CITI

Advanced Radio Communications

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Some references

Advanced Wireless Communications – 4G, Savo G Glisic, Wiley Ed.

UWB – Theory and Applications, Ian Oppermann - Matti Hamalainen – Jari Iinatti, Wiley Ed.

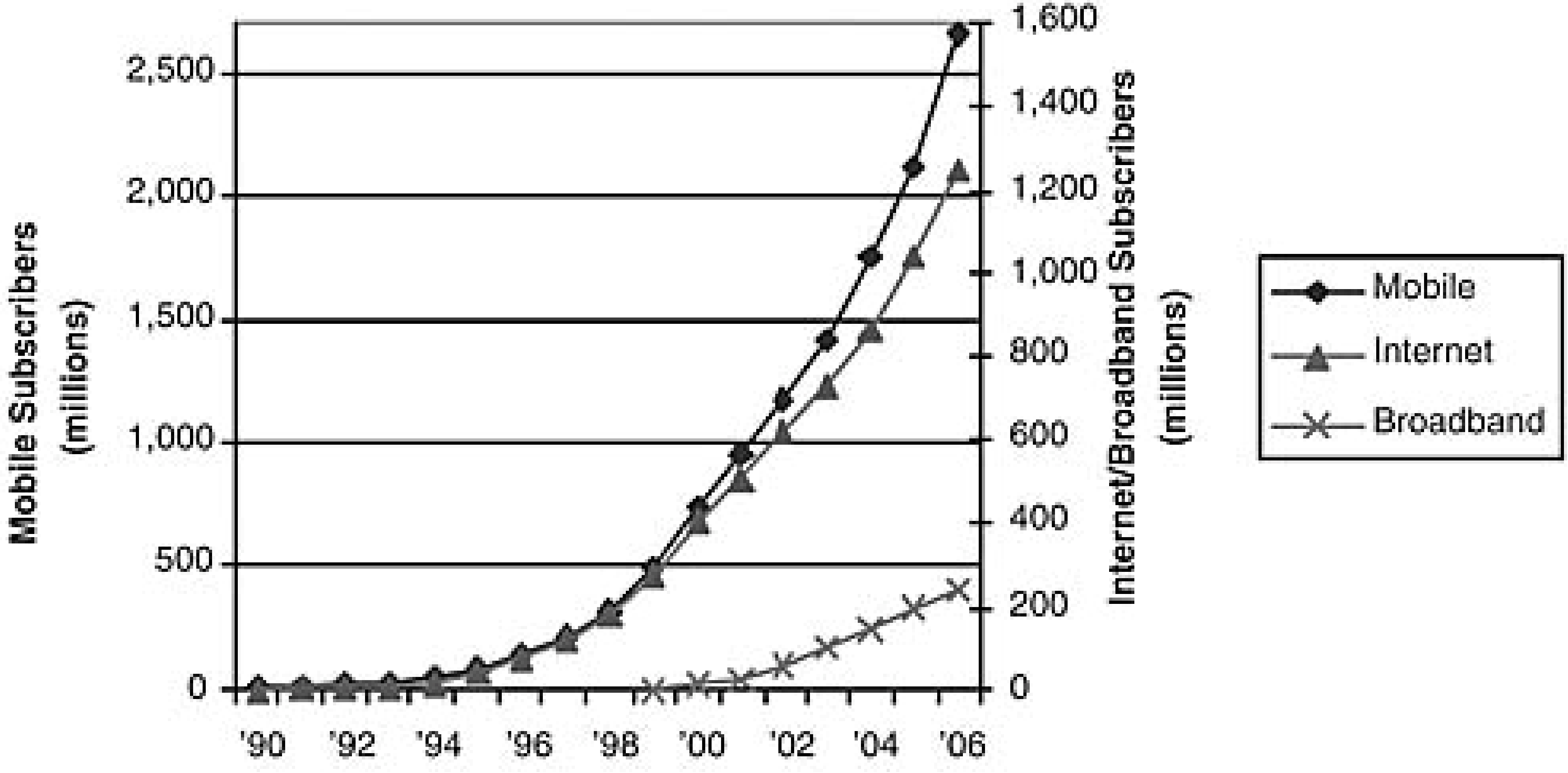
WiMax Forum: http://www.wimaxforum.org/

3GPP-LTE: http://www.3gpp.org/article/lte

WiMedia Alliance: http://www.wimedia.org/

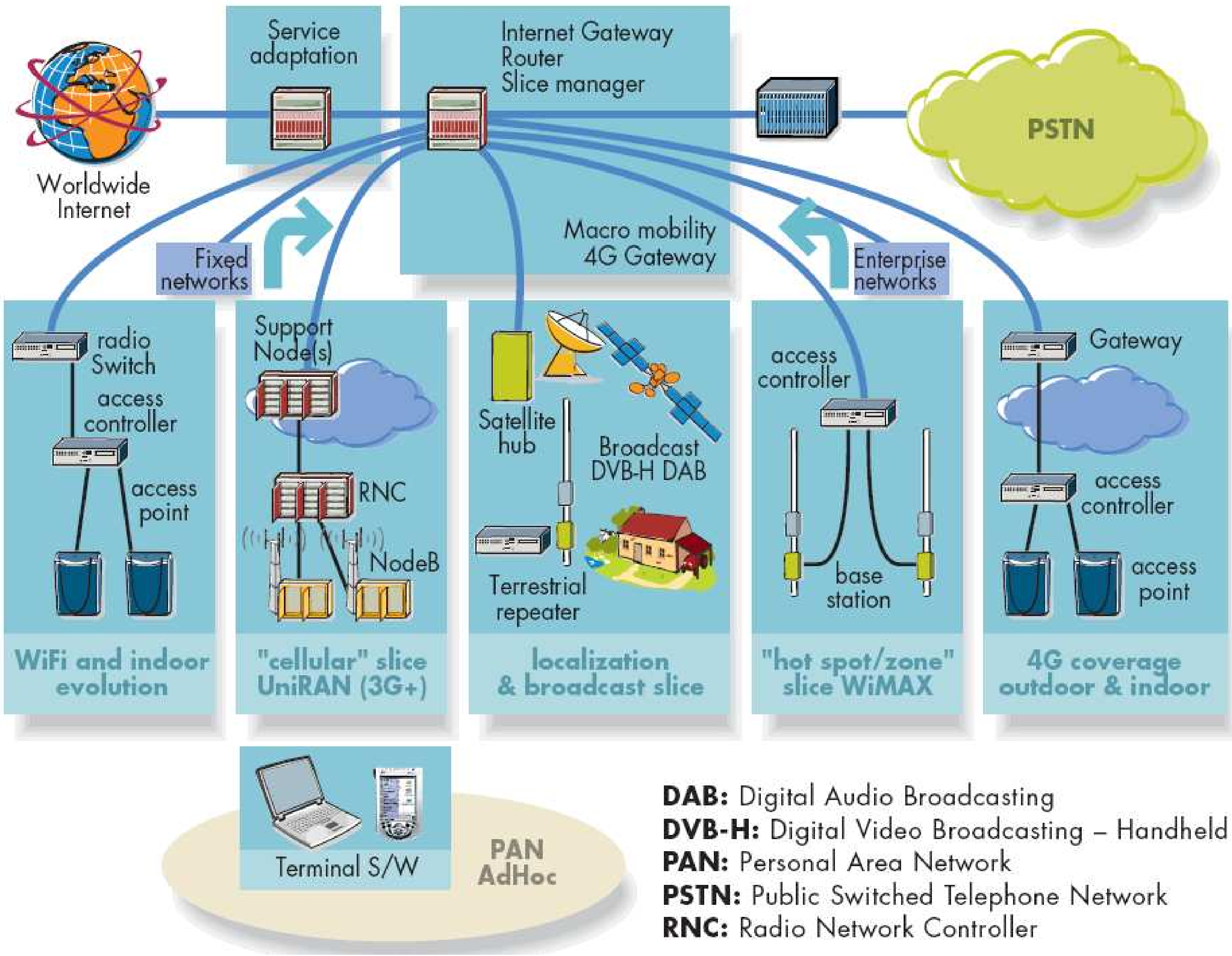
Agilent Technologies: http://www.home.agilent.com/

Just a fact...



Mobile Subscribers (millions)
2,500
2,000
1,500
1,000
500
0
'90
'92
'94
'96
'98
'00
'02
'04
'06
1,600
1,400
1,200
1,000
800
600
400
200
0
Internet/Broadband Subscribers (millions)
Mobile
Internet
Broadband

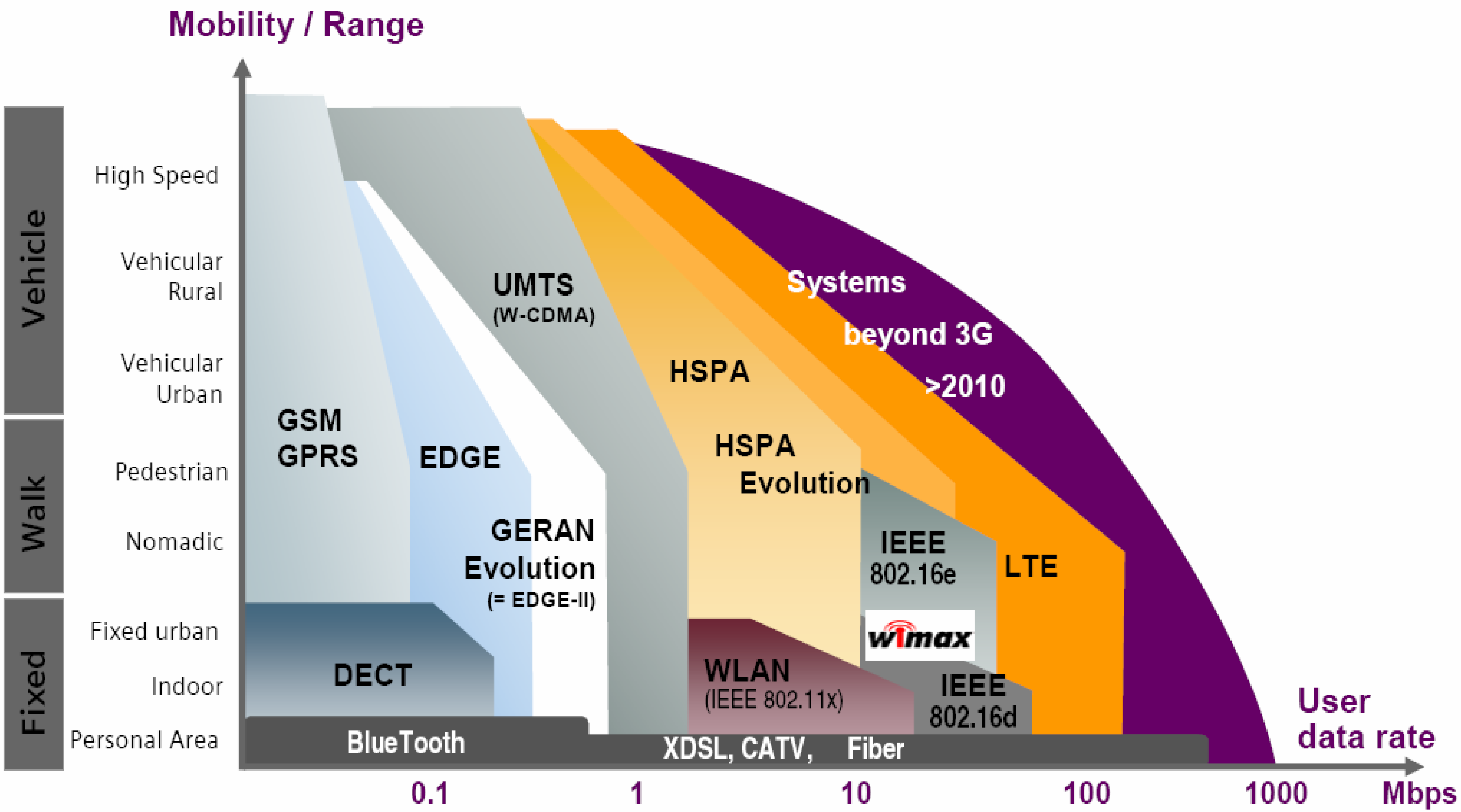
A wired and wireless world



DAB: Digital Audio Broadcasting
DVB-H: Digital Video Broadcasting – Handheld
PAN: Personal Area Network
PSTN: Public Switched Telephone Network
RNC: Radio Network Controller

Focus

Lots of new emerging technologies to increase data rate and/or mobility → key points ?



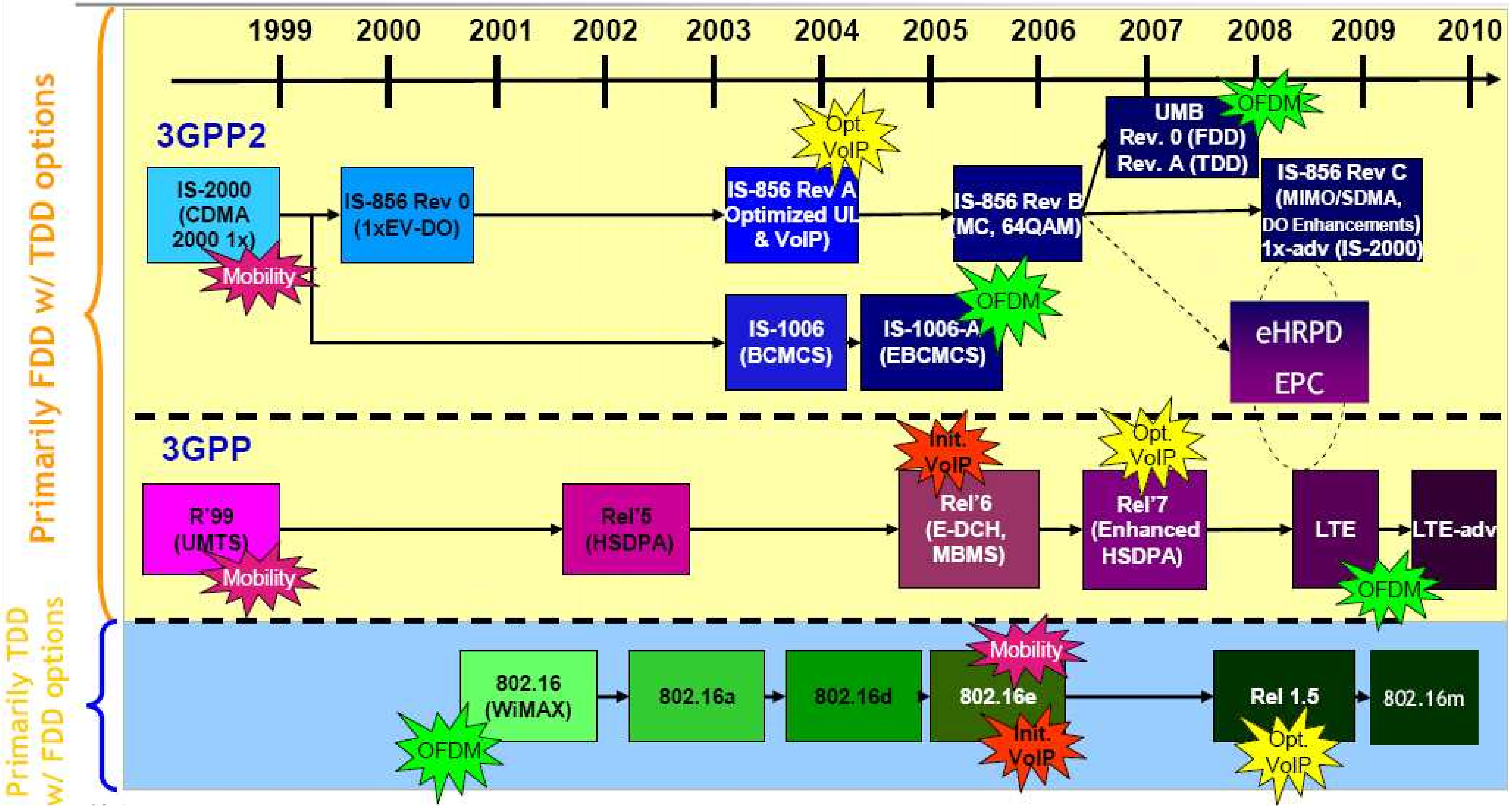
Outline

This course presents advanced techniques used to enhance wireless communications capabilities through 3 different examples: WiMax, LTE and UWB. Each technology could be further understood by the way of simulation and analysis tools.

- **Introduction and Common Concepts**
- **Wireless Broadband Access: WiMAX**
- **3GPP Long-Term Evolution for Mobile**
- **Ultra Wide Band technologies**
- **Simulation Project: ADS and VSA study**

Agilent Technologies

Roadmap



source Alcatel

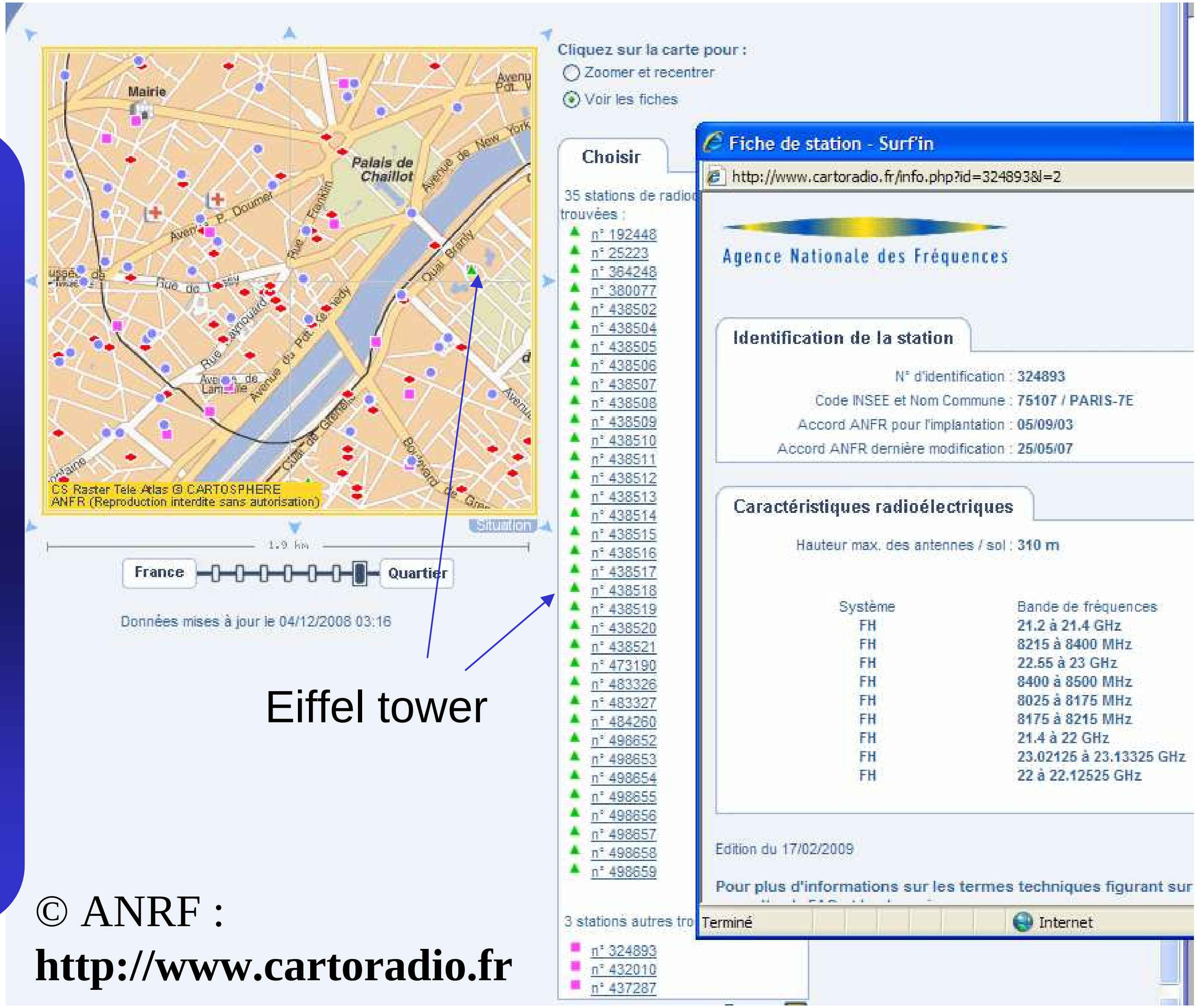
Brief overview

Standard	Family	Primary Use	Radio Tech	Downlink (Mbit/s)	Uplink (Mbit/s)	Notes
LTE	UMTS/4G	General 4G	OFDMA/MIMO/SC-FDMA	326.4	86.4	LTE-Advanced update to offer over 1 Gbit/s speeds.
802.16e	WiMAX	Mobile Internet	MIMO-SOFDMA	70	70	WiMAX-m update to offer over 1 Gbit/s speeds, (comparable to LTE advanced).
Flash-OFDM	Flash-OFDM	Mobile Internet mobility up to 200mph (350km/h)	Flash-OFDM	5.3 10.6 15.9	1.8 3.6 5.4	Mobile range 18miles (30km) extended range 34 miles (55km)
HIPERMAN	HIPERMAN	Mobile Internet	OFDM	56.9	56.9	
Wibro	WiBro	Mobile Internet	OFDMA	50	50	Mobile range (900 m)
iBurst	iBurst 802.20	Mobile Internet	HC-SDMA/TDD/MIMO	64	64	3–12 km
EDGE Evolution	GSM	Mobile Internet	TDMA/FDD	1.9	0.9	3GPP Release 7
UMTS-TDD	UMTS/3GSM	Mobile Internet	CDMA/TDD	16	16	Reported speeds according to IP Wireless using 16QAM modulation similar to HSDPA+HSUPA
1xRTT	CDMA2000	Mobile phone	CDMA	0.144	0.144	Succeeded by EV-DO
EV-DO 1x Rev. 0 EV-DO 1x Rev.A EV-DO Rev.B	CDMA2000	Mobile Internet	CDMA/FDD	2.45 3.1 4.9xN	0.15 1.8 1.8xN	Rev B note: N is the number of 1.25 MHz chunks of spectrum used. Not yet deployed.

Different kinds of links

Wireless everywhere

We can observe a growing number of antennas on rooftops in all cities.
Not only different use or standard, but also different operators.



Eiffel tower

© ANRF :
http://www.cartoradio.fr

Network structures

The more visible wireless network is probably broadcast systems (ex: TV, AM or FM radio…).

Features :

- *1 simplex link (downlink)*
- *1 omnidirectional emitter*
- *Directional or omnidirectional receivers*

Radio relay

High capacity radio point to point link, used to realize wireless bridges.

Features :

- *1 simplex or duplex link*
- *2 Tx/Rx with high gain antennas*
- *Possible repeaters*

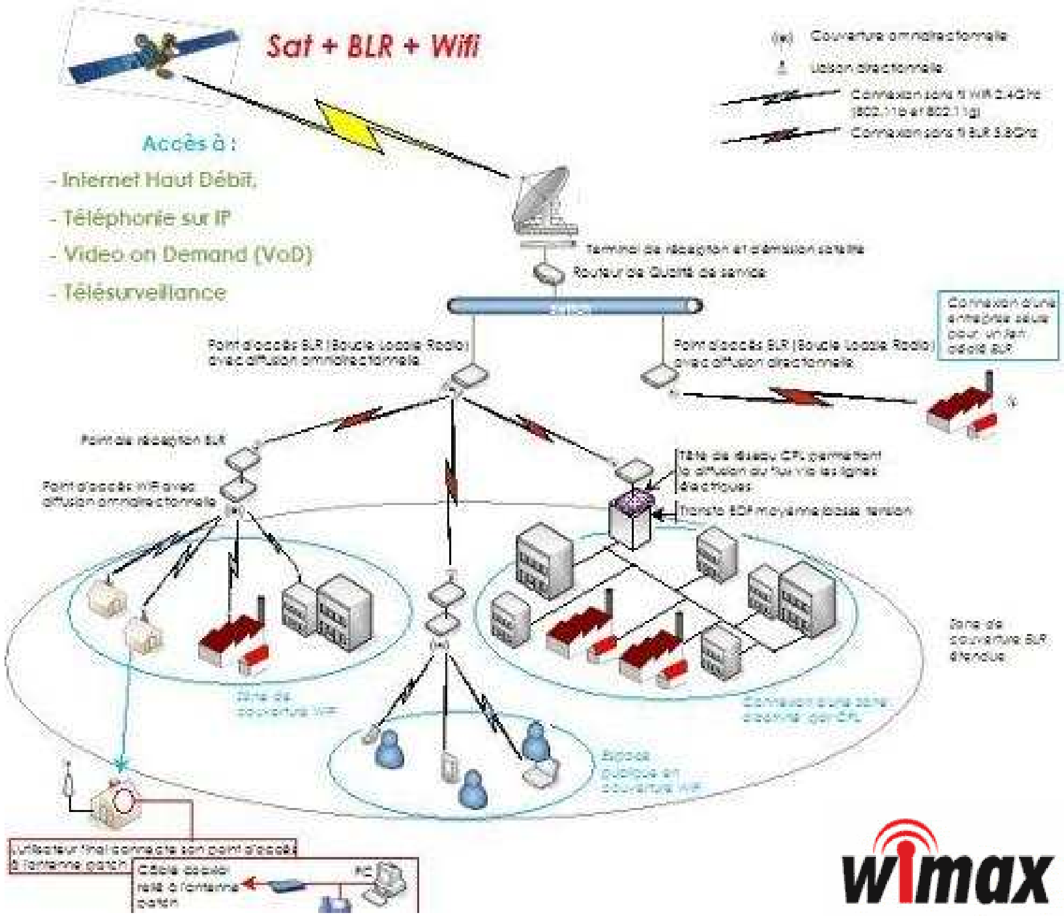
Point to Multi-point

Fixed architecture with Gateways (base stations, access points…).

Features :

- *1 duplex link*
- *1 omnidirectional or sectorial Tx/Rx*
- *1 highly Directional Tx/Rx for user*

Application: WLL

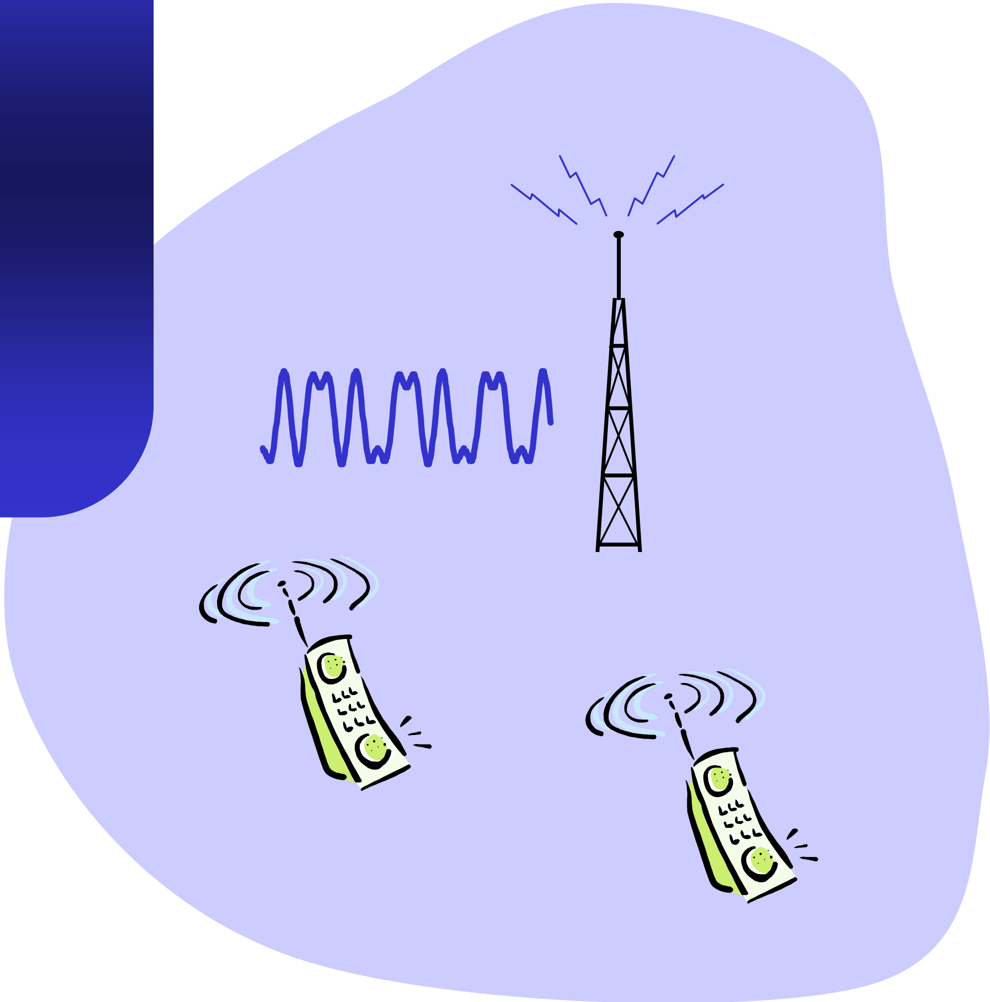


Mobile radio

Transmission between one fixed access point and mobile users.

Features:
- *1 duplex link*
- *2 omnidirectional Tx/Rx*

Application: police, firemen,emergency…

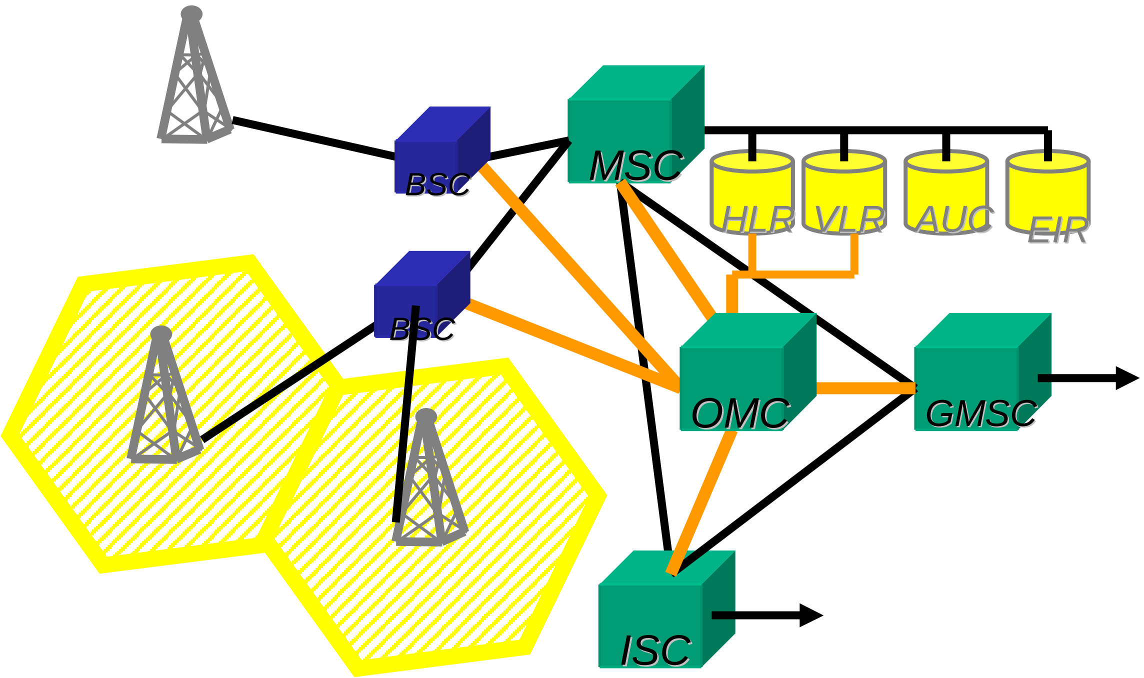


Cellular Networks

Cellular: extension of geographical region of coverage and increase of the number of possible users.

Features:

- *duplex links*
- *Omnidirectional or sectorial Tx/Rx for BS (cells)*
- *Omnidirectional Tx/Rx for MU*



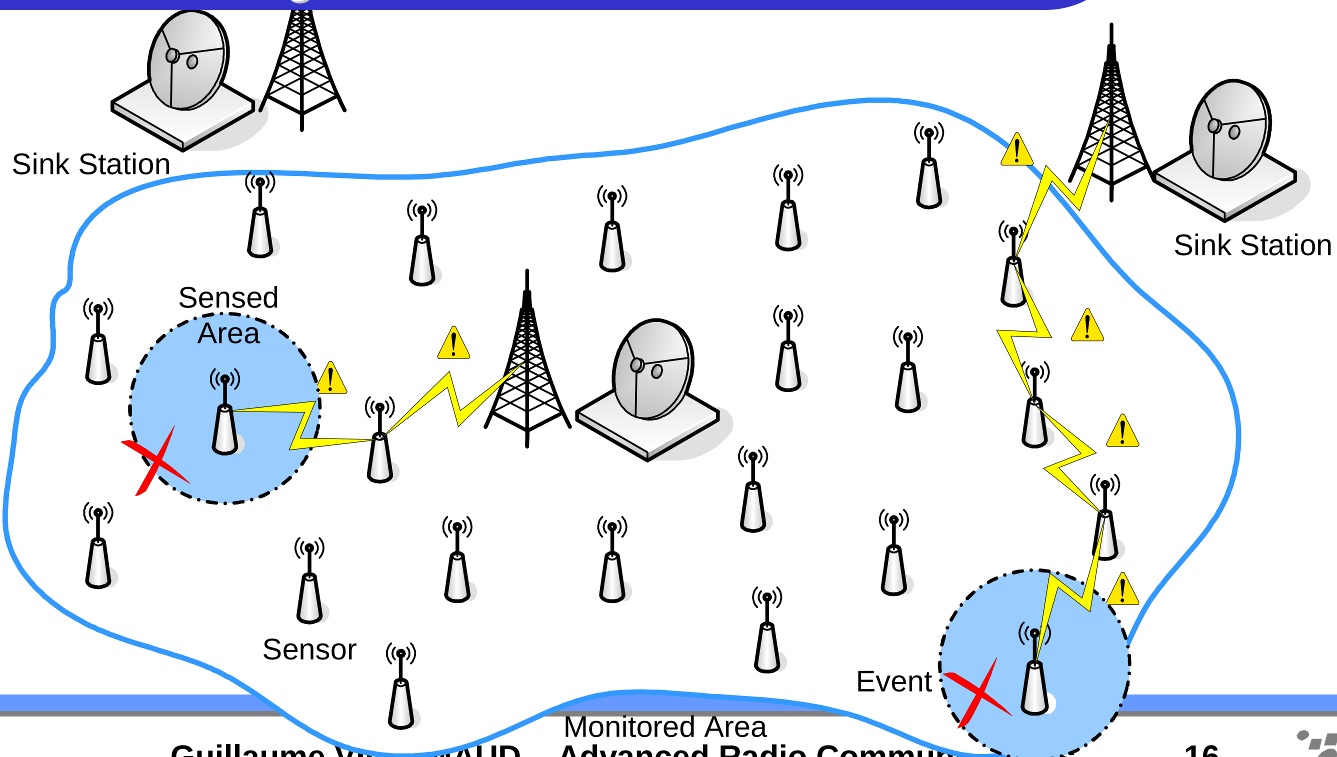
Ad hoc and sensor networks

Large scale networks with light (or null) infrastructure.

