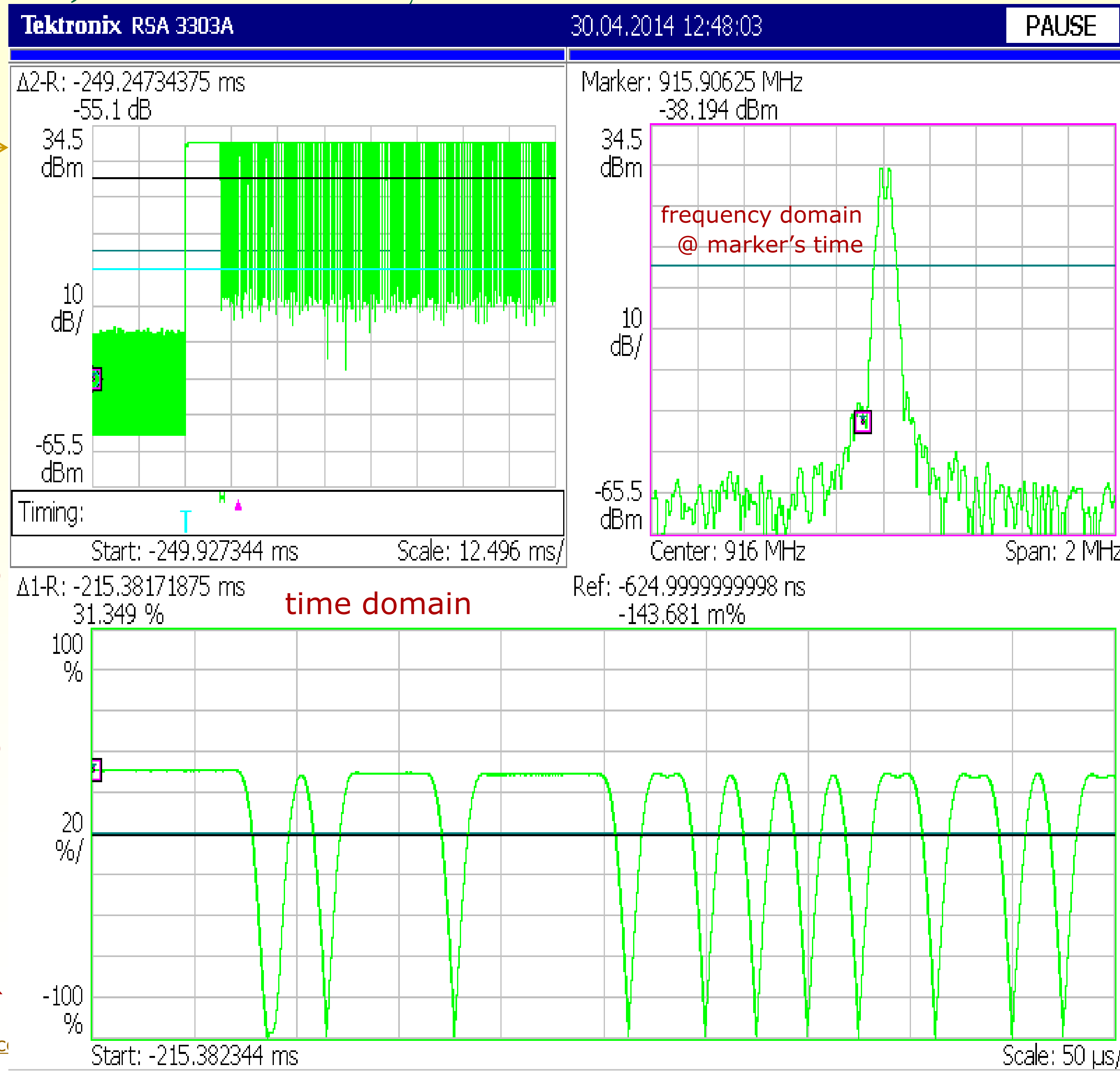
SRD, FSK signal, RF 916 MHz; 100 kbps; time domain



Same real SRD FSK signal, RF 916 MHz; RF domain

UHF RFID Reader; real time analyzer: time & RF domains view

power up phase, CW carrier & the modulation starting after about 10 ms



Phase-Reversal ASK (PR-ASK)

Tari 25 µs (40 kbps), Phase-Reversal ASK (PR-ASK)

Siemens SIMATIC RF680R

Dr. Haim Mazar (Madjar) haimma1@ac.sc

SRD to track (& preserve) short-toed snake-eagle (regulated by the author)

