Spectrum use efficiency, economic value and refarming

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Re-Deployment/ Re-Farming

Spectrum Engineering

Spectrum Use

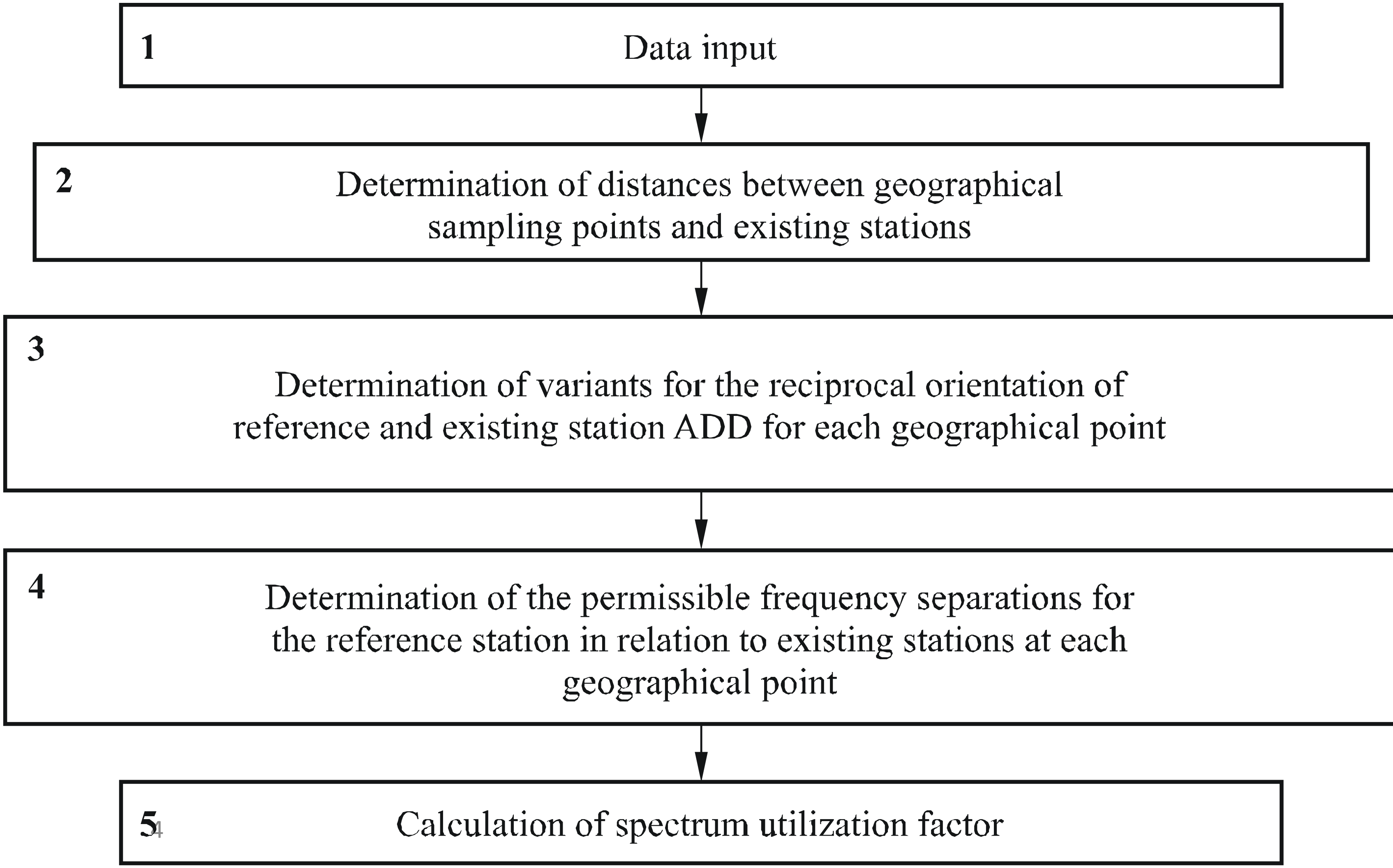
RF spectrum re-deployment and re-farming : Ref. Mazar 2016

1. ITU-R Recommendation SM.1603 *recommends1* defines spectrum redeployment (spectrum refarming) as 'a combination of administrative, financial and technical measures aimed at removing users or equipment of the existing frequency assignments either completely or partially from a particular frequency band. The frequency band may then be allocated to the same or different service(s). These measures may be implemented in short, medium or long time-scales'. Redeployment of spectrum, like frequency management, is a national responsibility. Spectrum redeployment is included in the administration's national spectrum strategy together with the mechanism identified to assist implementation of redeployment.
2. The U.S. was one of the refarming pioneers; 'refarming' is the informal name of a notice and comment rule-making proceeding (PR Docket No. 92-235) opened in 1992 to develop an overall strategy for using the spectrum in the private land mobile radio (PLMR) allocations more efficiently to meet future communications requirements.
3. There are two basic types: voluntary spectrum redeployment and regulatory spectrum redeployment.

Geographical & frequency distribution of the spectrum utilization factor for RF planning purposes
Rec ITU-R SM.1599-1

FIGURE 1

Consolidated flow chart for the algorithm method



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Rec ITU-R SM.1599-1 Variation of spectrum utilization factor in area 10 X 10 km^2 and in the frequency band 169-170 MHz

recommends

1 that administrations should, in the planning process, use data on the geographical and frequency distribution of the spectrum utilization factor;

2 that the methods used to determine the geographical and frequency distribution of the spectrum utilization factor should be those given in Annex 1.

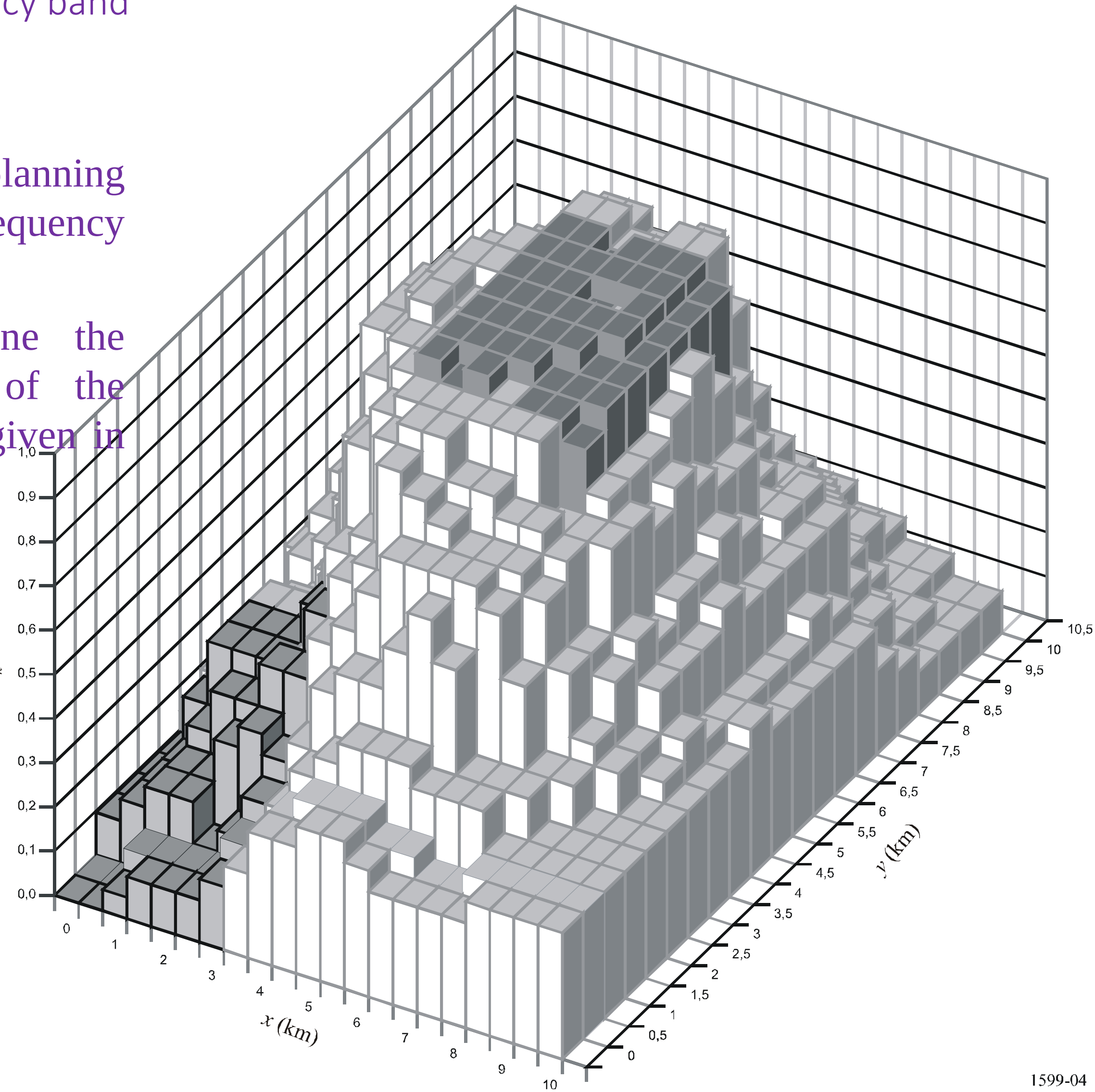

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Fig. shows how to identify the congested and available ranges of the spectrum and a territory in the given RF band and geographical area. This facilitates the selection of frequencies for new radio stations being brought into operation and helps to increase the efficiency of the frequency planning process as a whole.

Re-Farming & Some Practices; Reference Mazar Book

1. Refarming is a process to govern the repurposing of spectrum bands to more efficient technologies and/or new services
2. Service continuity and investment are critical for successful Refarming
3. Set out the approach to **refarming** & **renewal** in advance (some 3–4 years prior to expiry) to avoid network investment being postponed
4. In the case of **renewal**, incumbent licensees may have the rights of first-refusal
5. Provide stability, certainty & transparency through long-term planning, i.e. develop spectrum roadmaps
6. Progressively technology restrictions in existing mobile spectrum usage rights
7. Introduce flexible regulatory tools; consider sharing and spectrum trading , to facilitate better spectrum utilisation
8. Evaluate spectrum value in a holistic approach; focus on long-term socio-economic impact

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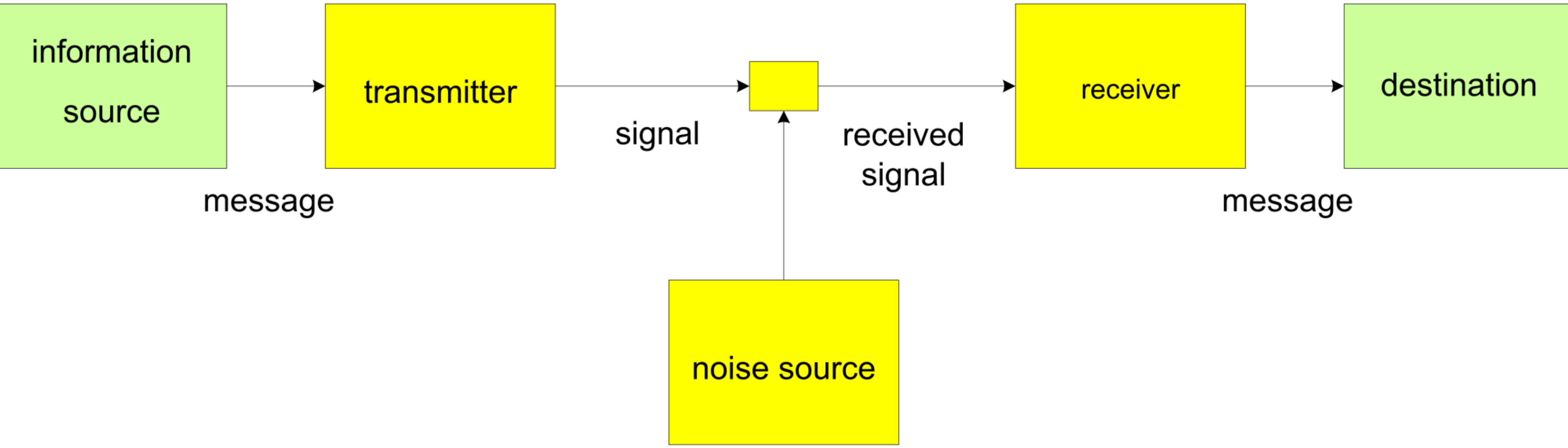
Common Wealth event

Mazar chairing panel on Spectrum Auction

End-to-end wireless communication

Engineering



Shannon’s 1949 schematic diagram of a general communication

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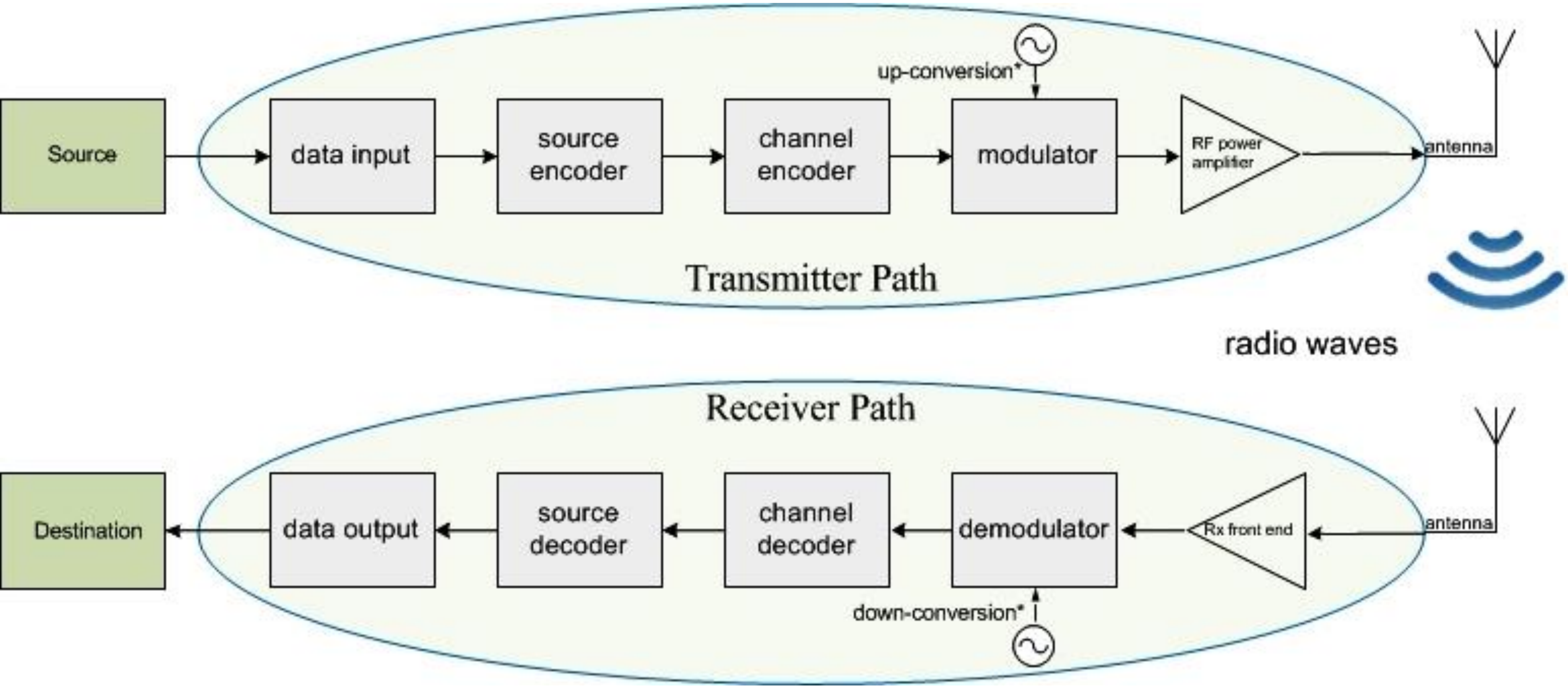
Schematic diagram of wireless communication; duality



* The modulation and the up-conversion are not always merged; there are many structures where a signal that is already modulated is up-converted in a separate (mixer-based) stage. Also the down-conversion is often separated from the demodulation and comes before it: first some down-conversion and then demodulation of a zero-IF or low-IF signal.