Features:

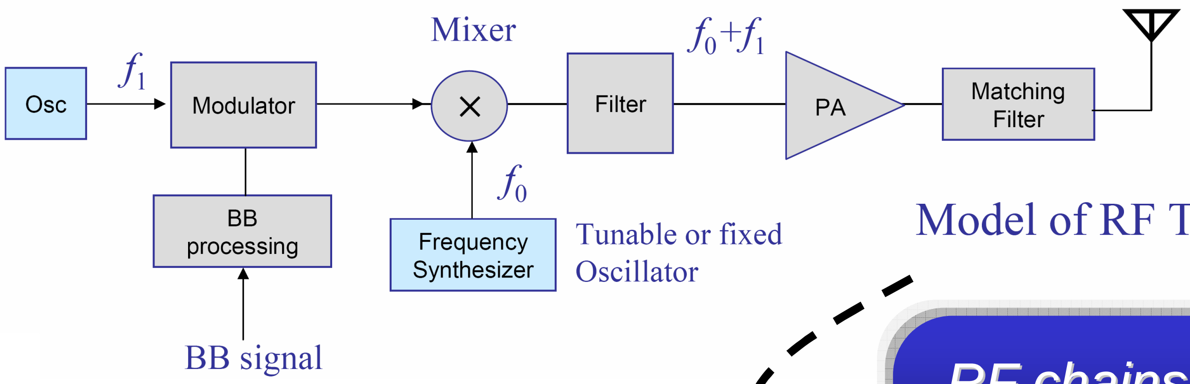
- *duplex links M2M*
- *omnidirectional Tx/Rx*
- *Low energy resources and cost*

Application: monitoring, detection, domotics…



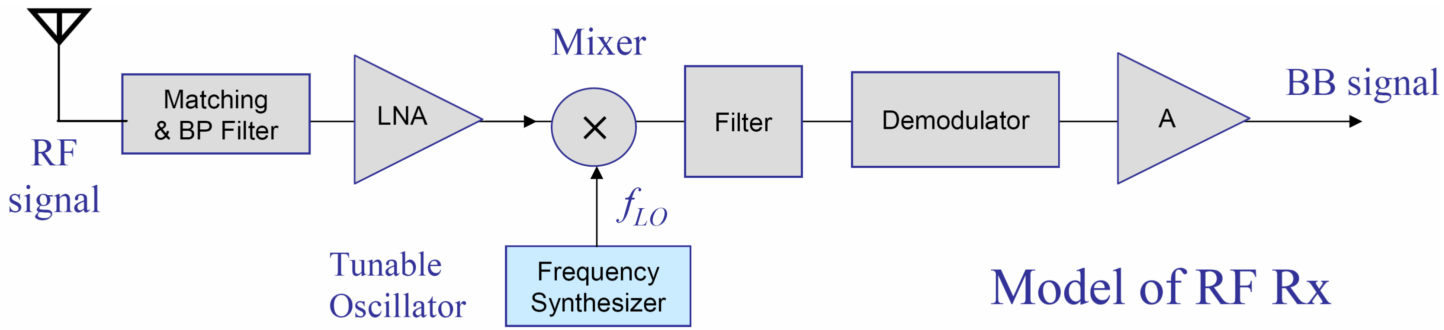
Transmission scheme

RF Vision



Model of RF Tx

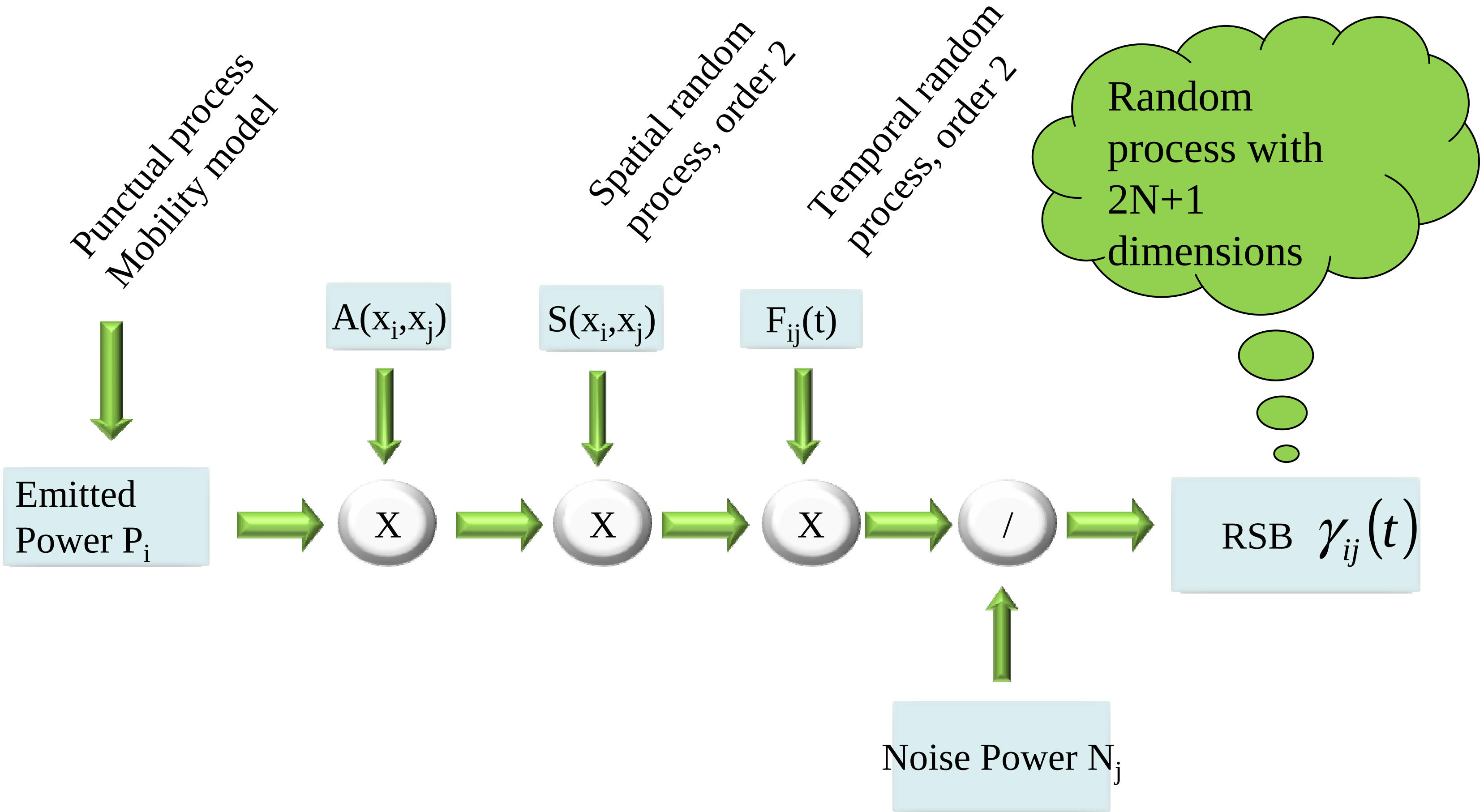
RF chains dimensioning depends on the dynamic of signals to deal with and tolerated distortions.



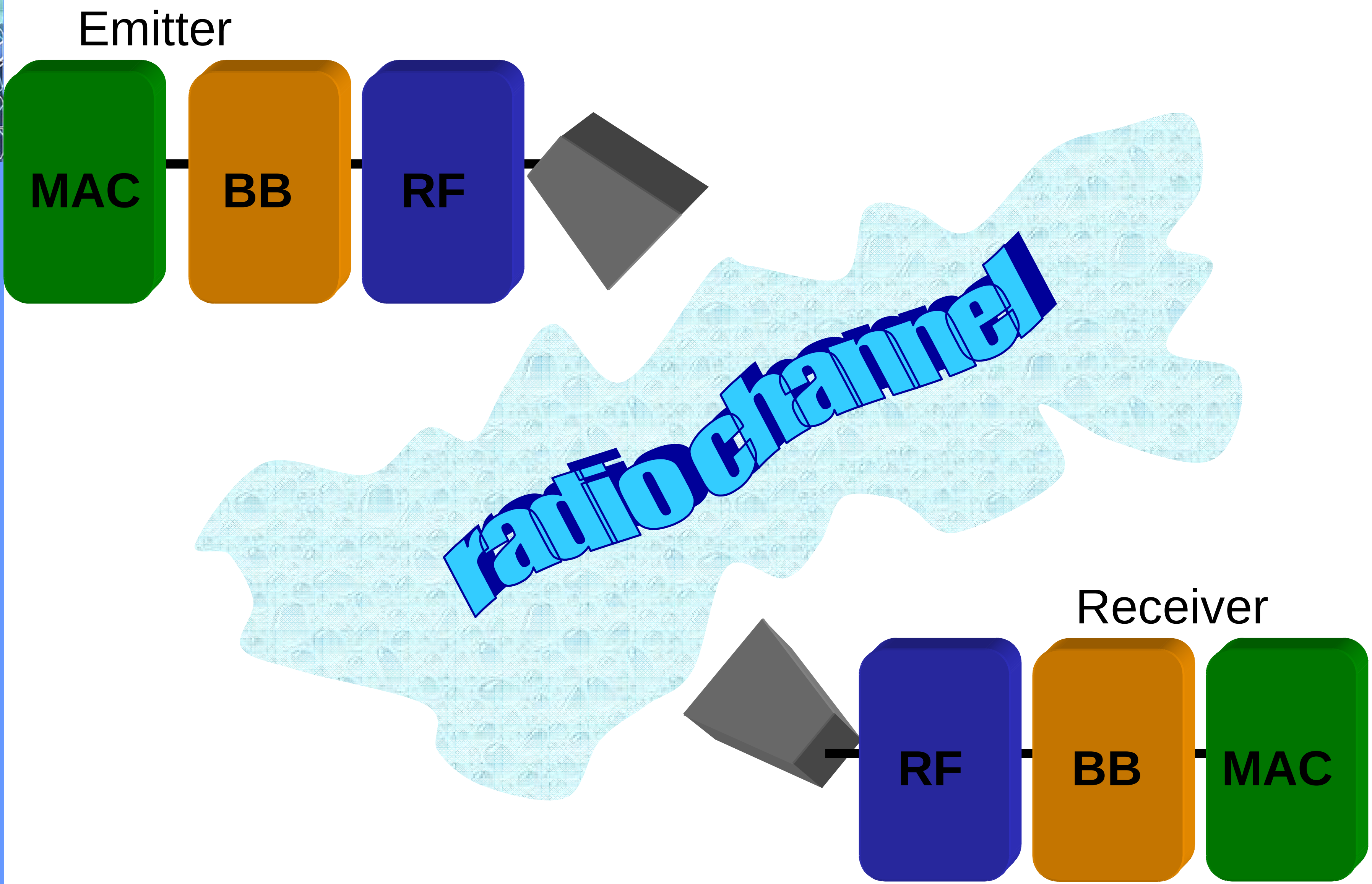
Model of RF Rx

Radio Channel Vision

Tends to express an analytical expression of radio channel variations.

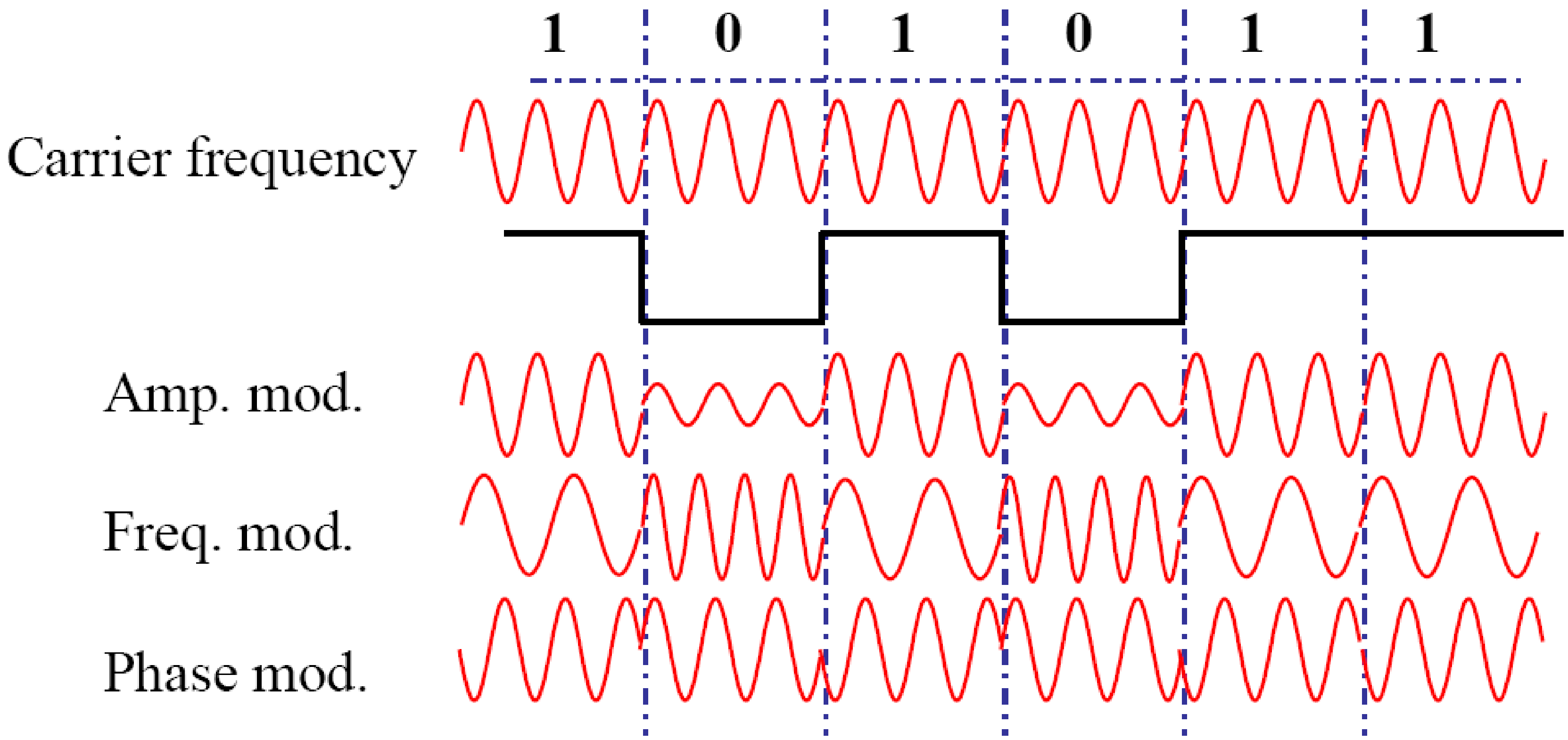


Global Vision



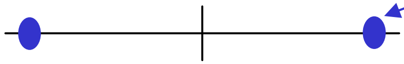
Modulation

Transmitting information



Phase shift keying

BPSK

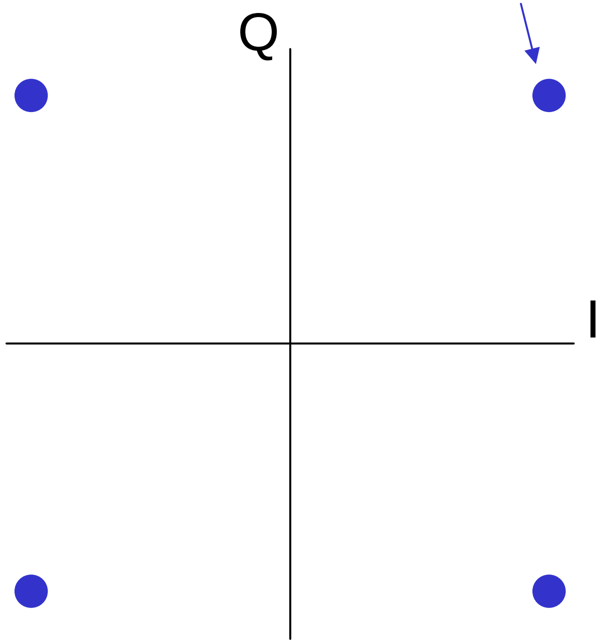


1 symbol = 1 bit

$$P_b = Q\left(\sqrt{\frac{2E_b}{N_0}}\right)$$

Increasing modulation order increases the encoded number of bits per emitted symbol.

1 symbol = 2 bits

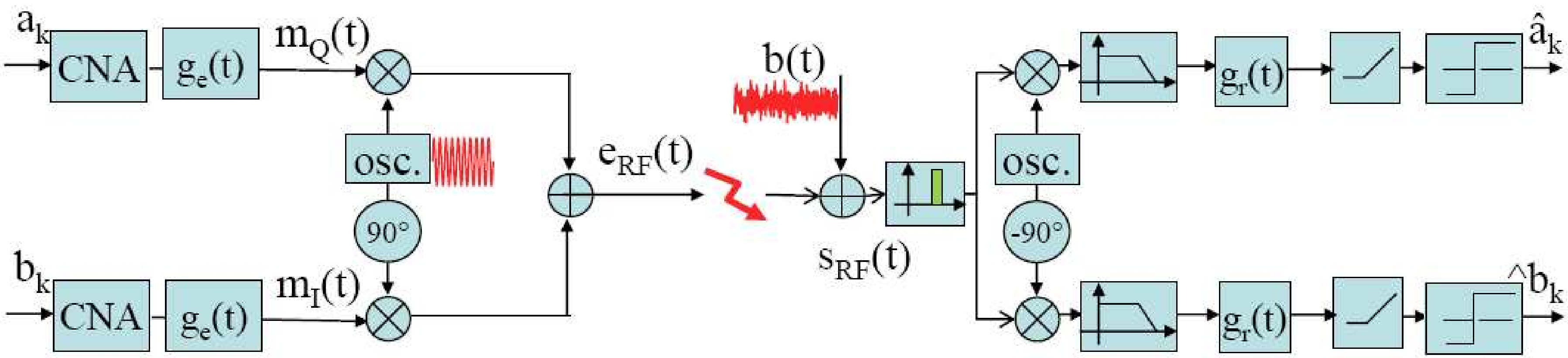


QPSK

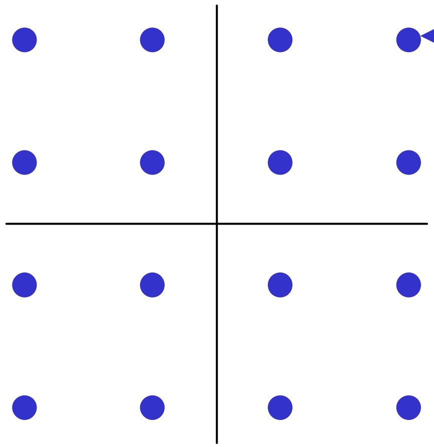
$$P_s \approx 2Q\left(\sqrt{\frac{E_s}{N_0}}\right)$$

IQ modulation

Information is mapped in a complex plane, modulated on an in-phase and in-quadrature branches.

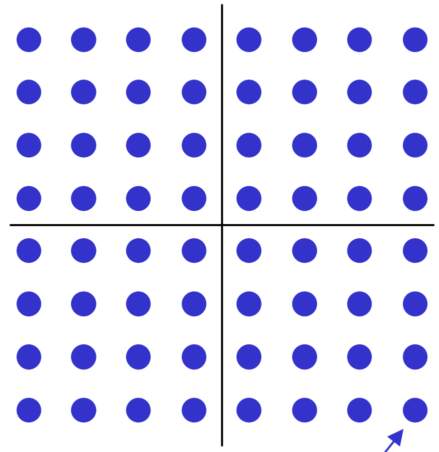


Quadrature Amplitude Modulation



1 symbol = 4 bits

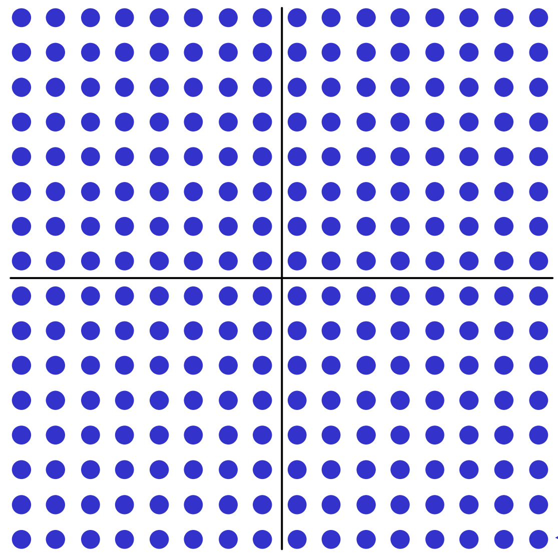
16 QAM



64 QAM

1 symbol = 6 bits

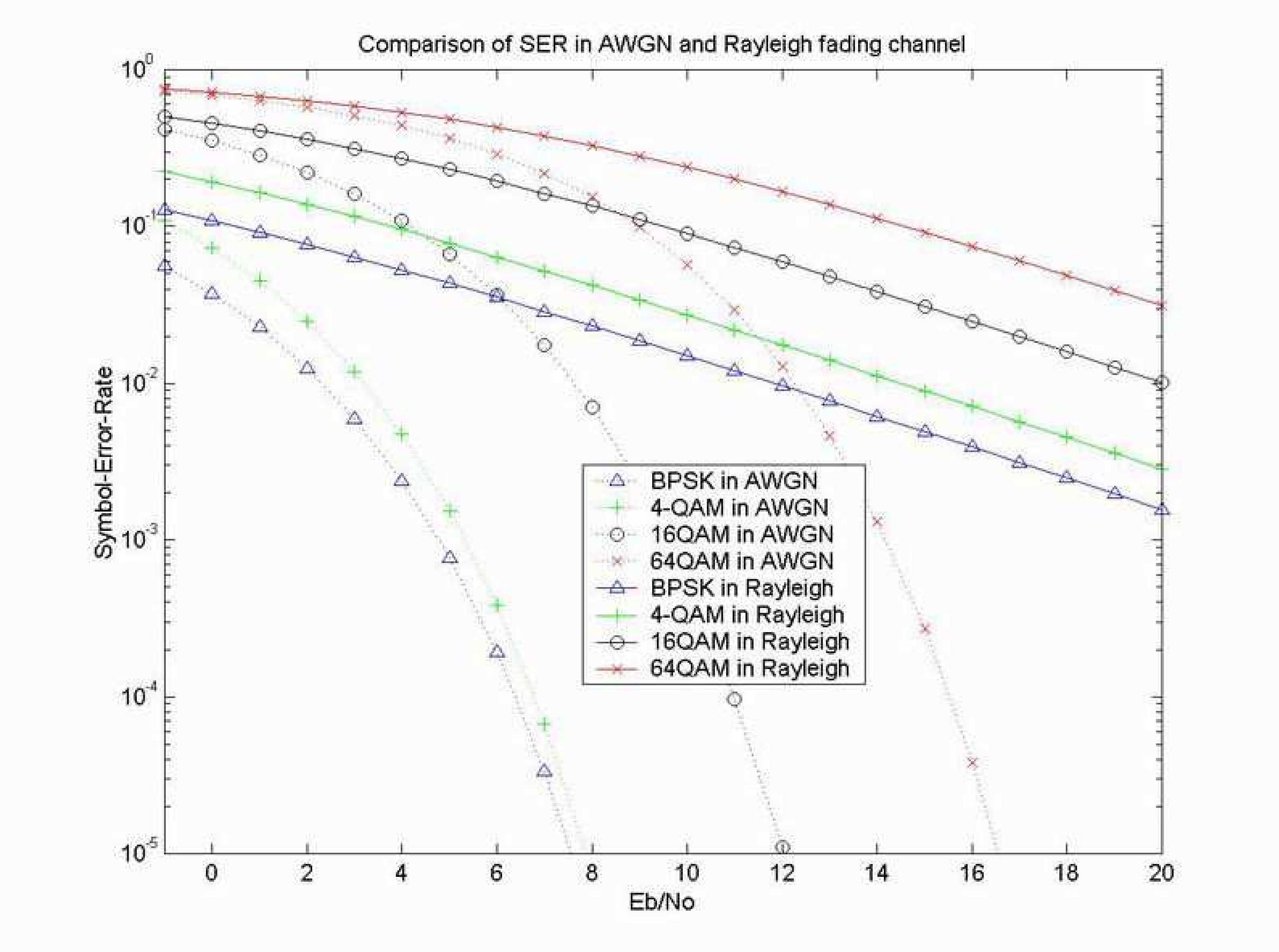
$$P_{sc} = 2\left(1 - \frac{1}{\sqrt{M}}\right) Q\left(\sqrt{\frac{3}{M-1}\frac{E_s}{N_0}}\right)$$