SRD applications are increasing, which result in increasing spectrum demands

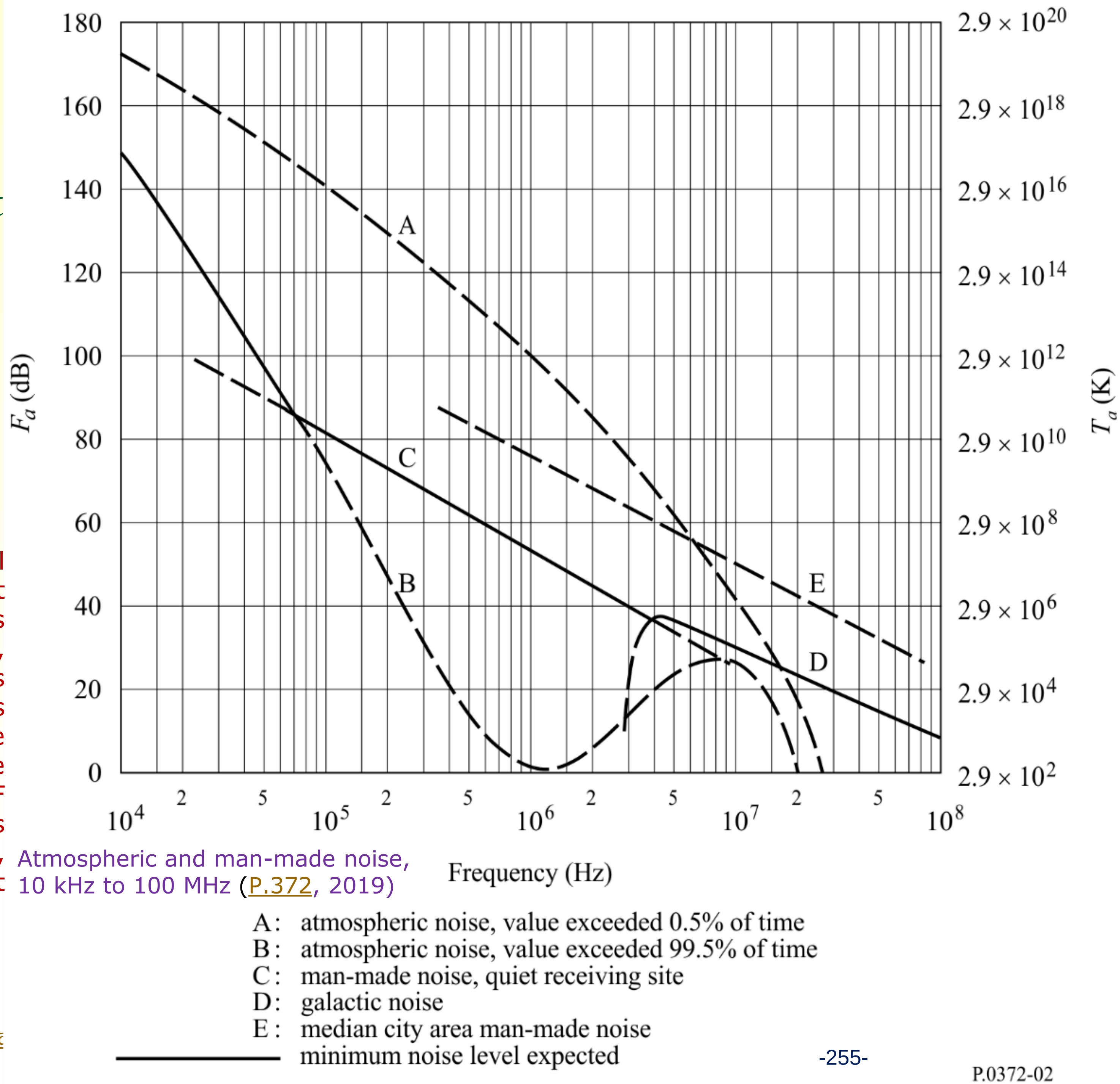
Water meter with built-in AMR radio module

Solar-powered wireless relay for AMR

Wireless wastewater & sewage level monitoring unit with tilt sensors

Interference of SRDs to wireless services: at low RF no significant degradation

Below 30 MHz, external noise is most influential at victim receiver. Thus, as atmospheric, man-made, galactic noises & emissions from atmospheric gases and hydrometeors are dominant: they are stronger than the KTBF power. Therefore, SRDs operating below 30 MHz, interfere less than SRDs at higher frequencies.



Atmospheric and man-made noise, 10 kHz to 100 MHz (P.372, 2019)

Four case-studies: Wi-Fi; RFID, Citizen Band, IoT

1. Wi-Fi, RLAN, WLAN, U-NII (Unlicensed-National Information Infrastructure) operating in 5.15-5.35 GHz and 5.470–5.85 GHz)- including Recs ITU-R M.1454 2000 & RS.1632 2006)
2. RFID : Report ITU-R SM.2255 (2012) Characteristics, standards and frequency bands for RFID and ETSI EN 302 208-2 (2011) RFID Equipment operating in the band 865 MHz to 868 MHz with power levels up to 2W
3. ISM and Citizen Band 26.96–27.28 MHz: RR ISM, applications, RR Article 5 allocations to radio services, technical parameters of SRDs around the world
4. Internet of Things

Wi-Fi Generations https://en.wikipedia.org/wiki/IEEE_802.11 26 Dec. 2022

Generation	IEEE Standard	Maximum Linkrate (Mbit/s)	Adopted	RF (GHz)
Wi-Fi 7	802.11be	1376 to 46120	(2024)	2.4/5/6
Wi-Fi 6E	802.11ax	574 to 9608[3]	2020	2.4/5/6
Wi-Fi 6			2019	2.4/5
Wi-Fi 5	802.11ac	433 to 6933	2014	5[4]
Wi-Fi 4	802.11n	72 to 600	2008	2.4/5
*(Wi-Fi 3)**	802.11g	6 to 54	2003	2.4
*(Wi-Fi 2)**	802.11a	6 to 54	1999	5
*(Wi-Fi 1)**	802.11b	1 to 11	1999	2.4
*(Wi-Fi 0)**	802.11	1 to 2	1997	2.4