Physical Quantities and their Units (1) Academic_Course_Advanced_Wireless_Communications_Mazar_Engineering_2020

Quantity	Symbol	Unit	Unit symbol	Remarks
Angle	θ (elevation); ϕ (azumuth) Ω (solid angle)	radian	rad	1rad≡180/π ^{0}≈57.3^0 Ω unit is steradian
		degrees	^{0}	
(effective) Area	A_e	square metre	(m^2)	
Bandwidth	b	Hertz	Hz	
Boltzmann's constant	K	Joule per Kelvin	J/K	
Capacity	c	bit per second	bit/s	
Carrier to Noise	c/n	dimensionless		interchangeable with s/n and carrier to noise ratio
logarithmic term	C/N, CNR	dB		
Conductivity	σ	Siemens per meter	S/m	
		mho per meter	Ω^{-1}/m	
(antenna) Directivity	d_0	dimensionless		
logarithmic term	D	dBi		
Distance	d	metre	m	
Efficiency (antenna)	η	dimensionless		η (antenna)≡g/d_0
Frequency	f	Hertz	Hz	
Electric field strength		Volt per metre	V/m	vector; µV/m and dB(µV/m) are practical E=20 log e
logarithmic term	E	dB(V/m)		
(antenna) Gain	g	dimensionless		
logarithmic term	G	dBi		dBd is also used
Impedance, resistance	r	Ohm	Ω	
Impedance (free-space intrinsic)	z_0	Ohm	Ω	≈ 120π

Quantity	Symbol	Unit	Unit symbol	Remarks
Magnetic field strength	$\vec{h}$	Ampere per metre		vector; µA/m and dB(µA/m) are practical H=20 log h
logarithmic term	H	dB(A/m)		
Noise factor	nf	dimensionless		
logarithmic term	NF	dB		also termed Noise Figure
Phase	ϕ	Radian	^{0}	
Phase rate	w	radian/second	^{0}/s	w=2πf
Permeability	µ	Henry/meter		at vacuum (free-space) $\mu_0 \equiv 4\pi \times 10^{-7}$
relative Permeability	μ_r	dimensionless		$\mu = \mu_r \mu_0$
Permittivity	ε	Farad/meter		at vacuum (free-space) $\varepsilon_0 \approx 8.854 \times 10^{-12}$
relative Permittivity	ε_r	dimensionless		$\varepsilon = \varepsilon_r \varepsilon_0$
Power	p	Watts	W	Kw is practical
logarithmic term	P	dBW		dBm is practical
Power density or power flux density	$\vec{s}$	Watt per square metre	W/m^2	Poynting vector; term pd also used for power density
		mWatt per square cm	mW/cm^2	
Reflection coefficient (Return Loss)	Γ	dimensionless		$\|\Gamma\| = \rho$; $\rho = \frac{vswr - 1}{vswr + 1}$
logarithmic term		dB		20 log $\|\Gamma\|$=20 log ρ

Physical Quantities and their Units (3) Academic_Course_Advanced_Wireless_Communications_Mazar_Engineering_2020

Quantity	Symbol	Unit	Unit symbol	Remarks
Sensitivity	s	Watts	W	µW, nanoW are used; µV used, as power= $\frac{v^2}{r}$
logarithmic term	S	dBW		dBm is more practical
signal to noise	s/n	dimensionless		interchangeable with c/n and
logarithmic term	S/N, SNR	dB		signal to noise ratio
Skin depth	δ	metre	m	
Temperature	t_0	Kelvin	K	
Time	t	second	s	
Velocity of light	c_0	metre / second	m/s	c_0=299 792 458≈ ≈ 300 10^6
Voltage standing wave ratio	vswr	dimensionless		$\lvert\frac{v_r}{vf}\rvert$ = ρ; $vswr = \frac{1+\rho}{1-\rho}$
logarithmic term	VSWR	dB		VSWR=20 log vswr
Wave length	λ	metre	m	
Wavenumber	K	1/metre	1/m	k≡ $\sqrt{\mu\varepsilon}$

Friis transmission equation and Free-space propagation loss- power

Using the international system of units (SI):

p_t = transmitter output power (Watts)

g_t = transmitter antenna gain (dimensionless, with no units)

d =observation distance from transmitter to receiver (m)

p_d = incident power density at the receiver (W/m^2)

A_e = effective area of receiver's antenna (m^2)

λ = wave length (m)

g_r = receiver antenna gain (dimensionless)

p_r = received power (Watts)

p_l = propagation loss (dimensionless)

$$p_d = \frac{p_t g_t}{4\pi d^2} \qquad A_e = \frac{g_r \lambda^2}{4\pi} \qquad p_r = \frac{p_t g_t}{4\pi d^2} \times A_e = \frac{p_t g_t}{4\pi d^2} \times \frac{g_r \lambda^2}{4\pi}$$

Free-space propagation loss- power (cont.)

Friis transmission equation relates the power delivered to the receiver antenna p_r to the input power of the transmitting antenna p_t. Expressing p_r and p_t in the same units, the *Friis transmission equation* expressed numerically looks

$$\frac{p_r}{p_t} = \frac{\frac{p_t g_t}{4\pi d^2} \times \frac{g_r \lambda^2}{4\pi}}{p_t} = g_t \times g_r \left(\frac{\lambda}{4\pi d} \right)^2$$

$\left(\frac{4\pi d}{\lambda} \right)^2$ is independent of antenna gains; it is called the *free-space loss factor*. Where d (distance) and λ (wave length) are expressed in the same unit,

$$p_l = \left(\frac{4\pi d}{\lambda} \right)^2 = \left(\frac{4\pi df}{c_0} \right)^2$$

The free-space path loss expressed logarithmically by wavelength or frequency, where c_o(velocity of light)≡λxf:

$$P_l\left(\text{dB}\right) = 20\ log\left(4\pi d / \lambda\right) = 20\ log\left(4\pi df\ / c_0\right) = 20\ log\left(4\pi df\right) - 20\ log c_0$$

$$P_l\left(\text{dB}\right) = 32.45 + 20\ log\ d\ \left(\text{km}\right) + 20\ log\ f\ \left(\text{MHz}\right)$$

Elements Influencing Propagation Loss (ITU-R P.1812)

1. *line-of-sight (need of 3 Fresnel zones to get free space)*
2. *diffraction* (embracing smooth-Earth, irregular terrain and sub-path cases)
3. *tropospheric scatter*
4. *anomalous propagation* (ducting and layer reflection/refraction)
5. *height-gain variation in clutter*
6. *location variability*
7. *building entry losses*
8. *Earth Radius* =6,371 *k*m

Free Space loss, Field Strength

P_t=T_xPower, g= antenna gain d=distance, P_t xg- EiRP E=field strength H=magnetic field

$$PoyntingVector = \frac{p_t g_t}{4\pi d^2} = (\vec{e} \times \vec{h}) = \frac{e_o^2}{z_o}$$

The impedance, Z_0 in ohms, relates the magnitudes of electric and magnetic fields travelling through free space. $Z_0 \equiv |E|/|H|$. From the plane wave solution to Maxwell's equations , the impedance of free space equals the product of the vacuum permeability (or magnetic constant) μ_0 and the speed of light c_0 in a free space.

$$z_0 \equiv \mu_0 c_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = \frac{1}{\varepsilon_0 c_0} \approx 120\pi \approx 376.730\ 313\ 461 \approx 377 Ohm$$

$$c_0 \equiv \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \qquad e_0 = \frac{\sqrt{30 \cdot p_t \cdot g_t}}{d} = \frac{\sqrt{30 \cdot eirp}}{d}$$

Free Space loss, Field Strength (logarithmic scale)

Based on ITU-R P.525 Field strength for a given isotropically transmitted power:

$$E = P_t - 20 \log d + 74.8 \qquad (7)$$

Isotropically received power for a given field strength:

$$Pr = E - 20 \log f - 167.2 \qquad (8)$$

Free-space basic transmission loss for a given isotropically transmitted power and field strength:

$$Lbf = P_t - E + 20 \log f + 167.2 \qquad (9)$$

Power flux-density for a given field strength:

$$S = E - 145.8 \qquad (10)$$

Pt : isotropically transmitted power (dB(W))

Pr : isotropically received power (dB(W))

E : electric field strength (dB(μV/m))

f : frequency (GHz)

d : radio path length (km)

Lbf :free-space basic transmission loss (dB)

S : power flux-density (dB(W/m^2)).

The free-space field strength relative to a half-wave dipole for 1 kW e.r.p. is given by:

$E = 106.9 - 20 \log d$

E: free-space field strength (dB(μV/m))

d: distance (km) between transmitting and receiving antenna.

Radar Free-Space Basic Transmission Loss Equation

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

$$p_{target} = pfd \cdot A_e = \left(\frac{p_t g_t}{4\pi d^2}\right) \times \sigma$$

$$P_{received} = \left(\frac{p_t g_t}{4\pi d^2}\right) \times \sigma \times \left(\frac{1}{4\pi d^2}\right) \times \left(\frac{g_r \lambda^2}{4\pi}\right) = p_{transmit} g^2 \times \sigma \times \left(\frac{\lambda}{4\pi d^2}\right)^2 \frac{1}{4\pi}$$

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

σ:radar target cross-section (m^2); d: distance from radar to target (km)
f : transmission frequency (MHz)

$$PL = 10 \log (p_t/p_r) = 103.4 + 20 \log f + 40 \log d - 10 \log \sigma - 2\,G \quad \text{(dB)}$$

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Correspondance e.i.r.p., e.r.p.; field strength, *e*, and pfd

E.I.R.P. (dBm)	e.i.r.p. (nW)	E.I.R.P. (dB(pW))	E.I.R.P. (dBW)	E.R.P. (dBm)	*E* field free space (dB(μV/m)) at 10 m	E_{max} OATS (dB(μV/m)) at 10 m	pfd free space (dB(W/m^2)) at 10 m	pfd maximum OATS (dB(W/m^2)) at 10 m
–90	0.001	0	–120	–92.15	–5.2	–1.2	–151.0	–147.0
–80	0.01	10	–110	–82.15	4.8	8.8	–141.0	–137.0
–70	0.1	20	–100	–72.15	14.8	18.8	–131.0	–127.0
–60	1	30	–90	–62.15	24.8	28.8	–121.0	–117.0
–50	10	40	–80	–52.15	34.8	38.8	–111.0	–107.0
–40	100	50	–70	–42.15	44.8	48.8	–101.0	–97.0
–30	1 000	60	–60	–32.15	54.8	58.8	–91.0	–87.0
–20	10 000	70	–50	–22.15	64.8	68.8	–81.0	–77.0
–10	100 000	80	–40	–12.15	74.8	78.8	–71.0	–67.0
0	1 000 000	90	–30	–2.15	84.8	88.8	–61.0	–57.0

The table is based on

$$e_0 = \frac{\sqrt{30 \times p_t \times g_t}}{d} = \frac{\sqrt{30 \times eirp}}{d} = \frac{\sqrt{30 \times erp \times 1.64}}{d}$$

(Table from web)

For d=10 m

Open Area Test Site (OATS)

$$e_0 = \frac{\sqrt{30 \times eirp}}{10} = \sqrt{0.30 \times eirp} = \frac{\sqrt{30 \times erp \times 1.64}}{10} = \sqrt{0.30 \times erp \times 1.64} = \sqrt{0.492 \times erp}$$

Far-Field, Near-Field

1. Near-field region:
    1) Angular distribution of energy depends on distance from the antenna; Reactive field components dominate (L, C)
    2) In the reactive near-field (very close to the antenna), the relationship between the strengths of the E and H fields is often too complex to predict
    3) The energy in the radiative near-field is all radiant energy, although its mixture of magnetic and electric components are still different from the far field
2. Far-field region:
    1) Angular distribution of energy is independent on distance
    2) Radiating field component dominates (R)

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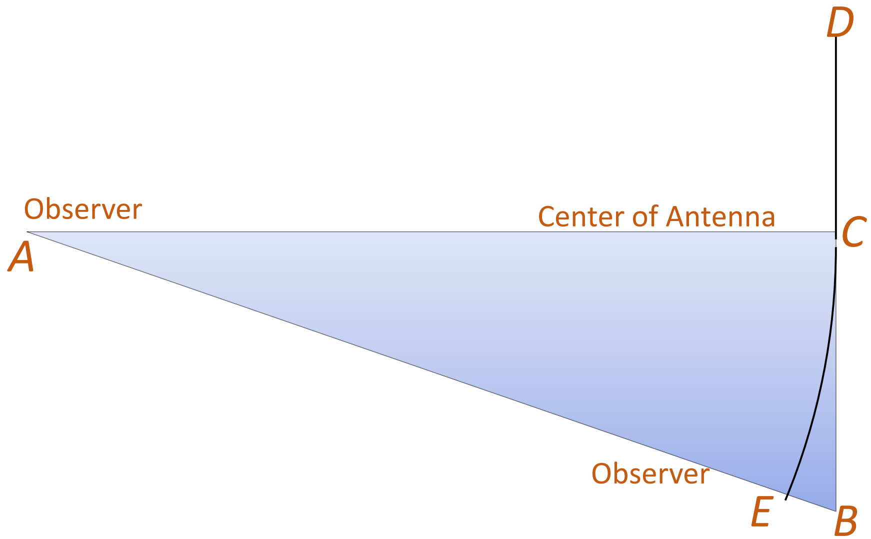
Far-Field, Near-Field

The Fraunhofer distance is the value of: 2 $\mathbf{D}^2/\lambda$, where **D** is the largest dimension of the radiator (or the cross-sectional diametre of the antenna and λ is the wavelength of the radio wave. Phase variation over the ant. Aperture is less than π/8 radians



AB = Tx/Rx distance

AC = X, limit far/near field

BD = **D**, largest dimension of Ant

BC = **D**/2

AE = *AC*; *EB*= λ/16

λ = wavelength of the radio wave

Phase difference 2∏ is equivalent to λ; phase diff ∏/8 equivalent to λ/16.