256 QAM

1 symbol = 8 bits

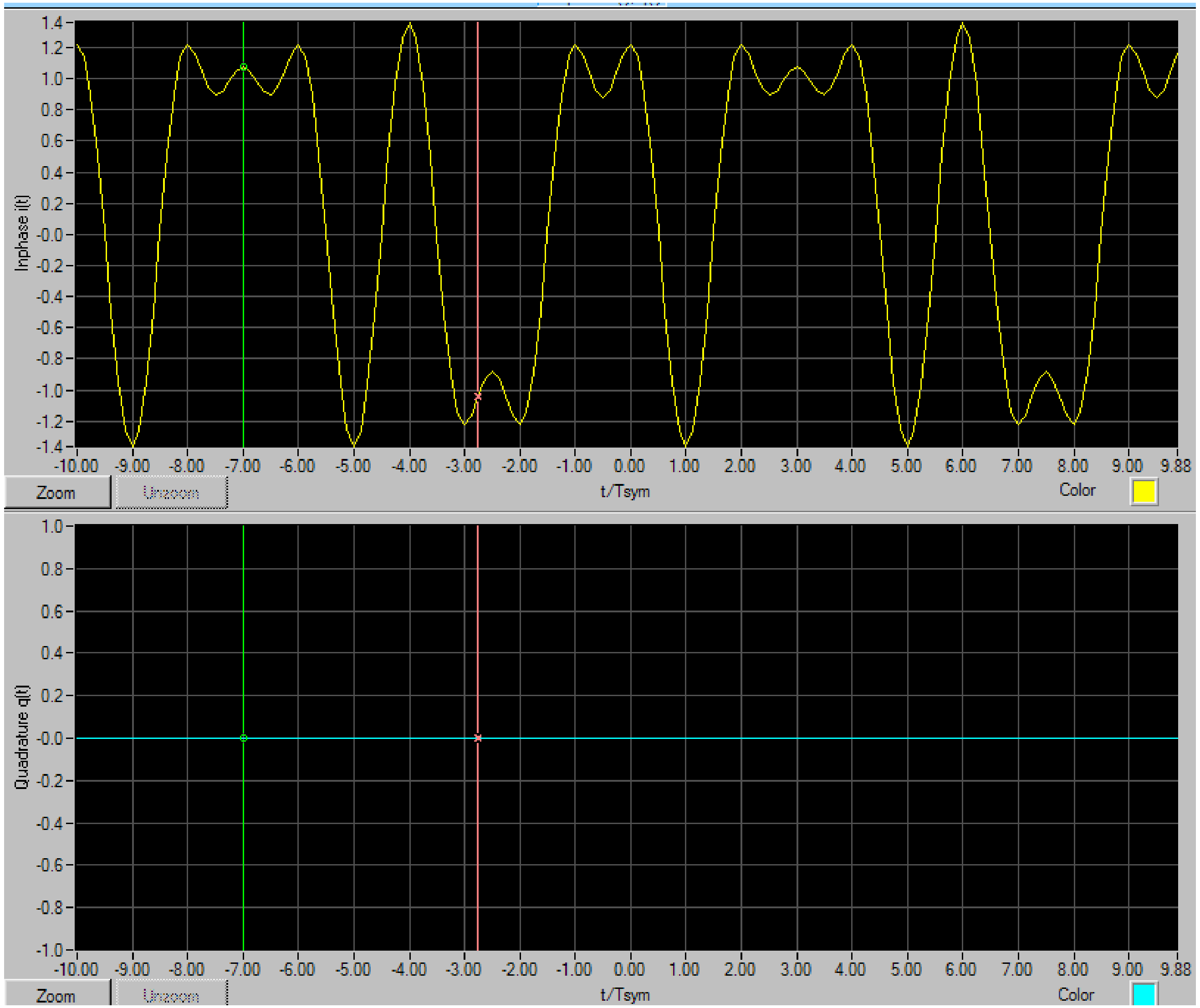
Symbol Error Rate Comparison



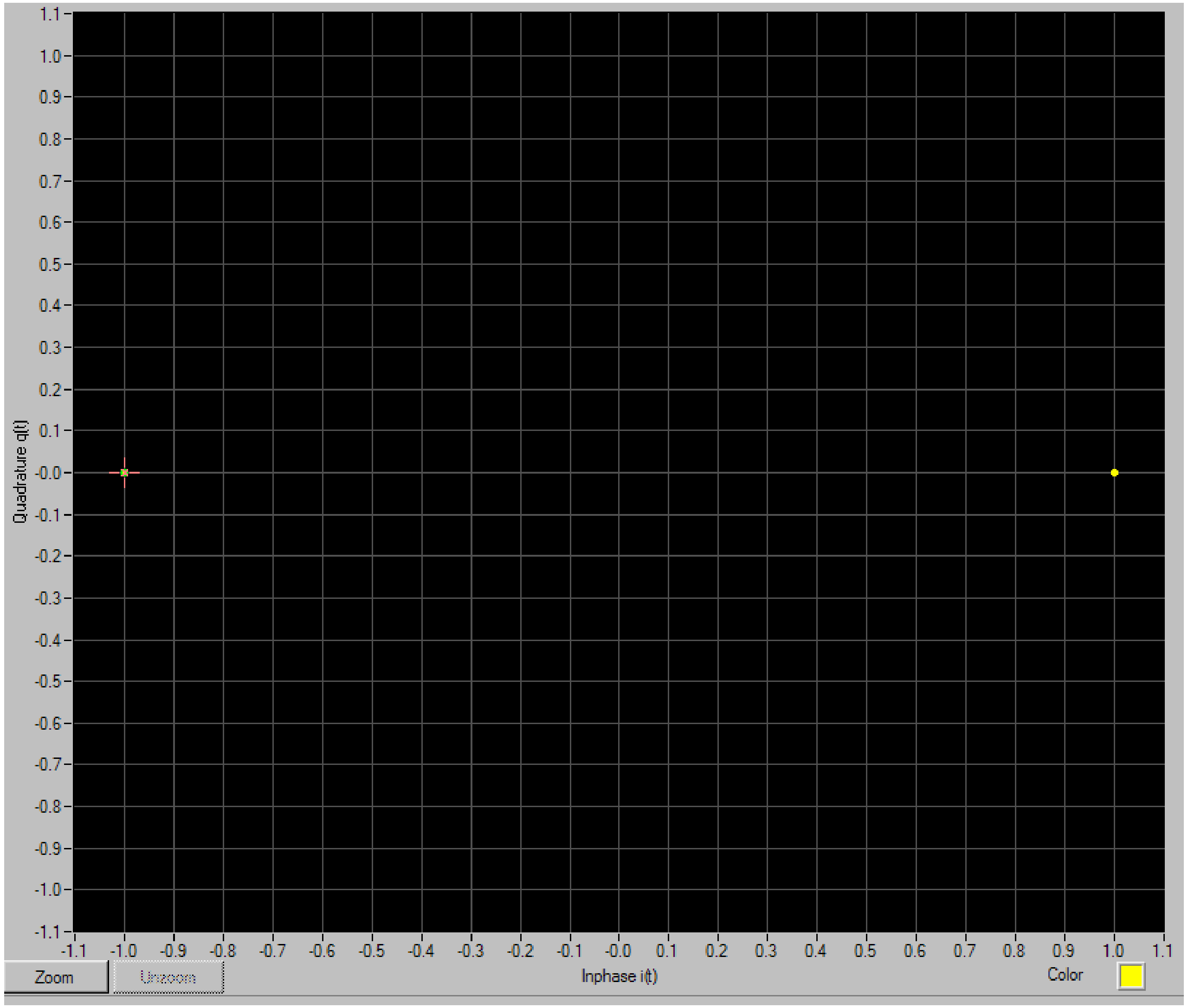
Some snapshots

sequence: 0100010110

BPSK



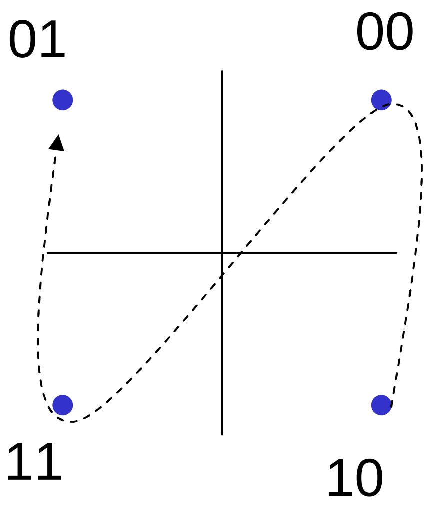
BPSK constellation

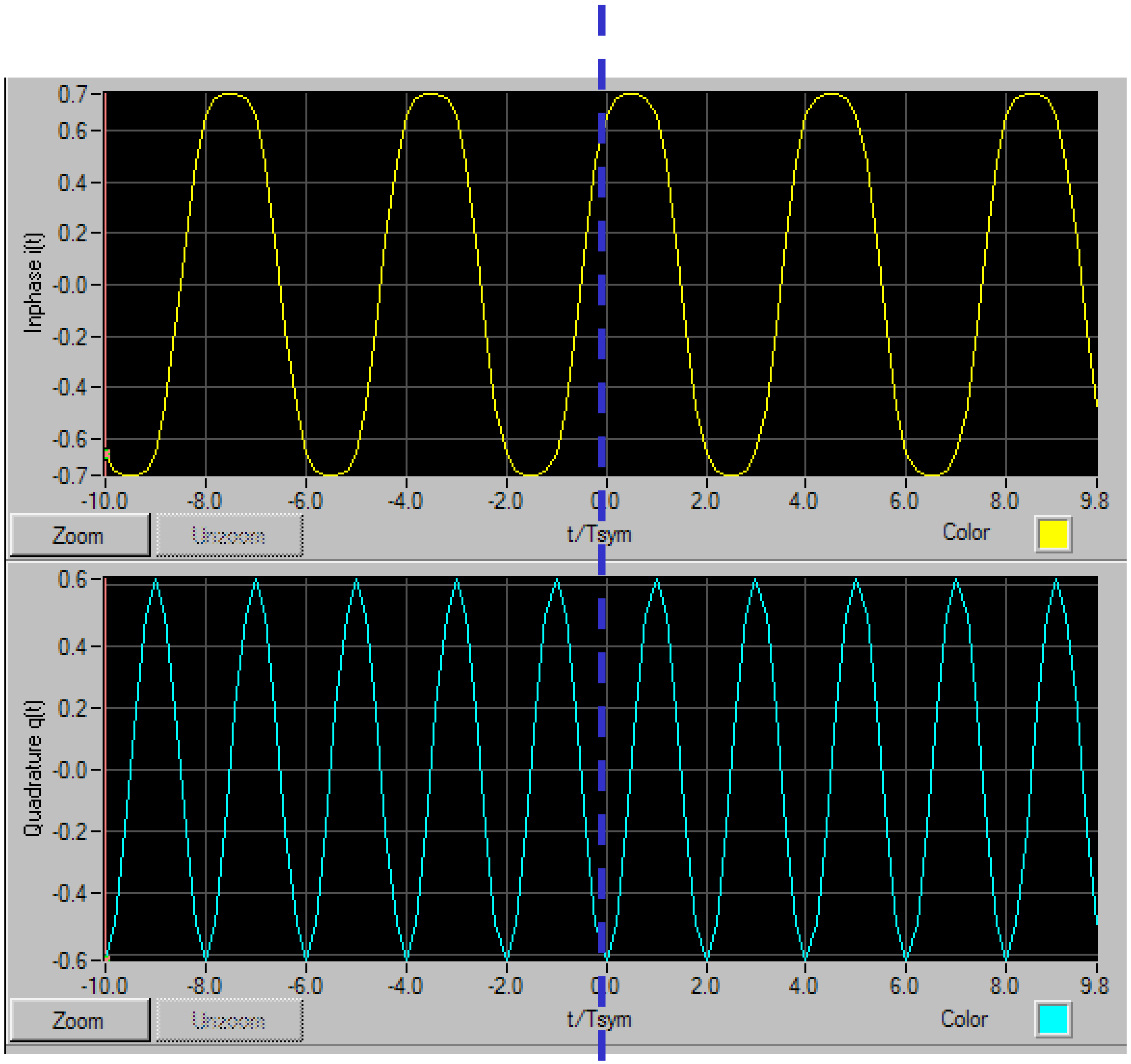


QPSK in time

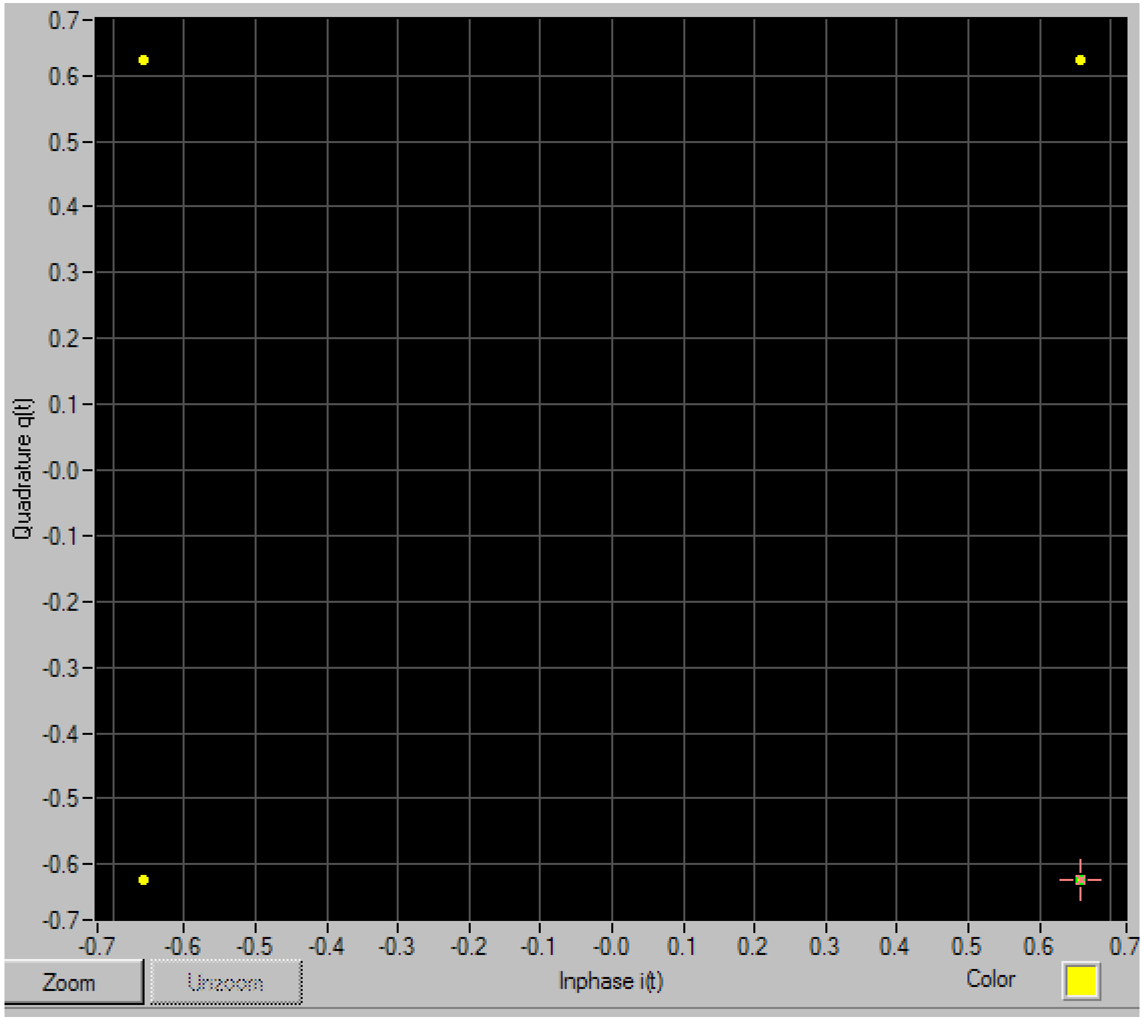
sequence: 10 00 11 01

QPSK



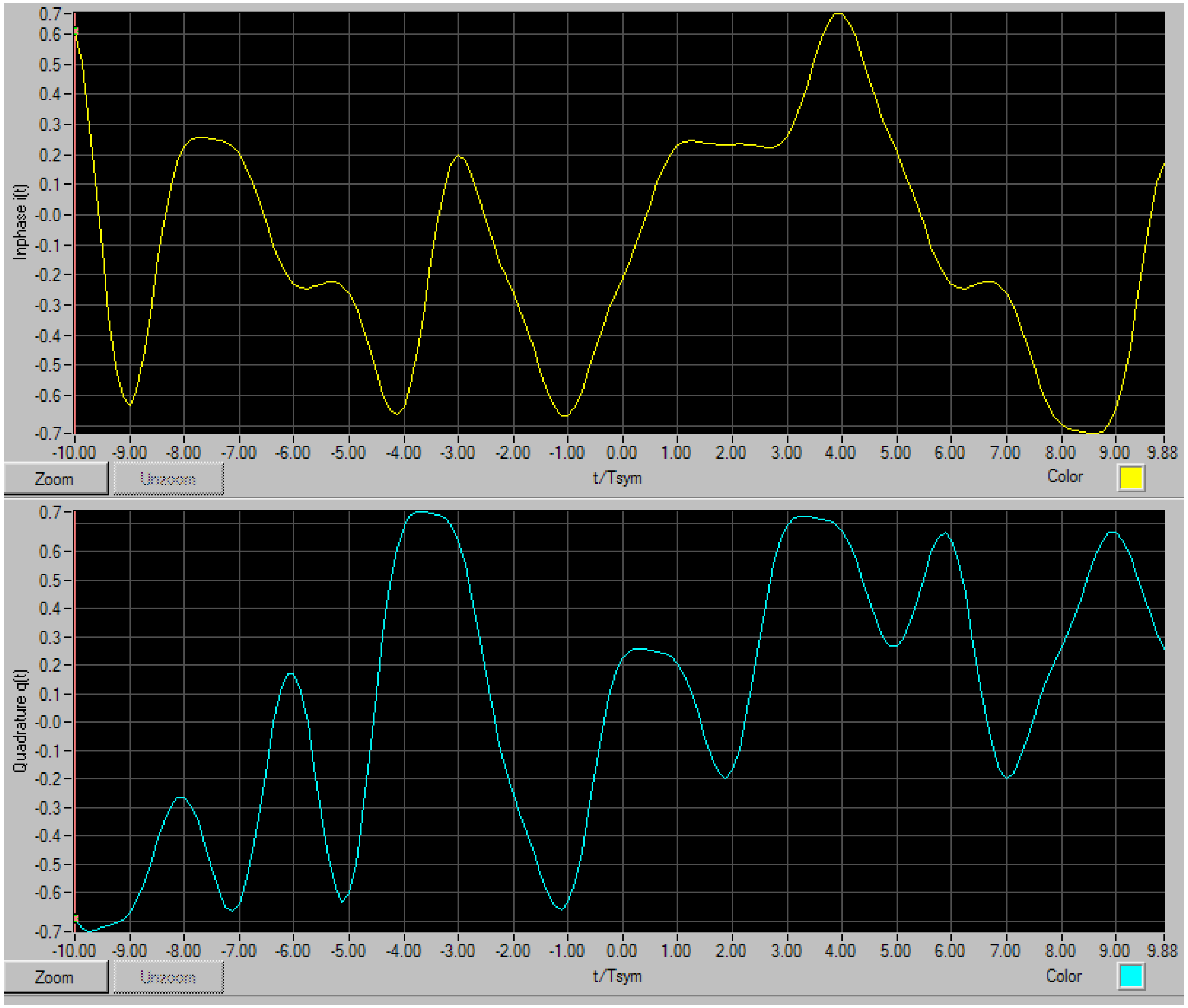


QPSK constellation

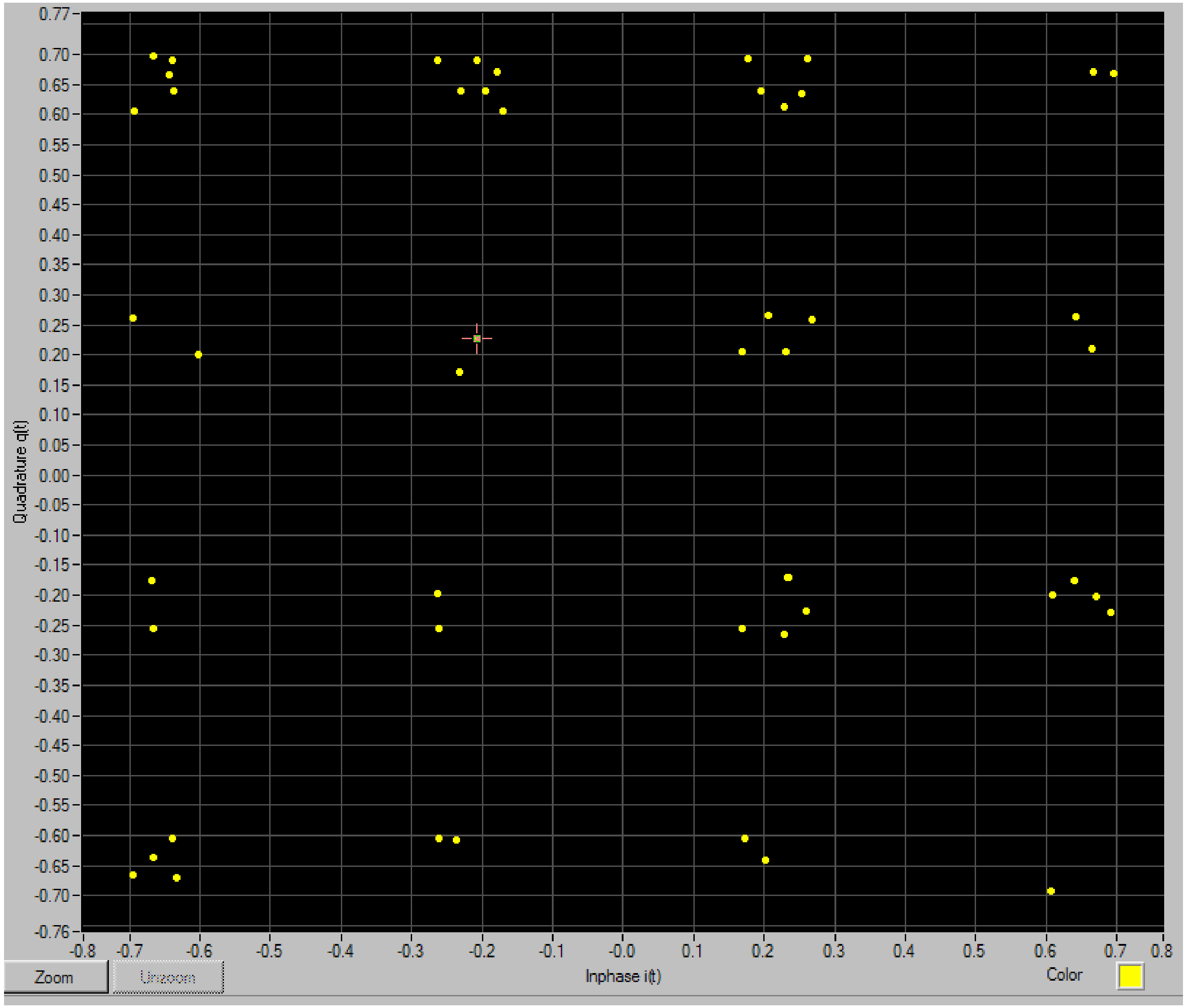


QAM in time

16QAM



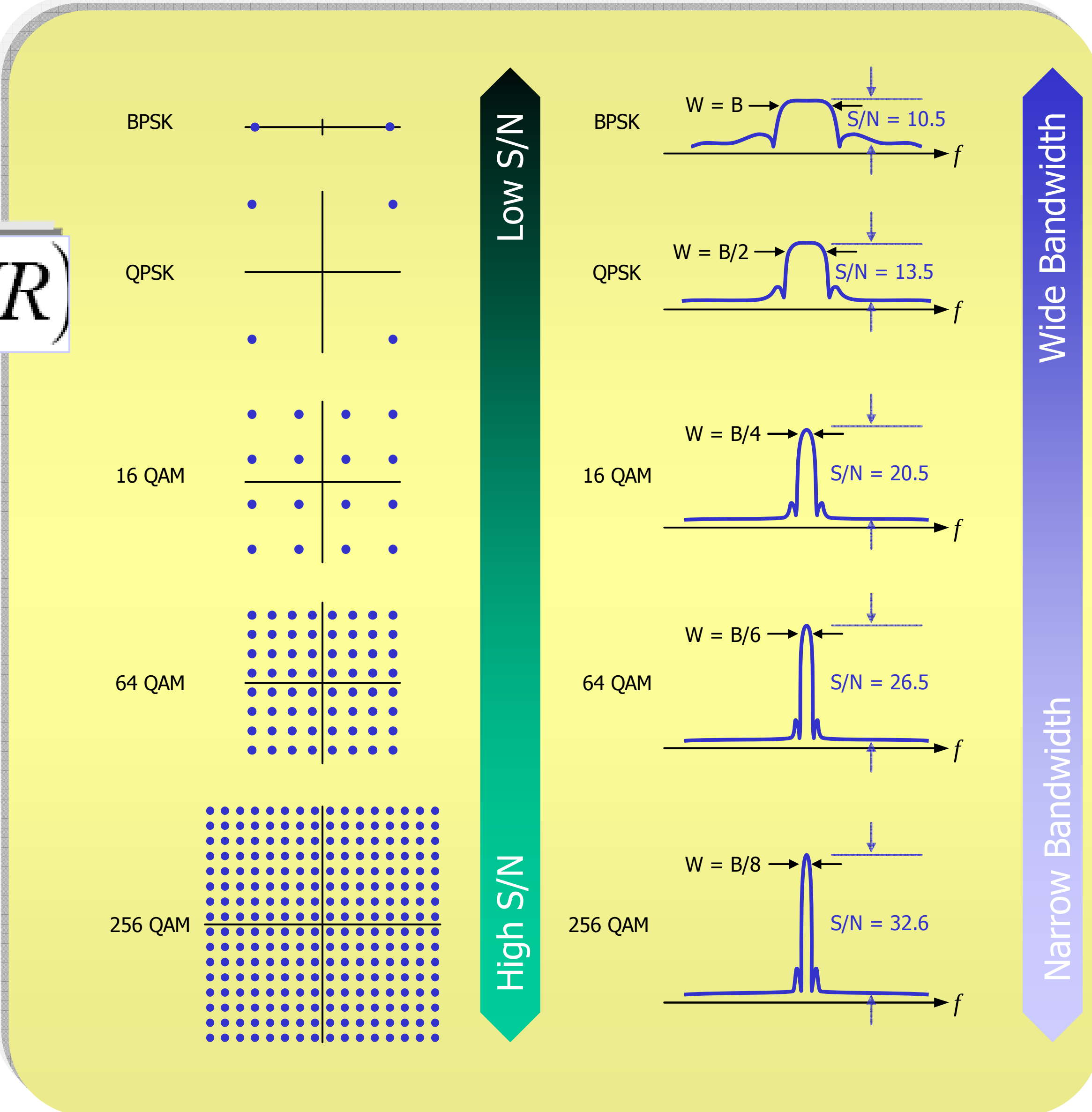
QAM constellation



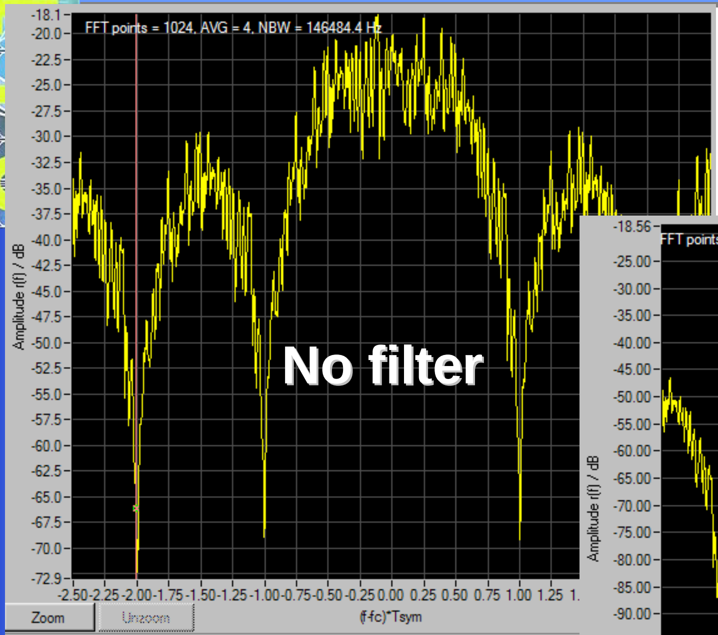
Channel capacity

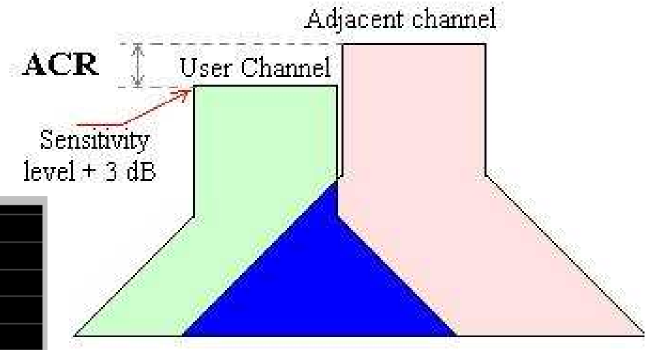
$$C = W \cdot \log_2 (1 + SNR)$$

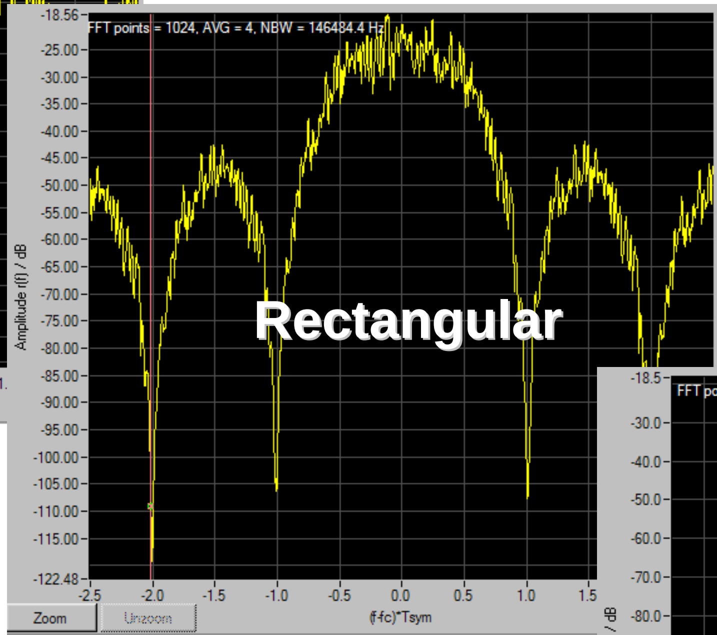
For a fixed W, the capacity depends on the available SNR (basis of adaptive modulation schemes).

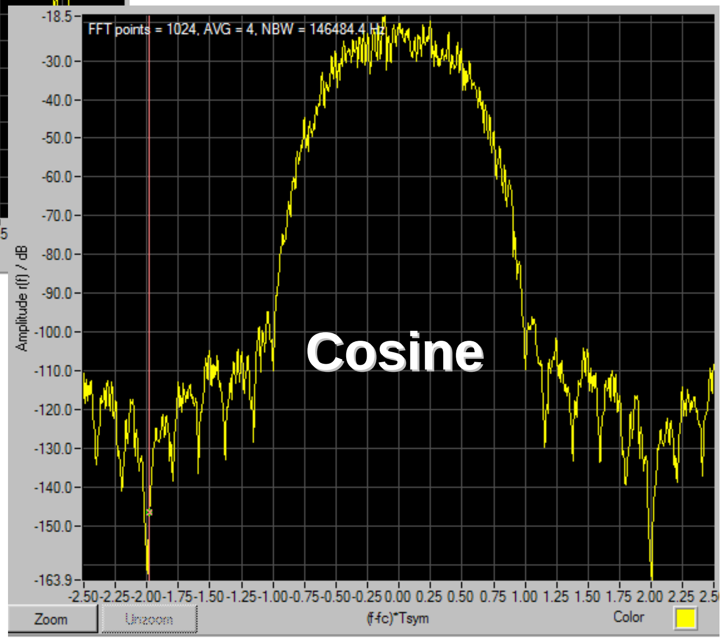


Spectrally viewing...







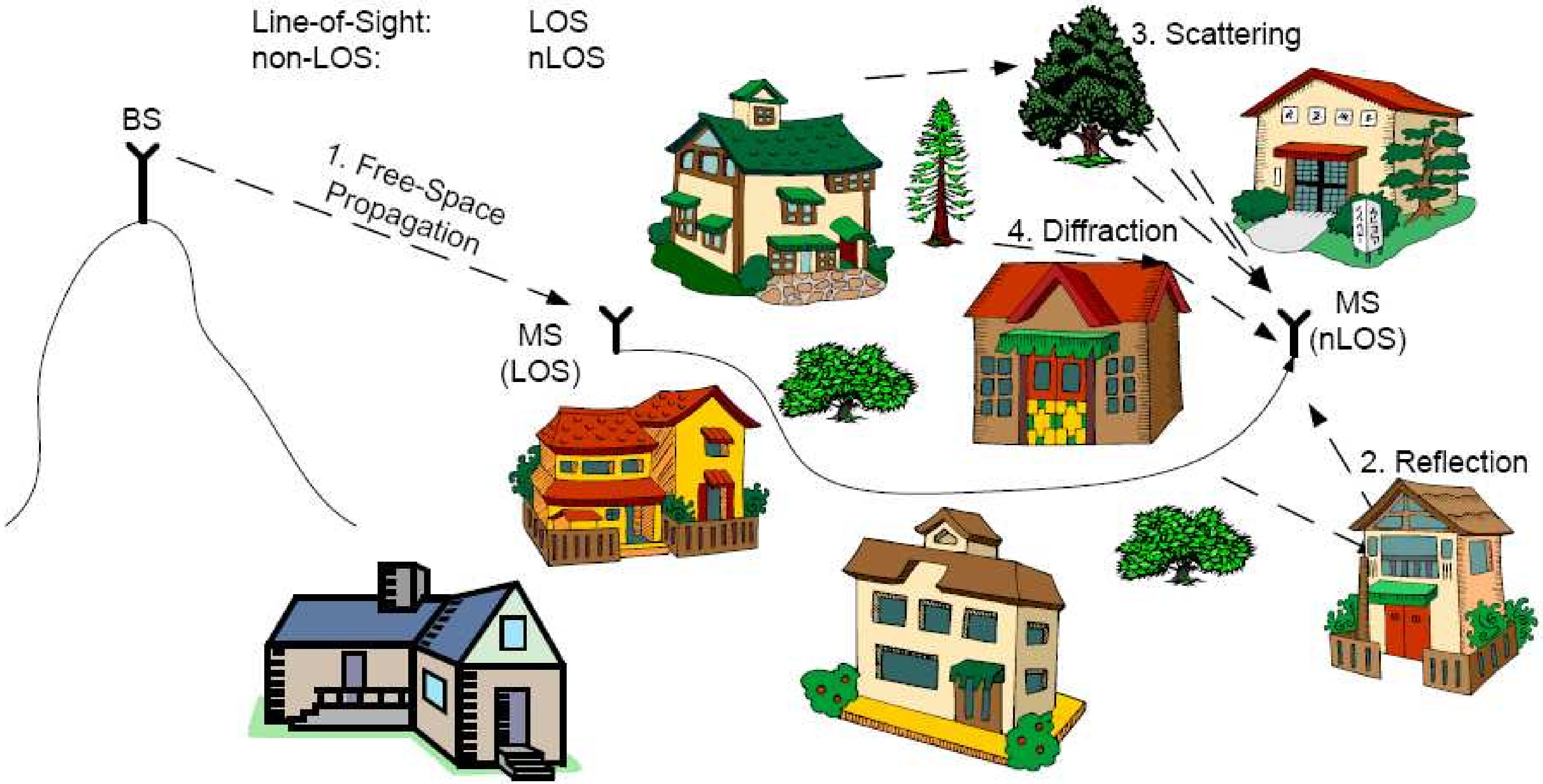


So don't forget the filters !!!

Wireless Channel

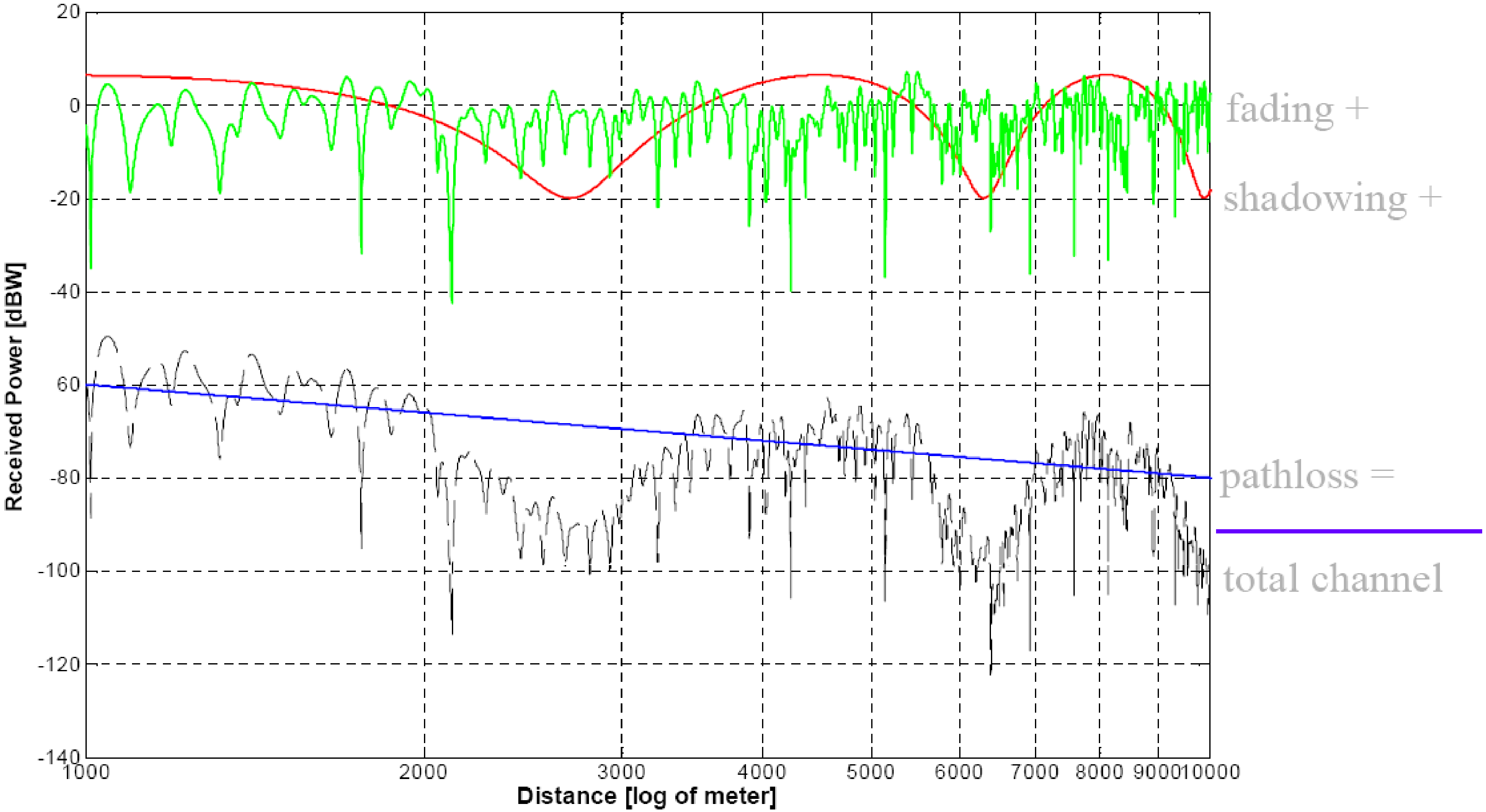
A look on topology

Base Station:	BS
Mobile Station:	MS
Line-of-Sight:	LOS
non-LOS:	nLOS



Propagation channel

To estimate radio link quality, we need to know the effective received power.



Link budget

Free space Friis' formula

$$P_r = \left(\frac{\lambda}{4\pi r}\right)^2 \cdot G_e \cdot G_r \cdot P_e$$

Pr : received power at Rx

Pe : emitted power at Tx

Ge : Tx antenna gain

Gr : Rx antenna gain

r : Tx/Rx distance

Antenna gain

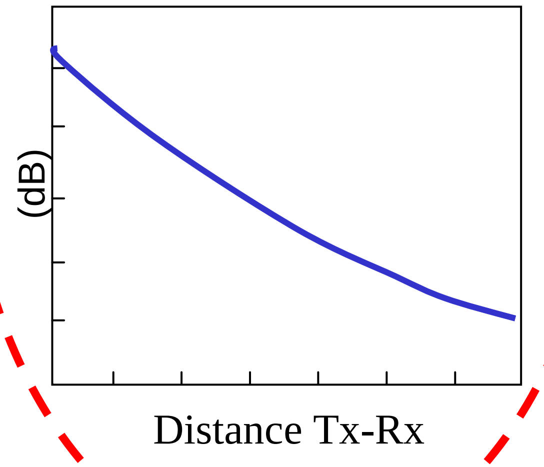
$$G(\theta,\phi) = \frac{\Delta P(\theta,\phi)}{P_f/4\pi}$$

Multiplying factor allowing to render the power density created in a particular direction. This factor does not depend on feeding power but includes losses of the antenna (matching and materials).

More details

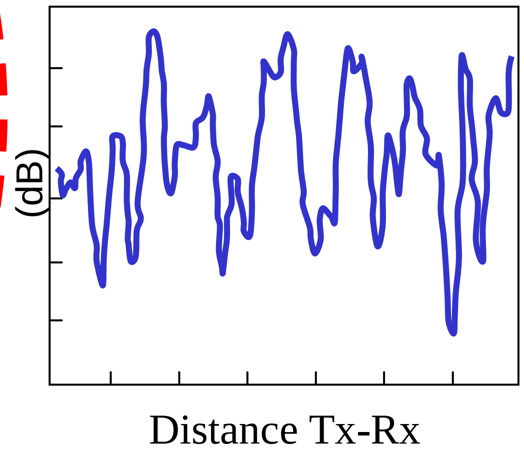
Path loss

Attenuation proportional to the distance



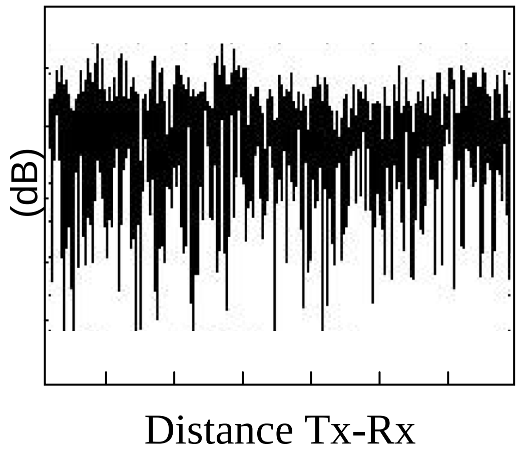
Shadowing

Slow variation due to obstacle



Fading

Fast variation due to multi-path



Reality

In a real environment, the 3 phenomenon are added (in dB, multiplied in linear scale !)