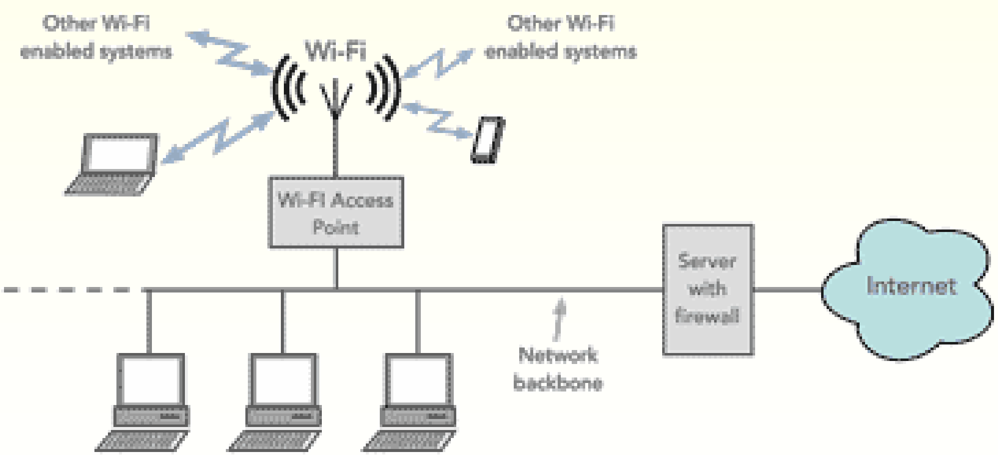
Frequency range, or type	Protocol	Release date[17]	Frequency (GHz)	Bandwidth (MHz)	Stream data rate[18] (Mbit/s)	Allowable MIMO streams	Modulation	Approximate range Indoor	Approximate range Outdoor
1-6 GHz	802.11-1997	Jun 1997	2.4	22	1, 2	—	DSSS, FHSS	20 m (66 ft)	100 m (330 ft)
	802.11b	Sep 1999	2.4	22	1, 2, 5.5, 11	—	DSSS	35 m (115 ft)	140 m (460 ft)
	802.11a	Sep 1999	5	5/10/20	6, 9, 12, 18, 24, 36, 48, 54 (for 20 MHz bandwidth, divide by 2 and 4 for 10 and 5 MHz)	—	OFDM	35 m (115 ft)	120 m (390 ft)
	802.11j	Nov 2004	4.9/5.0 [D][20]					?	?
	802.11y	Nov 2008	3.7[A]					?	5,000 m (16,000 ft)[A]
	802.11p	Jul 2010	5.9					250 m	1,000 m (3,300 ft)[21]
	802.11bd	*Dec 2022 (est.)*	5.9/60					500 m	1,000 m (3,300 ft)
	802.11g	Jun 2003	2.4					38 m (125 ft)	140 m (460 ft)
	802.11n (Wi-Fi 4)	Oct 2009	2.4/5	20	Up to 288.8[B]	4	MIMO-OFDM (64-QAM)	70 m (230 ft)	250 m (820 ft)[23]
				40	Up to 600[B]				
	802.11ac (Wi-Fi 5)	Dec 2013	5/6	20	Up to 346.8[B]	8	DL MU-MIMO OFDM (256-QAM)	35 m (115 ft)[24]	?
				40	Up to 800[B]				
				80	Up to 1733.2[B]				
				160	Up to 3466.8[B]				
	802.11ax (Wi-Fi 6, Wi-Fi 6E)	May 2021	2.4/5/6	20	Up to 1147[F]	8	UL/DL MU-MIMO OFDMA (1024-QAM)	30 m (98 ft)	120 m (390 ft) [G]
				40	Up to 2294[F]				
				80	Up to 4804[F]				
				80+80	Up to 9608[F]				
	802.11be (Wi-Fi 7)	*May 2024 (est.)*	2.4/5/6	80	Up to 11.5 Gbps[F]	16	UL/DL MU-MIMO OFDMA (4096-QAM)	30 m (98 ft)	120 m (390 ft) [G]
				160 (80+80)	Up to 23 Gbps[F]				
				240 (160+80)	Up to 35 Gbps[F]				
				320 (160+160)	Up to 46.1 Gbps[F]				
	802.11ba	Oct 2021	2.4/5	4/20	0.0625, 0.25 (62.5 Kbps, 250 Kbps)	—	OOK (Multi-carrier OOK)	?	?
mmWave	802.11ad	Dec 2012	60	2160 (2.16 GHz)	Up to 6757[26] (6.7 Gbps)	—	OFDM, single carrier, low-power single carrier	3.3 m (11 ft)[27]	?
	802.11aj	Apr 2018	45/60[C]	540/ 1080[28]	Up to 15000[29] (15 Gbps)	4[30]	OFDM, single carrier[30]	?	?
	802.11ay	Jul 2021	60	8000 (8.0 GHz)	Up to 20000[32] (20 Gbps)	4	OFDM, single carrier	10 m (33 ft)	100 m (328 ft)
Sub 1 GHz IoT	802.11af	Feb 2014	0.054 -0.79	6-8	Up to 568.9[34]	4	MIMO-OFDM	?	?
	802.11ah	May 2017	0.7/0.8 /0.9	1-16	Up to 8.67[35] (@2 MHz)	4		?	?
Light (Li-Fi)	802.11bb	*Dec 2023 (est.)*	800-1000 nm	20	Up to 9.6 Gbps	—	O-OFDM	?	?
	802.11-1997	Jun 1997	850-900 nm	?	1, 2	—	PPM	?	?