$X^2 + (\mathbf{D}/2)^2 = (X + \lambda/16)^2 = X^2 + X\lambda/8 + (\lambda/16)^2$

$(\lambda/16)^2$ is relatively small to Xλ/8 (as X >>λ/32), so $X^2 + (\mathbf{D}/2)^2 \approx X^2 + X\lambda/8$ and $(D/2)^2 \approx X\lambda/8$, $D^2 \approx X\lambda/2$ and $\mathbf{X \approx 2D^2/\lambda}$ *QED*

If X >= 2$\mathbf{D}^2/\lambda$, **far-field** region

If 2$\mathbf{D}^2/\lambda$ >X> λ/2∏ **radiating** near-field region

If λ/2∏ >X **reactive** near-field region

For non directive antenna, far field is beyond 3 λ

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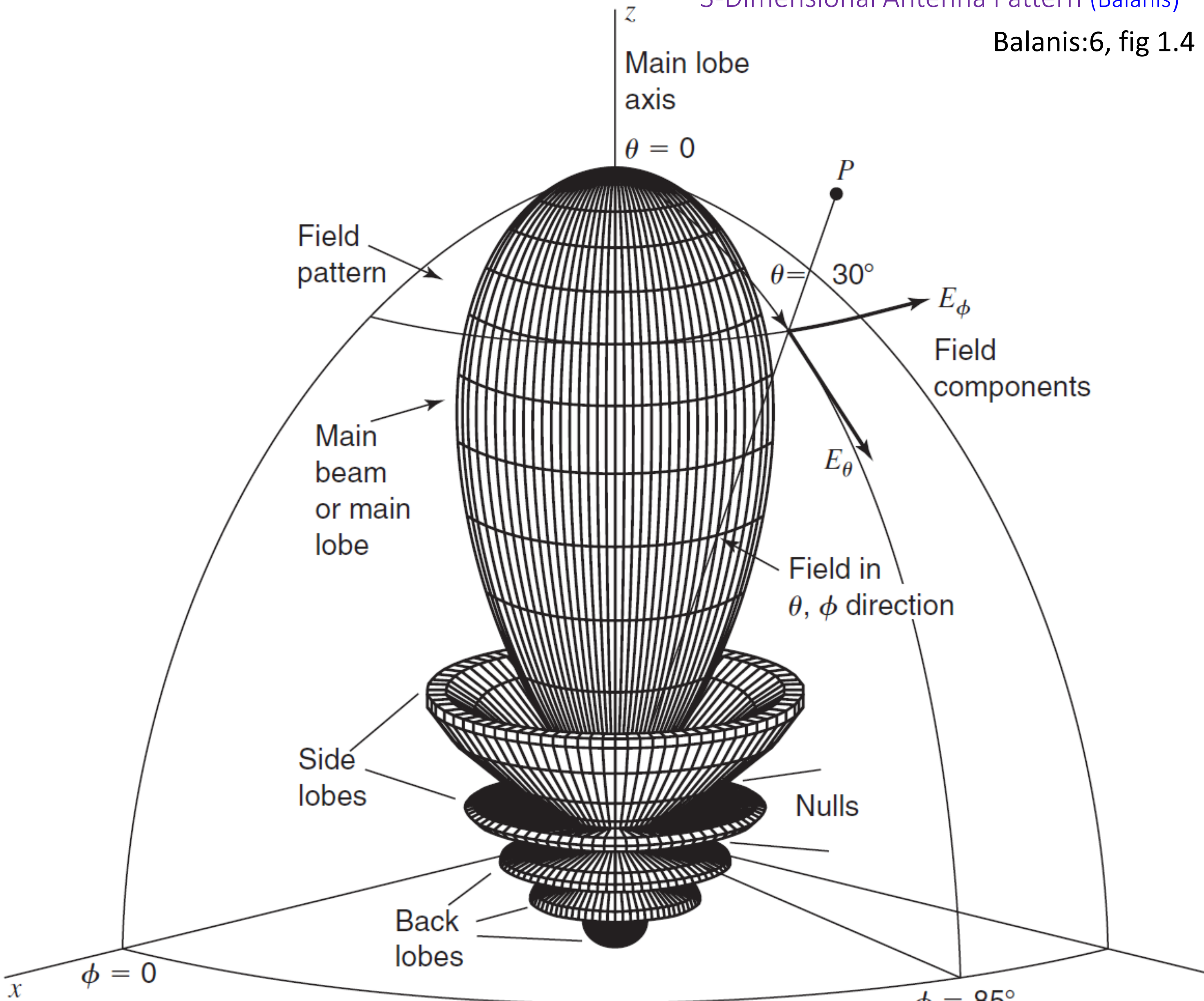
Balanis:6, fig 1.4

Azimuth Cut: E(ϕ)

Elevation Cut: E(θ)



Antenna Directivity and Gain

For η = Aperture efficiency; *A* = Physical aperture area, A_e = Effective aperture area;
d_0= max directivity; g_0= max Ant Gain , G= Ant Gain (dBi), Gd =Gi-2.15;
λ= wavelength, BW= Ant beamwidth, θ= BW_{elv} φ= $Bw_{az;}$

Balanis (2008:18, formula1.12) defines the maximum directivity d_0:

$$d_0 = \frac{4\pi}{\Omega_A(steradians)}$$

$$d_0 = \frac{4\pi}{\Omega_A(steradians)} \approx \frac{4\pi}{\phi(\text{radian})\theta(\text{radian})}$$

$$d_0 = \frac{4\pi}{\Omega_{\text{A}}(\text{steradian})} \approx \frac{4\pi}{\phi(\text{radian})\theta(\text{radian})} \approx \frac{4\pi}{\phi^0\theta^0}\left(\frac{180}{\pi}\times\frac{180}{\pi}\right) = \frac{41,253}{\phi^0\theta^0}$$

$$g_0 = \eta d_0 = \eta\frac{4\pi}{\Omega_{\text{A}}(\text{steradian})} \approx \eta\frac{4\pi}{\phi(\text{radian})\theta(\text{radian})} \approx \eta\frac{4\pi}{\phi^0\theta^0}\left(\frac{180}{\pi}\times\frac{180}{\pi}\right) \approx \eta\frac{41,253}{\phi^0\theta^0}$$

For typical antenna efficiency of η=0.73 the max g_0 for many practical antennas

$$g_0 \approx \eta\frac{41,253}{\phi^0\theta^0} \approx 0.73\frac{41,253}{\phi^0\theta^0} \approx \frac{30,000}{\phi^0\theta^0}$$

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Practical Formulas, for ant. gain

For η=0.7

$$g = \eta \frac{4\pi}{\varphi\theta(radians)} = \eta \frac{4\pi}{\varphi\theta(^0)}\left(\frac{360}{2\pi}\frac{360}{2\pi}\right) = \eta \frac{41{,}253}{\varphi\theta(^0)} = \eta \frac{41{,}253}{\varphi\theta(^0)} \approx \frac{28{,}800}{\varphi\theta(^0)}$$

G=44.6 dBi -10logθ^0 –10logφ^0; for circular Ant, G=44.6 dBi -20log θ

$$\varphi_e(\text{radian}) = \sqrt{\frac{1}{\eta}}(\lambda / a) \qquad \theta_e(\text{radian}) = \sqrt{\frac{1}{\eta}}(\lambda / b)$$

For circular antennas, where *λ/l* is not given, this ratio may be estimated; inserting

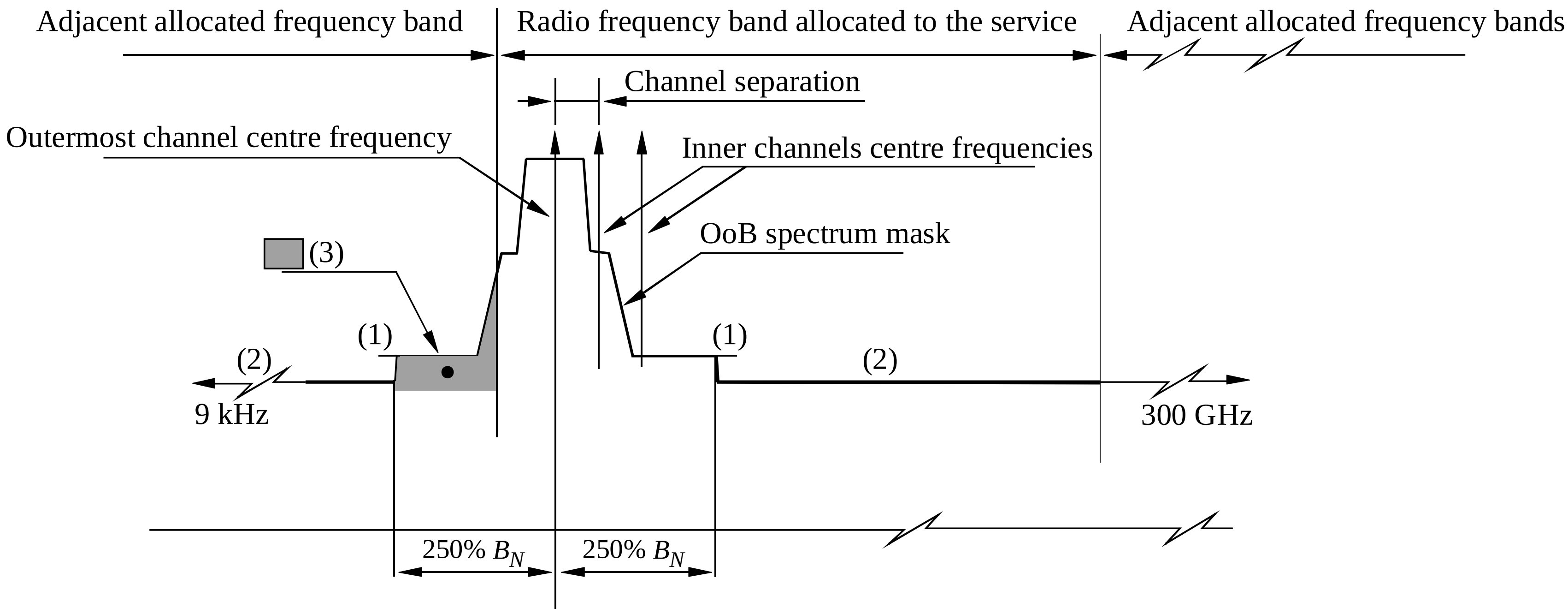
$\theta(\text{degrees}) \approx 70\frac{\lambda}{l}$ G=44.6 dBi -20log $(70\frac{\lambda}{l})$ *G*= 7.7 - 20log $(70\frac{\lambda}{l})$

Transmitters: Unwanted Emissions (Rec SM.1540, fig 1)

1. the frequency, output power, the bandwidth and unwanted emissions, consisting of spurious emissions and out-of-band Emissions; see ITU Radio Regulations RR 1.146, are the important parameters of Tx
2. The ITU RR Article 1 defines *spurious emission* (RR 1.145), *out-of-band emission* (RR 1.144), *occupied bandwidth* (RR 1.153), *necessary bandwidth* (RR 1.152), *assigned frequency band (*RR 1.147) and *assigned frequency* (RR 1.148).

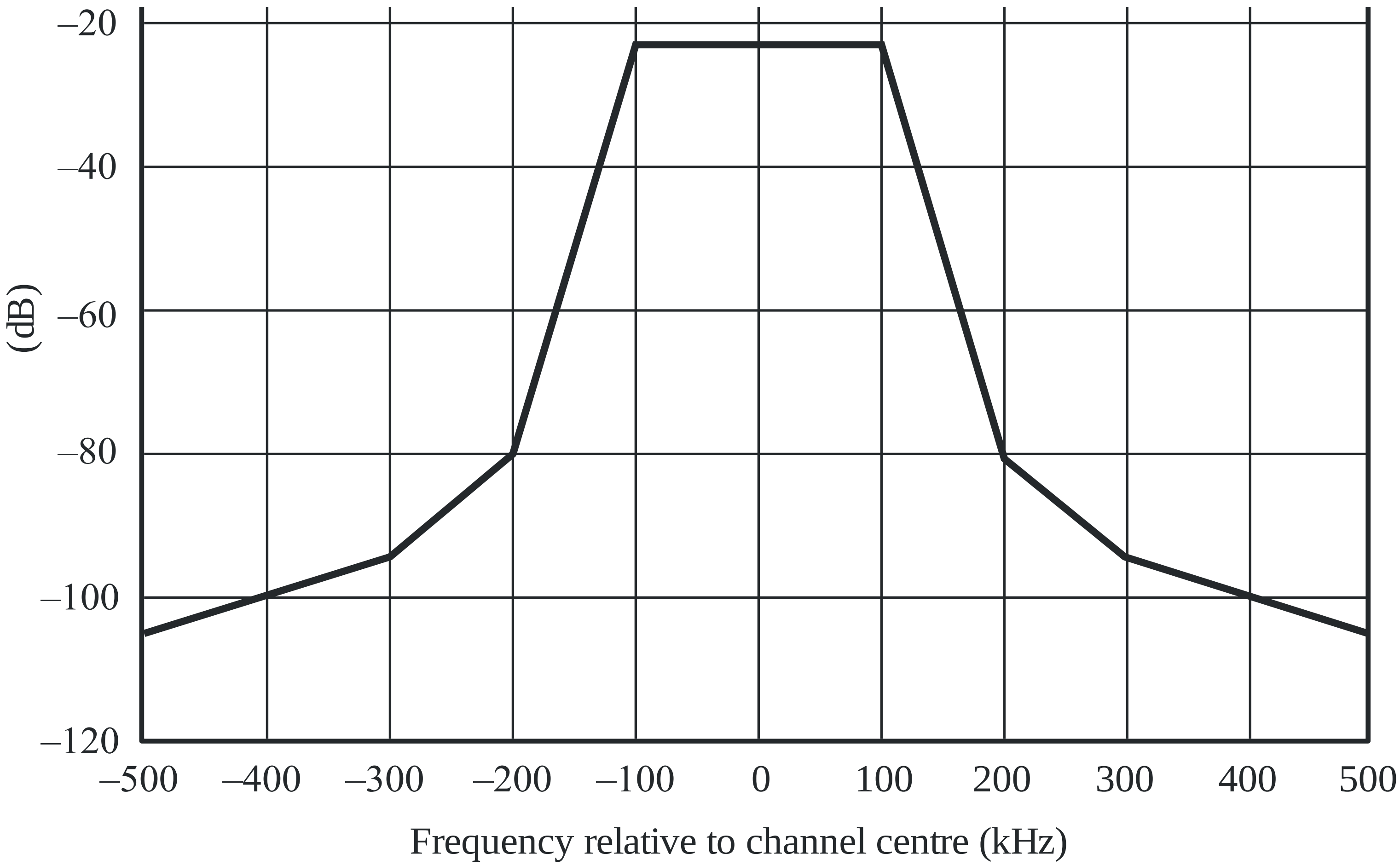
FIGURE 1

Example of evaluation of the unwanted emissions in the OoB domain failing into adjacent allocated band