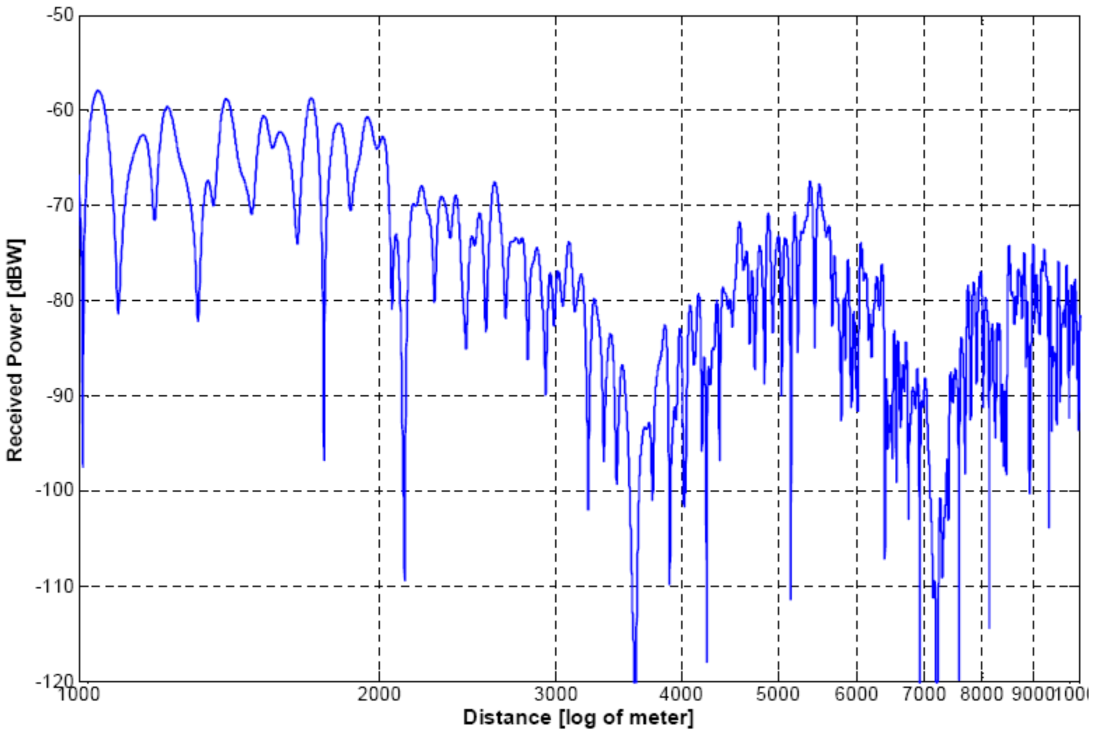
Path loss

+

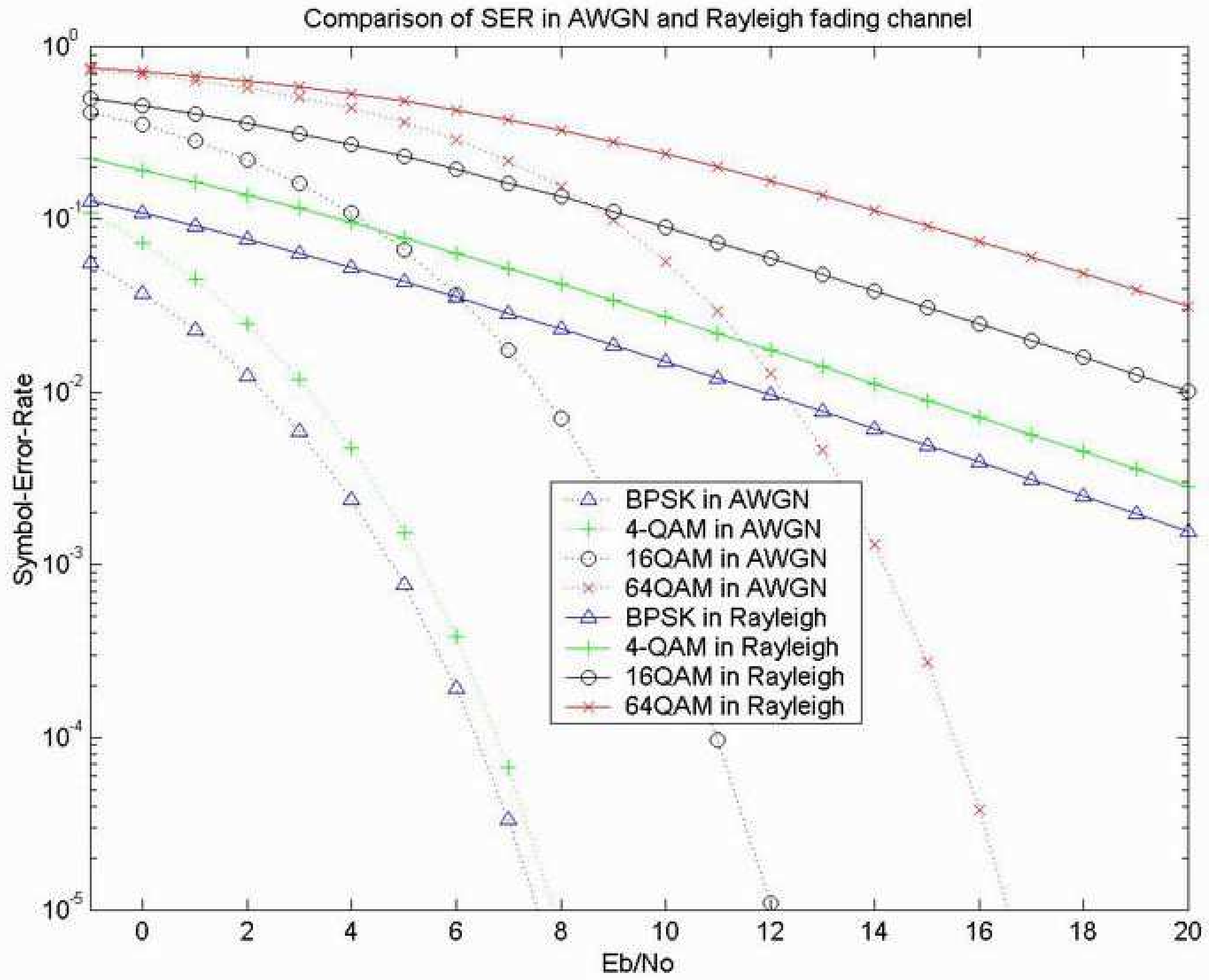
Shadowing

+

Fading



Back to the SER



More complete Friis' formula

$$P_r = P_e G_e G_r k \frac{\lambda^2}{r^n} \alpha_{shad} \alpha_{fading}$$

Long term (α_{shad}) — Short term (α_{fading})

Pe: constant
Ge and Gr function of direction (spatial filters)
k and n depending on environment

General modeling

Free-space pathloss model: $P(d) = P(d_0) \cdot \left(\frac{d_0}{d} \right)^2$

- loss of -20dB/decade distance
- very simple model, but not very realistic
- application in satellite channels and over short LOS distances

Single-slope pathloss model: $P(d) = P(d_0) \cdot (d_0 / d)^n$

- n = 1.5 (waveguides), n = 2…4 (LOS + clutter), n = 4…6 (nLOS + clutter)
- simple and more accurate model, but correct reference point d_0 has to be found
- application in WLANs, interference power in cellular systems, etc.

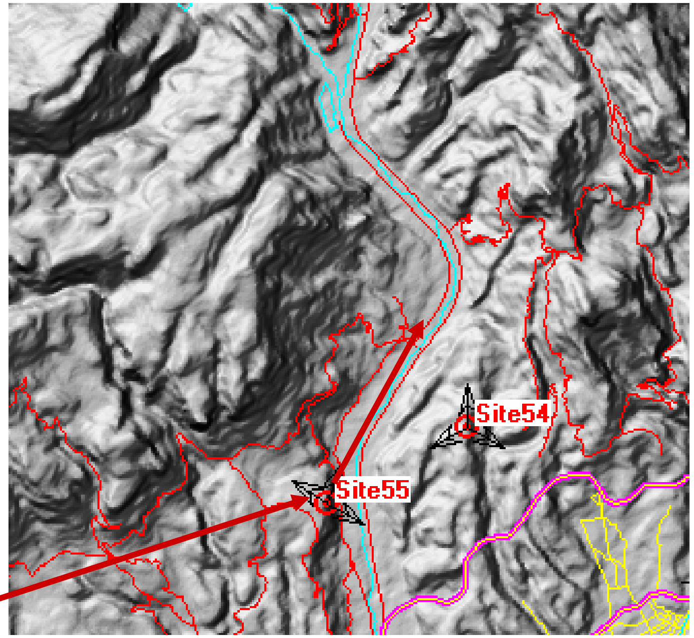
Dual-slope pathloss model: $P(d) = P(d_0) \cdot (d_0 / d)^{n_1}, P(d) = P(d_{BP}) \cdot (d_{BP} / d)^{n_2}$

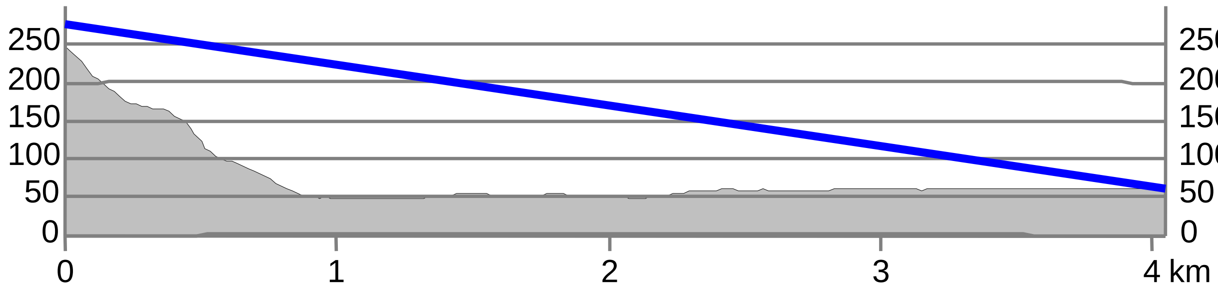
- $d < d_{breakpoint}$: $n_1 = 2$ (normally), $d > d_{breakpoint}$: $n_2 = 2 \ldots 6$ (nLOS + clutter)
- simple and more accurate model, but requires strong LOS + once refl. component
- application in long-range WLANs and cellular systems

Signal attenuation

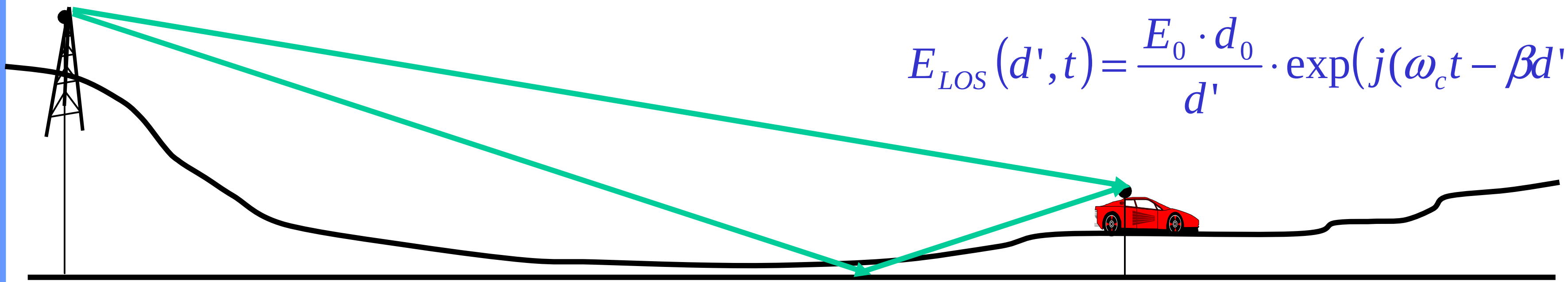
Ground effect

Need a lot of informations on the real environment to evaluate line-of-sight conditions.





Two-ray model



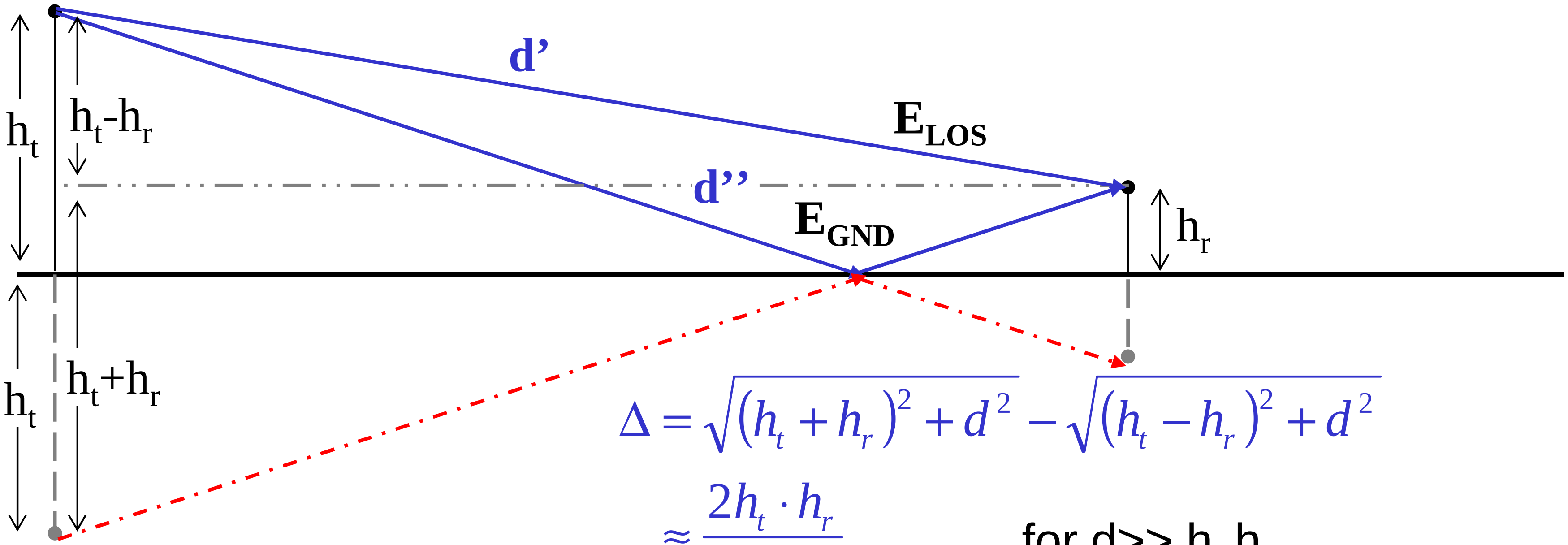
$$E_{LOS}(d',t) = \frac{E_0 \cdot d_0}{d'} \cdot \exp\left(j(\omega_c t - \beta d')\right)$$

$$E_{GND}(d'',t) = \underline{R} \cdot \frac{E_0 \cdot d_0}{d''} \cdot \exp\left(j(\omega_c t - \beta d'')\right)$$

$$E_{TOT}(d,t) = \frac{E_0 \cdot d_0}{d} \cdot \exp\left(j(\omega_c t - \beta d')\right) \cdot \left[1 + \underline{R} \cdot \exp(-j\beta\Delta)\right]$$

$$PL \approx 22 + 20\log(\frac{d}{\lambda}) - 20\log\left|1 + \underline{R} \cdot \exp(-j\beta\Delta)\right|$$

Geometrical model



$$\Delta = \sqrt{(h_t + h_r)^2 + d^2} - \sqrt{(h_t - h_r)^2 + d^2}$$

$$\approx \frac{2h_t \cdot h_r}{d}$$

for d>> h_t,h_r

PL becomes :

$$PL \approx 22 + 20\log\left(\frac{d}{\lambda}\right) - 20\log\left|\sin\left(\frac{\varphi}{2}\right)\right|$$

with : $\varphi = \frac{2\pi\Delta}{\lambda}$

At long distance

PL becomes :

$$PL \approx 22 + 20\log\left(\frac{d}{\lambda}\right) - 20\log\left|\sin\left(\frac{\varphi}{2}\right)\right|$$

with : $\varphi = \frac{2\pi\Delta}{\lambda}$

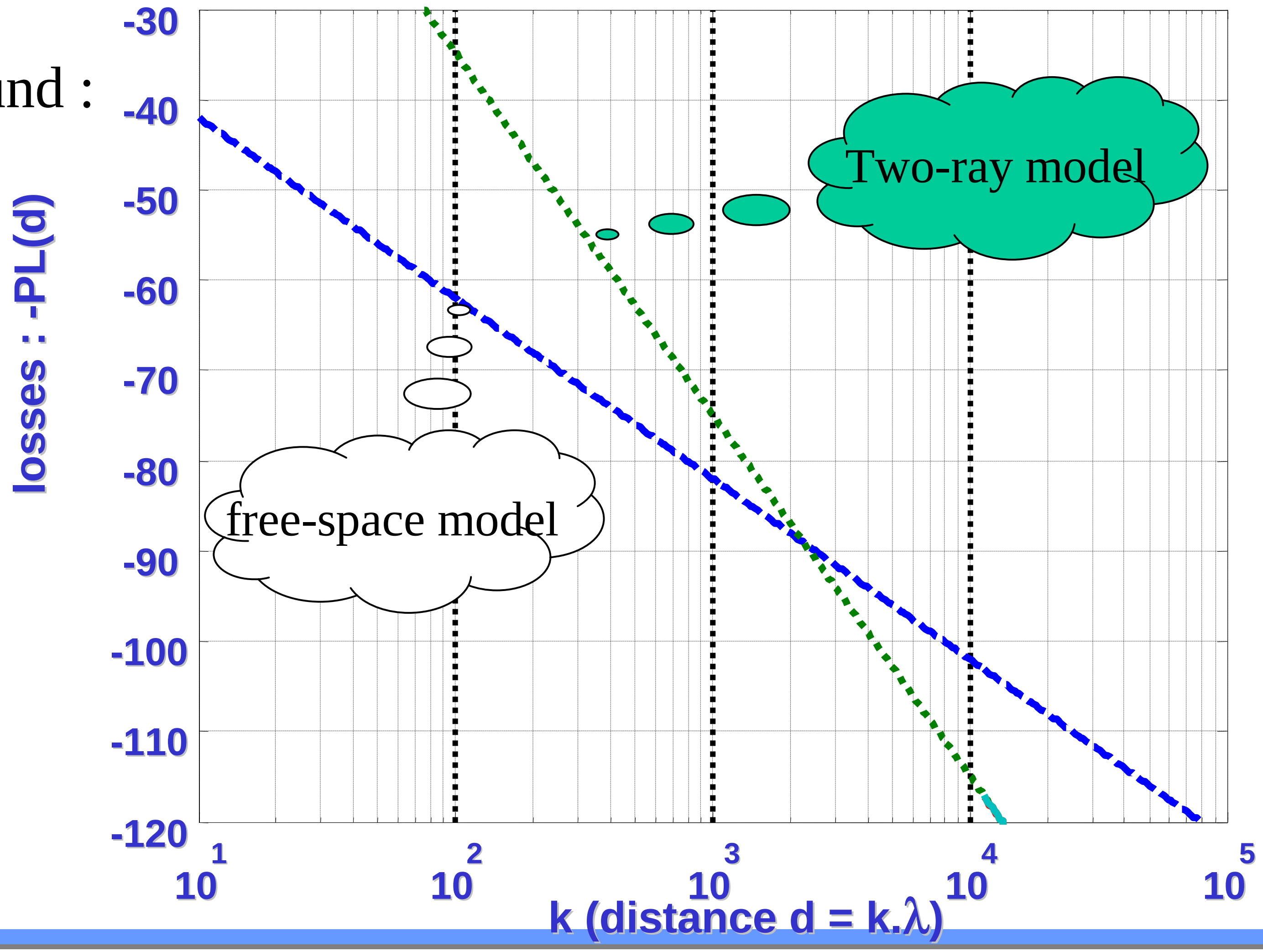
if $d > \frac{20 \cdot h_r \cdot h_t}{\lambda \cdot}$ (sin φ → φ)

we obtain :

$$PL = 40\log d - 20\log h_T - 20\log h_R$$

Example : GSM, λ=30cm, h_E=15m; h_R=1,5m

Dry ground : ε_r=5



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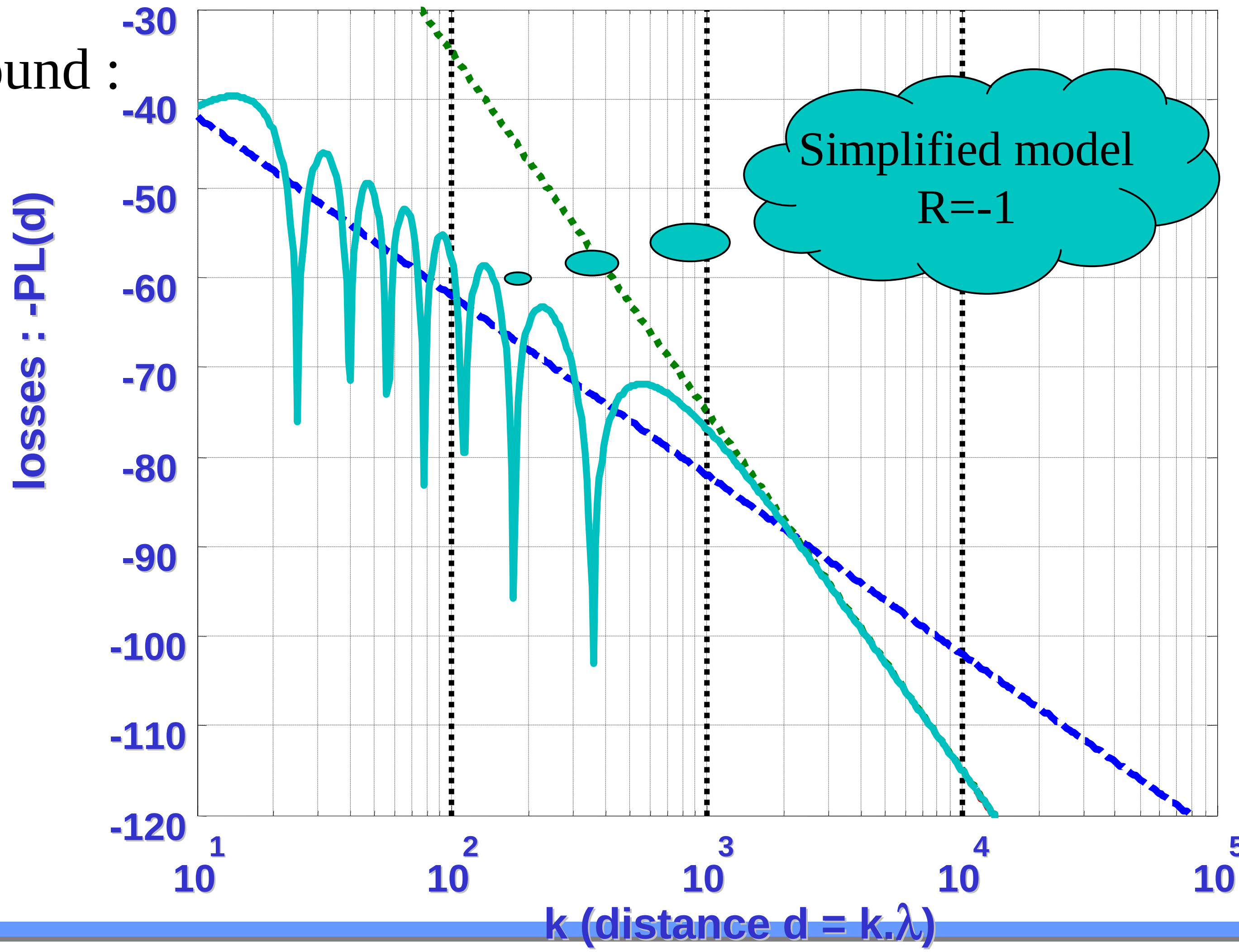
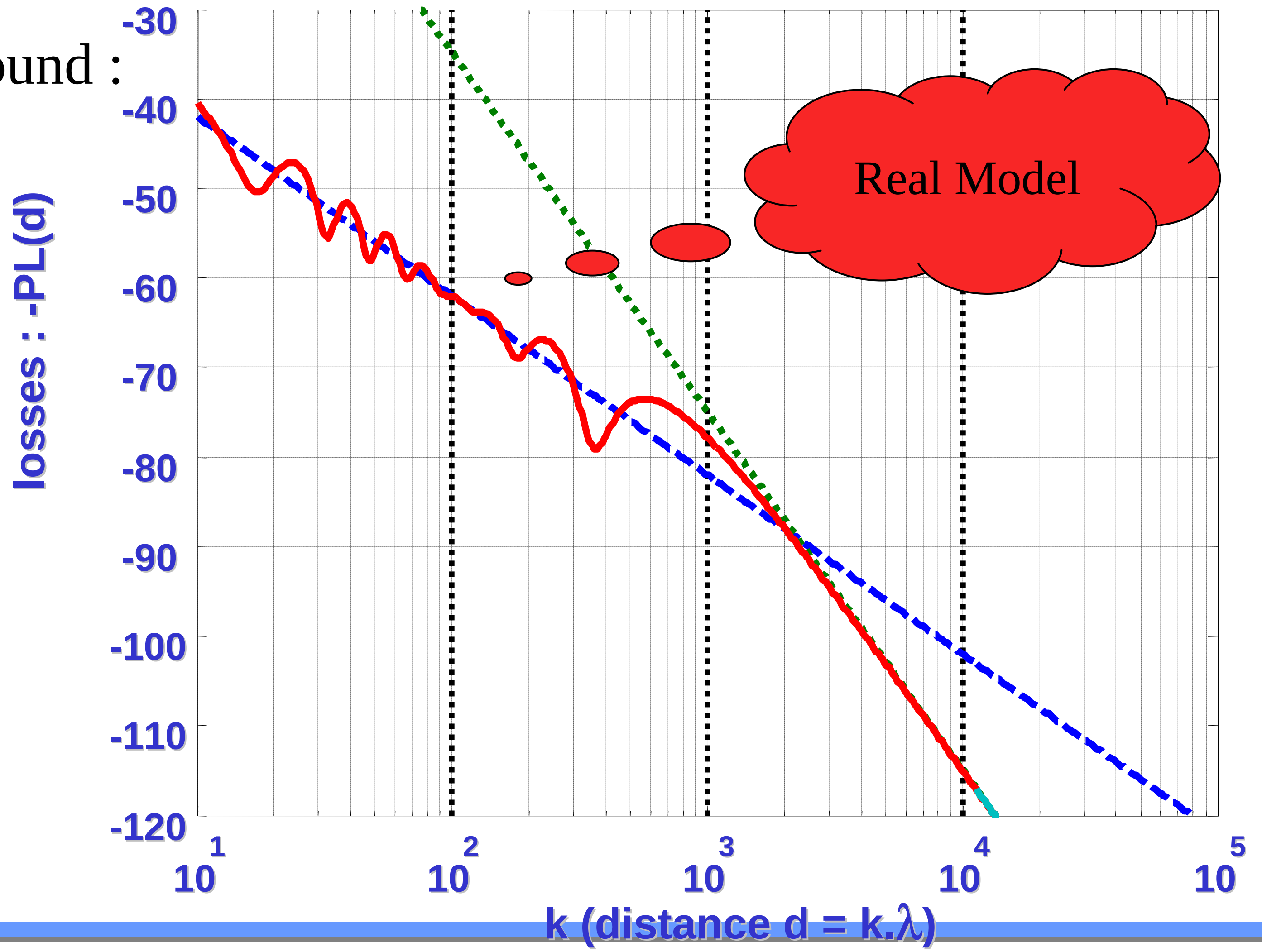
ε_r=5

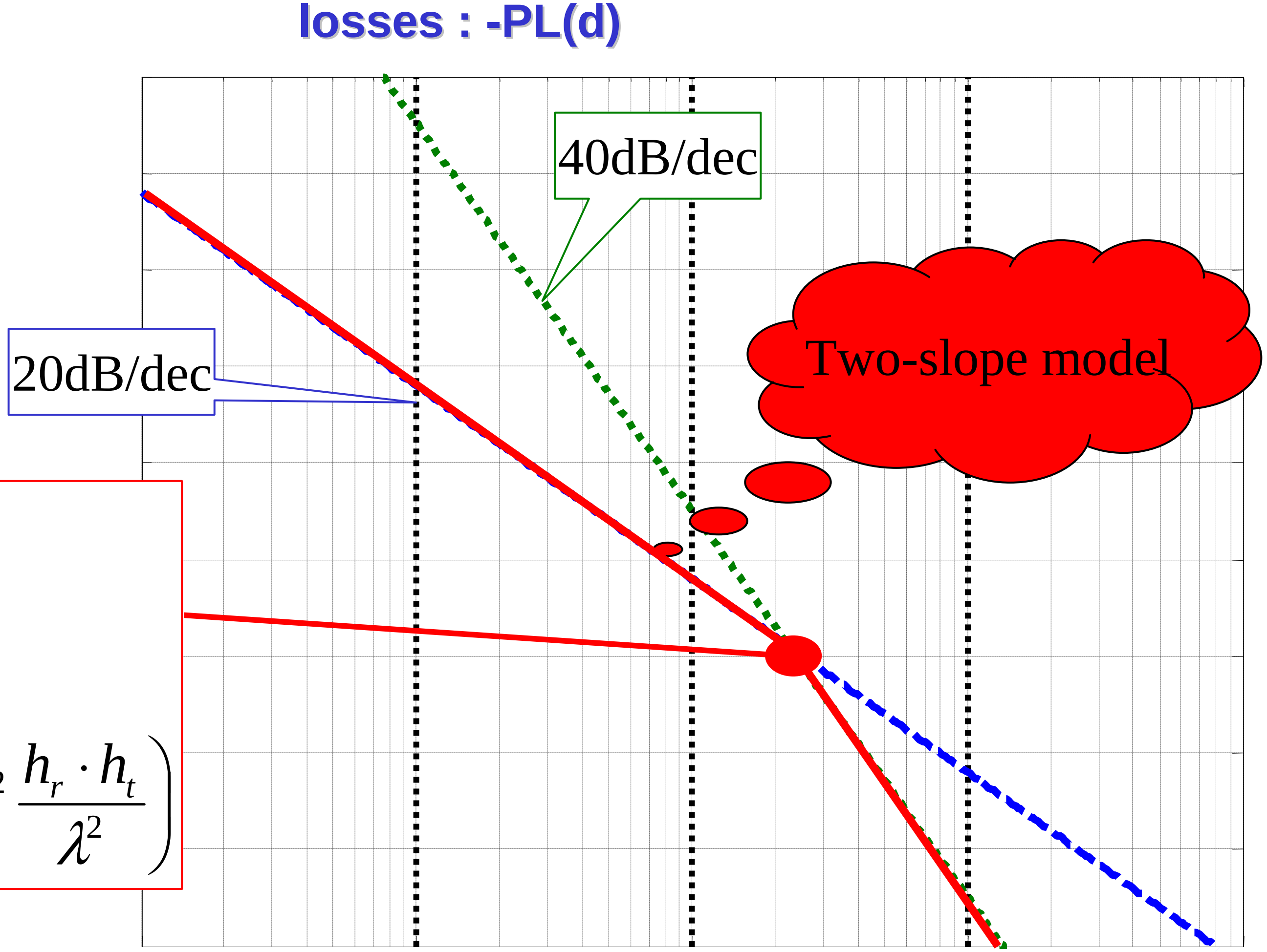


Example : GSM, λ=30cm, h_E=15m; h_R=1,5m

Dry ground :
ε_r=5



Example : GSM, λ=30cm, h_E=15m; h_R=1,5m

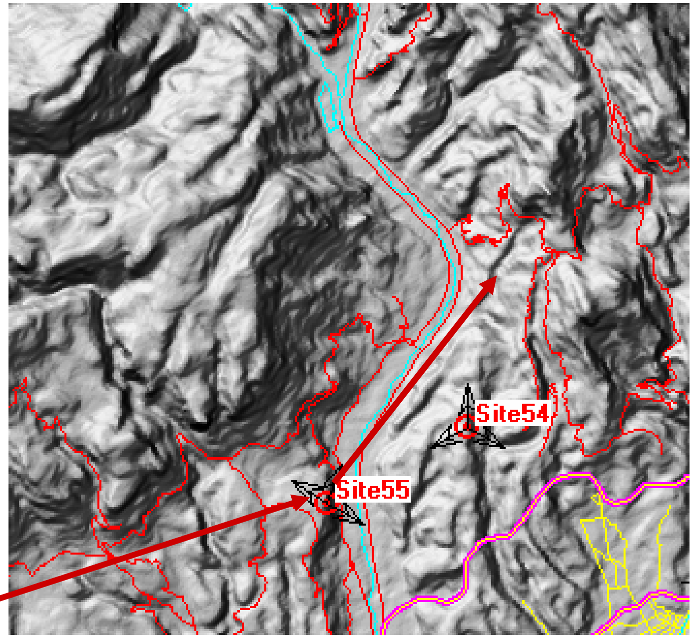


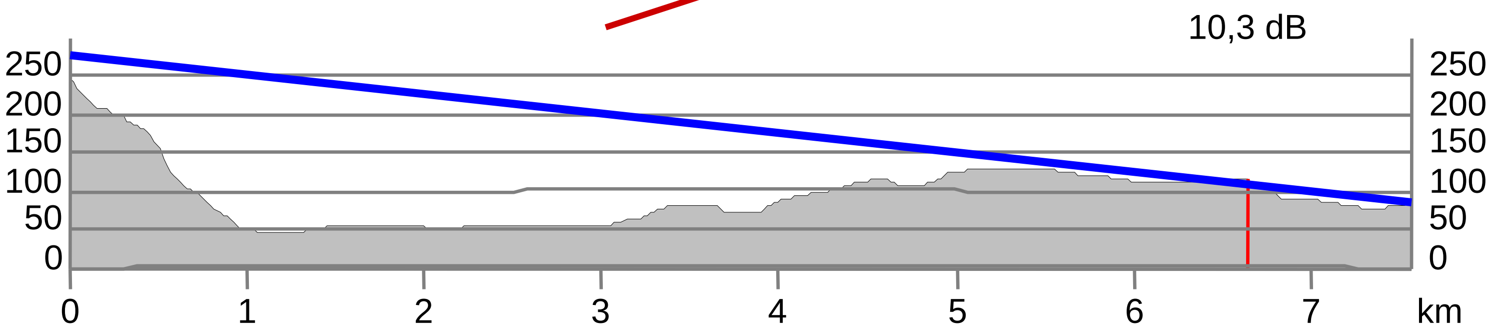
$$d = 4\pi \frac{h_r \cdot h_t}{\lambda}$$