IEEE 802 spreadsheet of the frequencies for which operation is defined in 802 standards, including in the 802.11 standard

Access Published IEEE 802 and IEEE 802.11 Standards (free download)

https://ieee802.org/11/ 26 Dec 2022

https://en.wikipedia.org/wiki/IEEE_802.11 **IEEE 802.11** is part of the IEEE 802 set of local area network (LAN) technical standards, and specifies the set of media access control (MAC) and physical layer (PHY) protocols for implementing wireless local area network (WLAN) computer communication. IEEE 802.11 uses various frequencies including, but not limited to, 2.4 GHz, 5 GHz, 6 GHz, and 60 GHz frequency bands. Although IEEE 802.11 specifications list channels that might be used, the radio frequency spectrum availability allowed varies significantly by regulatory domain.



This Linksys WRT54GS Wi-Fi router operates on the 2.4 GHz "g" standard, capable of transmitting 54 Mbit/s

Wi-Fi Global: derived from ITU-R Rec. M.1450 (2014)

Characteristics	IEEE Std 802.11-2012 (Clause 17, commonly known as 802.11b)	IEEE Std 802.11-2012 (Clause 18, commonly known as 802.11a)	IEEE Std 802.11-2012 (Clause 19, commonly known as 802.11g)	IEEE Std 802.11-2012 (Clause 18, Annex D and Annex E, commonly known as 802.11j)	IEEE Std 802.11-2012 (Clause 20, commonly known as 802.11n)	IEEE P802.11ac	IEEE Std 802.11ad-2012	ETSI EN 300 328	ETSI EN 301 893	ARIB HiSWANa,	ETSI EN 302 567
Frequency band	2 400-2 483.5 MHz	5 150-5 250 MHz 5 250-5 350 MHz(4) 5 470-5 725 MHz 5 725-5 825 MHz	2 400-2 483.5 MHz	4 940-4 990 MHz 5 030-5 091 MHz 5 150-5 250 MHz 5 250-5 350 MHz 5 470-5 725 MHz 5 725-5 825 MHz	2 400-2 483,5 MHz 5 150-5 250 MHz 5 250-5 350 MHz 5 470-5 725 MHz 5 725-5 825 MHz	5 150-5 250 MHz 5 250-5 350 MHz 5 470-5 725 MHz 5 725-5 825 MHz	57-66 GHz	2 400-2 483.5 MHz	5 150-5 350 and 5 470-5 725 MHz	4 900 to 5 000 MHz 5 150 to 5 250 MHz	57-66 GHz
Interference mitigation	LBT	LBT/DFS/TPC	LBT	LBT	LBT/DFS/TPC	LBT/DFS/TPC	LBT	DAA/LBT, DAA/non-LBT, MU	LBT/DFS/TPC	LBT	
Channel indexing	**5 MHz**				**5 MHz in 2.4 GHz 20 MHz in 5 GHz**	**20 MHz**	**2 160 MHz**		**20 MHz**	**20 MHz channel spacing 4 channels in 100 MHz**	

Characteristics associated with broadband RLAN standards

 Source: also Radio-Electronics.com

Summary of major 802.11 Wi-Fi Standards

	802.11a	802.11b	802.11g	802.11n	802.11ad^	802.11ac*	802.11af**
Date of standard approval (release)	Sept. 1999	Sept. 1999	June 2003	Oct. 2009	Dec. 2012	Dec. 2013	February 2014
Maximum data rate (Mbps)	**54**	**11**	**54**	**< 600**	**<7 Gbps**		**< 600*** **
Modulation	OFDM	CCK or DSSS	CCK, DSSS, or OFDM		SC and OFDM	OFDM	
RF Band (GHz)	5	2.4		2.4 or 5	60	5	TV bands below 1 GHz
Number of spatial streams	1			1 to 4	5 to 8	1,2,3,4 or 8	up to four streams
Channel width (MHz) nominal	20			20 or 40	80 or 160	20, 40, 80, 160	8 in Europe; 6 in N. America

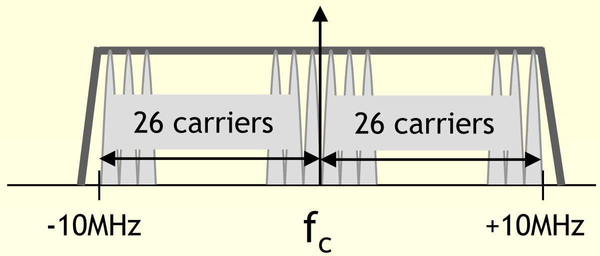
^ known also as µwave Wi-Fi; brand name WiGig operating in the 2.4, 5 and 60 GHz bands;
* known also as Gigabit Wi-Fi, 5G Wi-Fi and 5G very high throughput (VHT);
** known also as White-Fi and Super Wi-Fi;
*** maximum data rate is 426.7 Mbit/s in 6 and 7 MHz channels, and 568.9 Mbit/s for 8 MHz channels.

IEEE 802.11: IEEE Standard for Information technology--Telecommunications and information exchange between systems - Local and metropolitan area networks--Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications:

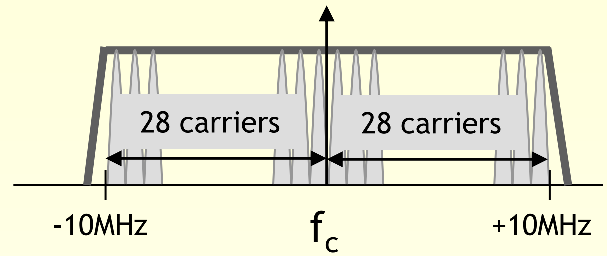
- **802.11aq-2018** 802.11aq-2018 - Amendment 5: Preassociation Discovery
- **802.11ak-2018** 802.11ak-2018 - Amendment 4: Enhancements for Transit Links Within Bridged Networks
- **802.11aj-2018** 802.11aj-2018 - Amendment 3: Enhancements for Very High Throughput to Support Chinese Millimeter Wave Frequency Bands (60 GHz and 45 GHz)
- **802.11ah-2016** 802.11ah-2016 - Amendment 2: Sub 1 GHz License Exempt Operation
- **802.11ai-2016**8 02.11ai-2016 - - 1: Fast Initial Link Setup
- **802.11-2016** 802.11-2016 Specifications