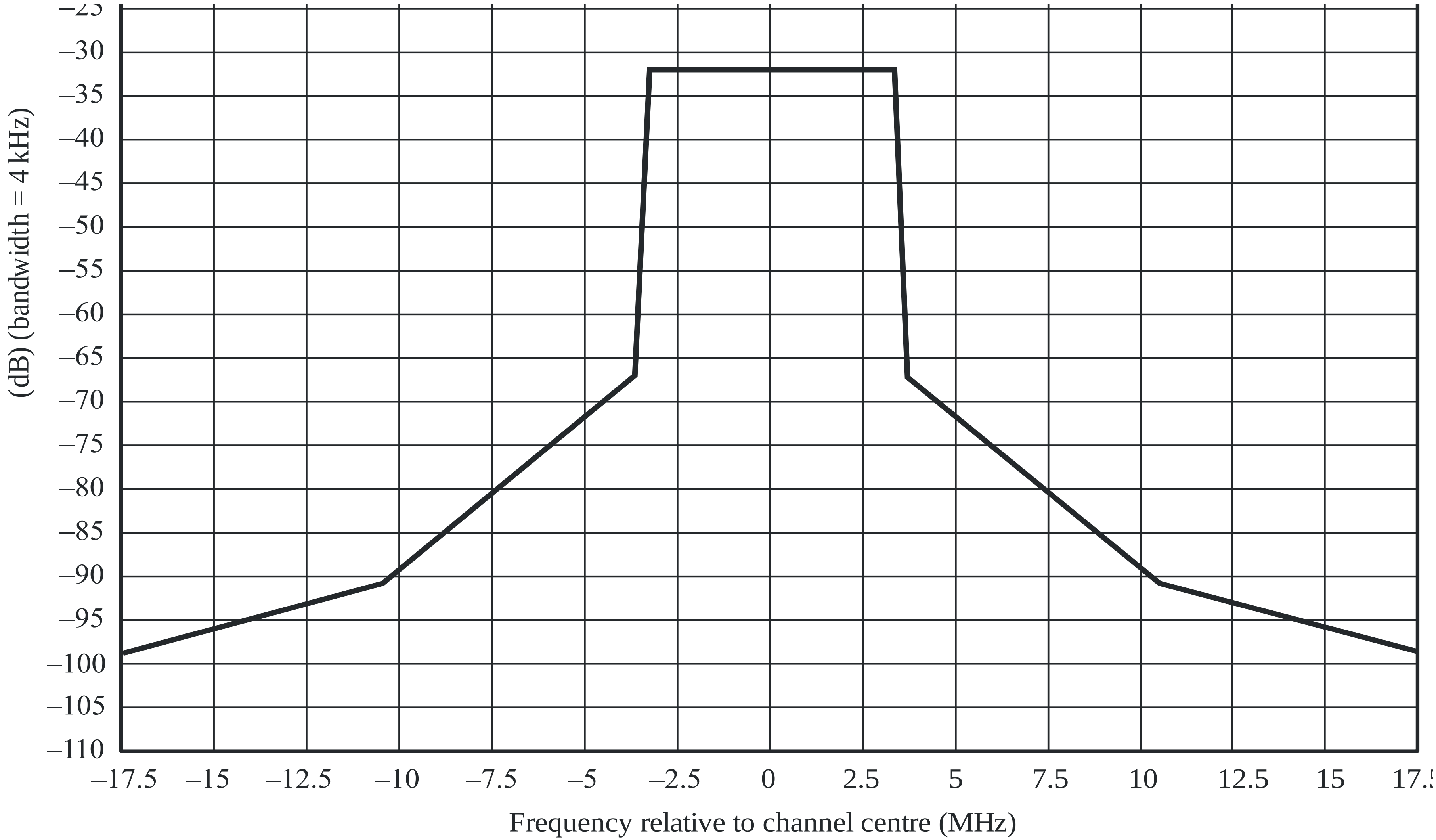
(1) Actual OoB mask for the system under consideration
(2) Spurious limit defined by RR Appendix 3 or Recommendation ITU-R SM.329
(3) Unwanted emissions in the OoB domain falling in the adjacent allocated frequency band

Spectrum Limit VHF FM sound (Rec ITU-R SM.1541)



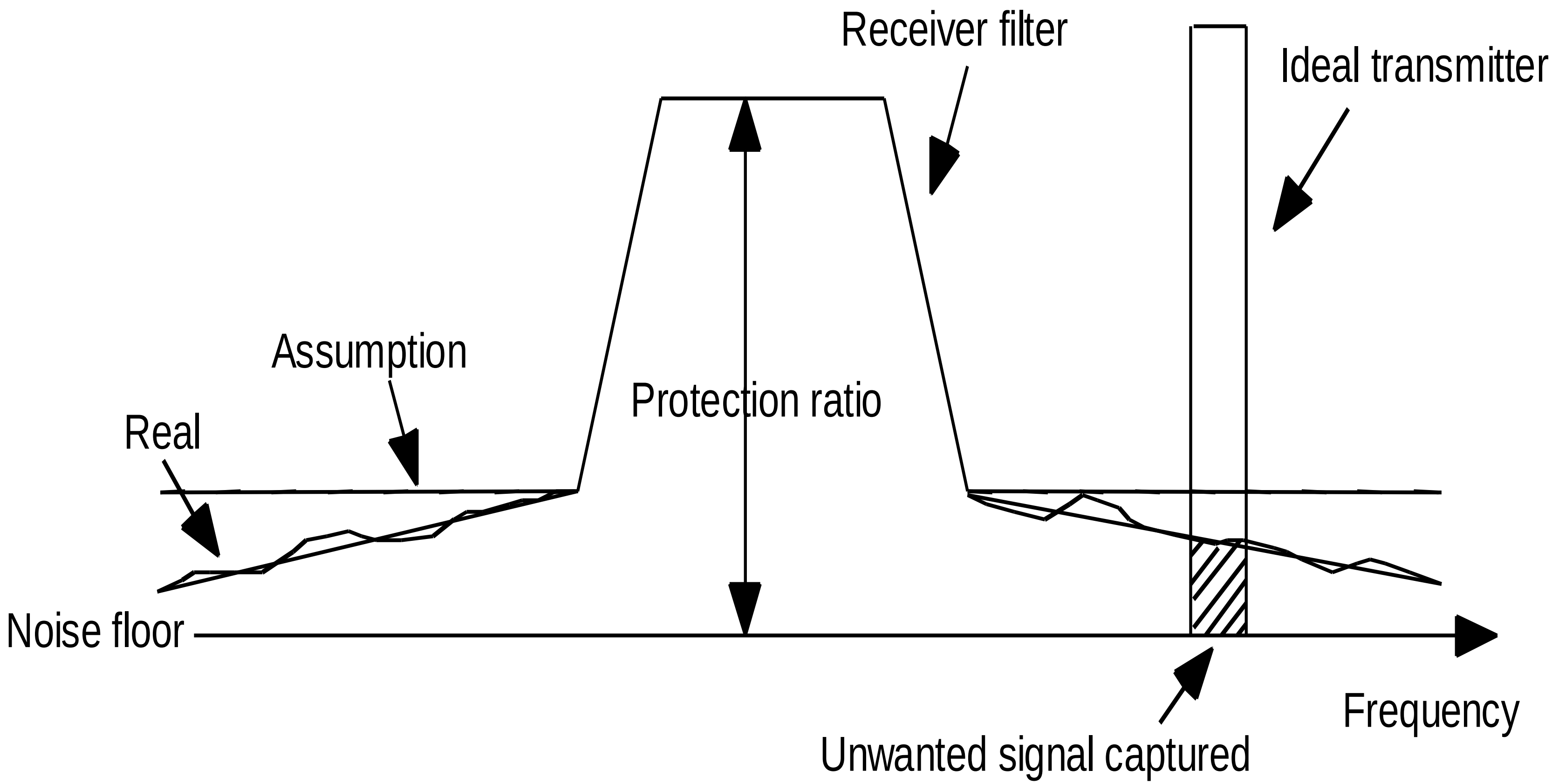
Limit mask for VHF FM sound broadcasting transmitters, 200 kHz channeling

Spectrum for 7 MHz DVB-T (Rec SM.1541)



Spectrum limit mask for 7 MHz DVB-T systems

Receiving Conditions



Receiver concept and selectivity (Report ITU-R SM.2028 Fig. 9)

Receiver Sensitivity (Watts)

s_{min} : sensitivity (W)

k : Boltzmann's constant = 1.38×10^{-23} J/K

t_0 : reference temperature (K) (absolute degrees, ^{0}Celsius + 273.15), taken as 290 K

b : power bandwidth of the receiving system (Hz)

The nominal receiver bandwidth equals the channel spacing, such as 12.5 kHz for simplex, 100 kHz for FM, 6-8 MHz for TV

nf : noise factor of the receiver

s/n: required signal to noise ratio;

s/n is interchanged with c/n: carrier to noise ratio

$$s_{min} = k \cdot t_0 \cdot b \cdot nf \cdot (s/n)$$

Receiver Sensitivity Expressed logarithmically

S_{min}: sensitivity (dBW)

K : Boltzmann's constant = $10\log(1.38 \times 10^{-23})$=-228.6 dB J/K

T_0 : reference temperature (K) taken as 10 log (290) dB K

B : RF bandwidth of the receiving system 10log *b*(Hz) dB Hz

NF : noise figure of the receiver 10 log *nf* dB

SNR, S/N: signal to noise ratio 10 log (*s/n*) dB

CNR, C/N: carrier to noise ratio 10 log (*c/n*) dB

SNR, S/N, CNR and *C/N* are interchanged

$$S_{min}=K+T_0+B+NF+SNR$$

Thermal noise power density @ 290 K (16.85 °C)= -204 dBW/Hz= =-174 dBm/Hz =-144 dBm/kHz=-144 dBW/MHz=**-114dBm/MHz**

Noise Figure (cont'd)

k : Boltzmann's constant = 1.38×10^{-23} J/K

b : noise power bandwidth of the receiving system (Hz)

f_r : noise factor of the receiver

$$f_a = \frac{p_n}{k\, t_0\, b} \qquad\qquad f_a = \frac{t_a}{t_0}$$

external noise factor can be expressed as a temp t_a, where, by definition of f_a:

t_a is the effective antenna temperature due to external noise

p_n from f_a in dB: $P_n = F_a + B - 204$ dBW

P_n = 10 log p_n available power (W)

B = 10 log b

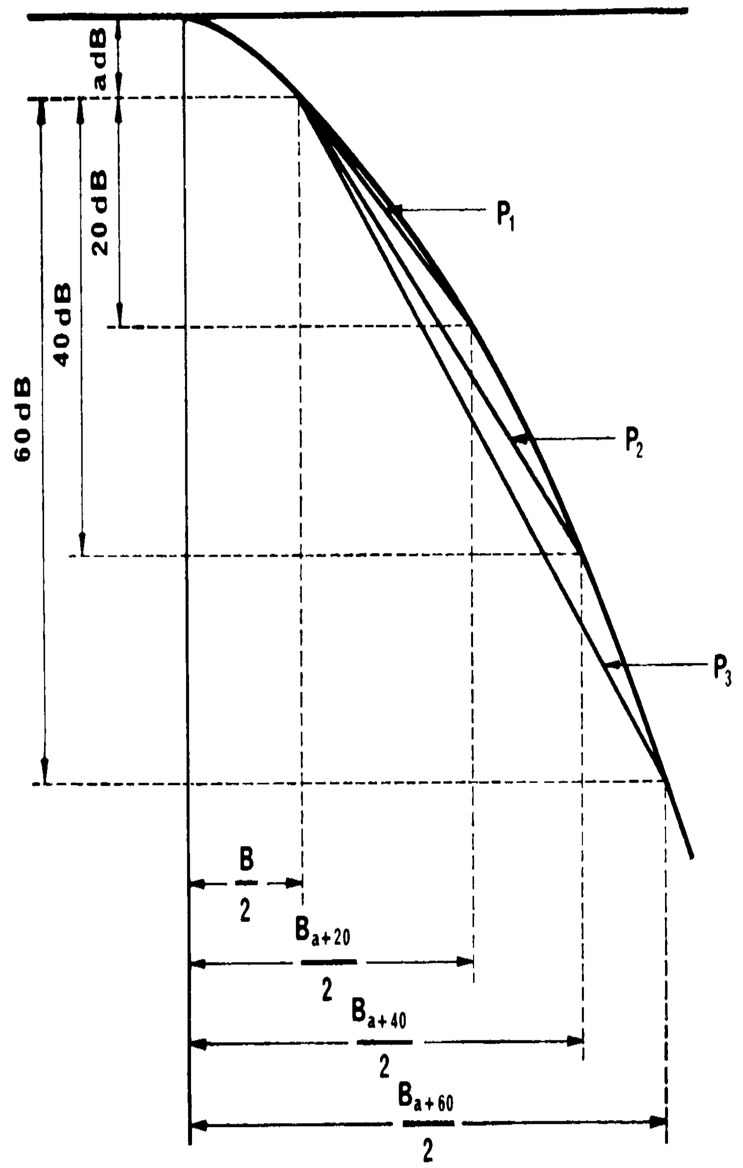
–204 =10 log k t_o (1.38 x 290 = 400.2)

for a half-wave dipole in free space:

$$P_r = \frac{E^2\, G\lambda^2}{Z_0 4\pi} = \frac{E^2 G c^2}{480\pi^2 f^2}$$

E_n = Fa + 20 log f(MHz) + B (MHz) – 98.9 dB(μ V/m)

Signal Selectivity (Rec ITU-R SM 332)



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

1. 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

1. 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

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

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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

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

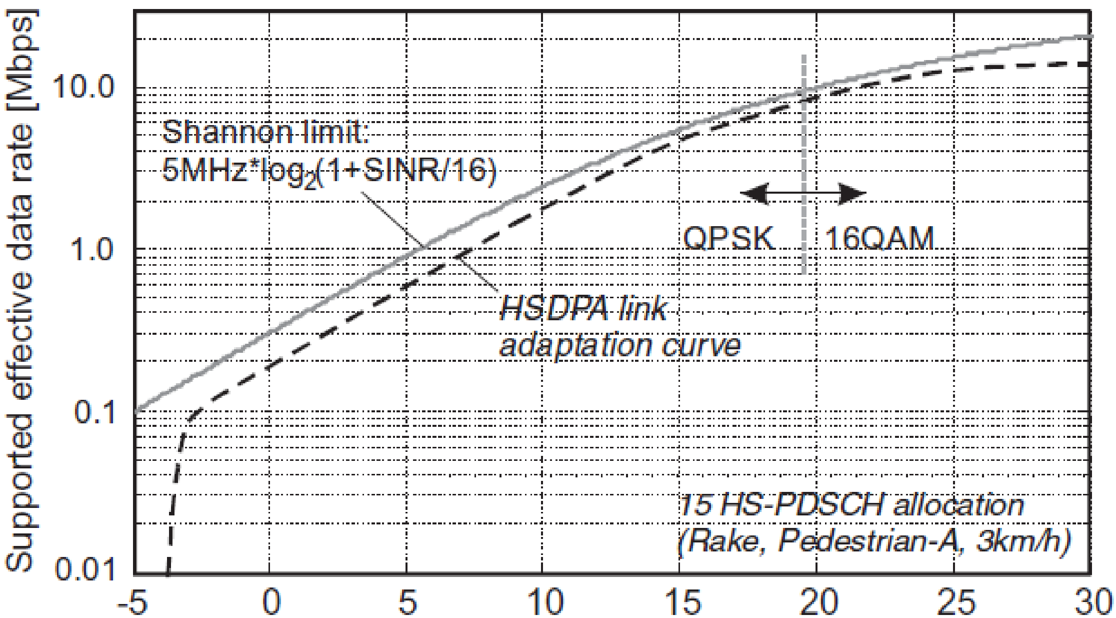
Table 22.8 Downlink range.