$$PL = 20\log\left(16\pi^2 \frac{h_r \cdot h_t}{\lambda^2}\right)$$

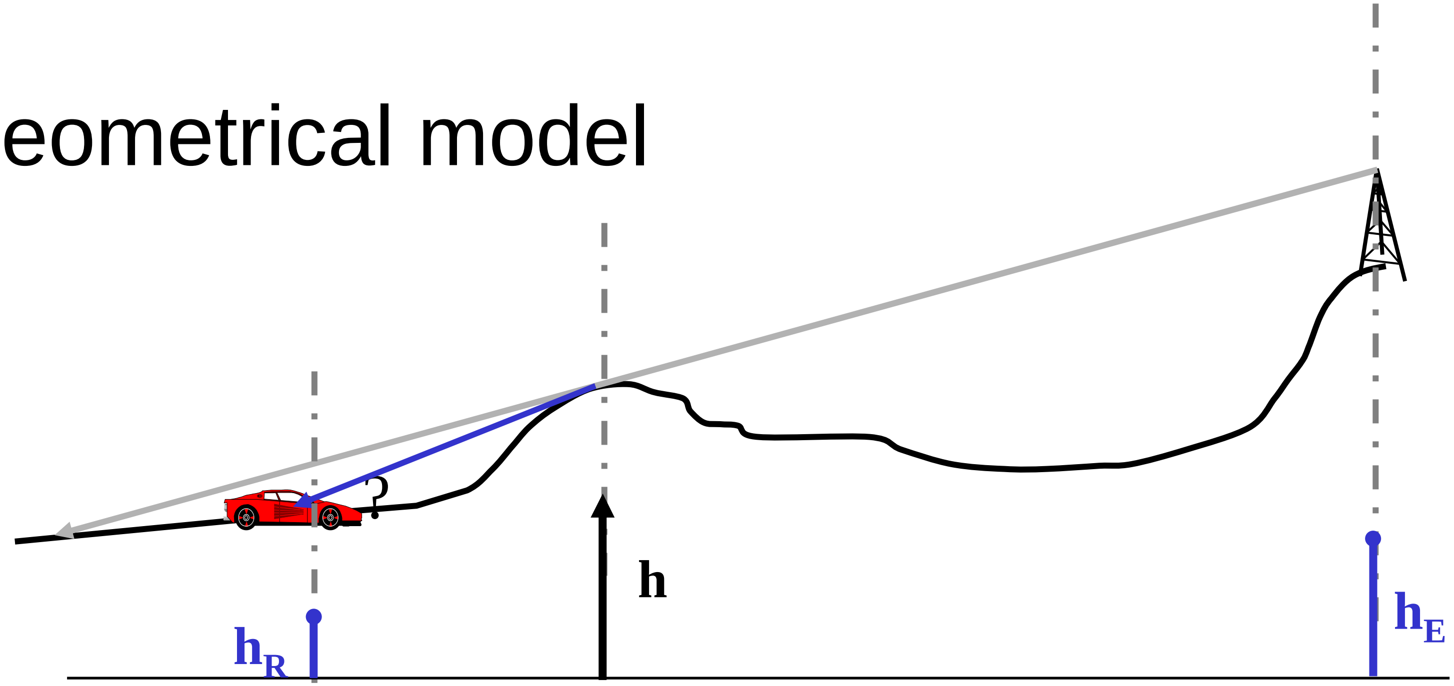
NLOS case

No direct visibility…
A pure geometrical approach would predict no signal

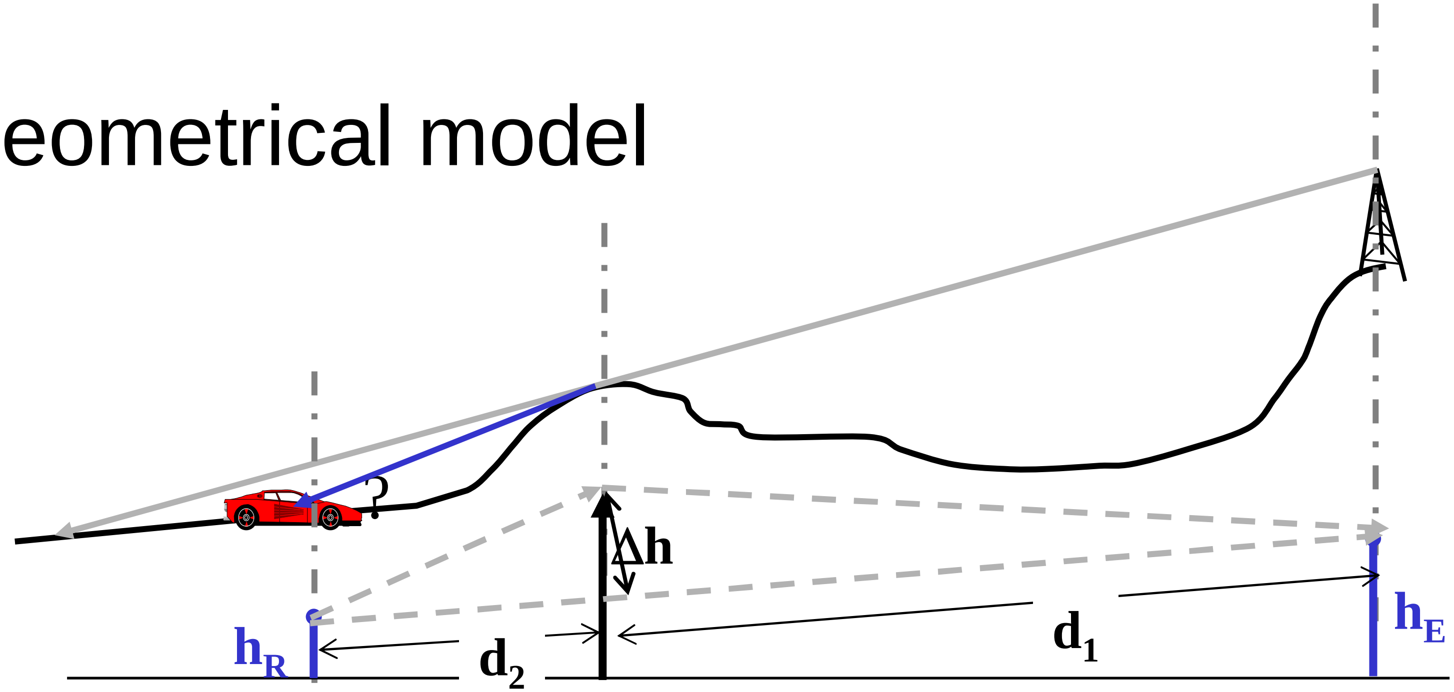




Geometrical model



Geometrical model

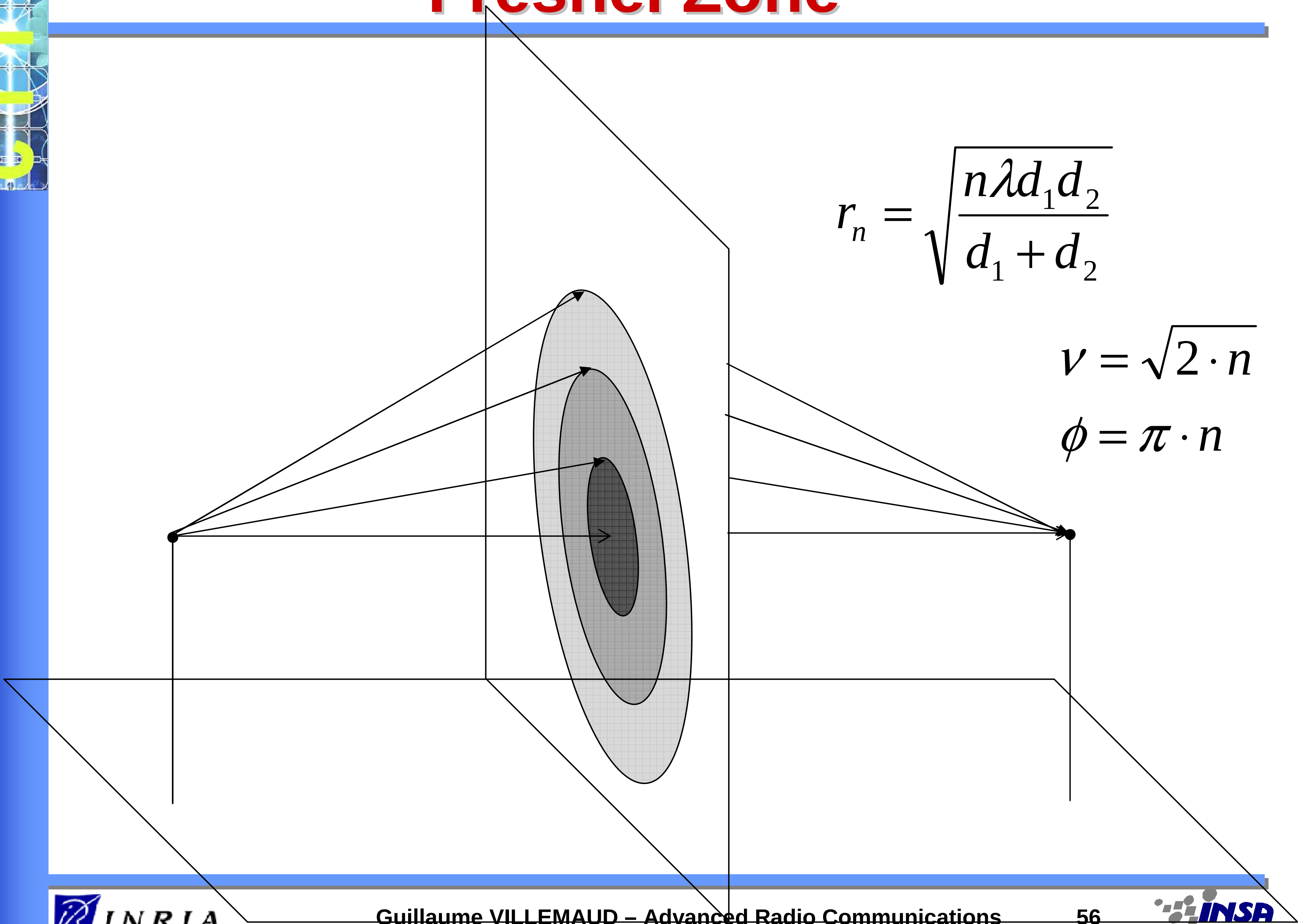


$$\Delta = \frac{\Delta h^2}{2} \cdot \frac{(d_1 + d_2)}{d_1 \cdot d_2}$$

$$\nu = \Delta h \cdot \sqrt{\frac{2(d_1 + d_2)}{\lambda \cdot d_1 \cdot d_2}}$$

$$\Phi = \frac{\pi \nu^2}{2}$$

Fresnel Zone

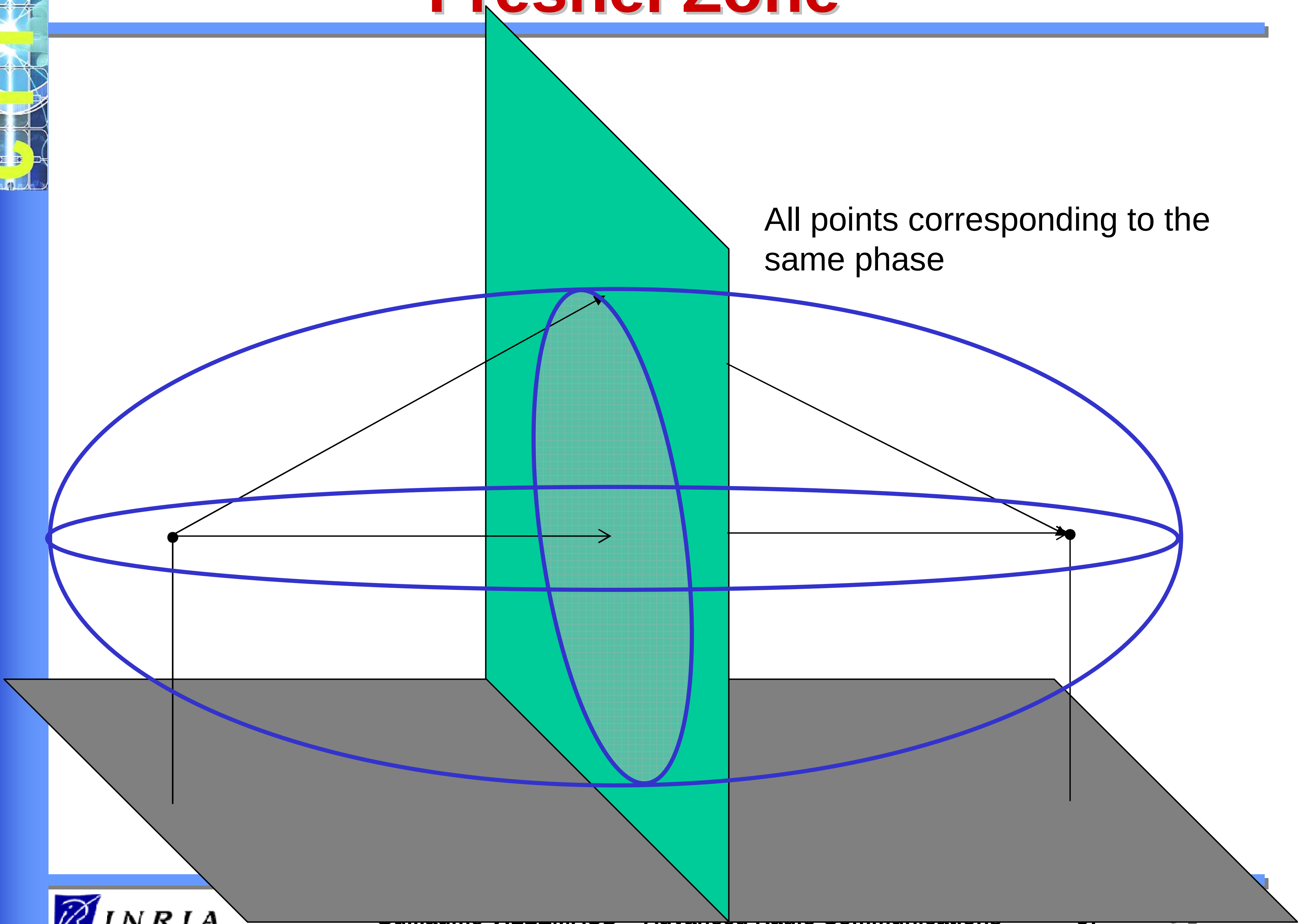


$$r_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}}$$

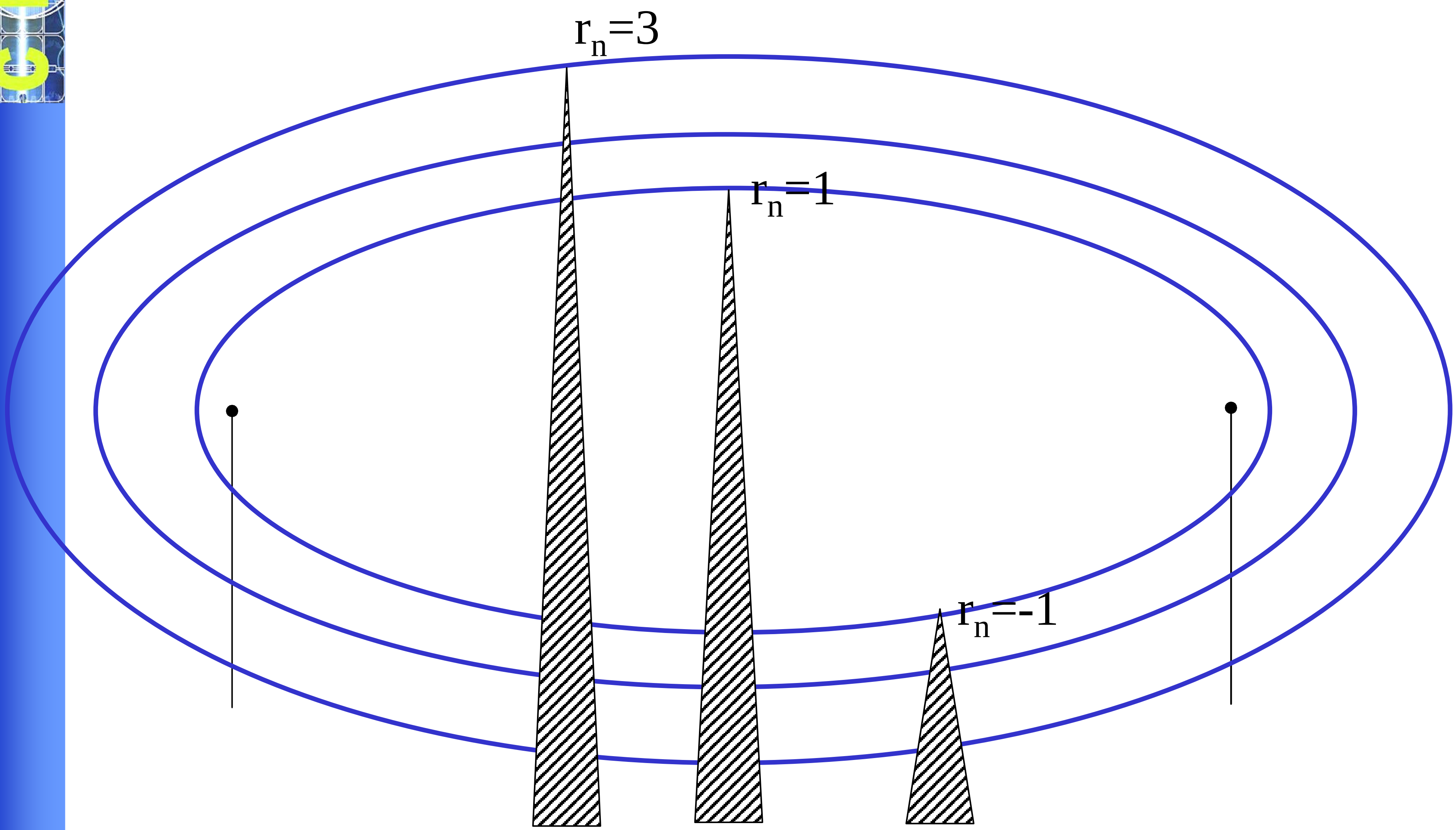
$$\nu = \sqrt{2 \cdot n}$$

$$\phi = \pi \cdot n$$

Fresnel Zone



Interception



Statistical Formulations

In multi-path environment , statiscal laws are based on distributions

$$P_r = P_e G_e G_r k \frac{\lambda^2}{r^n} \alpha_{shad} \alpha_{fading}$$

NLOS Rayleigh's law

$$p_\alpha(\alpha) = \frac{2\alpha}{\Omega} \exp\left(-\frac{\alpha^2}{\Omega}\right)$$

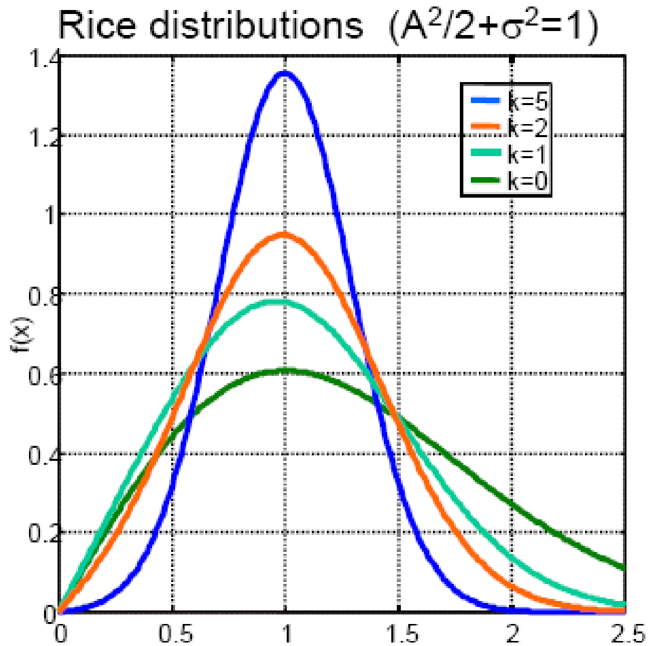
avec $\Omega = E\left(\alpha^2\right)$

Rice's law

Line-of-sight conditions plus multi-path.

$$p_\alpha(\alpha) = \frac{2\,(1+K)\,e^{-K}\alpha}{\Omega}\exp\left(-\frac{(1+K)\,\alpha^2}{\Omega}\right) I_0\left(2\alpha\sqrt{\frac{K\,(1+K)}{\Omega}}\right)$$

K factor can variate from 0 (Rayleigh) to infinity (AWGN)



Loi de Nakagami

Line-of-sight conditions plus multi-path.

$$p_\alpha(\alpha) = \frac{2m^m \alpha^{2m-1}}{\Omega^m \Gamma(m)} \exp\left(-\frac{m\alpha^2}{\Omega}\right)$$

Facteur m factor can variate from 1/2 (mono-lateral gaussian fading) and infinity (perfect)

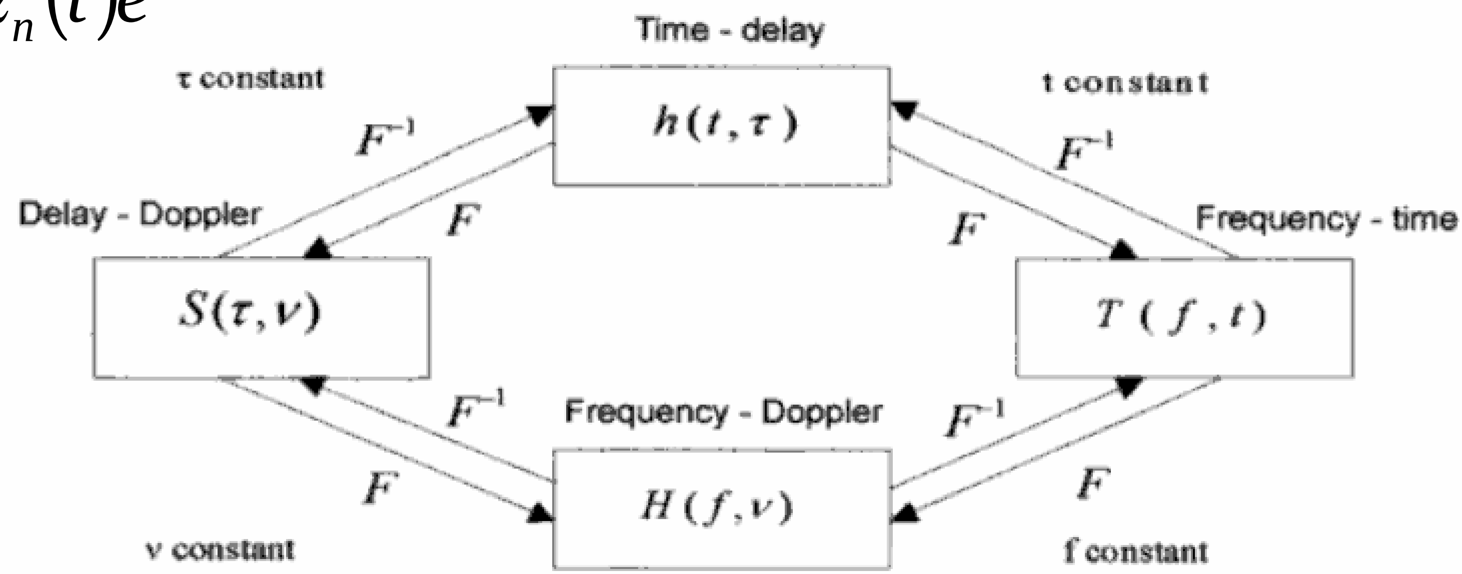
m=1 correspond à Rayleigh

Time domain aspect

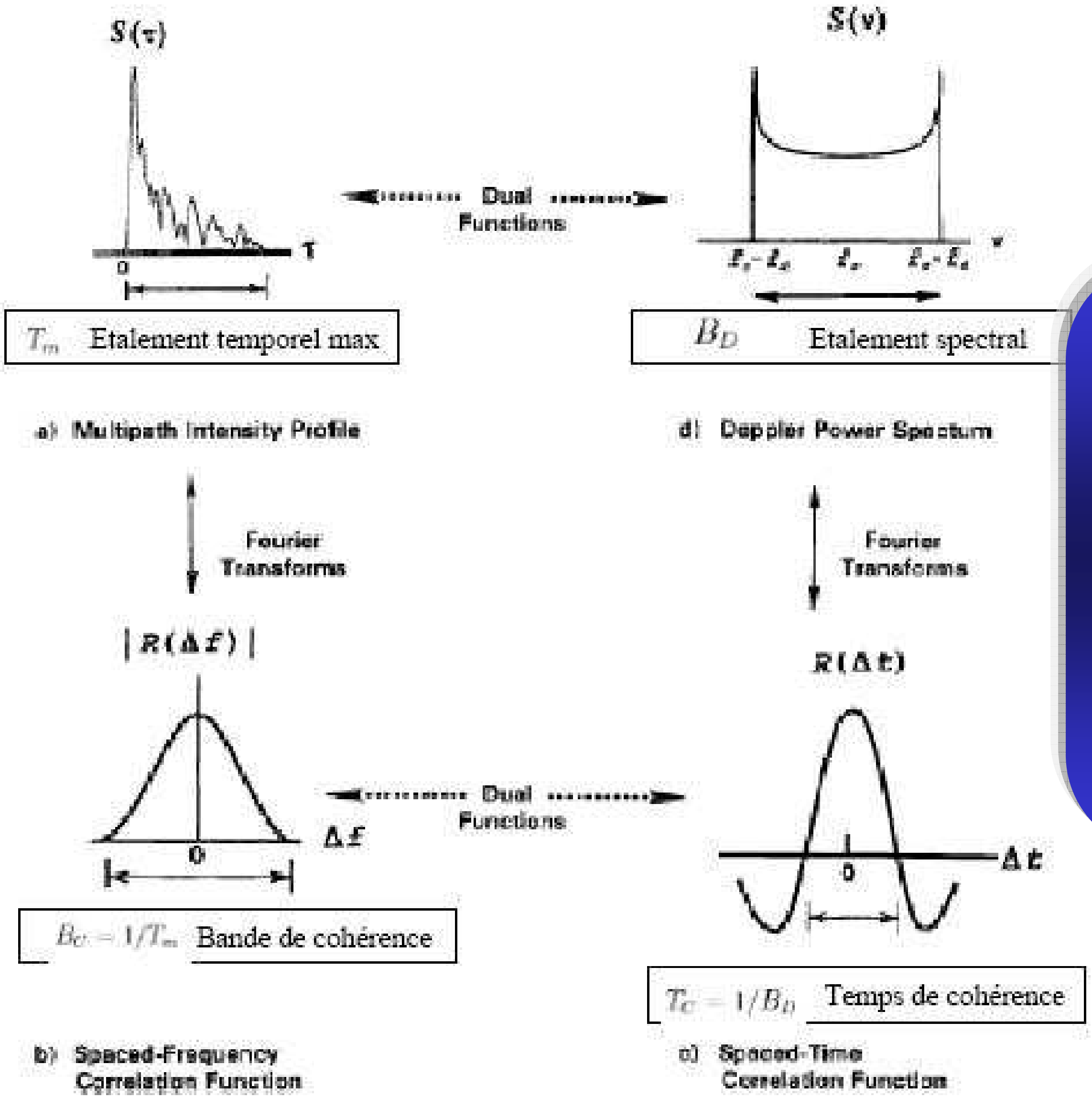
Shadowing and fading parameters are time-variant. Emitted signals are then dimensioned depending of time-domain behavior of the wireless channel.

$$h(t,\tau)=\sum_{n=1}^{L}h_n(t)\delta(\tau-\tau_n(t))$$

$$h_n(t)=\alpha_n(t)e^{j\theta_n(t)}$$



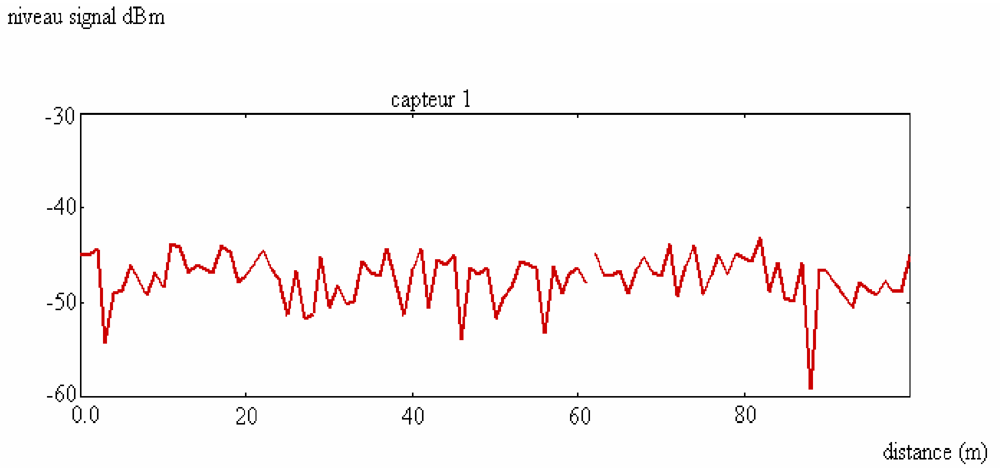
Coherence bandwidth

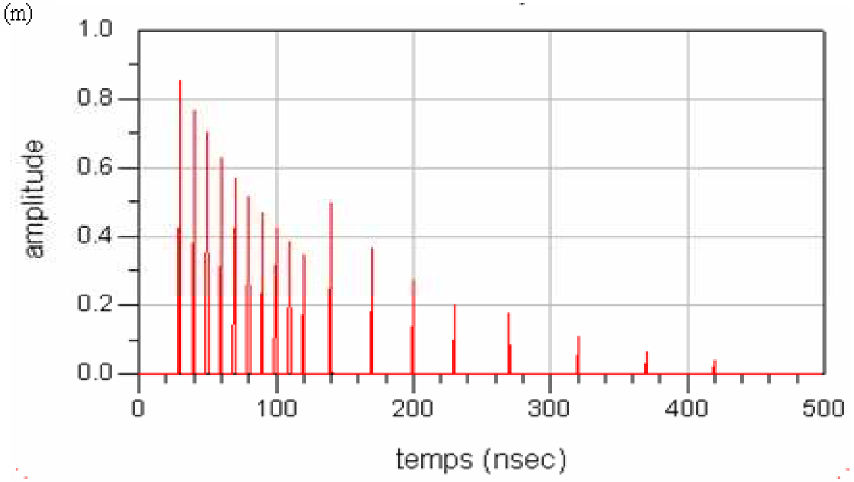


Numerous parameters are linked to the channel behavior: frame duration, equalizers length, training sequences...

Multi-path

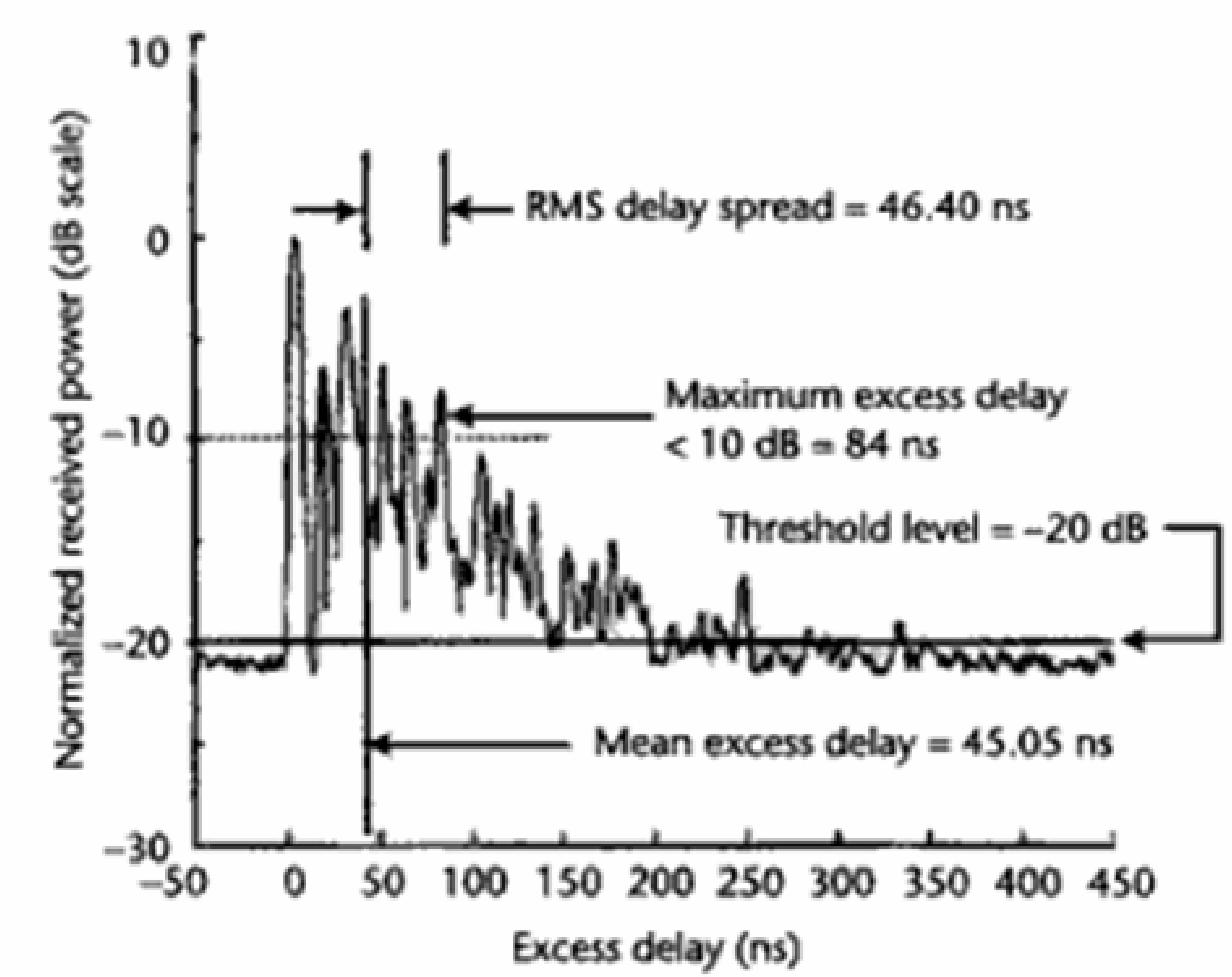
Multi-path produce important recieved power variations but also multiple delayed copies of te signal.