Sub-carriers for High Throughput (HT) & wider channels (Source: Aruba 2013)

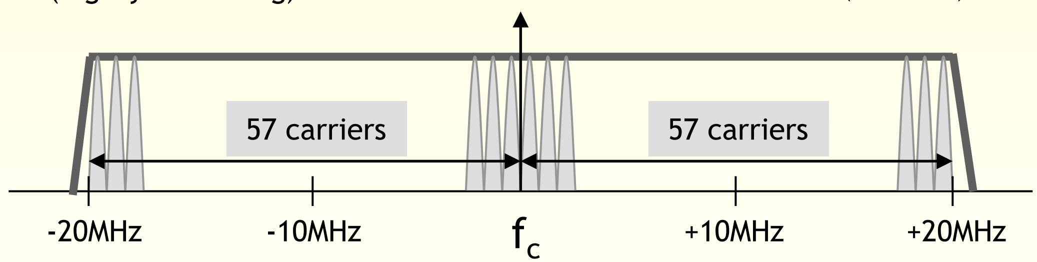
OFDM subcarriers used in 802.11a, 802.11n and 802.11ac



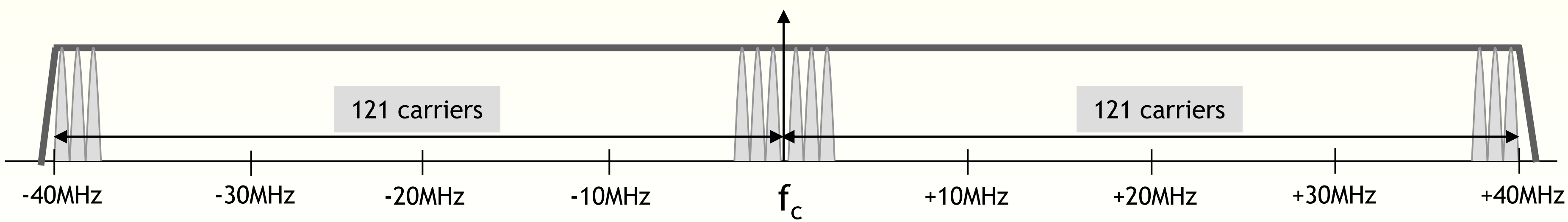
52 subcarriers (48 usable) for a **20 MHz non-HT** mode (legacy 802.11a/g) channel



56 subcarriers (52 usable) for a **20 MHz HT** mode (802.11n) channel



114 subcarriers (108 usable) for a **40 MHz HT** mode (802.11n) channel



242 subcarriers (234 usable) for a **80 MHz Very HT** mode (802.11ac) channel
An 80+80MHz or 16MHz channel is exactly two 80MHz channels, for 484 subcarriers (468 usable)

Wi-Fi offload to improve cellular capacity (2) (more on offload)

(Sources: KDDI May 2013 and Alvarion October 2013)

- In congested areas (outdoors & indoors), the growing need of mobile data exceeds the available cellular capacity
- Main usage: city centers, big malls, airports, train station, stadiums
- WiFi is the most cost effective solution for data offloading
  - RF Spectrum free of charge (at 2.4 GHz and 5 GHz)
  - Embedded in all smartphones and tablets

~150 access points (APs) & more than 1800 stations (STAs) were observed in Ch1 in 2.4GHz band, in Shibuya Metro
In Seoul KTX train station, 351 APs and 1101 STAs were observed in 2.4 GHz band. In underground COEX mall, 277 APs and 917 STAs were observed in 2.4 GHz band

Shibuya station of Tokyo Metro; 15 April 2013

Case Study: 2

RFID : Report SM.2255 (2012)Characteristics, standards and RF for RFID, ERC Rec 70-03 *Relating to the Use of SRDs*, ETSI EN 302 208-2 RFID operating at 865-868 MHz up to 2W, CFR 47 FCC Part 15—*Radio Frequency Devices*

Typical RFID application for safer & more efficient blood supply chain

RFIDs - general

In general, **passive and active tags** can be differentiated by the existence of the battery in the tag. Active tags use battery as power source to broadcast and communicate with the reader. The power and effective range of active tags are significantly higher than passive tags and therefore may interfere farther.

EPC - Electronic Product Code is one of the standards for Global RFID developed by GS1; it's an eventual successor to the bar code, using RFID technology. EPC is a string of numbers & letters ,consisting of a header and three sets of data: the first partition identifies the manufacturer; the second identifies the Product type and the third the serial number unique to the item (source : RFID Journal)

Better Visibility: getting more in less time with reduce costs. RFID reduces manual and error-prone activity, by automating product visibility (Source: Motorola)

The **pharmaceutical industry** distributes regular pharmaceuticals through a complex supply chain involving thousands of trading partners through multiple transaction levels. RFID assists to stem the influx of counterfeit drugs. RFIDs "track and trace" a precision drug from the time pharmaceutical product leaves the factory to the moment a patient receives it. Histories and authenticity are established. (Source : ALIEN)

RFID in **the DOD supply** chain: RFID allows military logisticians to synthesize and integrate end-to-end information about assets . On July 2004 the DOD issued a policy requiring the implementation of RFID across DOD (Source :Army Logistician)