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 (dB)

Remark: true Shannon limit is:

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

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

ITU Handbook Supplement 1 (revision 1) (2011)

Band (MHz)	Footnotes identifying the band for IMT
450-470	5.286AA
698-960	5.313A; 5.317A
1 710-2 025	5.384A, 5.388, 5.388A, 5.388B
2 110-2 200	5.388
2 300-2 400	5.384A
2 500-2 690	5.384A
3 400-3 600	5.430A, 5.432A, 5.432B, 5.433A

Current spectrum identified for IMT-2000

Unwanted Signals

- **Intermodulation**. Unwanted frequency components that are generated from the interaction of two or more spectral components acting on a device with non-linear behaviour. The unwanted components are related to the fundamental components by sums and differences of the fundamentals and various harmonics.

- **Third-order intermodulation** products could cause interference when the difference between one frequency and twice another falls within the pass-band of a receiver. Third-order IMP can occur when one interfering signal is in the proximity of the tuning frequency, e.g. in the adjacent channel. They also could be produced by combination of three interfering signals. 3rd order:

Two Signal Case: $2f_{t1} - f_{t2} = f_r \pm BW$

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e.g. The transmitted frequencies are f_1 = 232 MHz (mobile channel), f_2 = 229.75 MHz (Sound Carrier of TV channel 12, for European Standard B) and the interfered frequency is 234.25 MHz (another mobile channel): thus IMP = $2f_{t1} - f_{t2} = f_r \pm BW = 2 \times 232 - 229.75 = 234.25$ MHz

Three Signal Case: $f_{t1} - f_{t2} + f_{t3} = R f \pm BW$ where: $f_{t1} > f_{t2} > f_{t3}$

Passive Intermod (PIM) for different TxRx equipment combined to the same ant ports (Txs & Rxs are connected through the same cables to the same port and produce passive, due to their nonlinearity. E.g. 2 Txs deliver 50 watts each (47dBm) and the receiver sensitivity is -120 dBm, it means that a PIM value of up to 167dBc may be required. Ant. spec are -150dBc which is only valid for the antenna. Add the cable and connectors non linearity which degrade with weather, moisture and time

Three-signal case

The most critical combination is the intermodulation of three signals of the same power. To calculate the power of the interfering signal, according to Recommendations ITU-R SM.1134, Table 2 and SM.575 p.3, the power of the intermodulation product for the three-signal equals:

$$P_{IM3} = 3P_S - 2P_{IP3} + 6(\text{dB})$$

Where:

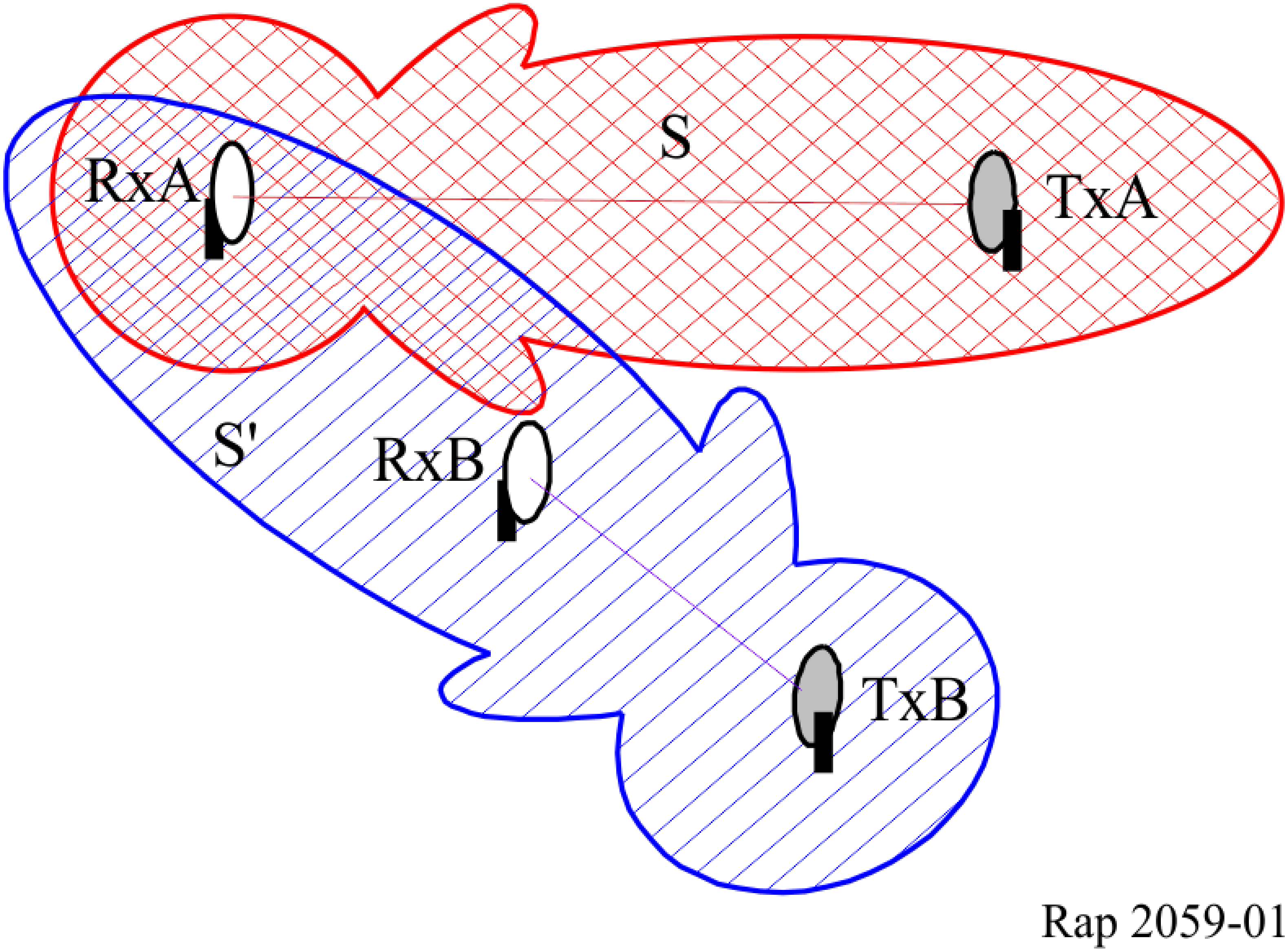
P_{IM3}: power of the 3rd order intermodulation product IM3 (dBm);

P_S: power of each single transmitter involved in the intermodulation (dBm);

P_{IP3}: 3rd order intercept point (IP3) of the receiver (dBm).

The Handbook on Satellite Communications AP5.2-3 pp. 337-342 also calculates the intermodulation products level.
All three transmitters have similar power.

General interference scenario; RF area (F.2059 2005)



Linear Carrier-to- Interference Ratio (CIR)

where:

ϕ_1 : interferer off-boresight angle, relative to the victim

ϕ_2 : victim off-boresight angle, relative to the interferer

P_l: propagation losses

G: antenna gains

$bw_{unwanted}$: bandwidth of the un-wanted signal

bw_{wanted}: bandwidth of the wanted signal

XPD: cross-polarization discrimination

P_l differs as the distance from the wanted and unwanted emitters to the victim is different

The attenuation 10 log $bw_{wanted} / bw_{unwanted}$ is considered only for $bw_{wanted} < bw_{unwanted}$

Disregarding line losses at the transmitter and receiver, according to the logarithmic wanted carrier received signal *C* equals at standard units:

$$C = P_t + G_t - P_{l\_want} + G_r = EIRP_{wanted} - P_{l\_want} + G_r$$

The interference *I* from the interferer *INT* equals:

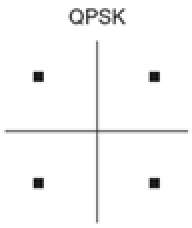
$$I = INT + G_{int}(\varphi 1) - P_{l\_int} + G_r(\varphi 2) - 10\log\frac{bw_{unwanted}}{bw_{wanted}} - XPD$$

The carrier-to- interference ratio *CIR* is 10 log *c/i* = *C* - *I* and equals:

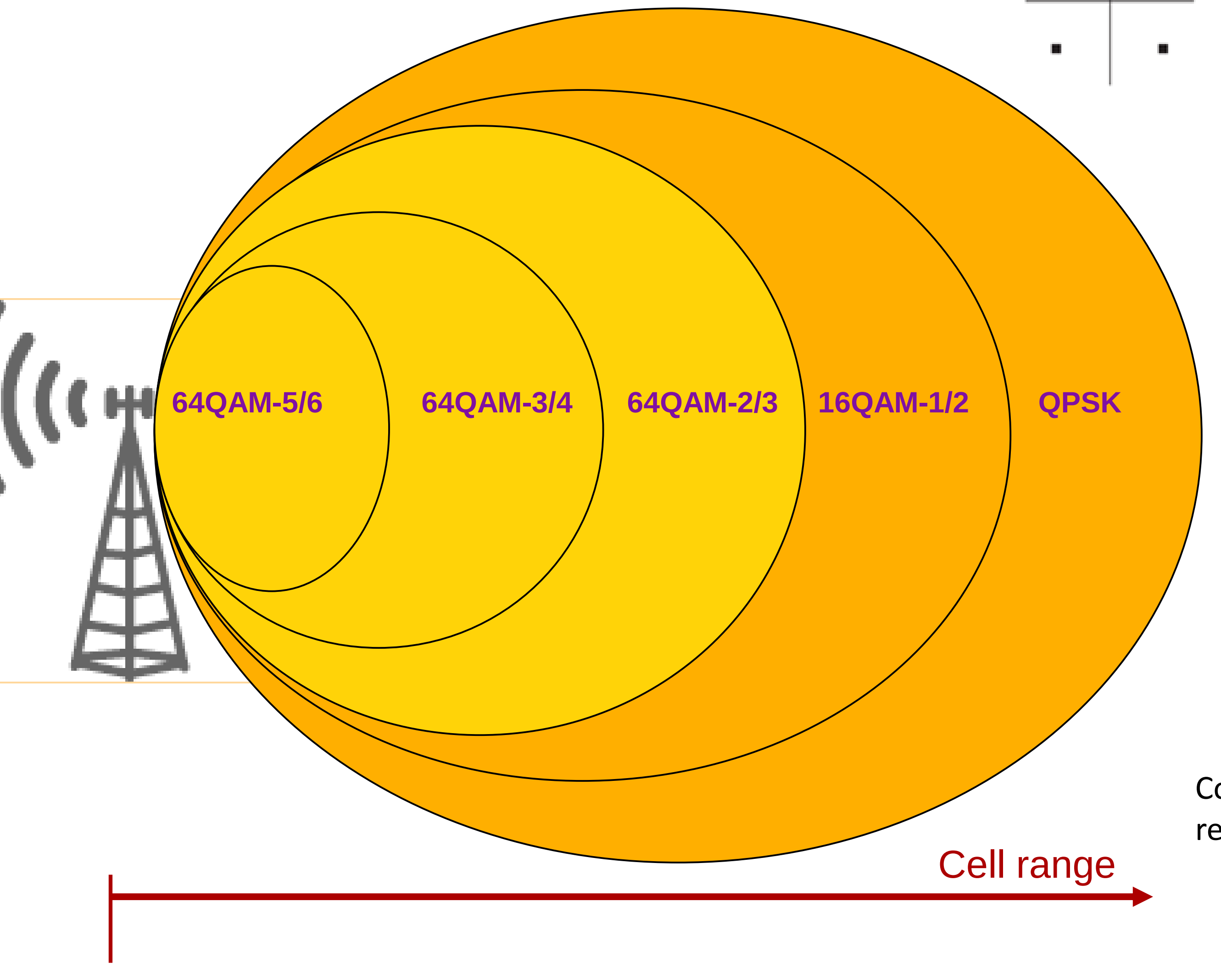
$$C - I = EIRP_{wanted} - P_{l\_want} + G_r - (INT + G_{int}(\varphi 1) - P_{l\_int} + G_r(\varphi 2) - 10\log\frac{bw_{unwanted}}{bw_{wanted}} - XPD)$$

Trade off between Coverage and Capacity

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



OFDM *PR*s, *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 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.