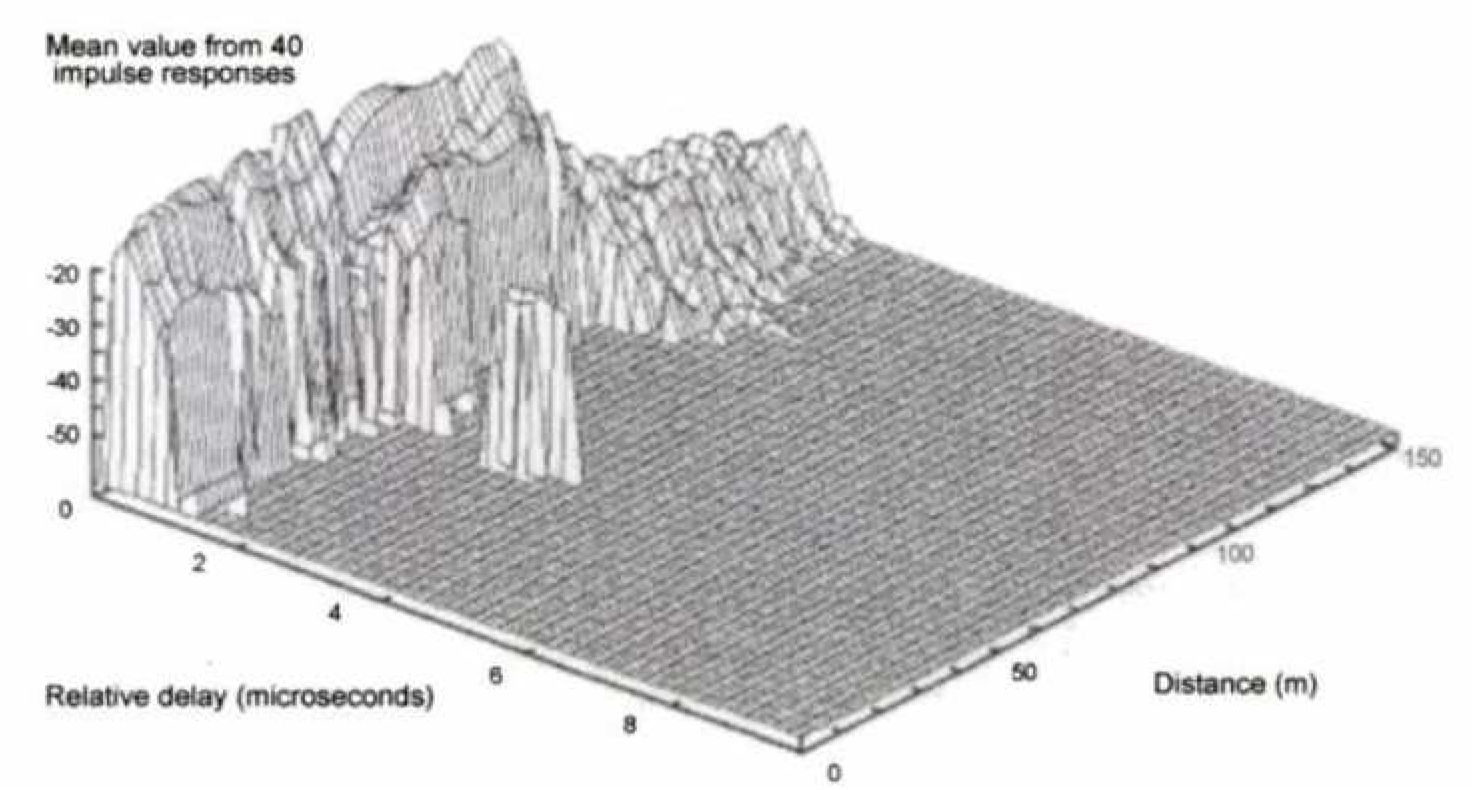


Impulse response

Usual parameters



Example



Mean value from 40
impulse responses
-20
-30
-40
-50
0
2
4
6
8
0
50
100
150
Relative delay (microseconds)
Distance (m)

Some values

	Delay spread at 50 percent	Delay spread at 90 percent
Inside buildings	70 ns	100 ns
microcell	300 ns	600 ns
Small cell	0.6 µs	1.3 µs
macrocell	few µs	a few µs

The point is…

$$P_r = P_e G_e G_r k \frac{\lambda^2}{r^n} \alpha_{shad} \alpha_{fading}$$

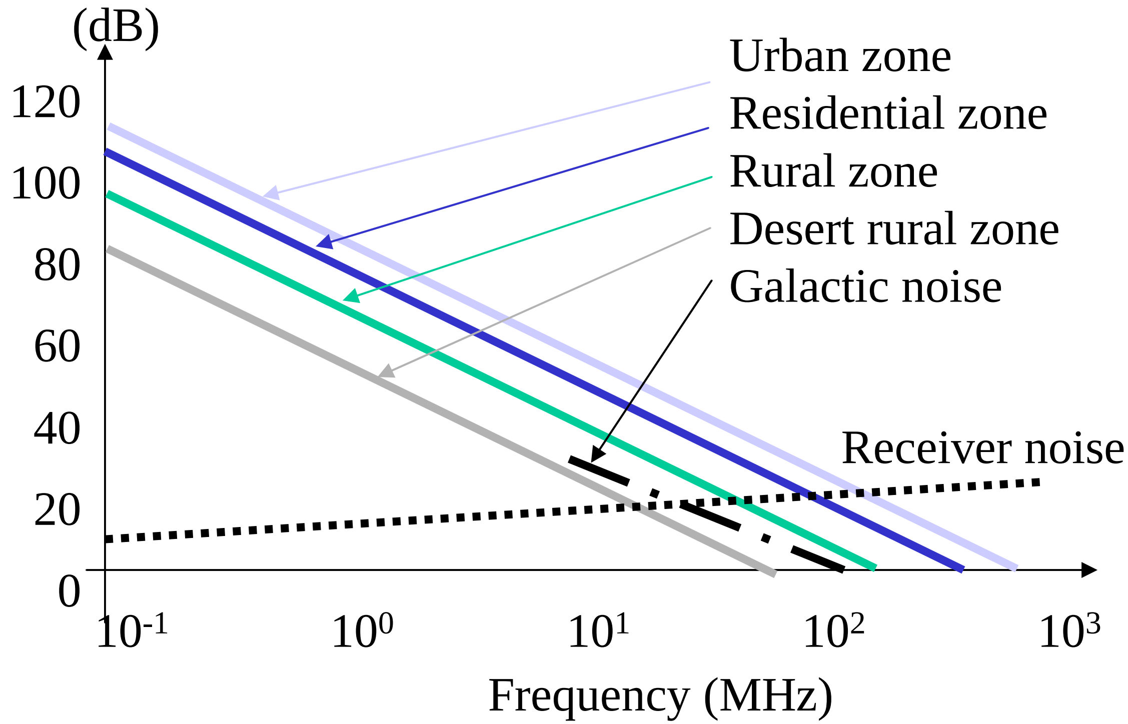
We can evaluate Pr versus Pe, but what about the radio link quality ?

We need to know the noise level

Noise sources

- galactic (15MHz, 100GHz)
- thermal (Johnson): white noise (up to infrared...)
- artificial: evolving, non predictible

Noise level relative to minimal thermal noise



Random aspect of noise

Additive White Gaussian Noise (**AWGN**) – random processes - classical model

Additive: $v(t) + x(t)$ (signal + noise) typical of LNA's and Mixers

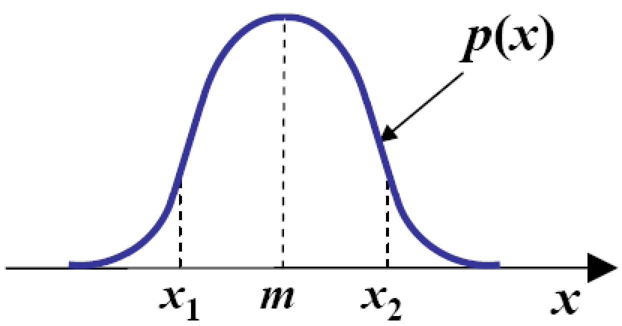
Gaussian Probability Distribution Function (**PDF**)

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp \frac{-(x-m)^2}{2\sigma^2}$$

x – amplitude,
m – mean value,
σ -standard deviation

$$P(x_1 < x < x_2) = \int_{x_1}^{x_2} p(x)dx$$

$$(m-3\sigma) < x < (m+3\sigma) \Rightarrow P = 0.9974$$



Time dependence: $x = x(t)$

For stationary noise the mean (and "mean square") values over the probability domain, and over the time domain are same:

$$\int_{-\infty}^{\infty} x \cdot p(x)dx = \lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} x(t)dt \quad \text{and} \quad \int_{-\infty}^{\infty} x^2 p(x)dx = \lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} x^2(t)dt$$

Mean square

$$\int_{-\infty}^{\infty} |x(t)|^2 dt = \int_{-\infty}^{\infty} |X(f)|^2 df$$ (*Parseval's Th.*)

Power Spectral Density (**PSD**): $$S_x(f) = \lim_{T\to\infty}\frac{\overline{|X_T(f)|^2}}{T}$$

average for multiple measurements

where $$X_T(f) = \int_0^T x(t)\,e^{-j2\pi f t}dt$$

Thermal noise :

$$P_N = k \cdot T \cdot B$$

avec k=1.379.10^{-23} W.Hz^{-1}.K^{-1}

example : *GSM : B=270kHz, T=290°K*

- Noise factor

$$F = \frac{N_{out}/G}{k.T.B} = \frac{N_{eq}}{k.T.B}$$

- Noise figure

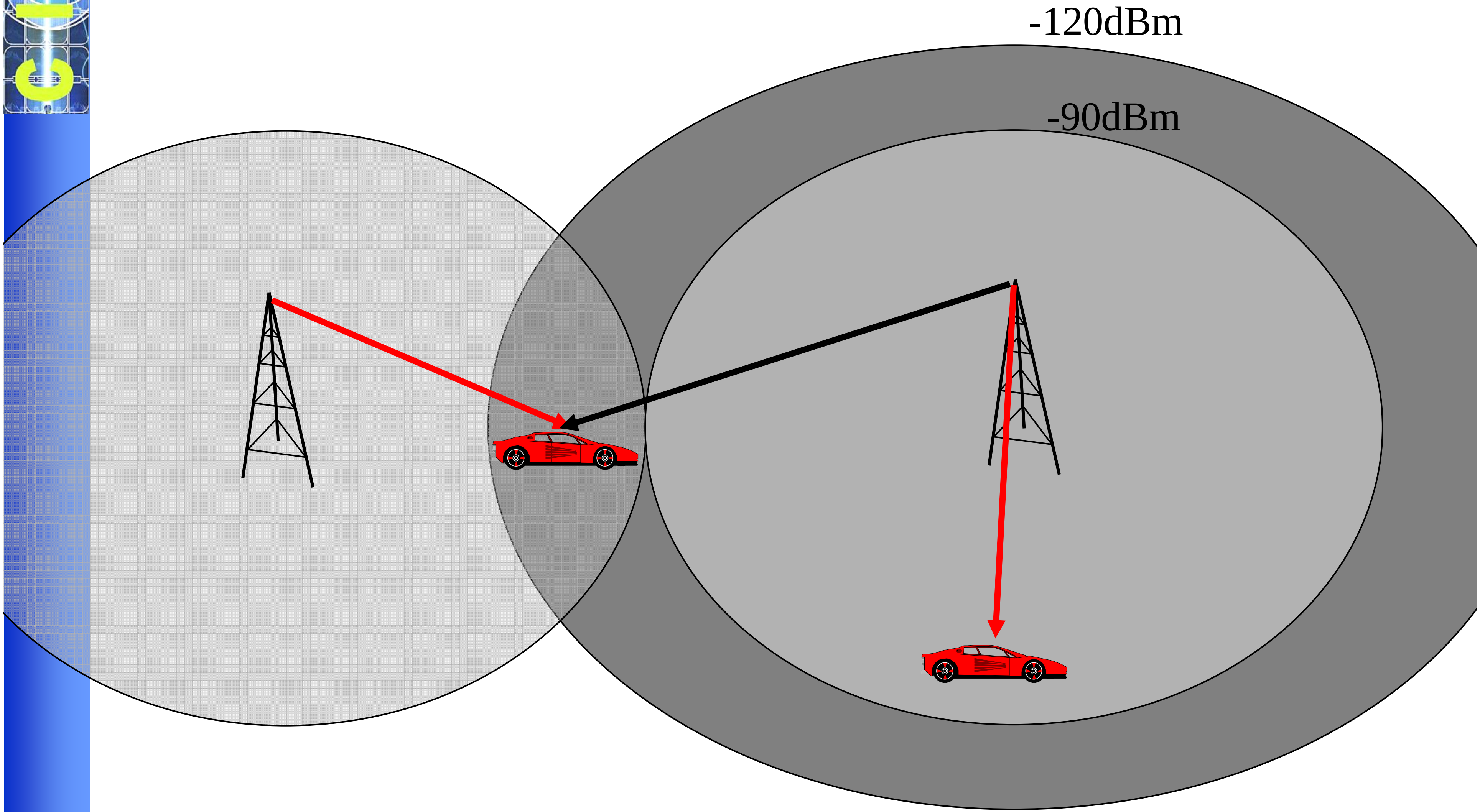
$$F_{dB} = 10.\log_{10}(F)$$

- Noise temperature

$$N_{eq} = k.T.B + k.T_{eq}.B$$

Mobile WiMAX Downlink				
Base Station Infrastructure	**MAP**	**Traffic-PUSC**		**Units**
Tx Power per Antenna Element	10.0	10.0	10.0	Watts
Number of Tx Antenna Elements	2	2	2	
Cyclic Combining Gain	3.0	3.0	3.0	dB
Tx Antenna Gain	15.0	15.0	15.0	dBi
Pilot Power Boosting Gain	-0.7	-0.7	-0.7	dB
EIRP	57.3	57.3	57.3	dBm
Base Permutation Zone	**PUSC**	**PUSC**	**PUSC**	
Number of Occupied Sub-Carriers	840	840	840	
Power per Occupied Sub-Carrier	28.1	28.1	28.1	dBm
Mobile Unit, (Handset Indoor)				
Rx Antenna Gain	-1.0	-1.0	-1.0	dBi
Rx Antenna Diversity Gain (2 Antennas)	3.0	3.0	3.0	dB
Rx Noise Figure	7.0	7.0	7.0	dB
Margins				
Log Normal Fade Margin	5.56	5.56	5.56	dB
Fast Fading Margin	6.0	2.0	2.0	dB
Interference Margin	2.0	2.0	2.0	dB
Penetration Loss	10.0	10.0	10.0	dB
Total Margin	**23.56**	**19.56**	**19.56**	**dB**
Mobile Rx Sensitivity				
Thermal Noise	-174	-174	-174	dBm/Hz
Sub-Carrier Spacing	10.94	10.94	10.94	kHz
Modulation	QPSK 1/8	QPSK 1/2	16QAM 1/2	
SNR Required	-3.31	3.49	8.93	dB
Delta from limiting cell range distance	0.82			
DL Traffic Data Rate		**2.88**	**5.76**	**Mbps**
Rx Sensitivity (per sub-carrier)	-129.9	-123.2	-117.7	dBm
Rx Sensitivity (composite)	-100.7	-93.9	-88.4	dBm
System Gain	**160.0**	**153.3**	**147.8**	**dB**
Maximum Allowable Path Loss	**136.4**	**133.7**	**128.2**	**dB**

Interference



Orthogonality trends

Spreading techniques

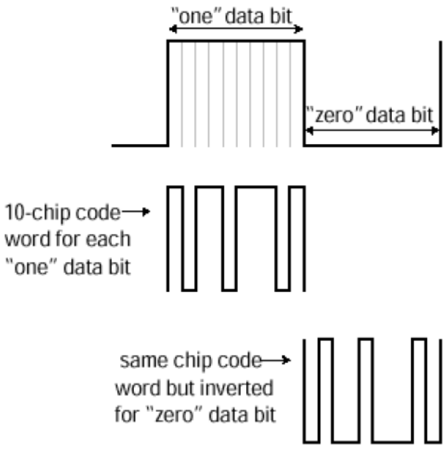
A way of strengthening a signal against channel effects and interference is to spread it spectrally.

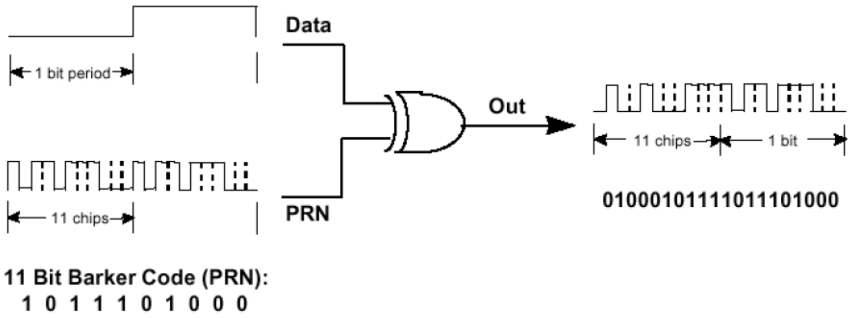
Two kinds of spreading: FHSS (ex: Bluetooth) and DSSS (ex:802.11b).

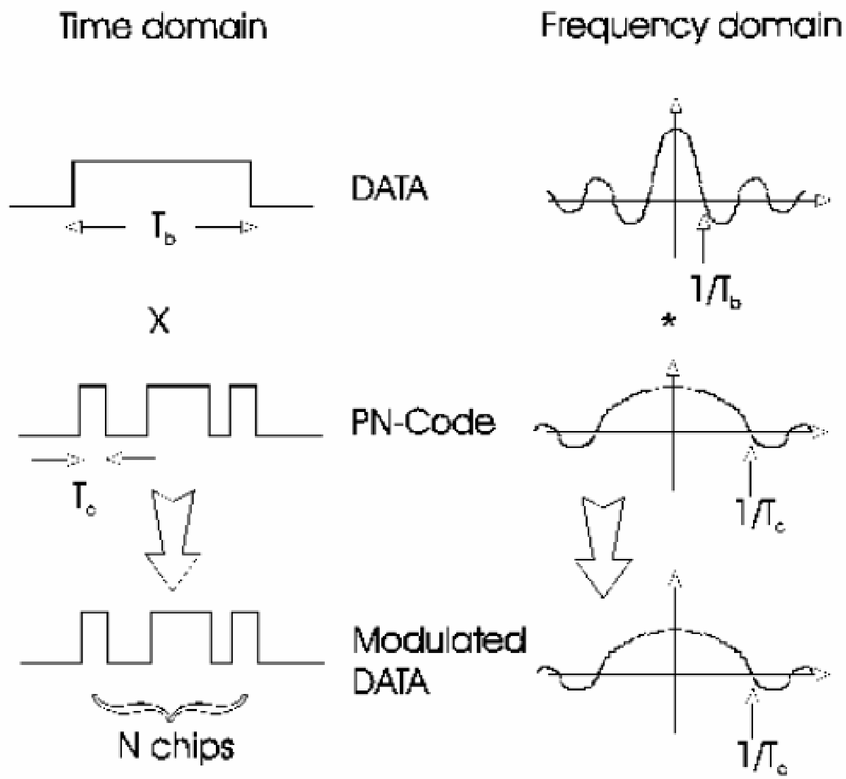
The consequence is that the total bandwidth is increased but the power is spreaded.

By using the DSSS principle with a set of orthogonal codes allows to re-use the same band for multiple users: CDMA (basis of 3G technologies).

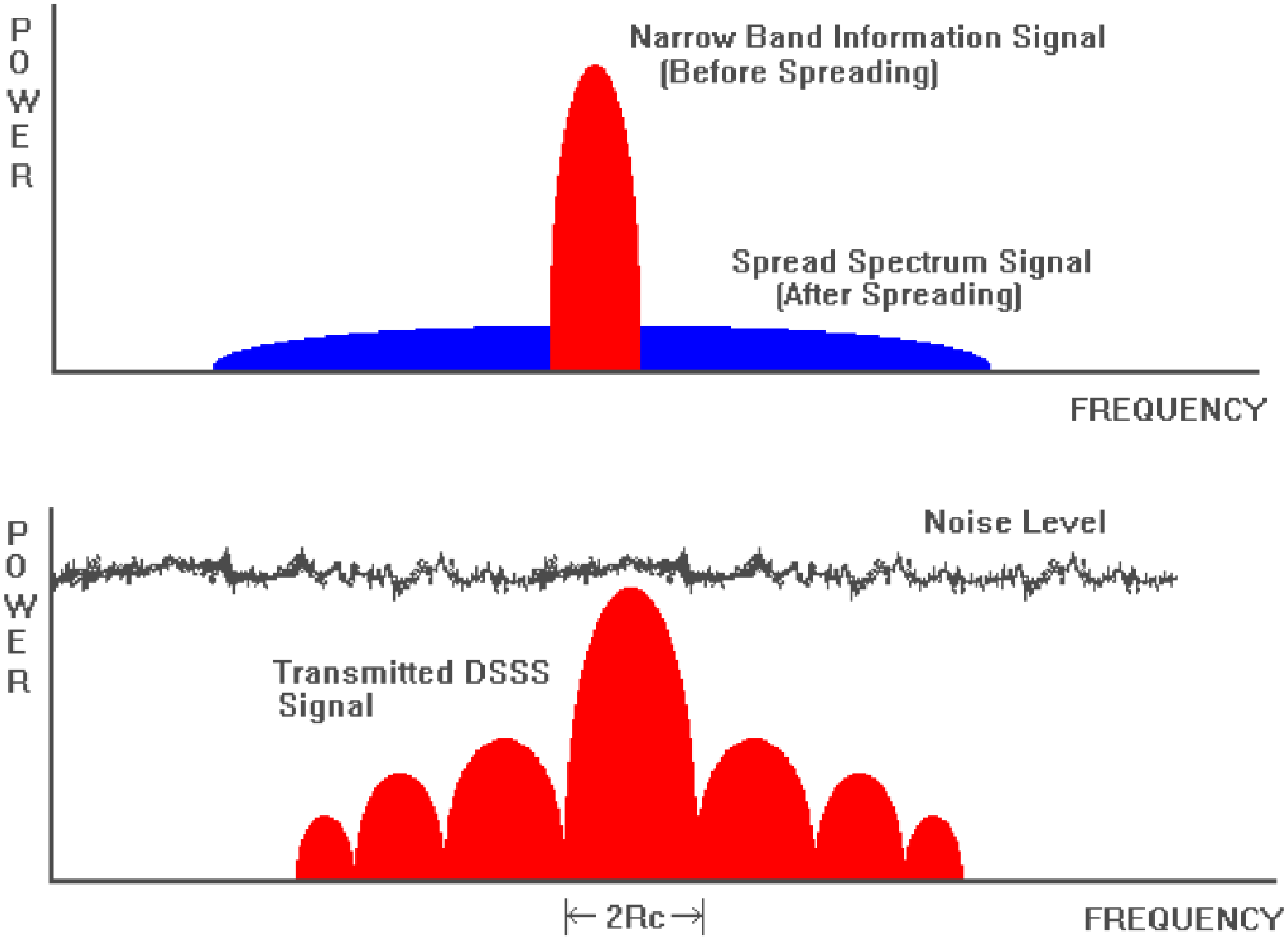
Direct sequence spreading





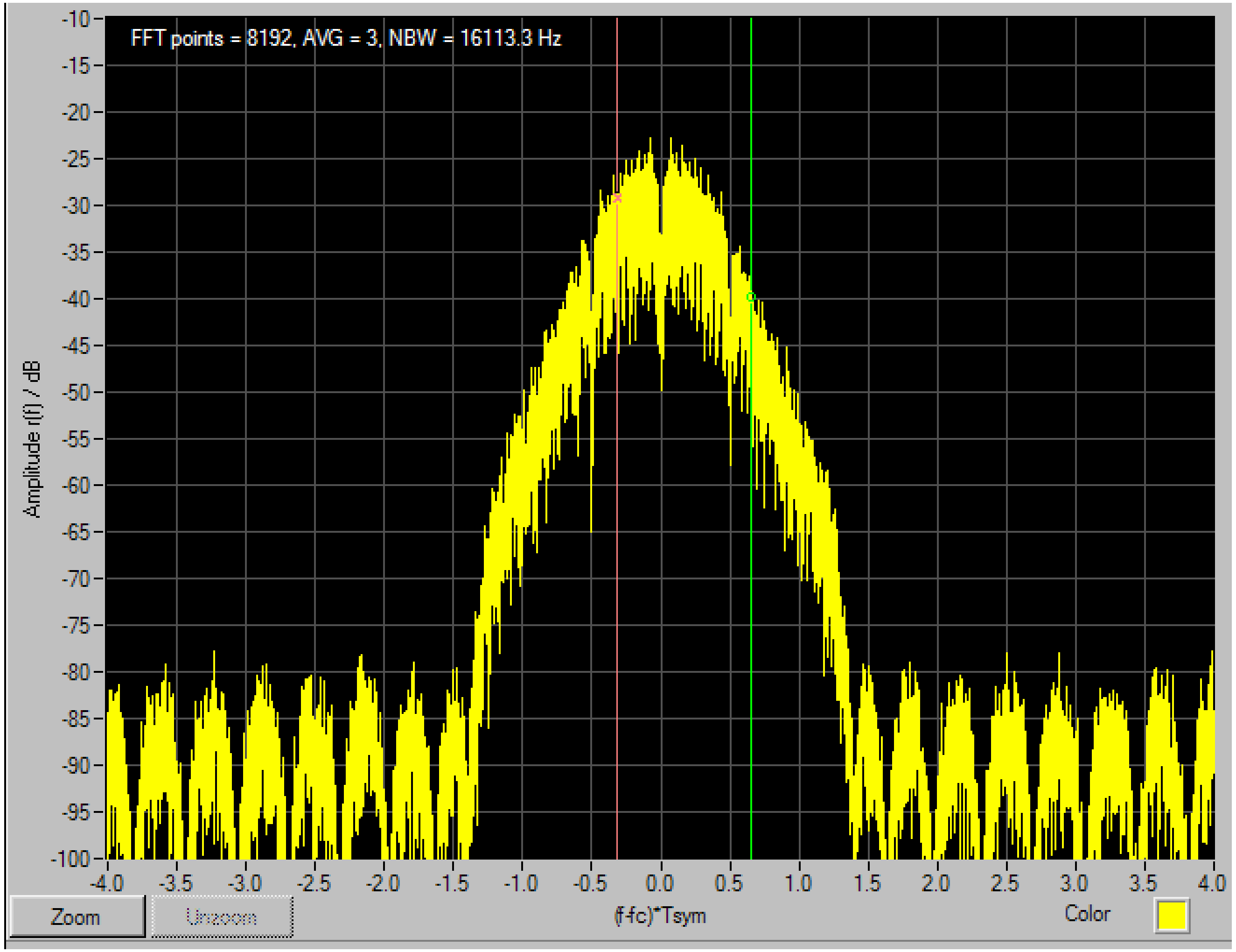


DSSS spectrum



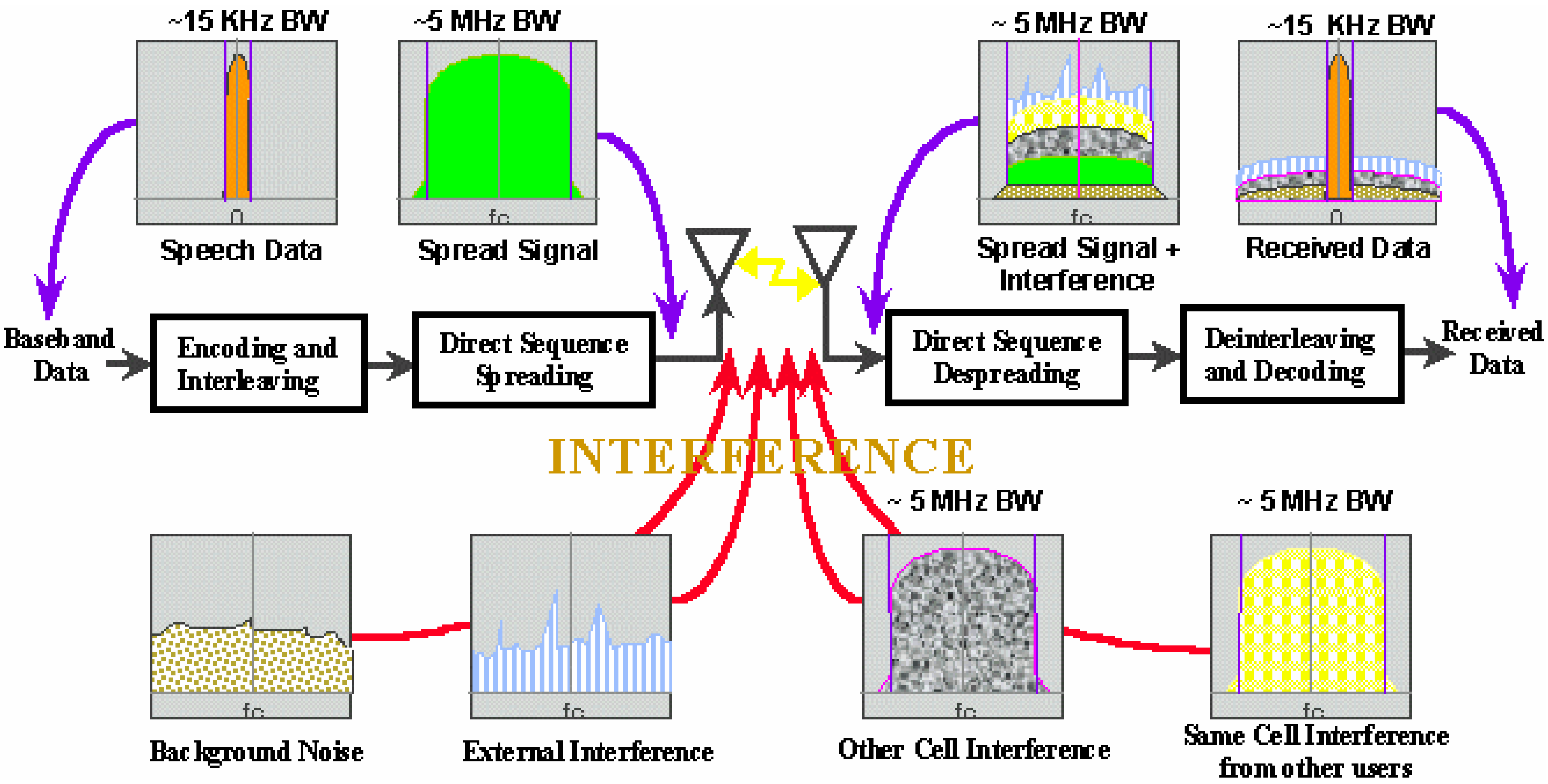
WiFi

802.11b

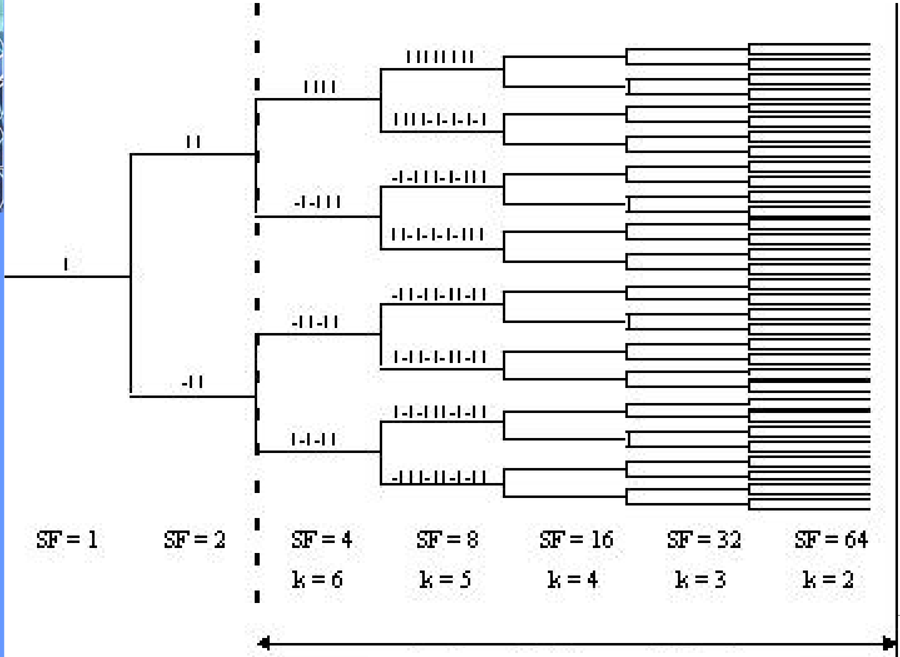


FFT points = 8192, AVG = 3, NBW = 16113.3 Hz
Amplitude r(f) / dB
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
-4.0
-3.5
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
(f-fc)*Tsym
Zoom
Unzoom
Color

CDMA

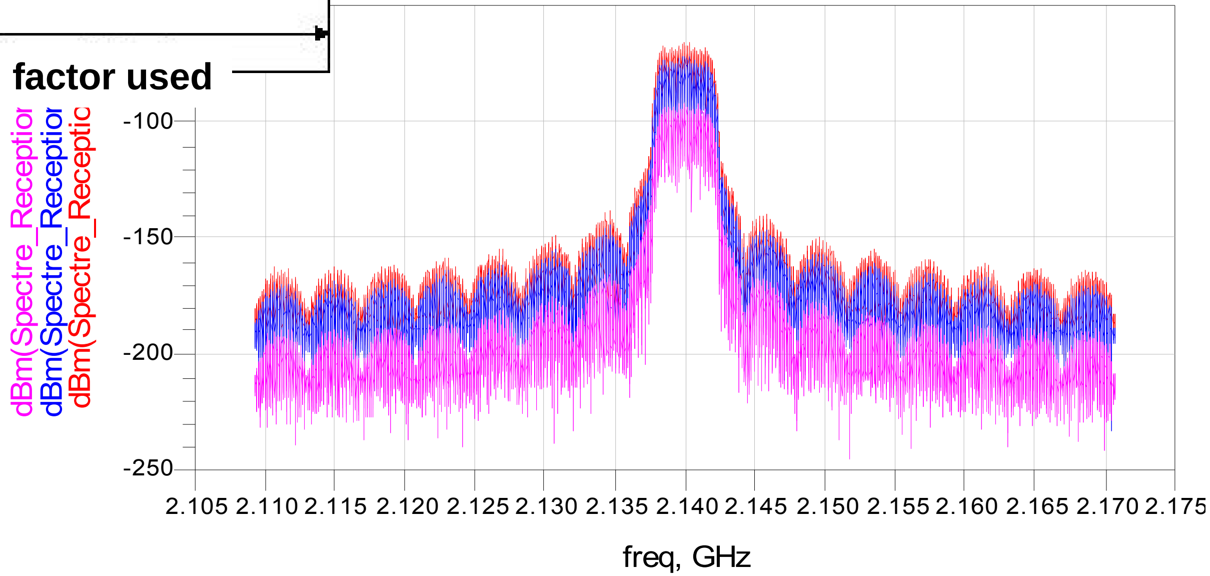

~15 KHz BW
~5 MHz BW
~ 5 MHz BW
~15 KHz BW
Speech Data
Spread Signal
Spread Signal + Interference
Received Data
Baseband Data
Encoding and Interleaving
Direct Sequence Spreading
Direct Sequence Despreading
Deinterleaving and Decoding
Received Data
INTERFERENCE
~ 5 MHz BW
~ 5 MHz BW
Background Noise
External Interference
Other Cell Interference
Same Cell Interference from other users