Advantages over Barcode:

- Legible without visibility; enables reading of several labels simultaneously
- Legible from great distance -active RFID up to 300 feet and more
- No need for line of sight with the object
- Able to read and write, can add data and identify individual items
- Resistant to humidity and temperature; immune to dirt and dust

Some RFIDs Applications

1. **Asset Management:** RFID marked assets combined with mobile scanners provide a way to identify and manage them
2. **Inventory Systems:** RFIDs enable control of movement and constant monitoring of stored items (such as spare parts) and their inventory level
3. **Product Tracking:** Products are tracked through the manufacturing process from start to finished product ,finished product store and further through supply chain to end customer
4. **Transportation** and **Logistics:** Yard management, shipping containers; freight control at distribution centers use RFID tracking. *Voice Directed Warehousing*: workers wear a headset which tells the worker where to go and what to do using verbal prompts. Workers confirm by predefined commands. The speech recognition software has to be taught the few commands; the communication is wireless. *Pick To Light Warehousing*: The system includes lights above the bins or racks where the worker picks different items .The worker scans a barcode on the picking container that represents the customer order .A light on the bin or rack illuminates with a quantity to pick .The worker presses a button to confirm that the picking of definite item has been completed .The communication between the barcode reader and the TCP/ip controller is wireless
5. The communication between the controller and the ligts is performed by two alternative methods :
6. -Transmits and receives data and power using 4 wires
7. -Tansmits data using WIFI antennas
8. **Animal Tracking and Identification:** implantable tag is used for wild animals, pets and ear tags for cattle and sheep
9. **Hospitals** and **Healthcare:** RFID wristbands are used to identify patients and active tags are used to mark medical equipment ,especially essential ,to locate them in the hospital area
10. **Timing Races:** racers wear tags and antennas in mats across the track
11. **Toll Road Management:** instead of toll boxes or gates ,transponders are mounted on the windshield and readers installed above the road. As the vehicle passes the reader its transponder is read and data sent to be processed
12. **Cutting Tools:** modern machining produce expensive parts; RFIDs guarantee that a part is processed with the correct tool. RFID tag is mounted on the tool carrier; tag is read by a reader on the machine CNC program can be verified
13. **Waste Management:** waste disposal trucks equipped with RFID readers pick up bins equipped with RFID tags. Tags are read: bin number, collection place and time are recorded and sent (e.g. via cellular modem) for further processing

מצב קיים פקודת הטלגרף האלחוטי [נוסח חדש], התשל"ב - 1972

חובת רישוי (תיקון מס' 6) תשע"ח-2018

4א. (א) לא ייצר אדם, לא יחזיק, לא יפעיל ולא יתקין מכשיר אלחוטי, לרבות בכלי שיט או בכלי טיס הרשומים בישראל, ולא יסחר במכשיר אלחוטי, אלא אם כן בידו רישיון לכך מאת המנהל ובהתאם לתנאי הרישיון ולהוראות לפי פקודה זו.

(ב) לא יקים אדם, לא יחזיק ולא יפעיל תחנת אלחוט, לרבות בכלי שיט או בכלי טיס הרשומים בישראל, אלא אם כן בידו רישיון לכך מאת המנהל ובהתאם לתנאי הרישיון ולהוראות לפי פקודה זו.

חובת אישור התאמה (תיקון מס' 6) תשע"ח-2018

4ט. (א) על אף הוראות סעיף 4א, השר רשאי לקבוע כי ייבוא וייצור של מכשיר אלחוטי שמתקיימים לגביו או לגבי הייבוא או הייצור שלו התנאים שקבע, ובכלל זה עמידה במפרט טכני מסוים, יהיו פטורים מחובת רישוי לפי הסעיף האמור ויהיו טעונים אישור התאמה (בפקודה זו – מכשיר במסלול אישור).

(ב) לא ייבא אדם בייבוא שאינו ייבוא אישי ולא ייצר דרך עיסוק מכשיר במסלול אישור, אלא אם כן בידו אחד מאלה:

(1) אישור התאמה לפי הצהרה;

(2) אישור התאמה מאת המנהל.

(ג) לא ייבא אדם בייבוא אישי ולא ייצר שלא דרך עיסוק מכשיר במסלול אישור, אלא אם כן בידו אישור התאמה מאת המנהל.

מצב קיים (המשך) תקנות הטלגרף האלחוטי (פטור מרישוי), התשפ״א–2021

1. פטור למכשיר אלחוטי [תיקון: תשפ״ב]: הוראות פרק ג׳ לפקודה לעניין רישיון לא יחולו על מכשיר אלחוטי מהסוגים המפורטים להלן, או על מכשיר שתכונותיו הטכניות היחידות לפי מבנהו ומעגליו תואמות אחד או יותר מאלה:.... שימו לב לתת סעיף 7 , להפנייה ל RED: כדוגמא מזרים וידאו Streamer שמתקיימות בו הוראות הדירקטיבה האירופית Radio Equipment Directive (2014/53/EU), והוא נושא סימון CE המעיד על כך;
2. בנוסף, קיים צו-אי תחולה לשנת 2021, שביטל את התשמ"ב-1982

RFID and RFID regulation in Israel ; see ttps://www.nevo.co.il/law_html/law01/164_008.htm

צו הטלגרף האלחוטי (אי תחולת הפקודה) (מס' 2), תשמ"ב-1982

צו תשס"ג-2003 צו תשע"ב-2012

(י1) הפועלים בתוך פס התדרים 915 עד 917 מה"ץ בתנאים אלה:

צו תשע"ב-2012

(1) בתדר מרכזי של 915.5 עד 916.3 מה"ץ, אשר הספקם אינו עולה על 2 וואט e.i.r.p;

(2)ברמת שידורי שווא –

צו תשע"ג-2012

(א) מתחת לתדר 915 מה"ץ, שאינה עולה על 71 -dBmבממוצע לשעה, בתחום של 200 קה"ץ;

צו תשע"ג-2012

(ב) מעל לתדר 917 מה"ץ, שאינה עולה על 63.6 -dBmבתחום של 25 קה"ץ;

- RF 915 -917 MHz. Evidence is needed about Out Of Band emissions.