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

Source: Shalev

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Thresholds power & field-strength for cellular & BWA

Technology (MHz)	CS (kHz) Channel Separation	SENS (dBm)	FS (dBµV/m)
GSM 900	200	-104	30
GSM 1,800	200	-104	36
UMTS 2,100	5,000	-80	61
LTE 700/800	5,000	-80	53
LTE 1,800–2,000	5,000	-80	61
	10,000	-77	64
	20,000	-74	67
LTE-TDD 2,300/2,600	5,000	-80	63
	10,000	-77	66
	20,000	-74	69

Thresholds power & field-strength for cellular & BWA

Technology (MHz)	CS (kHz)	SENS (dBm)	FS (dBµV/m)
WiMAX 2,300/2,600	5,000	-80	63
	10,000	-77	66
	20,000	-74	69
WiMAX 3,500	5,000	-80	66
	10,000	-77	69
	20,000	-74	72
WiMAX5400	5,000	-80	70
	10,000	-77	73
	20,000	-74	76
WiMAX10500	5,000	-80	76
	10,000	-77	79
	20,000	-74	82

Spectrum Use Efficiency

1. Spectral efficiency, spectrum efficiency or bandwidth efficiency refers to the information rate that can be transmitted over a given bandwidth in a specific communication system. It measures how efficiently a limited frequency spectrum is utilized
2. The spectral efficiency of a digital communication system is measured in bit/s/Hz
3. The upper bound for the spectral efficiency possible without bit errors in a channel with a certain SNR, if ideal error coding and modulation is assumed, is given by the Shannon-Hartley theorem

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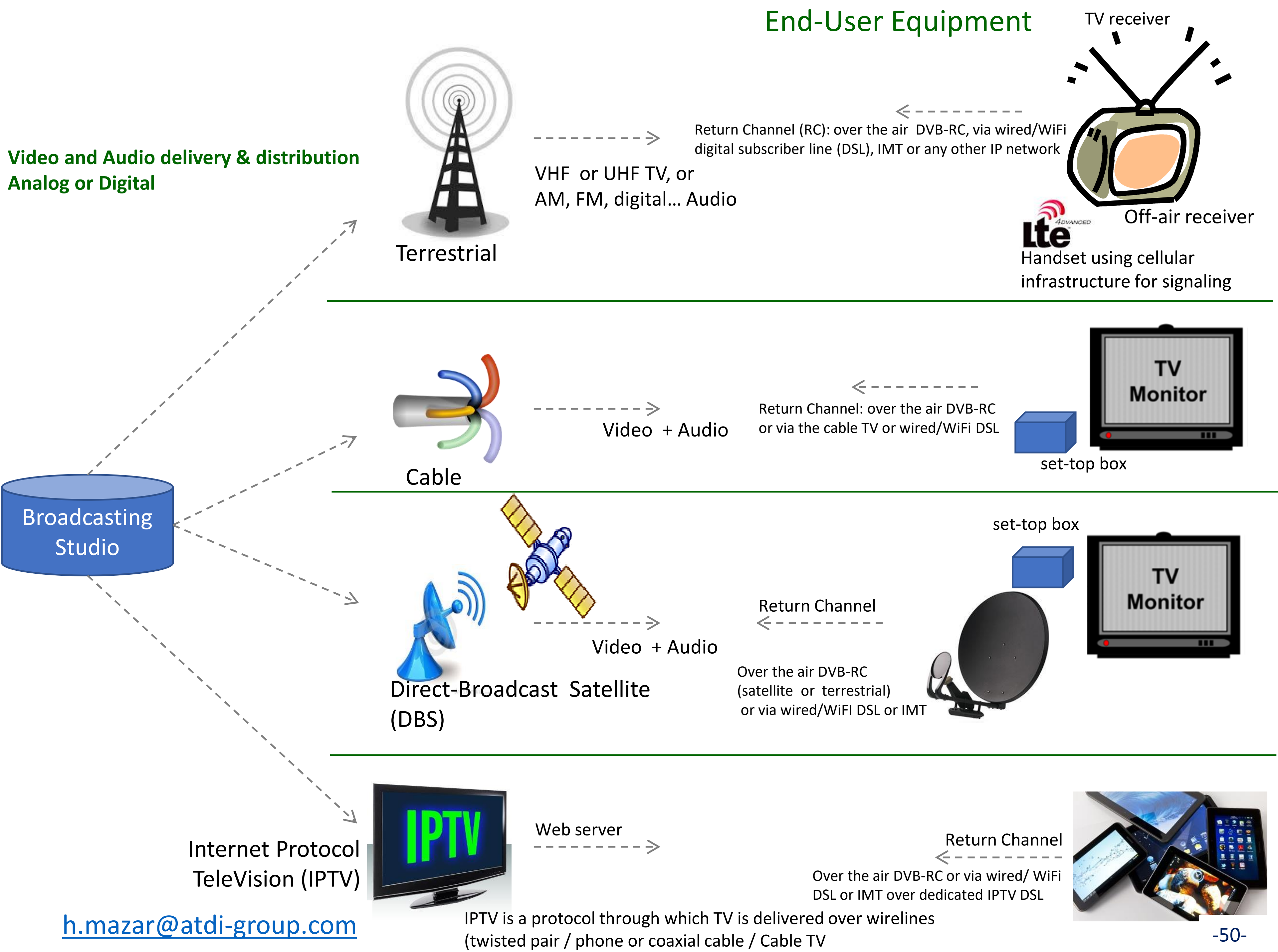
End-User Equipment
Video and Audio delivery & distribution
Analog or Digital
Terrestrial
VHF or UHF TV, or
AM, FM, digital… Audio
Return Channel (RC): over the air DVB-RC, via wired/WiFi
digital subscriber line (DSL), IMT or any other IP network
TV receiver
Off-air receiver
Handset using cellular
infrastructure for signaling
Cable
Video + Audio
Return Channel: over the air DVB-RC
or via the cable TV or wired/WiFi DSL
TV
Monitor
set-top box
Broadcasting
Studio
set-top box
TV
Monitor
Return Channel
Video + Audio
Direct-Broadcast Satellite
(DBS)
Over the air DVB-RC
(satellite or terrestrial)
or via wired/WiFI DSL or IMT
IPTV
Web server
Internet Protocol
TeleVision (IPTV)
Return Channel
Over the air DVB-RC or via wired/ WiFi
DSL or IMT over dedicated IPTV DSL
IPTV is a protocol through which TV is delivered over wirelines
(twisted pair / phone or coaxial cable / Cable TV
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Public protection and disaster relief (PPDR) CEPT harmonization measure on PPDR 698 to 791 MHz

698-703	703-708	708-713	713-718	718-723	723-728	728-733	733-736	736-752	753-758	758-763	763-768	768-773	773-778	778-783	783-788	788-791
PPDR a) up-link	PPDR b) uplink (MFCN)						PPDR c) up-link	...	PPDR a) down-link	PPDR b) downlink (MFCN)						PPDR c) down-link
5 MHz	30 MHz (6 blocks of 5 MHz)						3 MHz		5 MHz	30 MHz (6 blocks of 5 MHz)						3 MHz

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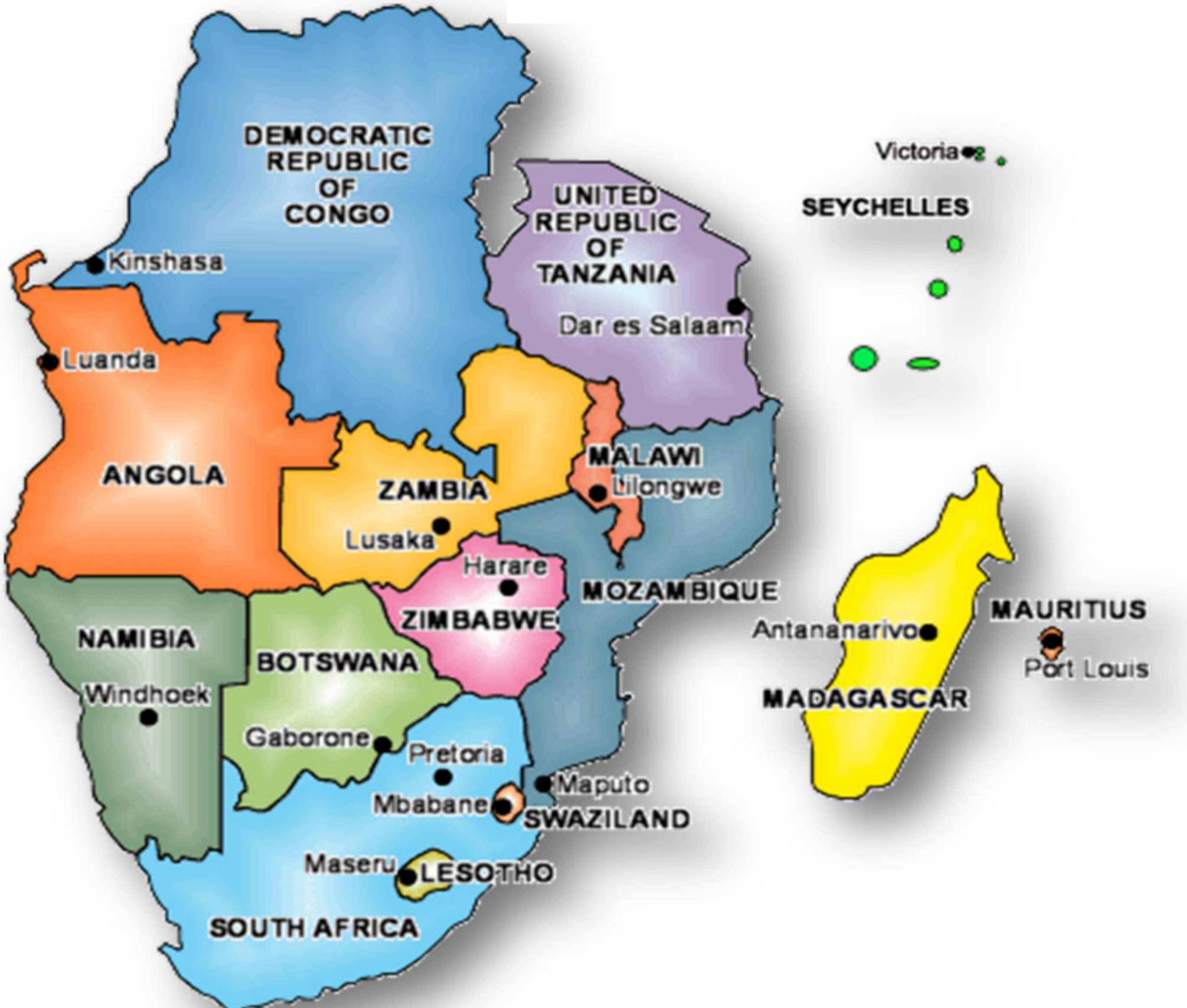
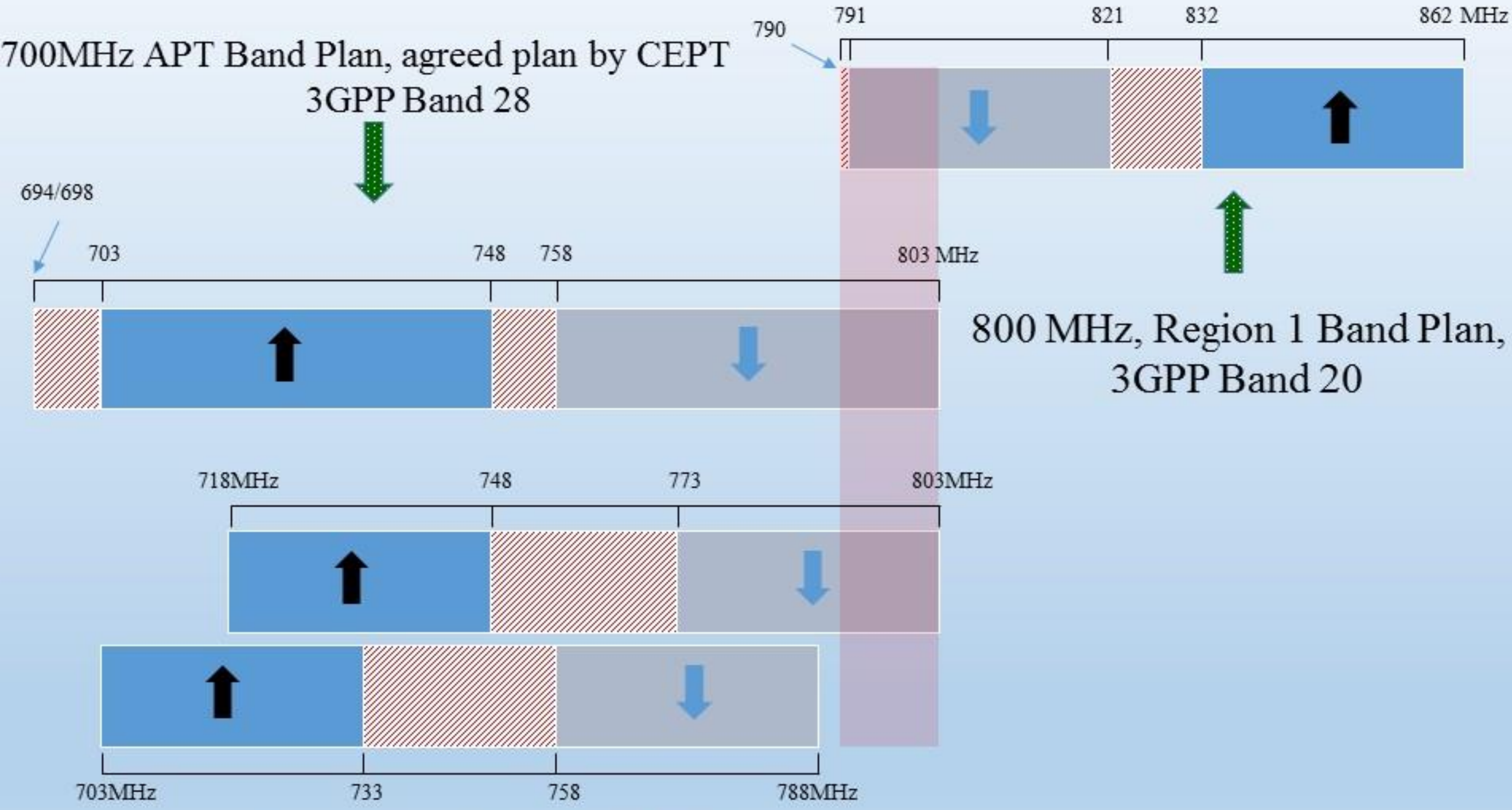
Member States of the Southern African Development Community (SADC)



Digital Dividends: 700/800MHz band plan (source GSMA)