3G technology



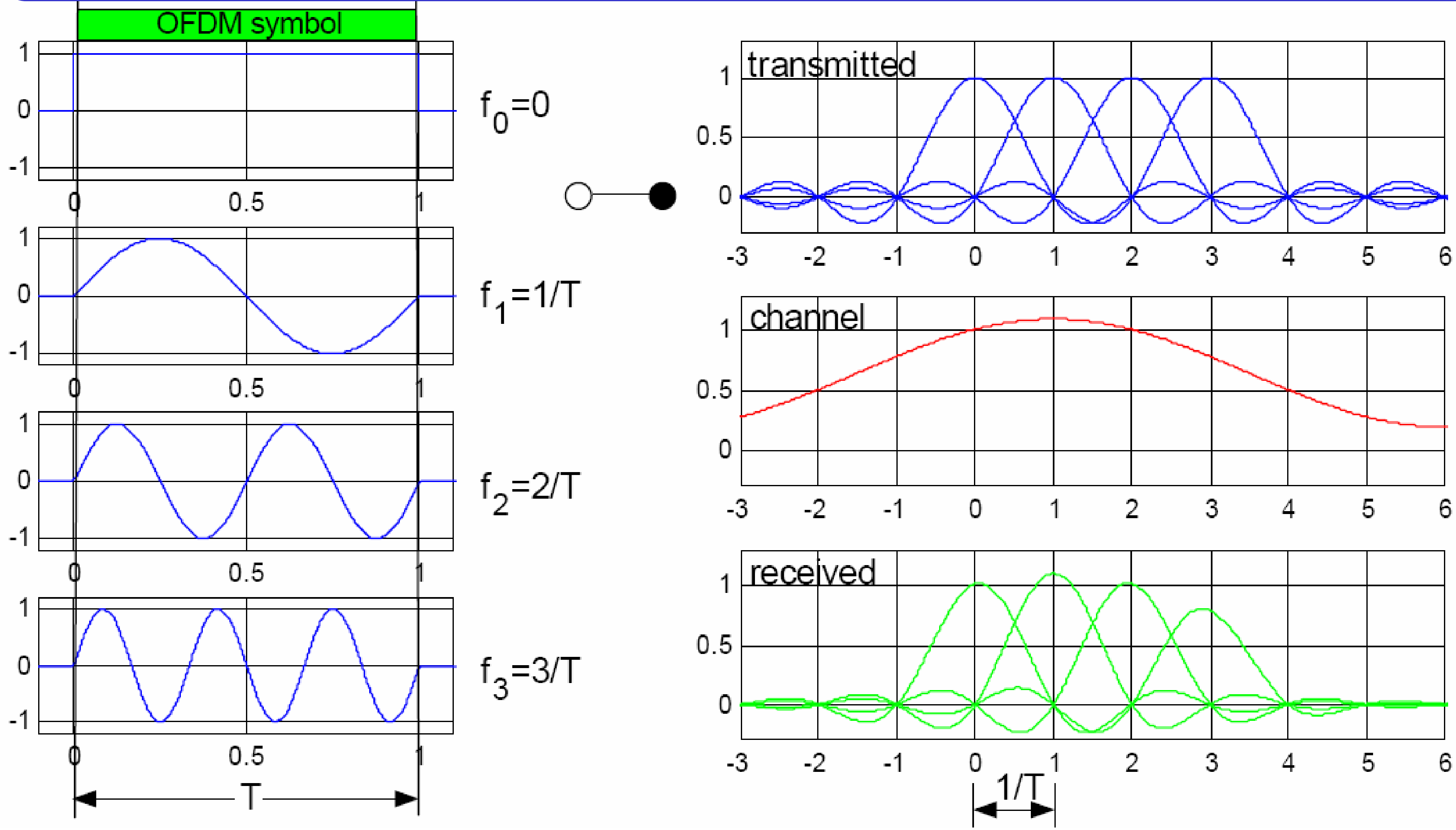
Spreading factor used

W-CDMA



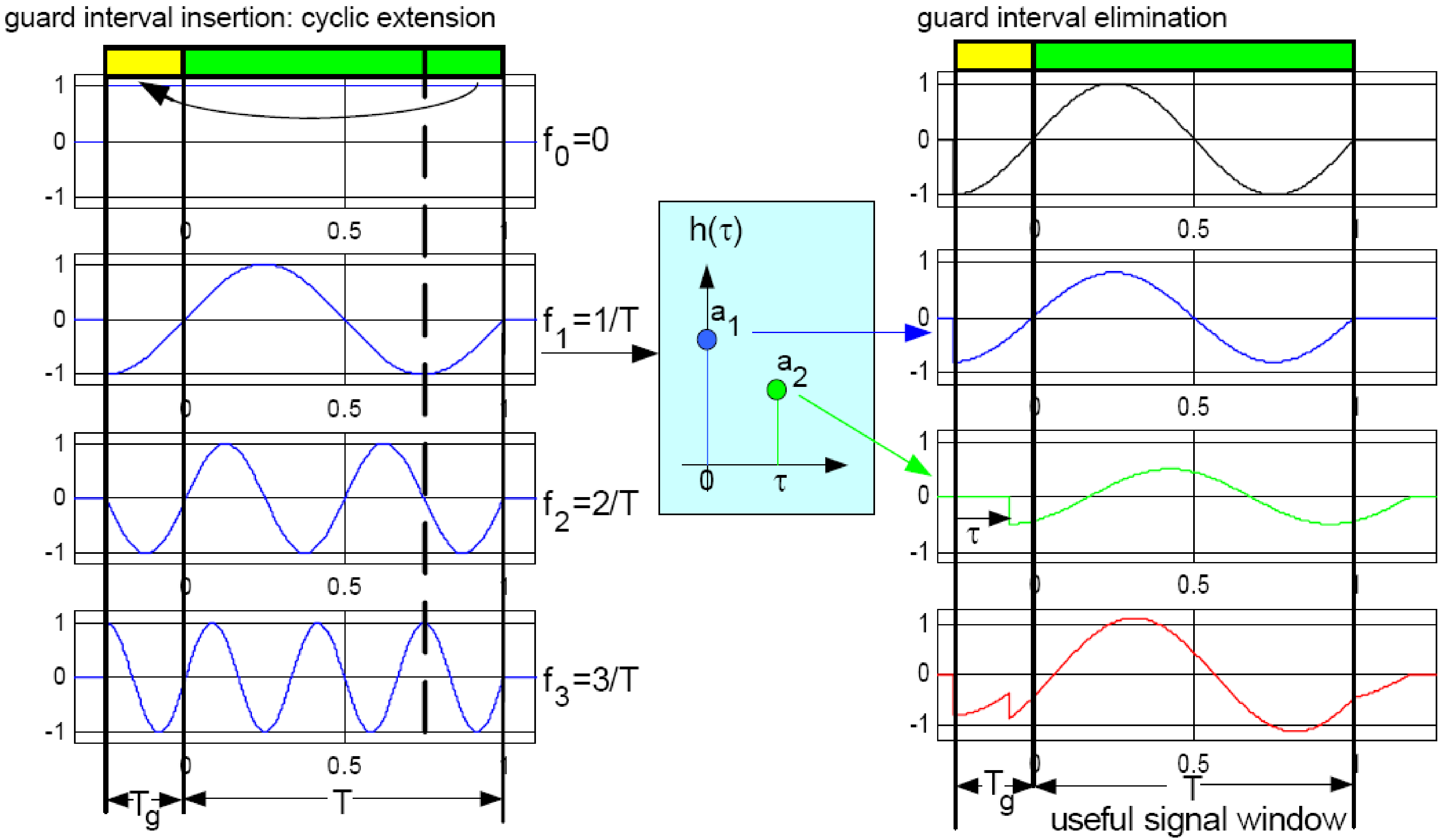
OFDM

Orthogonal Frequency Division Multiplexing is in use in every emerging technologies (802.11a/g/n, WiMAX, LTE, DVB…)



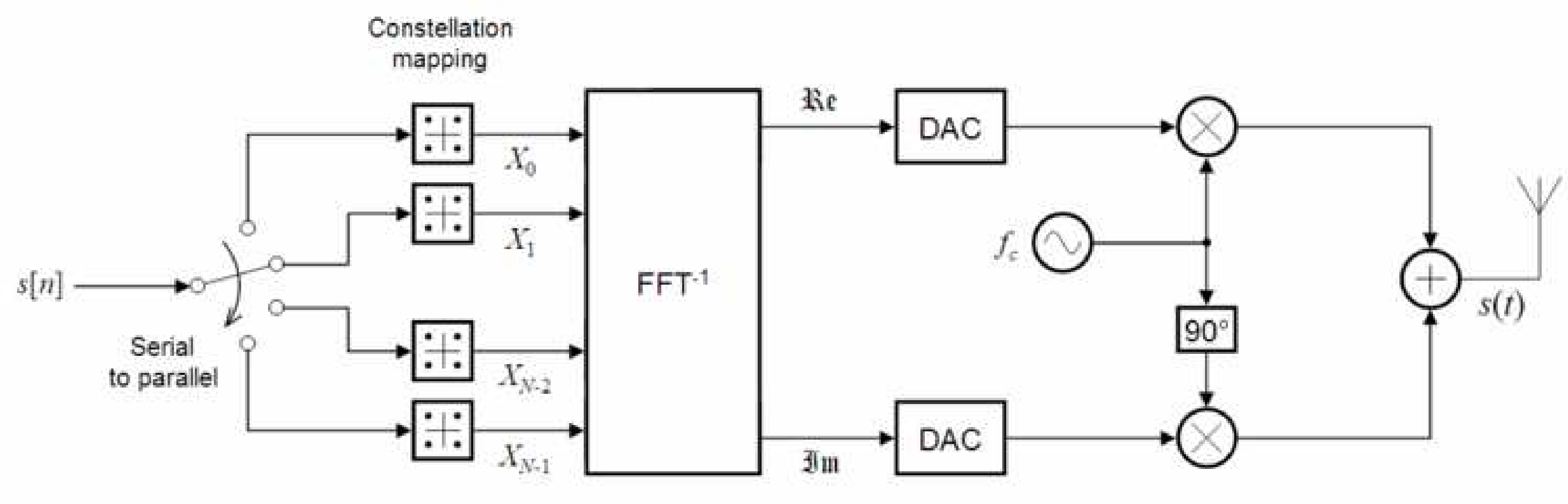
Cyclic prefix

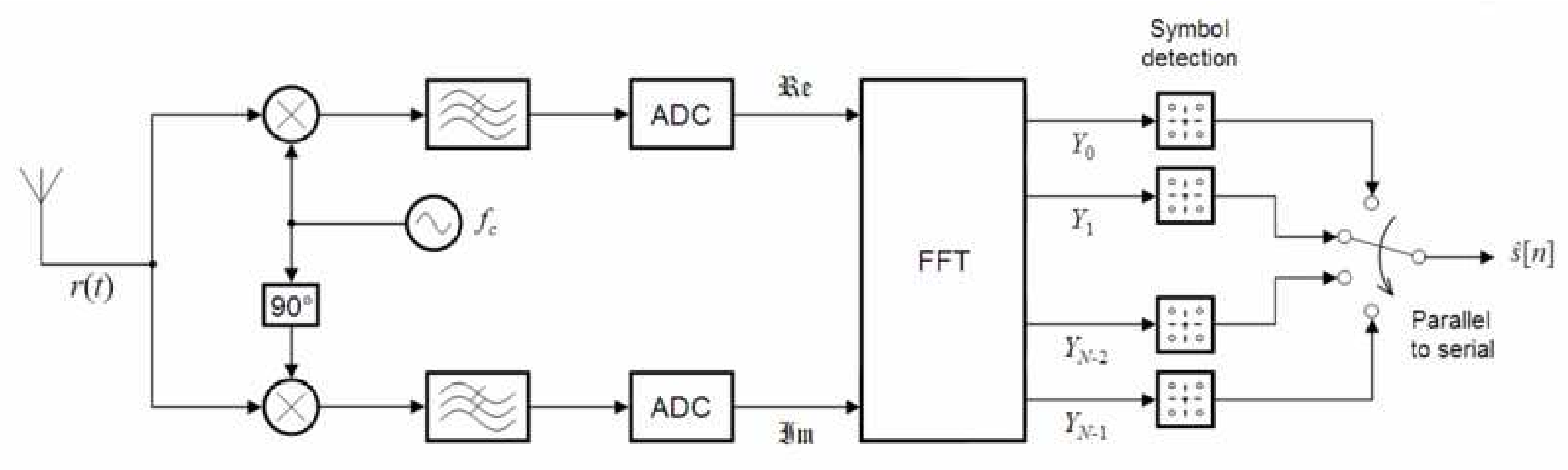
A cyclic prefix is introduce at the beginning of each OFDM symbol to prevent from ISI



A simple example: *If one sends a million symbols per second using conventional single-carrier modulation over a wireless channel, then the duration of each symbol would be one microsecond or less. This imposes severe constraints on synchronization and necessitates the removal of multipath interference. If the same million symbols per second are spread among one thousand sub-channels, the duration of each symbol can be longer by a factor of a thousand, i.e. one millisecond, for orthogonality with approximately the same bandwidth. Assume that a guard interval of 1/8 of the symbol length is inserted between each symbol. Intersymbol interference can be avoided if the multipath time-spreading (the time between the reception of the first and the last echo) is shorter than the guard interval, i.e. 125 microseconds. This corresponds to a maximum difference of 37.5 kilometers between the lengths of the paths.*

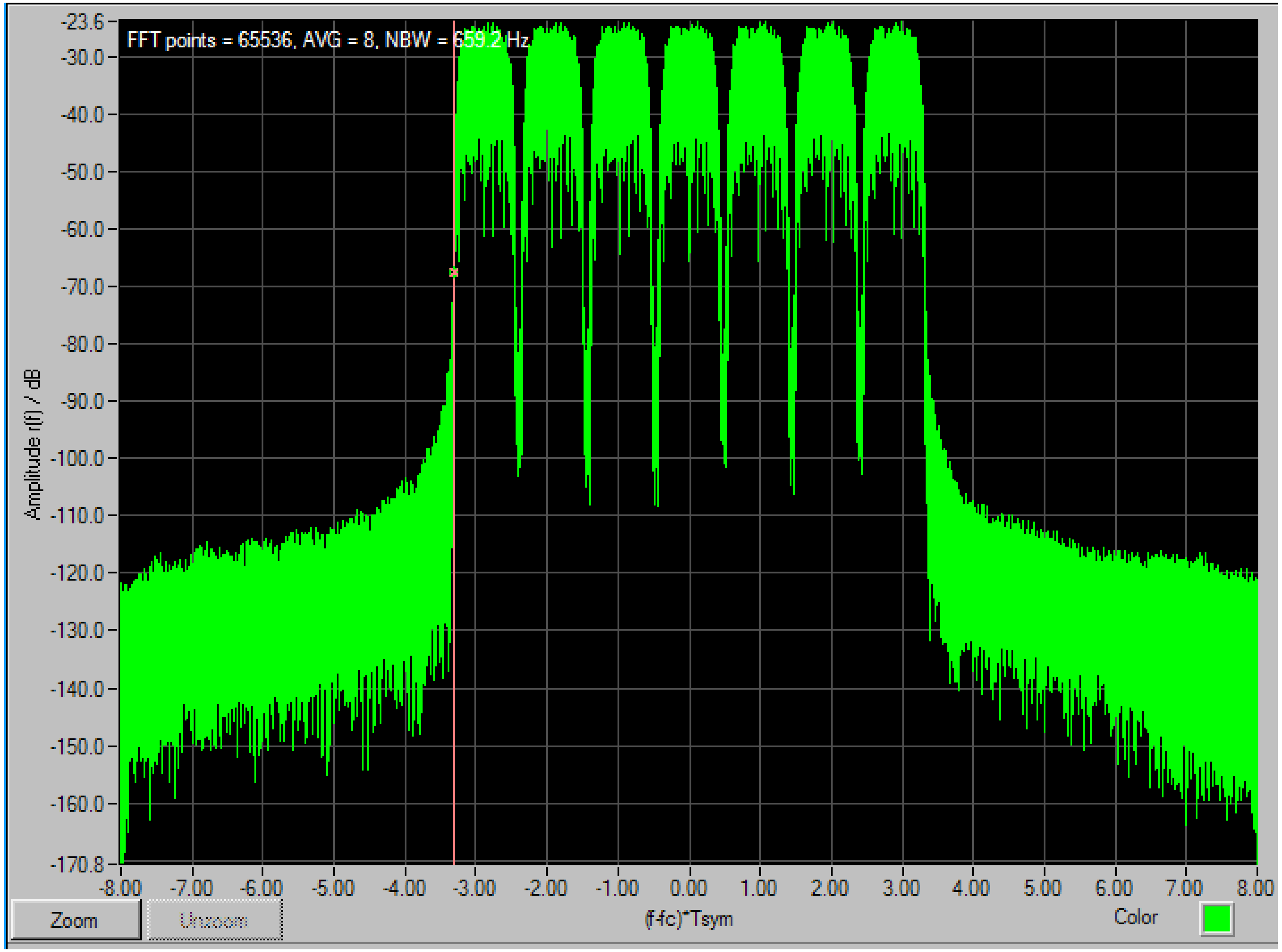
Multiplexing structure



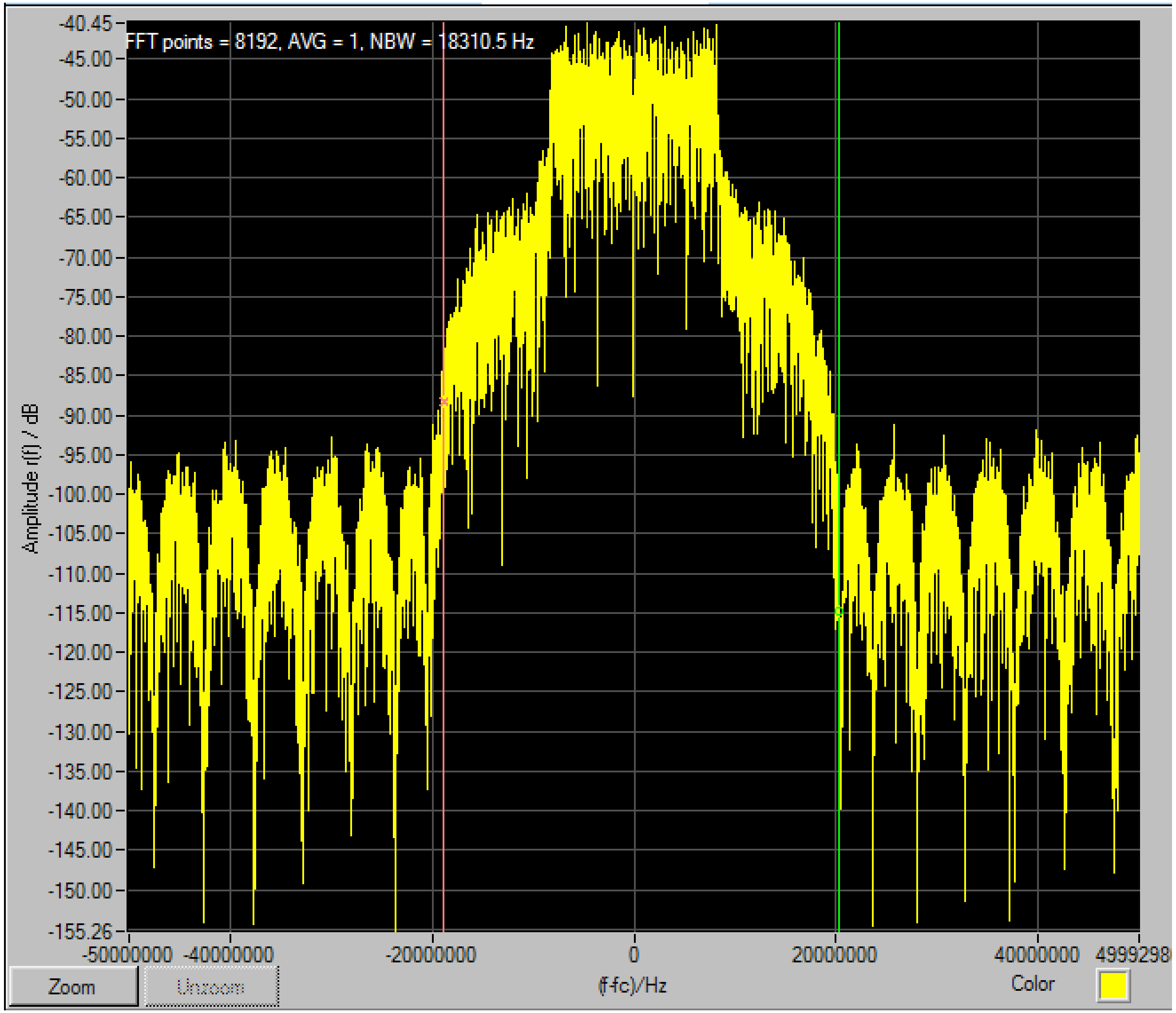


Example of values

Symbol	Description	Relation	Example WiMAX value
B^*	Nominal bandwidth	$B = 1/T_s$	10MHz
L^*	Number of subcarriers	Size of IFFT/FFT	1024
G^*	Guard fraction	% of L for CP	1/8
$L_d{}^*$	Data subcarriers	L–pilot/null subcarriers	768
T_s	Sample time	$T_s = 1/B$	1 μ sec
N_g	Guard symbols	$N_g = GL$	128
T_g	Guard time	$T_g = T_s N_g$	12.8 μ sec
T	OFDM symbol time	$T = T_s(L + N_g)$	115.2 μ sec
B_{sc}	Subcarrier bandwidth	$B_{sc} = B/L$	9.76 KHz

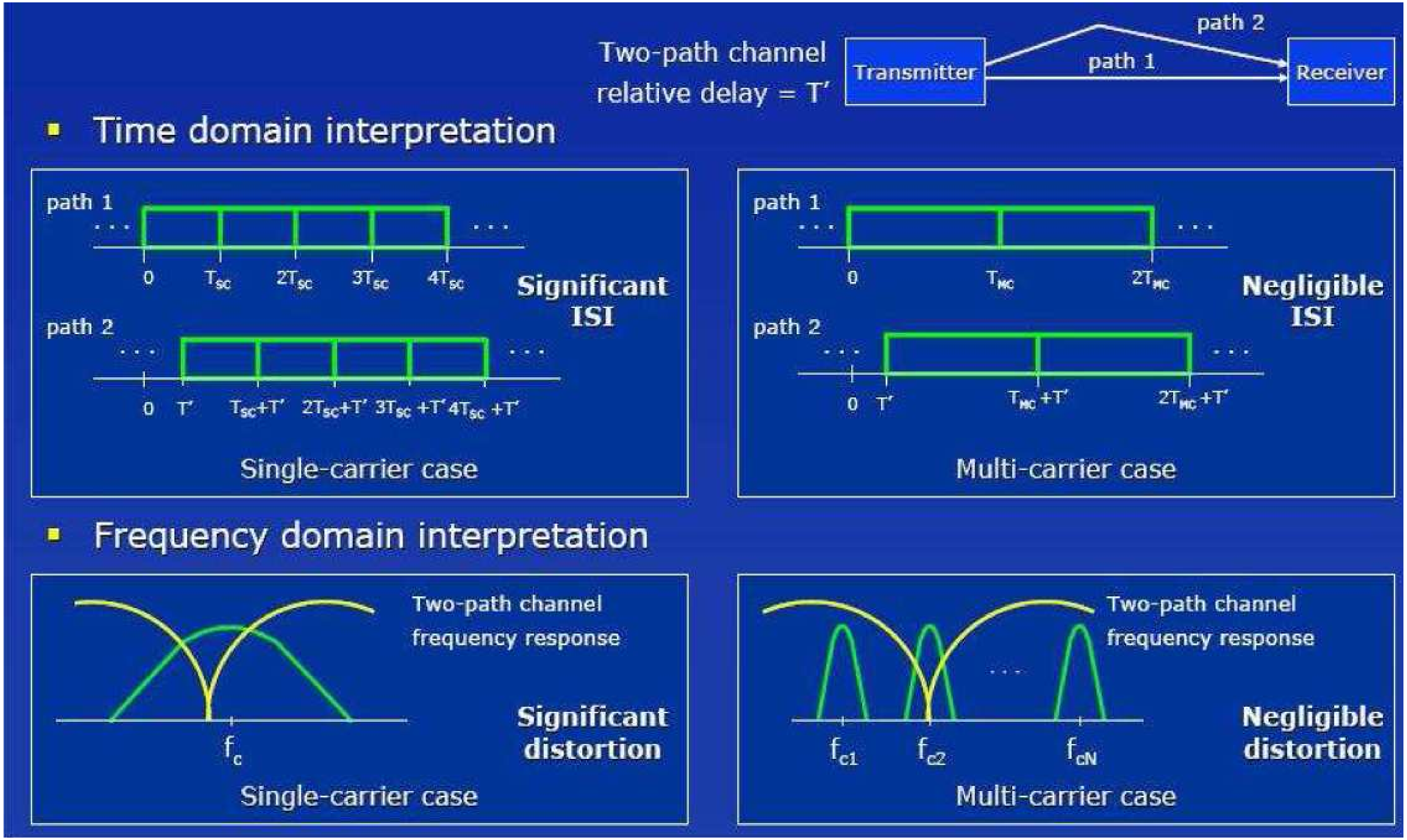

FFT points = 65536, AVG = 8, NBW = 659.2 Hz
Amplitude r(f) / dB
-23.6
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
-100.0
-110.0
-120.0
-130.0
-140.0
-150.0
-160.0
-170.8
-8.00 -7.00 -6.00 -5.00 -4.00 -3.00 -2.00 -1.00 0.00 1.00 2.00 3.00 4.00 5.00 6.00 7.00 8.00
(f-fc)*Tsym
Zoom
Unzoom
Color

802.11g



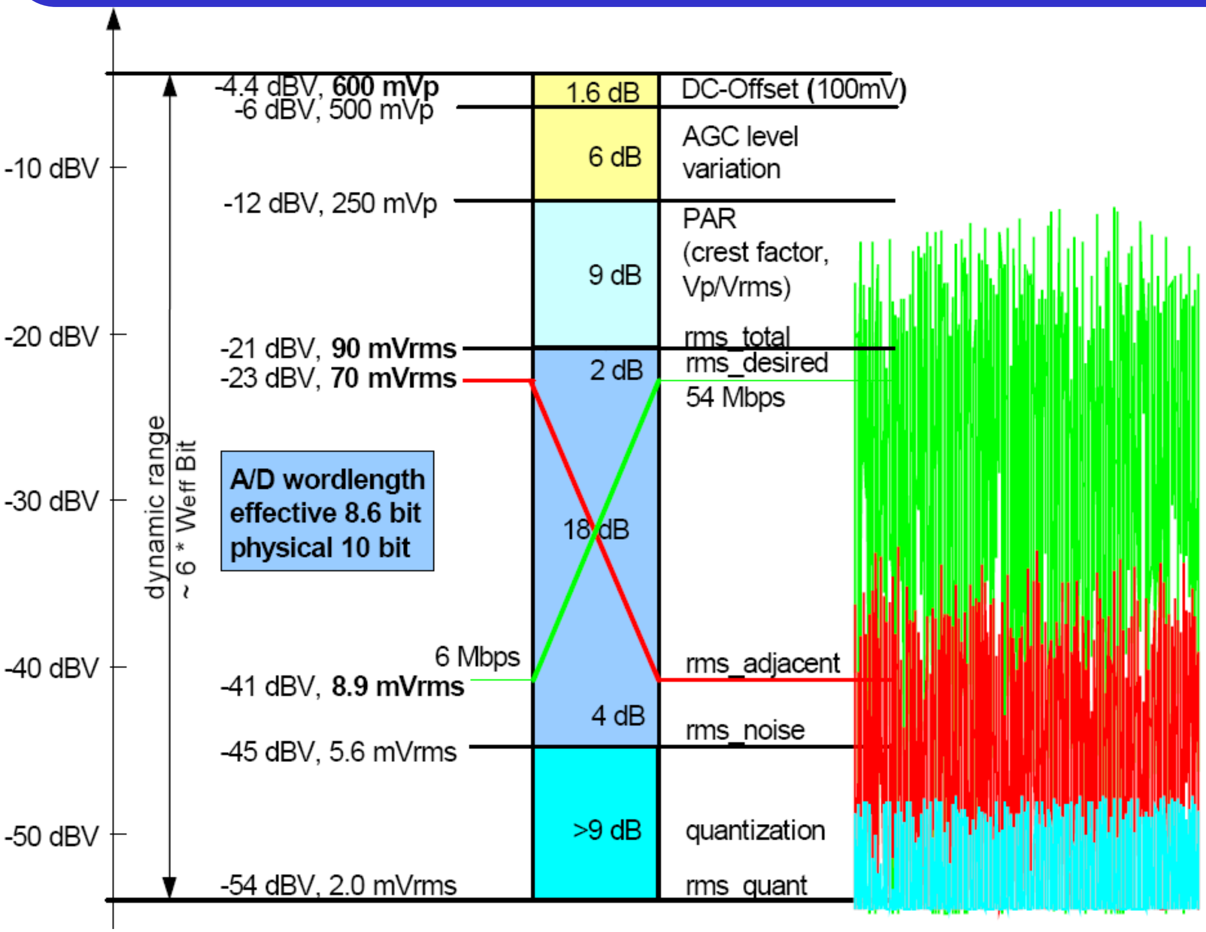
FFT points = 8192, AVG = 1, NBW = 18310.5 Hz
Amplitude r(f) / dB
-40.45
-45.00
-50.00
-55.00
-60.00
-65.00
-70.00
-75.00
-80.00
-85.00
-90.00
-95.00
-100.00
-105.00
-110.00
-115.00
-120.00
-125.00
-130.00
-135.00
-140.00
-145.00
-150.00
-155.26
-50000000 -40000000 -20000000 0 20000000 40000000 4999298
(f-fc)/Hz
Zoom
Unzoom
Color

Interest in multi-path



Drawback: high PAPR

An OFDM signal exhibits a high peak-to-average power ratio (PAPR) because the independent phases of the sub-carriers mean that they will often combine constructively.



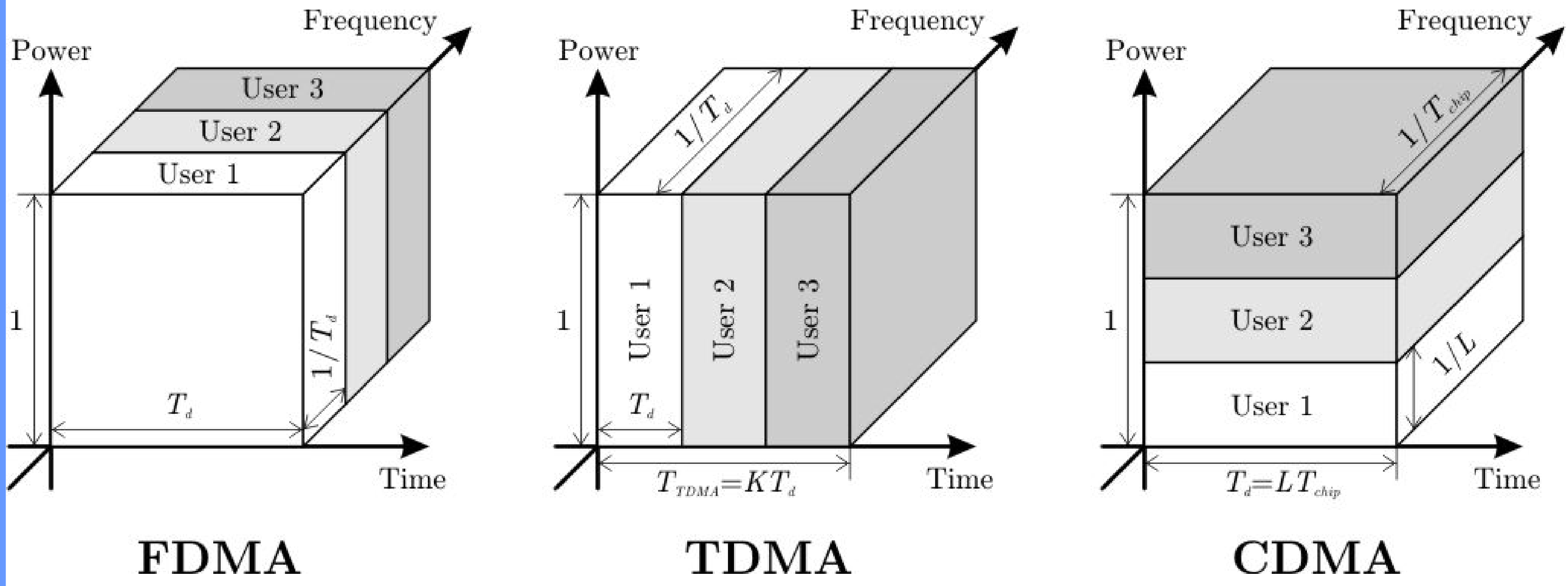
High resolution DAC/ADC needed.

Also needs of fine synchronization and linearity

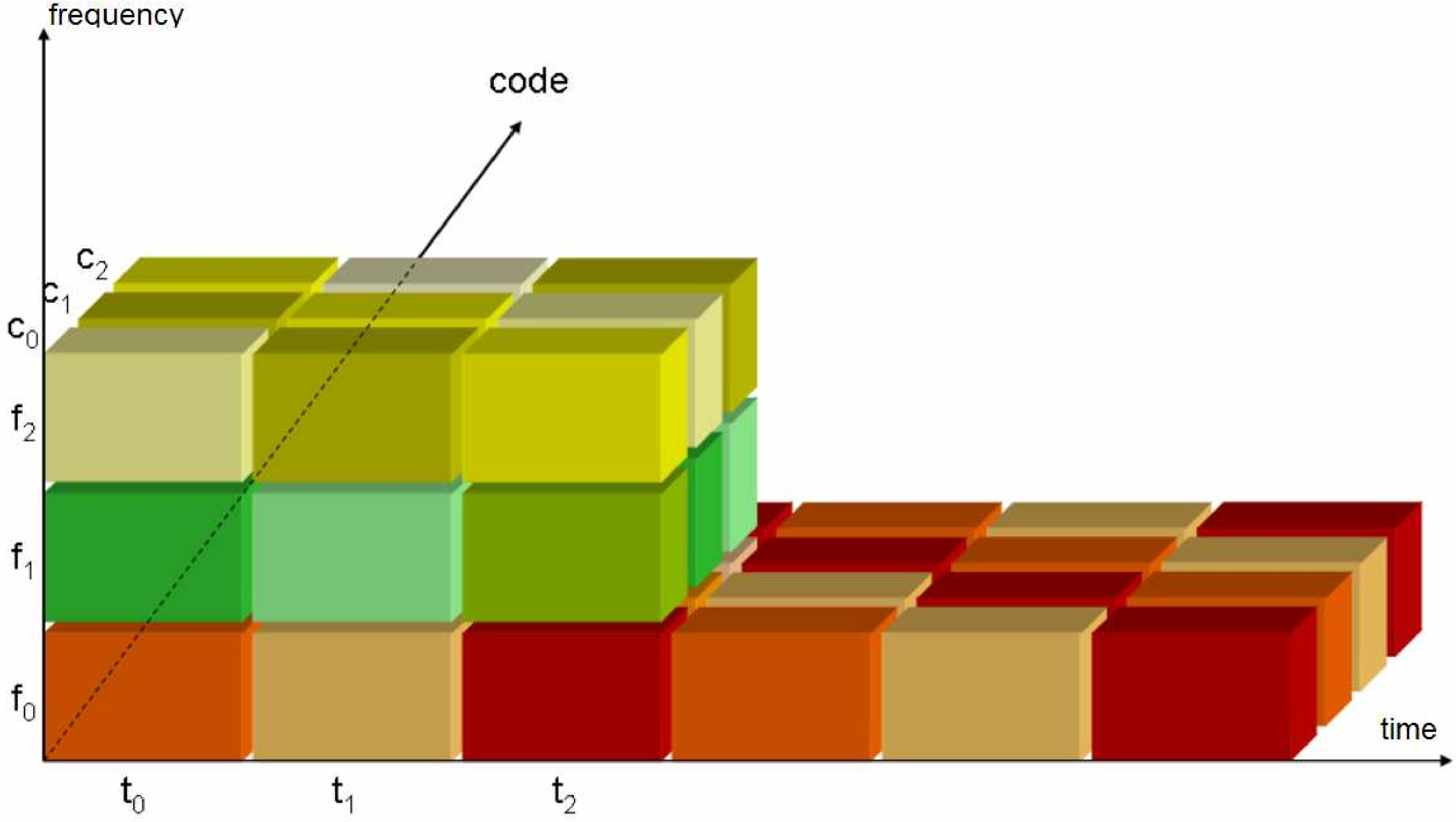
Access sharing

Multiple Access

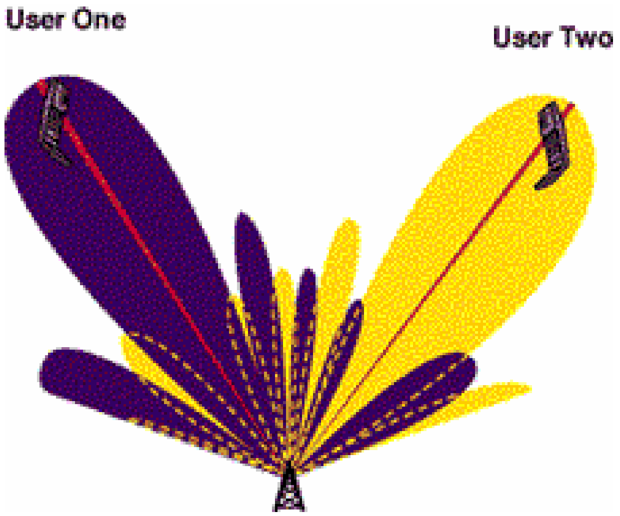
Beyond the unitary link capacity, wireless systems need to share the resource between multiple users.
Different approaches: TDMA, FDMA, CDMA, SDMA, OFDMA, CSMA-CA.