Spectrum mask of interrogators: EiRP: 2 Watts

- Out of Band power density per 100 KHz, average per hour:
  - Below 915 MHz -74 dBm;
  - Above 917 MHz -57 dBm.

Case Study: 3
ISM & Citizen Band (CB) 26.96-27.28 MHz

- Definitions
- RR Article 5 allocations
- technical parameters of SRDs around the world

ISM and Citizen Band **26.96-27.28** MHz: RR ISM & applications

- Used around the world also as Citizen Band
- Applications: voice like walkie-talkie, baby monitoring, remote control, model control (in the air, on land or over or under the water surface), telecommand, anti-theft and car alarms

Global technical parameters of SRDs at ISM Band 26.957-27.283 MHz, See also Report ITU-R SM.2153 (2012)

Region/Country	Type of use	Specific Frequencies (MHz)	Emission limit	Reference
CEPT and many other countries	annex 1: non-specific SRD	26.957-27.283	42 dB(μA/m) at 10 m; 10 mW e.r.p.	ERC Recommendation 70-03
		26.995, 27.045, 27.095, 27.145, 27.195	100 mW e.r.p. < 0.1 % duty cycle	
	annex 8: model control		100 mW e.r.p.	
	annex 9: inductive applications	26.957-27.283 (as in annex 1)	42 dB(μA/m) at 10 m	
Americas	any	26.965, 26.975, 26.985, 27.005, 27.015, 27.025, 27.035, 27.055, 27.065, 27.075, 27.085, 27.105, 27.115, 27.125, 27.135, 27.155, 27.165, 27.175, 27.185, 27.205, 27.215, 27.225, 27.255, 27.235, 27.245, 27.265, 27.275, 27.285, 27.295, 27.305, 27.315, 27.325, 27.335, 27.345, 27.355, 27.365, 27.375, 27.385, 27.395, 27.405 : 40 channels	10 mV/m at 3 m equiv. to 30 μW (e.i.r.p.)	15.227 Operation within 26.96-27.28 MHz § 95.407 On what channels may I operate?
China	model & toy remote-control devices	26.975, 26.995, 27.025, 27.045, 27.075, 27.095, 27.125, 27.145, 27.175, 27.195, 27.225, 27.255 max bandwidth: 8 kHz	750 mW (e.r.p.)	Report ITU-R SM.2153
	other SRDs	26.957 to 27.283	42 dB(μA/m) at 10 m	
Korea	simplex	See Americas	3 W	Report ITU-R SM.2153
	Radio controller for: model automobile and ship craft	26.995, …, 27.195 MHz (5 channels, 50 kHz space	10 mV/m @10 m Equiv to 333 μW (e.i.r.p.)	
	Radio controller for: toy, security alarm or telecommand	26.958-27.282 MHz		
Russia	car alarm	26.939-26.951 MHz	2 W. Duty cycle < 10%. Max ant gain 3 dB	
	security alarm	26.954-26.966 MHz		
Belarus, Kazakhstan, Russia	anti-theft alarm	26.945	2 W	SM.2153
	alarm & distress	26.960		

Case Study: 4
SRDs and Internet of Things (IoTs)