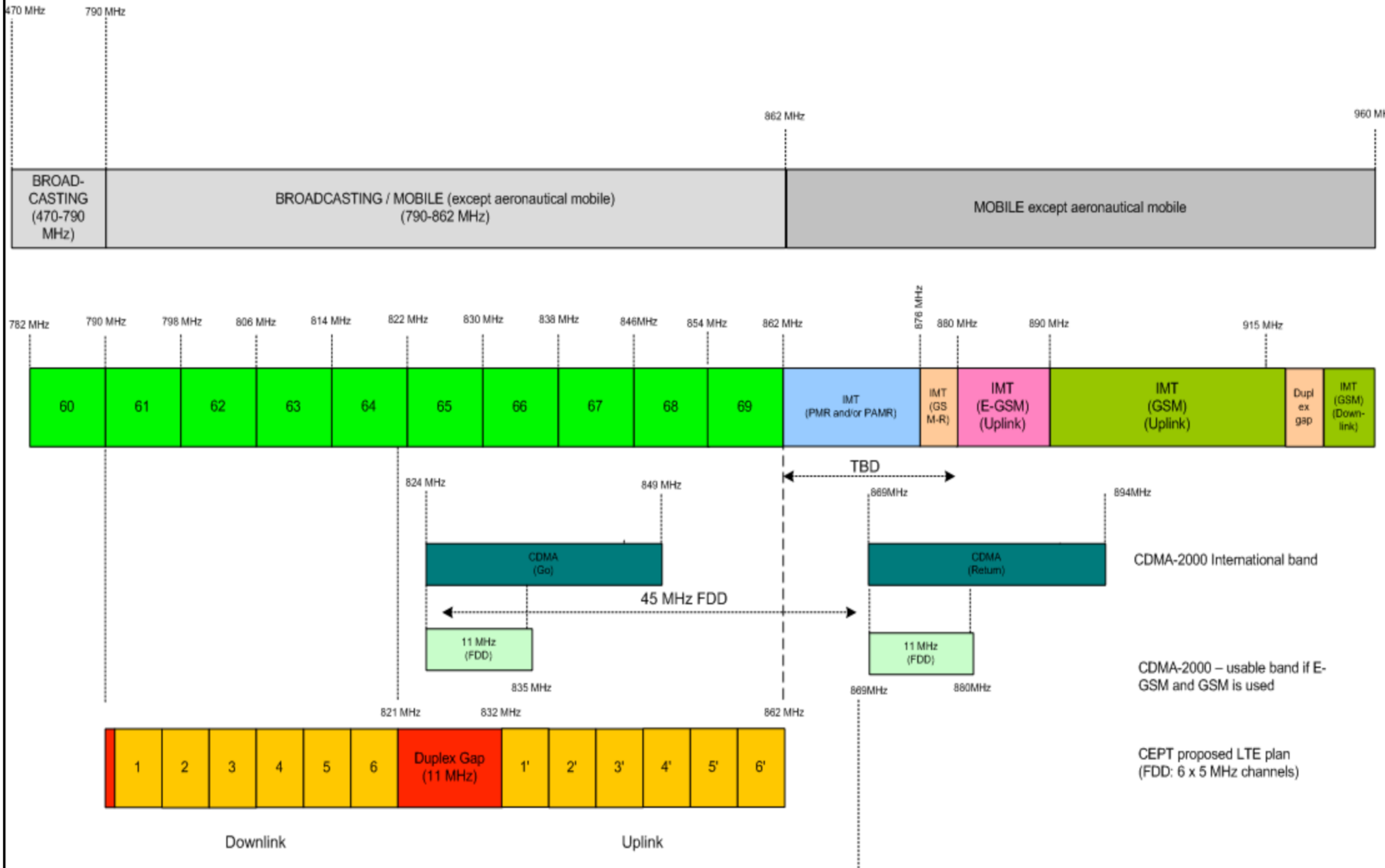


harmonised plan: 2x30MHz

Digital Dividends at 694-862 MHz according to SADC Frequency Allocation Plan

ITU Region 1 allocations and footnotes	ZICTA allocation/s and relevant ITU footnotes	SADC proposed common sub-allocations / utilisation	Additional information
694-790 MHz **MOBILE except aeronautical mobile MOD 5.312A 5.317A** **BROADCASTING** **MOD 5.300 5.311A 5.312**	**694-790 MHz** **MOBILE except aeronautical mobile MOD 5.312A 5.317A** **BROADCASTING** **MOD 5.300 5.311A** **MOD 5.312**	**IMT**	
790–862 MHz **FIXED** **MOBILE except aeronautical mobile 5.316B 5.317A** **BROADCASTING** **5.312 5.319**	**790–862 MHz** **FIXED** **MOBILE except aeronautical mobile 5.316B 5.317A** **BROADCASTING** **5.319** **SADC13**	**IMT**	**Band IV/V analogue television to migrate to digital television according to SADC time lines.** **WRC-07, WRC-12 and WRC-15 allocated this band to Mobile service except aeronautical mobile and identified it for IMT. This band should be made available for IMT as soon as possible after the migration of analogue television to digital.** **Fixed links operating in this band will have to be migrated in order to accommodate IMT**

Spectrum allocations 790 MHz to 915 MHz



Zambia Allocations (source, ZICTA, Sep. 2019)

ITU Region 1 allocations and footnotes	ZICTA allocation/s and relevant ITU footnotes	SADC proposed common sub-allocations / utilisation	Additional information
470-694 MHz **BROADCASTING** **5.149 5.291A 5.294 5.296 5.300 5.304 5.306 5.311A 5.312**	470-694 MHz BROADCASTING 5.149 5.291A 5.294 5.296 5.300 5.304 5.306 5.311A 5.312	DTT broadcasting (470-694 MHz)	Band IV/V Analogue television to migrate to digital television in line with SADC time lines
694-790 MHz **MOBILE except aeronautical mobile MOD 5.312A 5.317A** **BROADCASTING** **MOD 5.300 5.311A 5.312**	694-790 MHz MOBILE except aeronautical mobile MOD 5.312A 5.317A BROADCASTING MOD 5.300 5.311A MOD 5.312	IMT	
790-862 MHz **FIXED** **MOBILE except aeronautical mobile 5.316B 5.317A** **BROADCASTING** **5.312 5.319**	790-862 MHz FIXED MOBILE except aeronautical mobile 5.316B 5.317A BROADCASTING 5.319 SADC13	IMT	Band IV/V analogue television to migrate to digital television according to SADC time lines. WRC-07, WRC-12 and WRC-15 allocated this band to Mobile service except aeronautical mobile and identified it for IMT. This band should be made available for IMT as soon as possible after the migration of analogue television to digital. Fixed links operating in this band will have to be migrated in order to accommodate IMT.

Zambia Assignments for 900 MHz countrywide (source, ZICTA, Sep. 2019)

Mobile Operator	900 MHz Band	Comment
MTN Zambia	16	
Airtel Zambia	20	
Zamtel	16	
Uzi Zambia	-	16 MHz reserved at Tender

[1] Operator Uzi Zambia has not commenced operations in Zambia and the indicated spectrum holding is based on Authority's offer to the MNO subject to payment of fees.

Zambia Assignments for 900 MHz countrywide (source, ZICTA, Sep. 2019)

Airtel:

900 MHz Assignment (10 FDD)
885-890 MHz/ 907-912 MHz
930-935 MHz / 952 – 957 MHz

Zamtel:

900 MHz (8 MHz FDD)
890.20-898.20 MHz
935.20-943.20 MHz

MTN:

900 MHz (8 MHz FDD)
898.40-906.40
943.40-951.40

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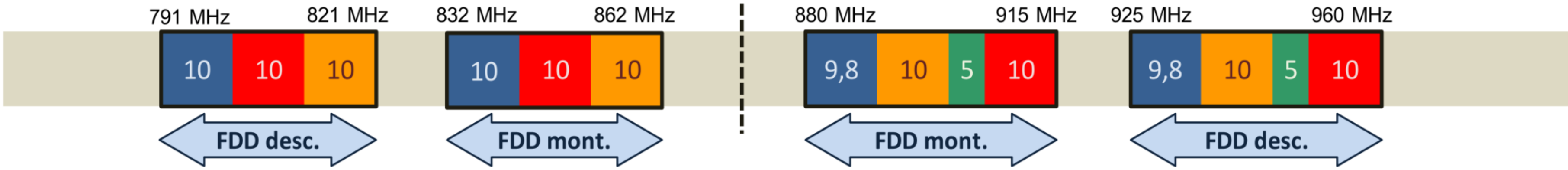
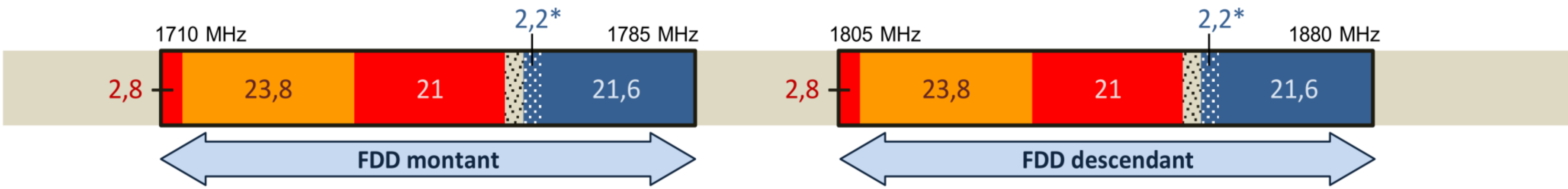
French, 2017 assignments at 800, 900, 1800, 2100 & 2600 MHz

Bandes 800 MHz et 900 MHz

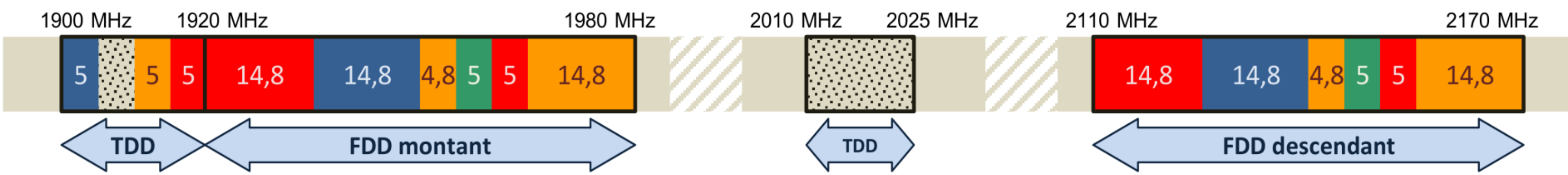


Bande 1800 MHz

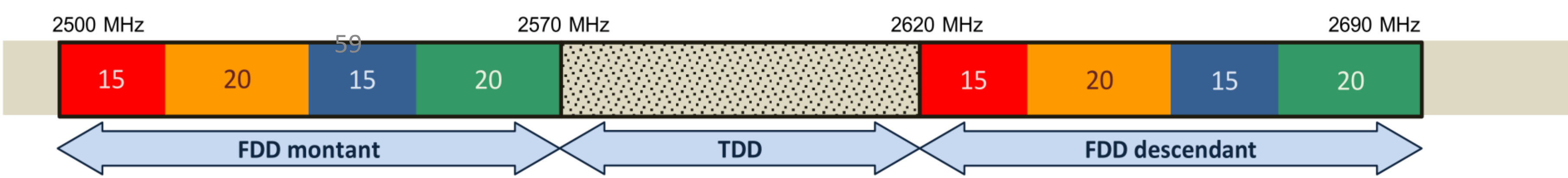


* Uniquement dans les zones très denses de Lyon, Marseille-Aix, Nice et Paris

Bande 2,1 GHz



Bande 2,6 GHz



Orange | SFR | Non attribué

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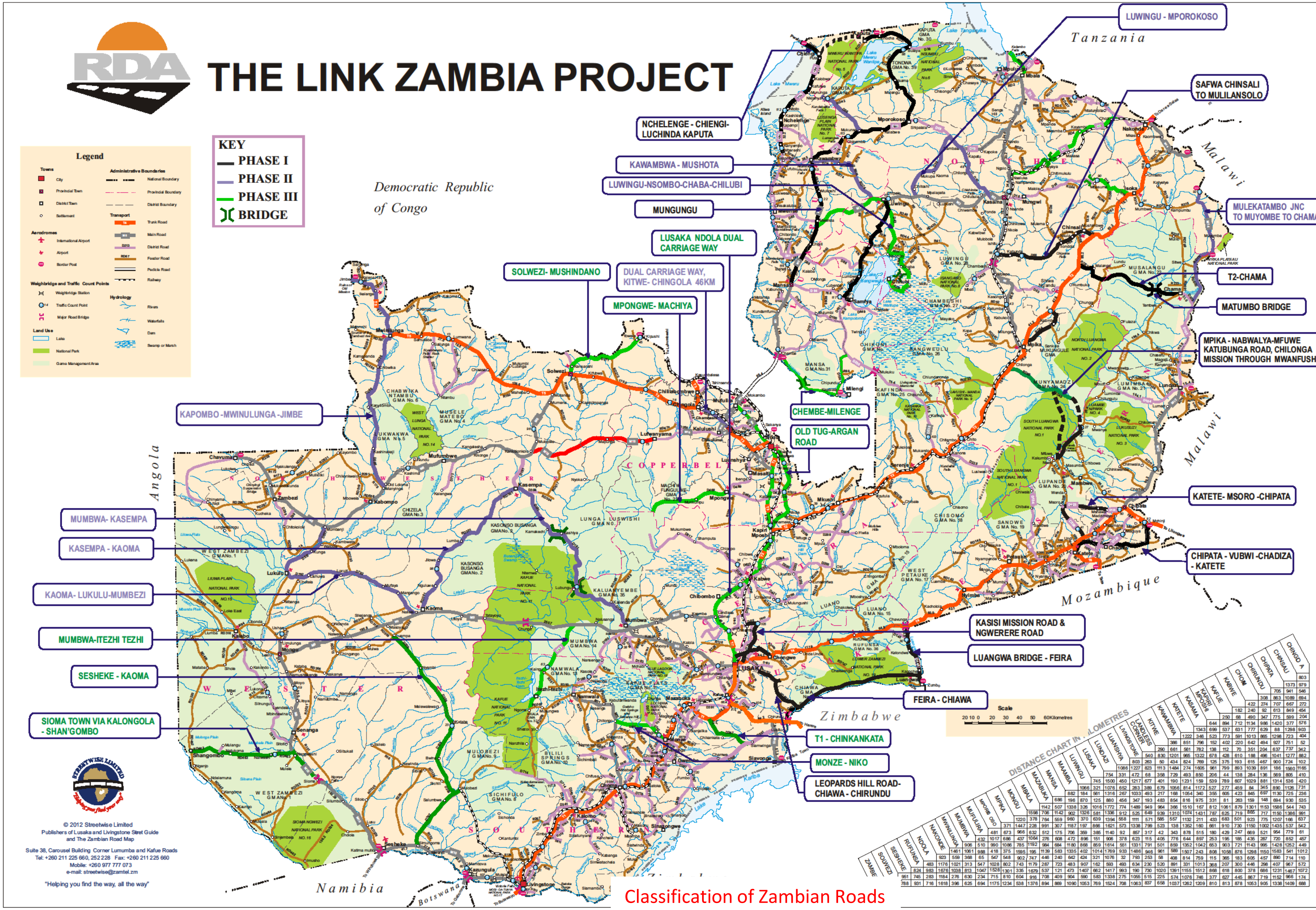
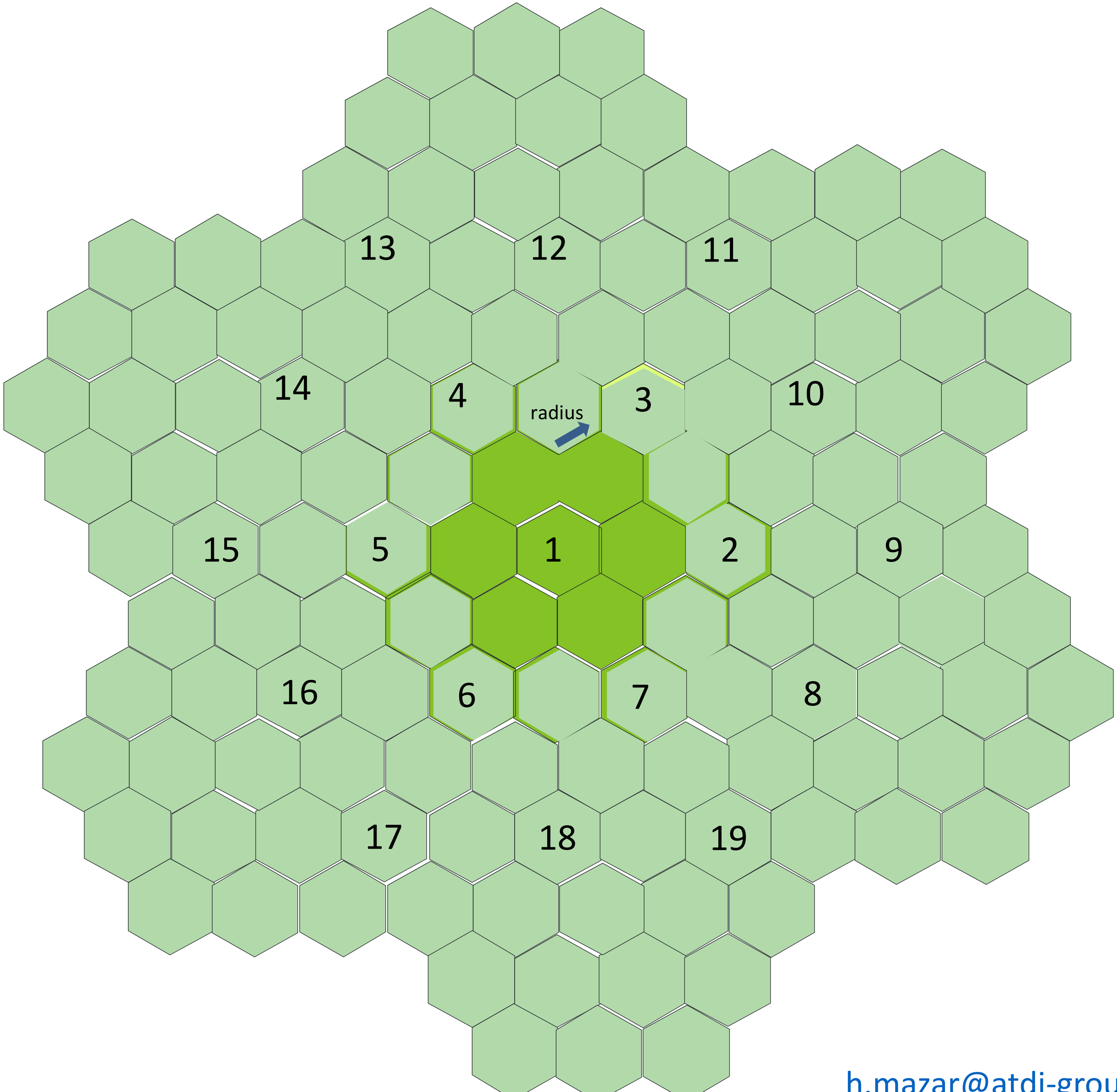


Classification of Zambian Roads

Parameters influencing the min. RF required

1. Technology: spectral-efficiency, RF aggregation, MIMO
2. Number of BTS
3. Population density
4. Propagation scenarios
5. Center Frequency
6. Network topology: heterogeneous network reduces needed RF
7. Is Internet provided by fixed lines (ADSL), by cellular by hot-spots
8. Traffic forecast
9. Licence obligations:
    1) QoS
    2) coverage
    3) capacity requirements
    4) indoor requirements
    5) Offloading by RLANs- unlicensed RF bands ease the coverage and capacity;
    6) human-hazards limits- restricted thresholds force more BTS, therefore less RF may be assigned.

Typical cellular network based on the 19 cell reference network unit



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Spectral efficiency of common communication systems; see Wiki 1st page

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Spectral efficiency of common communication systems

Service	Standard	Launched year	Max. net bitrate *R* per carrier per 1 spatial stream (Mbit/s)	Bandwidth *B* per carrier (MHz)	Max. link spectral efficiency *R/B* ((bit/s)/Hz)		Typical reuse factor 1/*K*	System spectral efficiency ((bit/s)/Hz per site)
					SISO	MIMO		
2.75G cellular	CDMA2000 1× voice	2000	0.0096 per phone call × 22 calls	1.2288	0.0078 per call	N/A	1	0.172 (fully loaded)
2.75G cellular	GSM + EDGE	2003	0.384 (typ. 0.20)	0.2	1.92 (typ. 1.00)	N/A	⅓	0.33
2G cellular	GSM	1991	0.013 × 8 timeslots =0.104	0.2	0.52	N/A	⅑ (⅓ in 1999)	0.17 (in 1999)
3.5G cellular	HSDPA	2007	21.1	5	4.22		1	4.22
3G cellular	WCDMA FDD	2001	0.384	5	0.077	N/A	1	0.51
3G cellular	CDMA2000 1x PD	2002	0.153	1.2288	0.125	N/A	1	0.1720 (fully loaded)
3G cellular	CDMA2000 1×EV-DO Rev.A	2002	3.072	1.2288	2.5	N/A	1	1.3
4G cellular	LTE	2009	81.6	20	4.08	16.32(4x4)	1	16.32
4G cellular	LTE-Advanced	2013	75	20	3.75	30.00(8x8)	1	30
4G MBWA	iBurst HC-SDMA	2005	3.9	0.625	7.23		1	7.23
Broadband modem	ADSL2 downlink		12	0.962	12.47	N/A	N/A	N/A
Broadband modem	ADSL2+ downlink		28	2.109	13.59	N/A	N/A	N/A
Digital cable TV	DVB-C 256-QAM mode		38	6	6.33	N/A	N/A	N/A
Digital radio	DAB	1995	0.576 to 1.152	1.712	0.34 to 0.67	N/A	⅕	0.08 to 0.17
Digital radio	DAB with SFN	1995	0.576 to 1.152	1.712	0.34 to 0.67	N/A	1	0.34 to 0.67
Fixed WiMAX	IEEE 802.16d	2004	96	20	4.8		¼	1.2
Wi-Fi	IEEE 802.11a/g	2003	54	20	2.7		⅓	0.900
Wi-Fi	IEEE 802.11n	2007	72.2 (short GI)	20	3.61		⅓	1.2
Wi-Fi	IEEE 802.11ac	2012	433.3 (short GI)	80	5.42			
WiGig	IEEE 802.11ad	2013	6756	2160	3	3	⅓	1

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RF bandwidth required for the deployment of a network MNOs and ISPs

$$BW\,(MHz) = NominalBW \times dr \times subs \times freq$$

***dr*: data rate - relative to a nominal (throughput); the basic *dr* changes with technology**

Comparing subscriber/BTS in some countries

Country	Population M.	Users Million	Rate%	BTS	Users/BTS	Comments
China	1,382.7	1,322	95.60	3,075,600	430	Area & population distribution; 770M. 4G users among those 1,322M deploy 1800/2000/2100/2600MHz, rather than below 1GHz bands like other countries
India	1,226.1	867,803.583	70.78	746,602	1,162	
Japan	126.9	158.6	125	194,548	816	
Israel	8.0	10.5	1.33	7,931	1,324	
Zambia	16.1	12.017	74.47	4,706	2,554	

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Number of Subscriber per BTS (or site)- relative to 1,000

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BW required for FDD network

.3kbit/s for GSM900 & GSM1800; 40Mbits/s for UMTS & WiMAX; 200 Mbits/s for LTE
GSM 1.4MHz x 2 at 900 MHz; UMTS 30MHzx2, at 2000MHz; LTE 20MHzx2 at 1,800 MHz

BW required, FDD UMTS national network

$$BW(MHz) = 30 \times \frac{dr(Mbits/s)}{40} \times \frac{subs}{1,000} \times \frac{freq(MHz)}{2,000} \times 2$$

BW required, FDD LTE national network

$$BW(MHz) = 20 \times \frac{dr(Mbits/s)}{200} \times \frac{subs}{1,000} \times \frac{freq(MHz)}{1,800} \times 2$$

BW vs min BW for FDD cellular; MHz

Operator	RF band	Technology	Total RF	Minimal RF	Missing/ Excess
MNO: AIRTEL	2,100	UMTS	20	30	30-20 =10
	1,800	GSM-1800	20	(1800/900) x1.4 = 2.8	2.8-20 =-17.2
	800/900	GSM- 900	8+ 2=10	1.4	1.4-10 =-8.6
MNO: MTN	2,100	UMTS	20	30	30-20 =10
	1,800	LTE	5	20	20-5 =15
	1,800	GSM-1800	20	(18/9) x1.4 =2.8	2.8-20 =-17.2
	900	GSM- 900	8	1.4	1.4-8 =-6.6
MNO: ZAMTEL	1,900	UMTS	15	30	30-15 =-15
	800	GSM- 900	8	1.4	1.4-8 =-6.6

BW vs min BW for TDD ISPs; units MHz

Operator	RF band	Technology	Total RF	Minimal RF	Missing/ Excess
	2,300	LTE-TDD	30	30	30-30
ISP: AFRICONNECT	2,600	WiMAX	40	(2600/2300)x40=45	45-40
	5,400		40	(5400/2300)x40=94	94-40=
ISP: CEC- Liquid	2,300	LTE-TDD and WiMAX	20	WiMAX 40 MHz needed LTE-TDD 30 MHz needed	WiMAX 40-20= LTE-TDD 30-20=
ISP: HAI	3,500	WiMAX	21	(3500/2300)x40=61	61-21=
	5,400		20	(5400/2300)x40=94	94-21=
ISP: VODAFONE	2,300	LTE TDD	30	30	30-30
	3,500		21	(3500/2300)x30=46	46-21=
ISP: PARATUS TELECOM	3,500	WiMAX	42	(3500/2300)x40=61	61-42=
	5,400		20	(5400/2300)x40=94	94-20=
ISP: ISAT AFRICA	3,500		21	(3500/2300)x40=61	61-21=
ISP: ZAMREN	10.5GHz		7	(10500/2300)x40=183	183-7=1
ISP: MICROLINK	2,600	WiMAX and LTE	60	WiMAX(26/23)x40 MHz =45MHZ needed LTE-TDD (26/23)x 30 34MHz needed	WiMAX 45-60= LTE-TDD 34-60=
ISP: ZAMNET	2,600	WiMAX	30	(2600/2300)x40=45	45-30=

Relevant Material from Dr. Haim Mazar presentations (1); see http://mazar.atwebpages.com/Downloads

1. Academic_Course_Advanced_Wireless_Communications_Mazar1_Engineering_2020.pdf
2. Academic_Course_Advanced_wireless_communications_Mazar2_Services_2020.pdf
3. Academic_Course_Advanced_Wireless_Communications_Mazar3_Regulation_EMC_HumanHazards_2020.pdf
4. Cameroon_EconomicModels_African_RF_Spectrum23Aug19French.pdf
5. Cameroon_Yaounde_Commonwealth_SM Forum_Mazar_Nov16_Spectrum re-farming.pdf
6. CamerounCellulaires_ affectation_bande_470 694_21Dec18_French.pdf
7. CamerounSolutions_techniquesDTTV_MPT_UHF_21Dec2018_French.pdf
8. China_Beijing_SRMC 9July15_National Spectrum Control.pdf
9. China_Beijing_SRMC 9July15_SRD.pdf
10. China_Chengdu_National Spectrum Control Xihua University.pdf
11. Delft_Univ_Cultural_Factors_Shaping_RF_Spectrum_Governance_24Sept2010_Mazar.pdf
12. European vs North American Wireless Regulations_Mazar_ITU world telecom 2011_2633.pdf
13. Geneva_ITU-RSG1SG5-IoT-Workshop_Mazar_22Nov16.pdf
14. Heron5G_RF_regulations_6June19_Mazar.pdf
15. How_Geography_and_Culture_influence_RF_regulation_NZL_case_Wellington_4Feb2010_Mazar.pdf
16. IMT_5G_frequencies_HERON_ATDI_Mazar.pdf
17. ITUD_Gambia_Optimised_Ways_to_Transmit_the_Video_Signals_16July2010_Mazar.pdf
18. ITUD_Gambia_Policies_and_Strategies_to_Optimise_RF_Spectrum_Use_14July2010_Mazar.pdf
19. ITU_regional_SM_conference_connecting_Yerevan13Dec2017.pdf

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Relevant Material from Dr. Haim Mazar presentations (2); see http://mazar.atwebpages.com/Downloads

20. ITU_regional_SM_workshop_parameters_Yerevan14Dec2017.pdf
21. ITU_workshop_international_regional_and_national_regulation_of_SRDs_Mazar.pdf
22. International_Regional_National_RF_Regulation_Standardisation_Ruppin_Mazar.pdf
23. International_Regional_National_RF_Spectrum_Management_13Dec2011_Afeka_Tel_Aviv_Academic_College_of_Engineering_Mazar.pdf
24. January 2016_National Spectrum Control_China@SRTC&XHU.pdf
25. January 2016_SRD_Mazar_SNG&SRTC&XHY&GDRTC.pdf
26. Lusaka_ZICTA_Auctioning_Training_30Sept-4Oct19_Mazar.pdf
27. Paper WT11 Technical Symposium TS11 Haim Mazar_A Comparison between European and North American Wireless Regulations.pdf
28. Presentation WT11 Technical Symposium TS11 Haim Mazar_A Comparison between European and North American Wireless Regulations.pdf
29. Regulating_SRD_Israel_MoC_28Jan2019_Mazar.pdf
30. Regulation of SRDs_Mazar_TCBC_Baltimore_15April2015.pdf
31. Regulation_and_Standardization_of_Wireless_Communications_Israel_Europe_America_22Dec09_Ort_Braude_College_Mazar.pdf
32. WarsawEMF2019_Mazar_WRC19_5G_IMT2020_ITU4Dec19.pdf
33. Webinar_International_GoGlobal_Haim_Mazar_UHF_RFID_global_and_regional_ruling_19Feb13.pdf
34. Wireless_Communications_Coexistence_between_Israel_and_Neighbors_Ashdod_17May2010_Mazar.pdf
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