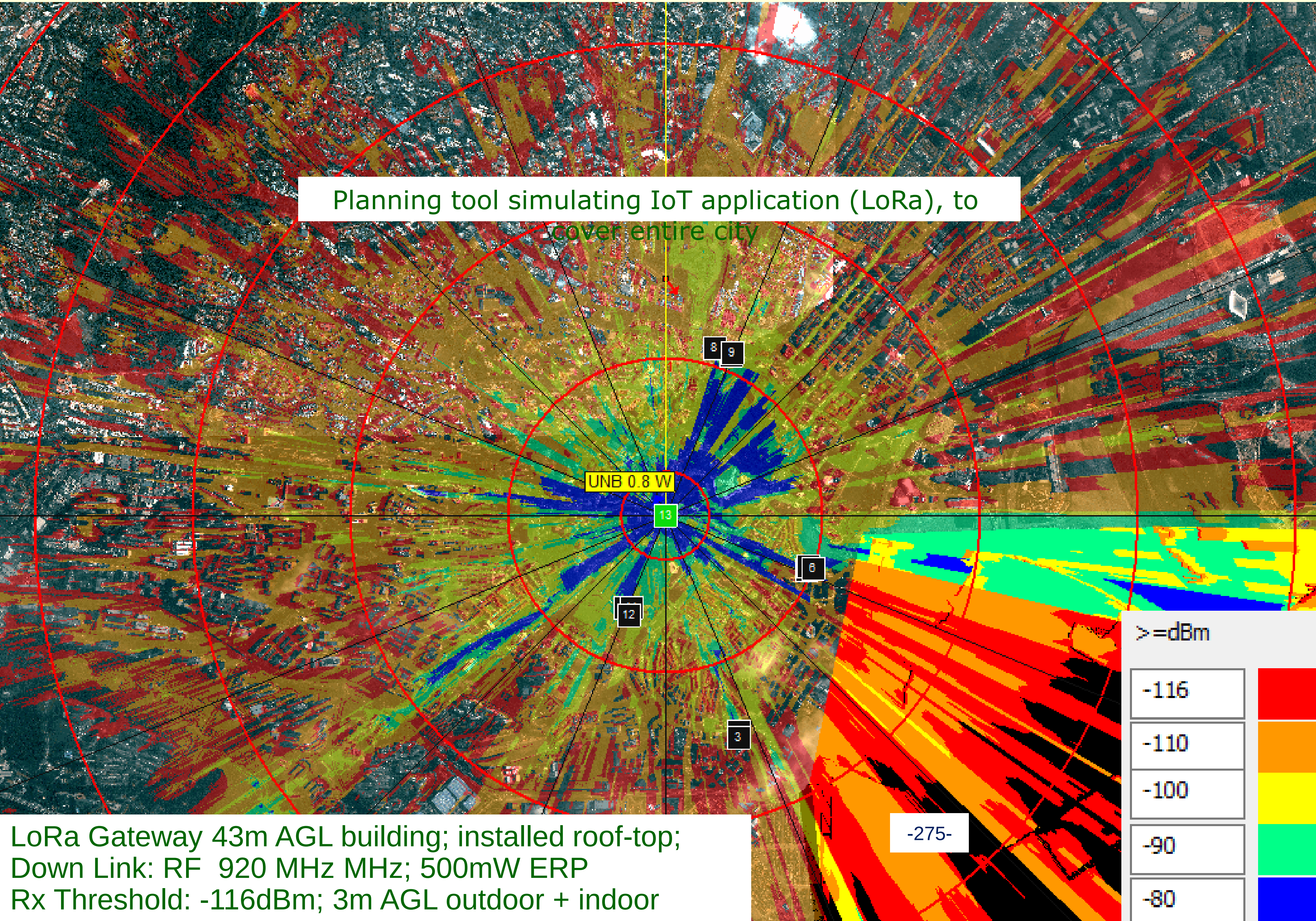
SRDs may connect IoT to wireless networking

M2M via cellular or WiFi infrastructure, & other SRDs means

Smart grids, homes, and cities; intelligent transportation & smart energy management

Examples for M2M/IoT applications include: RFID; Home automation and Smart meters

LoRaWAN™: Low Power Wide Area (LPWA) Network ATDI coverage predictions



List of Acronyms and Abbreviations

AFA	Adaptive Frequency Agility
AMR	Automatic Meter Reading
APT	Asia Pacific Telecommunity
bps	Bits per Second
CB	Citizen Band
CEPT	European Conference of Postal and Telecommunications Administrations
CFR	Code of Federal Regulations
DAA	Detect and Avoid
DFS	Dynamic Frequency Selection
ECC	Electronic Communications Committee
EPC	Electronic Product Code
ERC	European Radiocommunications Committee
ERM	Electromagnetic Compatibility and Radio Spectrum Matters
ETSI	European Telecommunications Standard Institute
EU	European Union
FHSS	Frequency Hopping Spread Spectrum
FSK	Frequency Shift Keying
ISM	Industrial, Scientific and Medical applications
IoT	Internet of Things
LBT	Listen Before Talk
R&TTE	Directive 1999/5/EC on radio equipment & telecommunications terminal equipment
RF	Radio Frequency
RR	ITU Radio Regulations
RFID	Radio Frequency Identification
RLAN	Radio Local Area Network
SRD	Short Range Devices
TPC	Transmitter Power Control
UWB	Ultra Wide Band
WLAN	Wireless Local Area Network

Some author's presentations on SRDs

1. UHF Global And Regional Ruling and Standardization - The Case Of Different Allocations To Short Range Devices (SRDs) & Electronic Devices , Go Global Compliance Academy ™ Webinar, 19 Feb. 2013
2. International, Regional & National Regulation of SRDs ITU Workshop on SRDs, Geneva 3 June 2014
3. Telecommunication Certification Body, Council; 15 April 2015, Baltimore MD; USA TCB is accredited by FCC to approve electronic devices
4. http://mazar.atwebpages.com/Downloads/China_Beijing_SRMC%209July15_SRD.pdf
5. http://mazar.atwebpages.com/Downloads/January%202016_SRD_Mazar_SNG&SRTC&XHY&GDRTC.pdf
6. ITU Workshop on IoT IoT deployment in SRD networks Geneva 22 Nov. 2016; video includes Author's my 16 minutes presentation 2:36:13 till 2:53:10
7. Regulating SRD in Israel; 28 Jan 2019
8. On-line English workshop 20th April to 1st May 2020
9. *Atelier de renforcement des capacités sur la gestion moderne du spectre* 11-15 *mai* 2020

First and third files of the course are found at

- Advanced_Wireless_Communications_Mazar1_Engineering_2020.pdf identifier DOI 10.13140/RG.2.2.11529.80488
- Advanced_Wireless_Communications_Mazar3_Regulation_EMC_HumanHazards_2020.pdf identifier DOI 10.13140/RG.2.2.29984.74247

Dr. Haim Mazar (Madjar) h.mazar@atdi-group.com haimma1@ac.sce.ac.il

More info in my Wiley book 2016 'Radio Spectrum Management: Policies, Regulations, Standards and Techniques' : policies, regulations, standards and techniques'

http://mazar.atwebpages.com/