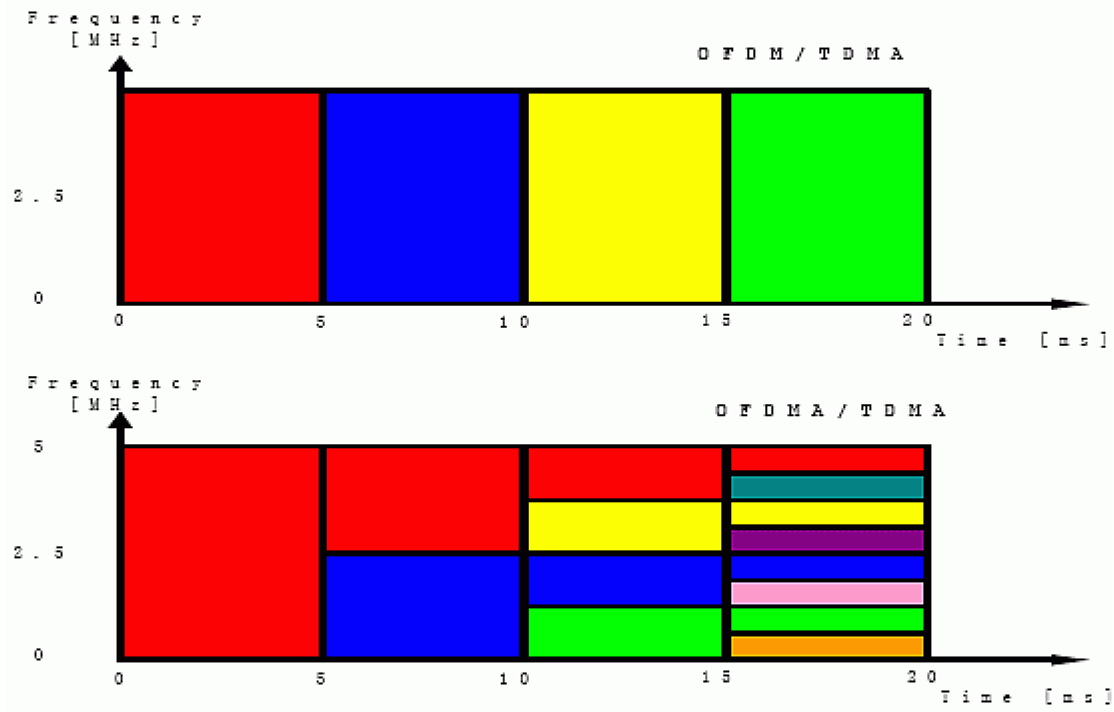


Possible combinations



More recent techniques



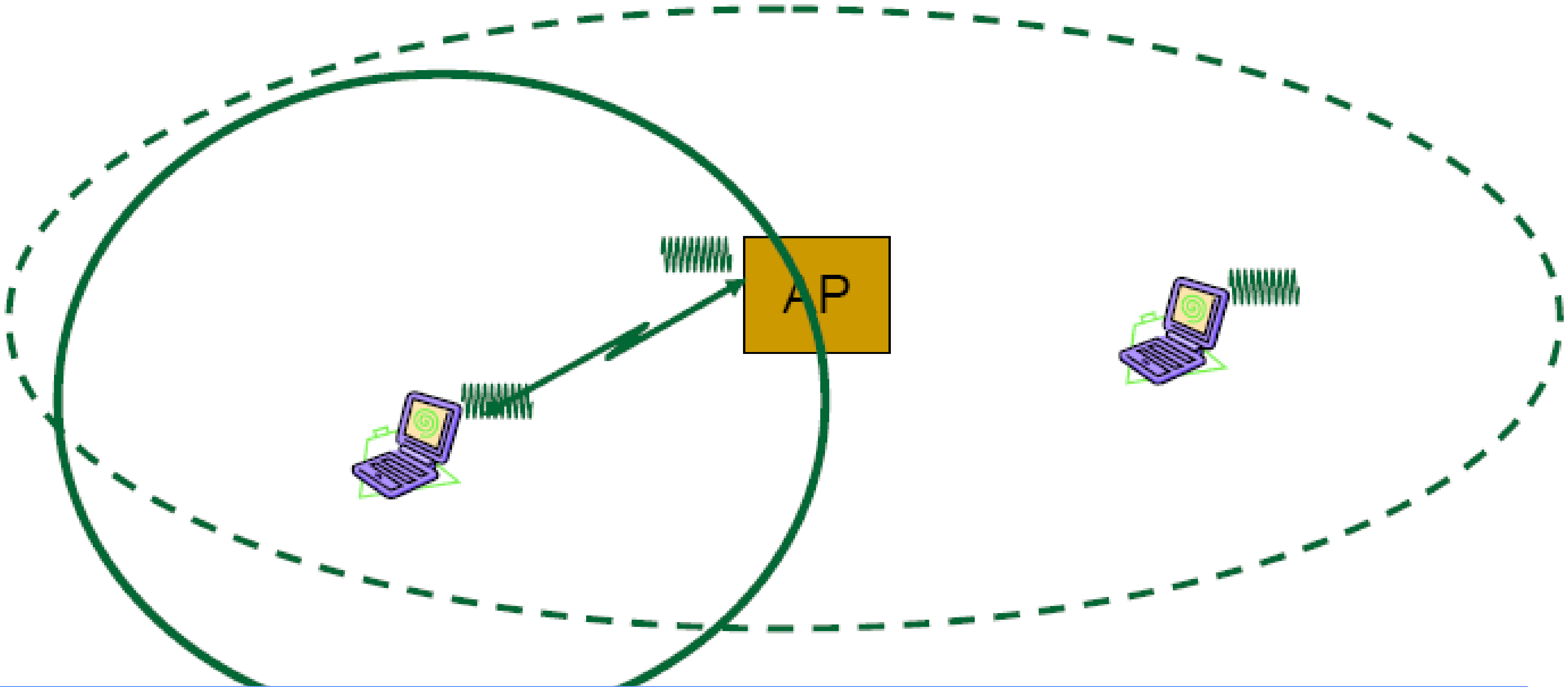


SDMA

OFDMA

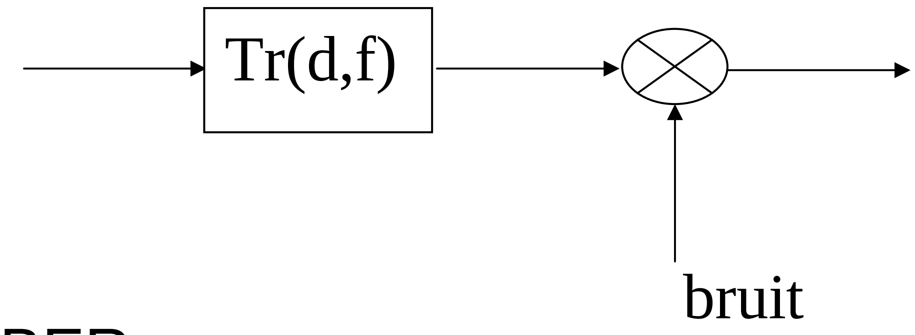
CSMA-CA

To avoid centralized and highly synchronized architectures, each emitter senses the medium before sending data.



RF part

Receiver threshold



– Modulation, coding, BER

➔ acceptable SNR :

(notations : SNR, SINR, C/I, Eb/No).

Decibels :

$$C/I = 10 \cdot \log_{10}\left(\frac{E_b}{N_0}\right)$$

Sensitivity

Key parameter for system dimensioning, it allows to know the amount of received power needed to ensure a desired level at the mixer input.

$$S(dBW) = 10 * log(\bar{\gamma}_m in) + 10 * log(k.To.B) + F(dB)$$

Mean SNR at the antenna

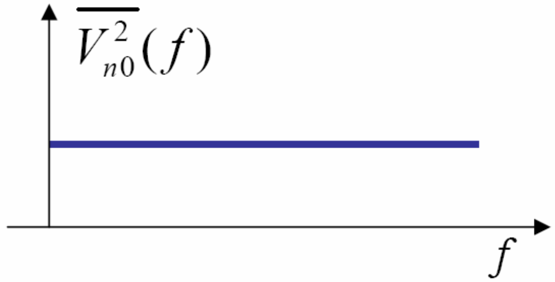
Back to white noise…

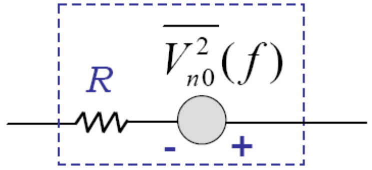
Thermal noise in resistors (white, Gaussian)

$$S_x(f) = \frac{\overline{V_{n0}^2}}{R} = 4kT \qquad \overline{V_n^2} = \overline{V_{n0}^2} \cdot \Delta f$$

flat for f < 100GHz

White noise

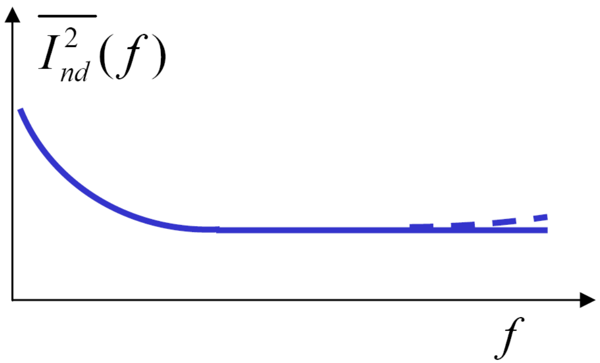


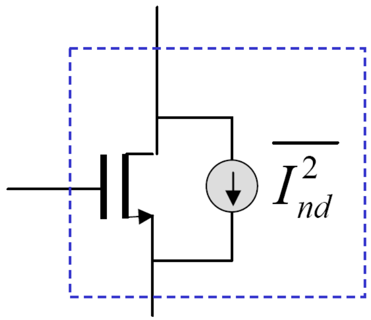


Noisy resistor

Noise in semiconductor devices (white and colored)

Colored noise of MOSFET





Noisy device

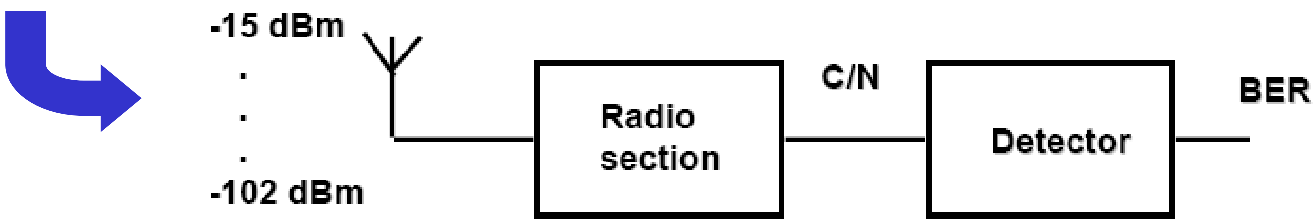
Example of GSM

Source Nokia

Table 1: Reference sensitivity performance

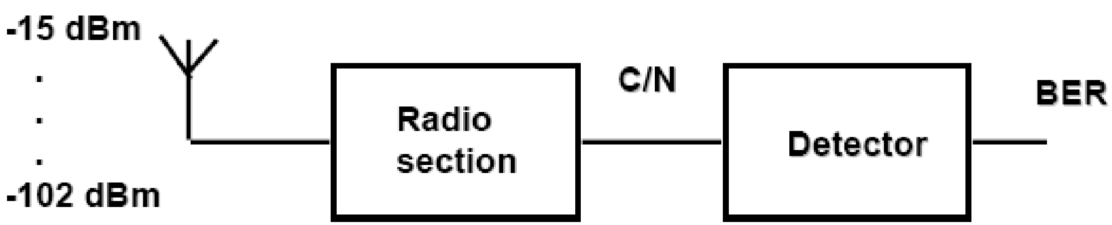
GSM 900

Type of channel	Propagation conditions: static	TU50 (no FH)	TU50 (ideal FH)	RA250 (no FH)	HT100 (no FH)
FACCH/H (FER)	0.1 %	6.9 %	6.9 %	5.7 %	10.0 %
FACCH/F (FER)	0.1 %	8.0 %	3.8 %	3.4 %	6.3 %
SDCCH (FER)	0.1 %	13 %	8 %	8 %	12 %
RACH (FER)	0.5 %	13 %	13 %	12 %	13 %
SCH (FER)	1 %	16 %	16 %	15 %	16 %
TCH/F9.6 & H4.8 (BER)	10^{-5}	0.5 %	0.4 %	0.1 %	0.7 %
TCH/F4.8 (BER)	-	10^{-4}	10^{-4}	10^{-4}	10^{-4}
TCH/F2.4 (BER)	-	$2\ 10^{-4}$	10^{-5}	10^{-5}	10^{-5}
TCH/H2.4 (BER)	-	10^{-4}	10^{-4}	10^{-4}	10^{-4}
TCH/FS (FER)	0.1α %	6α %	3α %	2α %	7α %
class Ib (RBER)	0.4/α %	0.4/α %	0.3/α %	0.2/α %	0.5/α %
class II (RBER)	2 %	8 %	8 %	7 %	9 %
TCH/HS (FER)	0.025 %	4.1 %	4.1 %	4.1 %	4.5 %
class Ib (RBER, BFI=0)	0.001 %	0.36 %	0.36 %	0.28 %	0.56 %
class II (RBER, BFI=0)	0.72 %	6.9 %	6.9 %	6.8 %	7.6 %
(UFR)	0.048 %	5.6 %	5.6 %	5.0 %	7.5 %
class Ib (RBER,(BFI or UFI)=0)	0.001 %	0.24 %	0.24 %	0.21 %	0.32 %
(EVSIDR)	0.06 %	6.8 %	6.8 %	6.0 %	9.2 %
(RBER, SID=2 and (BFI or UFI)=0)	0.001 %	0.01 %	0.01 %	0.01 %	0.02 %
(ESIDR)	0.01 %	3.0 %	3.0 %	3.2 %	3.4 %
(RBER, SID=1 or SID=2)	0.003 %	0.3 %	0.3 %	0.21 %	0.42 %



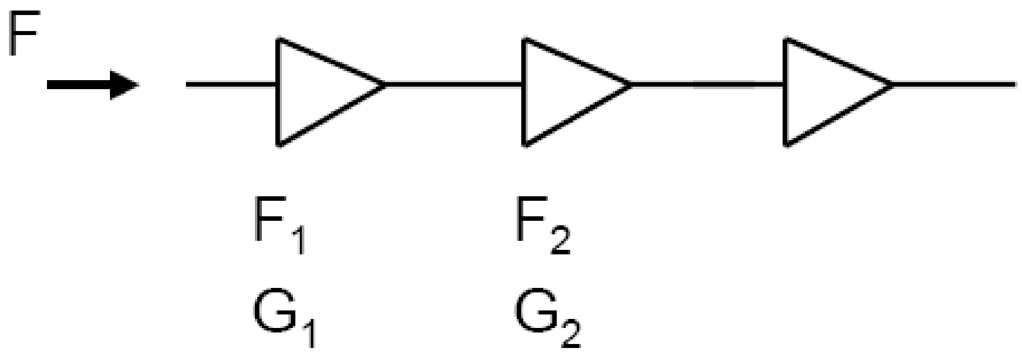
Dimensioning

- From the bit error rate (BER) requirement of the whole phone we can derive secondary specifications for the radio section (Gain, Signal to Noise ratio, Linearity)
- System specification and detector implementation define the required S/N ratio
- GSM needs 8…9 dB S/N (number includes some implementation margin 2…3 dB)



Noise figure

- Cascaded noise figure
  - NF = 10 log F, where NF is noise figure and F is noise factor
  - $F = F_1 + (F_2-1)/G_1 + (F_3-1)/G_1G_2 + \dots + (F_n-1)/ G_1G_2\dots G_{n-1}$
- RF section must have enough gain to provide adequate signal level for A/D converter
- Minimum input level is -102 dBm -> 1.8 uV @ 50 ohm. If we need for example 100 mV at A/D converter input, voltage gain needs to be 20 log(100mV/1.8uV) = 95 dB



Signal must be 9 dB above noise floor, so requirement for receiver noise figure (NF) is

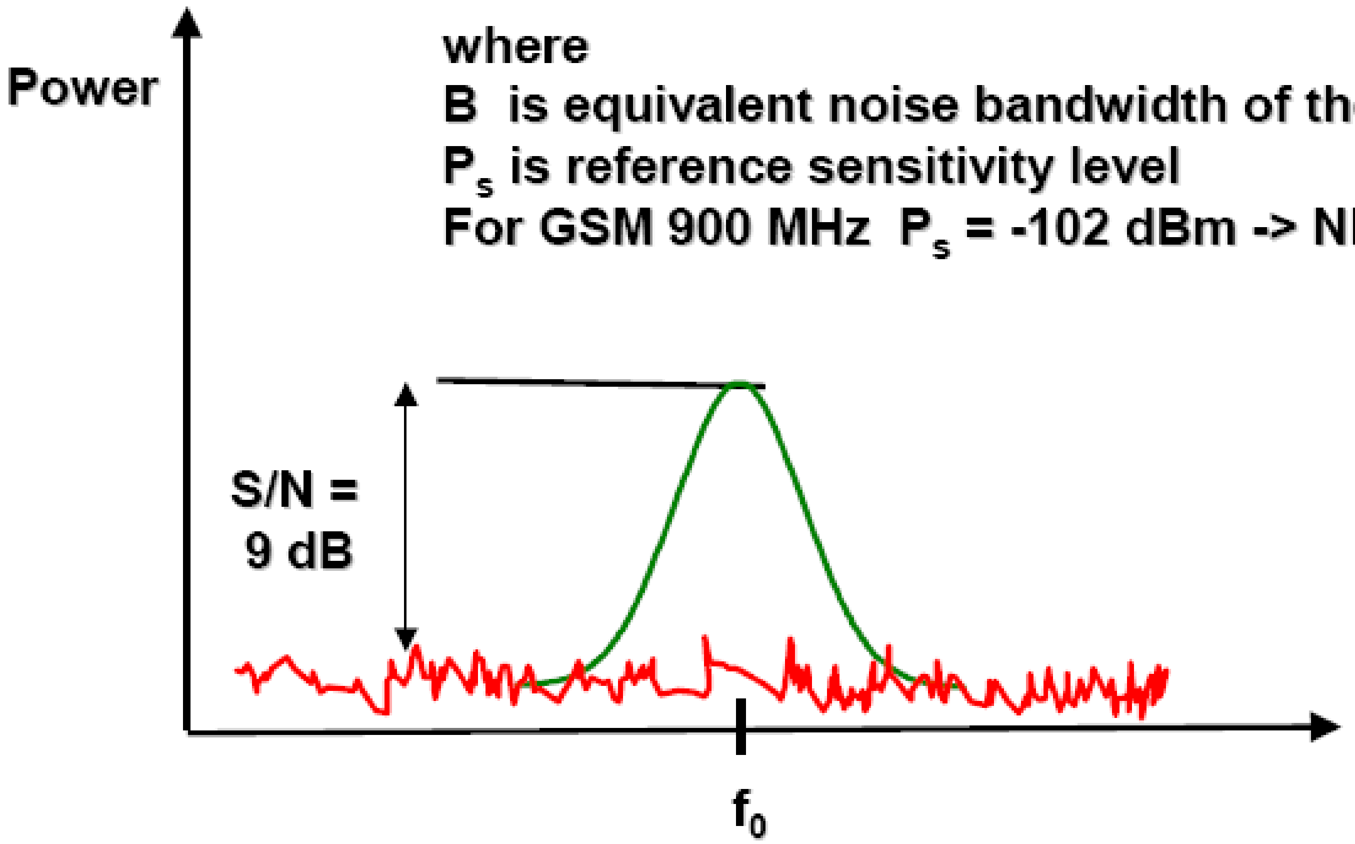
$$NF = P_s + 174 \text{ dBm} - 10 \log B - S/N$$

where

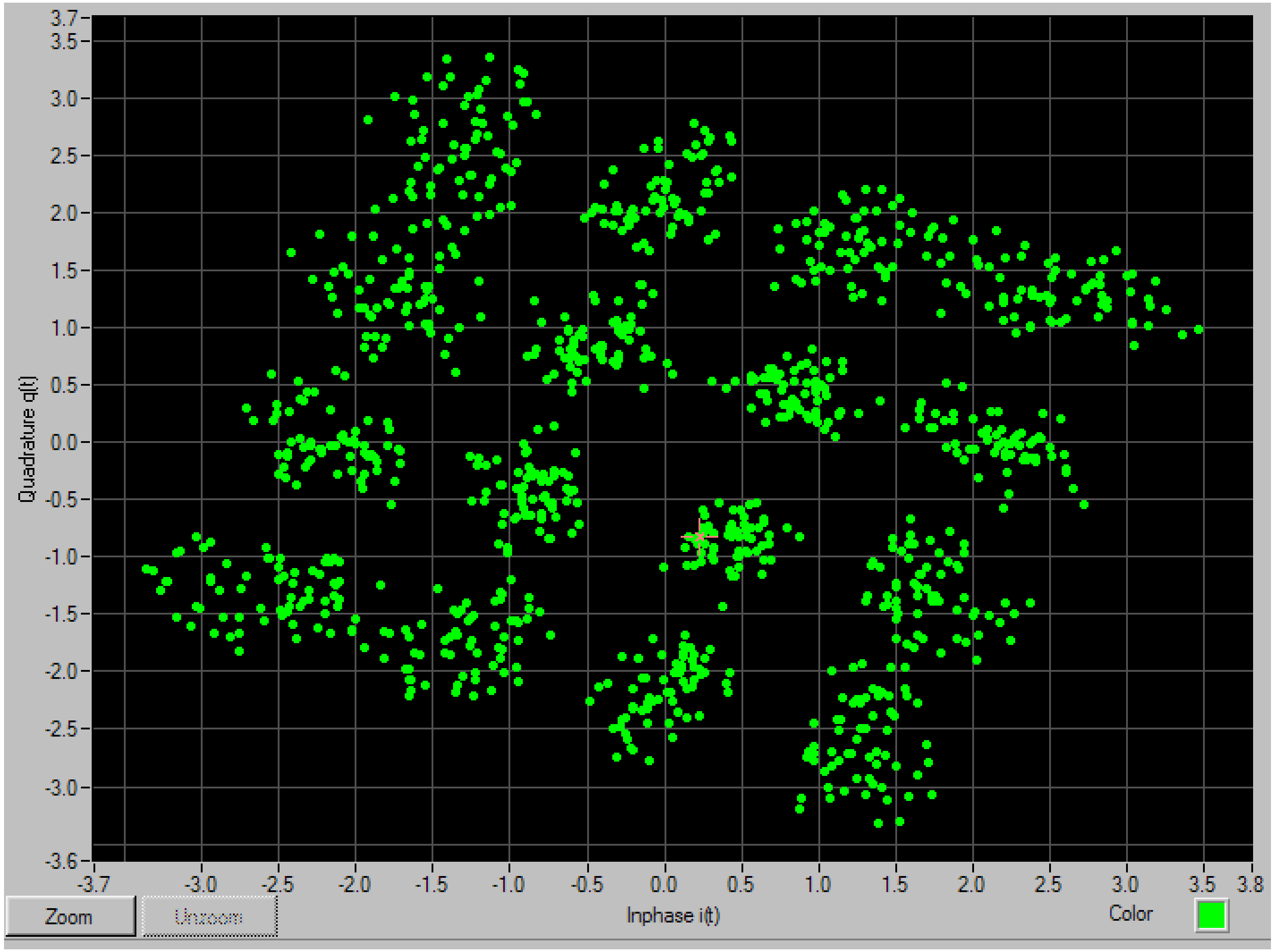
B is equivalent noise bandwidth of the receiver

P_s is reference sensitivity level

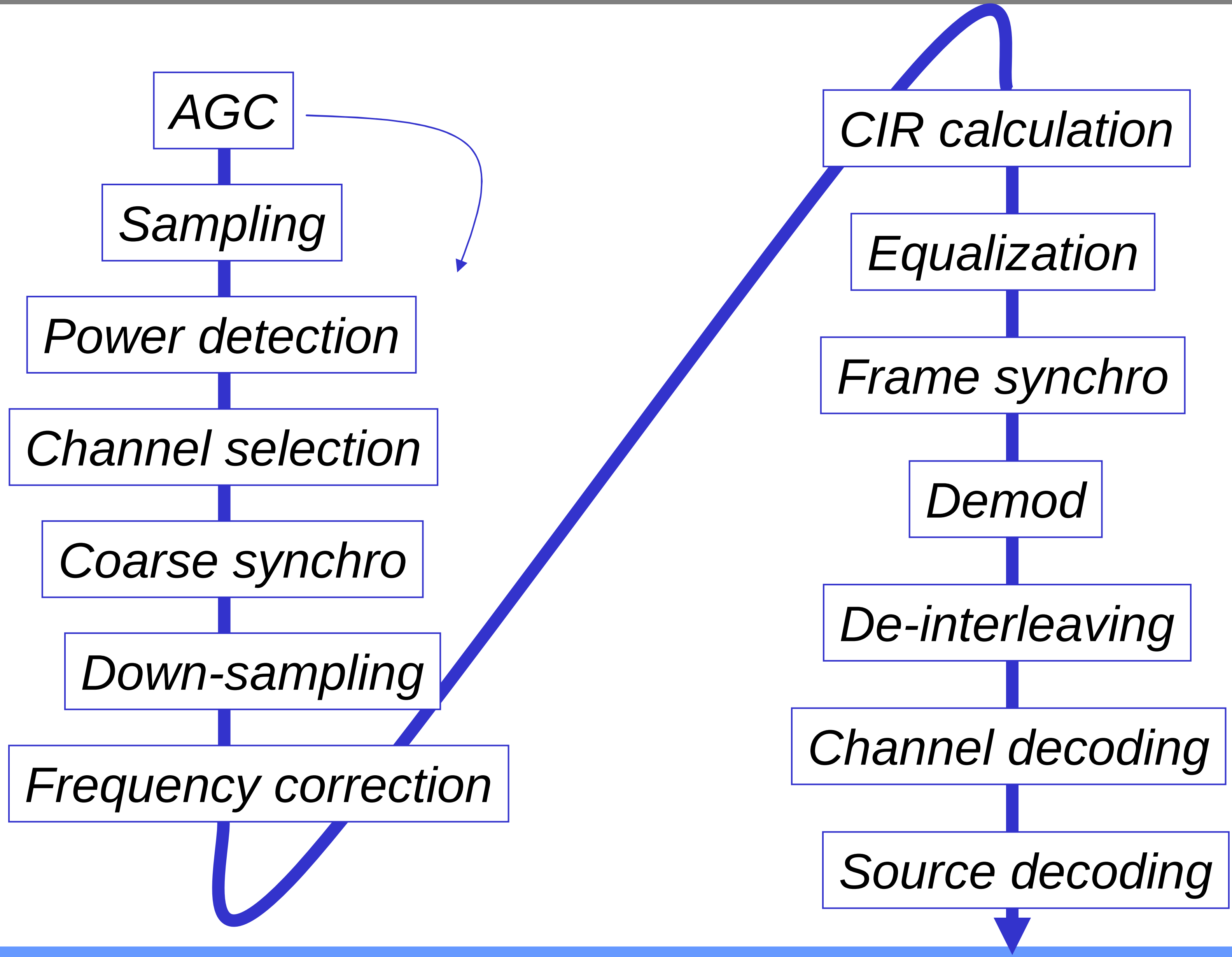
For GSM 900 MHz P_s = -102 dBm -> NF = 10 dB



Some words on baseband

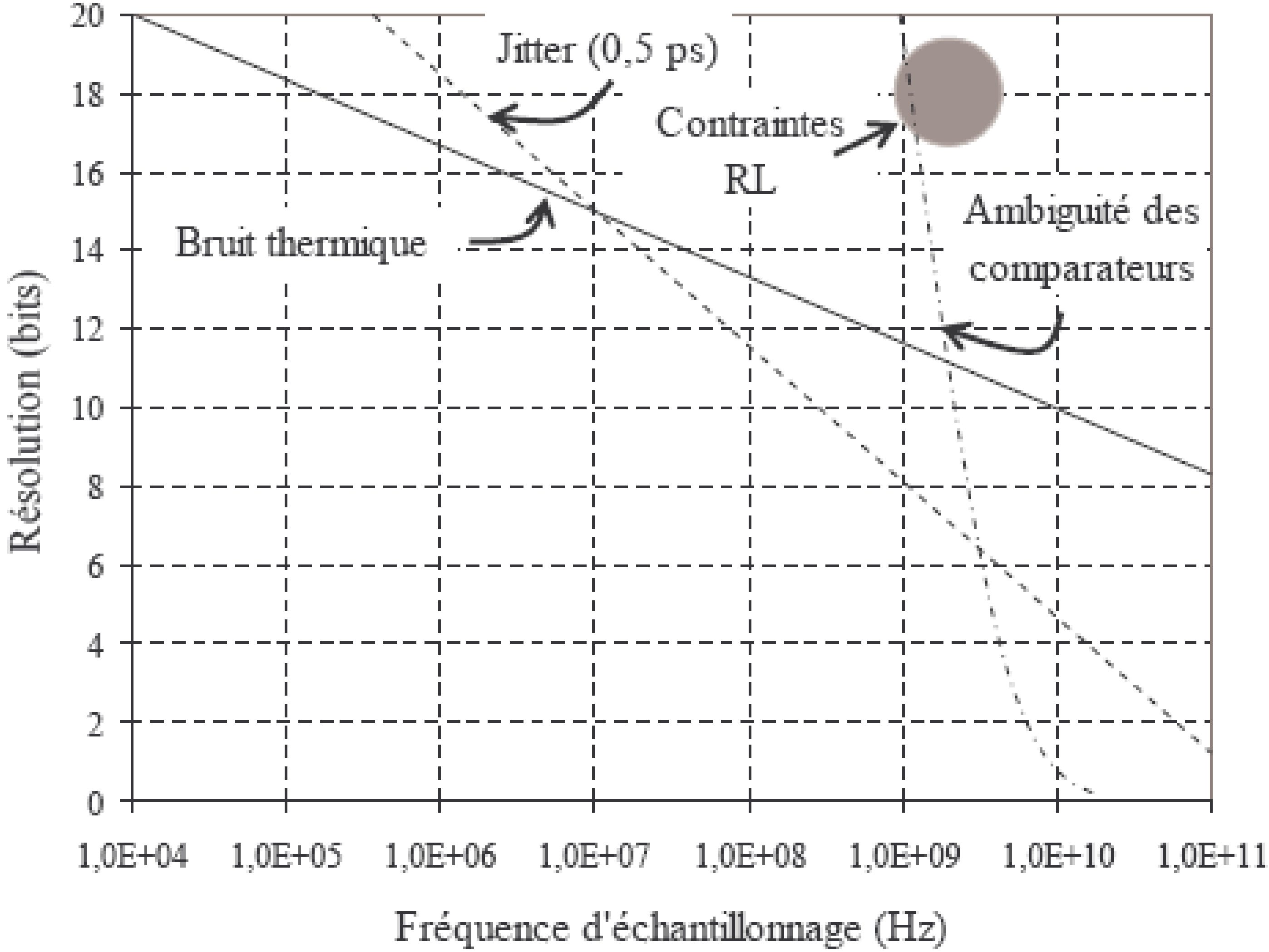

3.7
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.6
Quadrature q(t)
-3.7
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
3.8
Zoom
Unzoom
Inphase i(t)
Color

Main steps of receiving



A/D Conversion

Limitations



SNR for ADC

Plus distortions SNDR

$$SNR = 6{,}02N + 1{,}76 + 10.\log\left(\frac{f_s}{2.f_{\max}}\right)$$

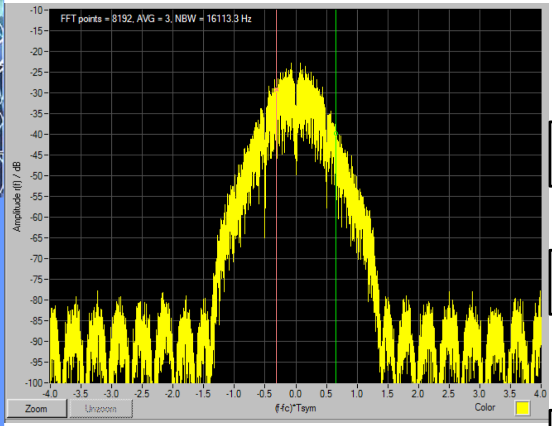
N represents considered number of bits for ADC, fs the sampling frequency and fmax the maximum frequency contained in the signal to digitize.

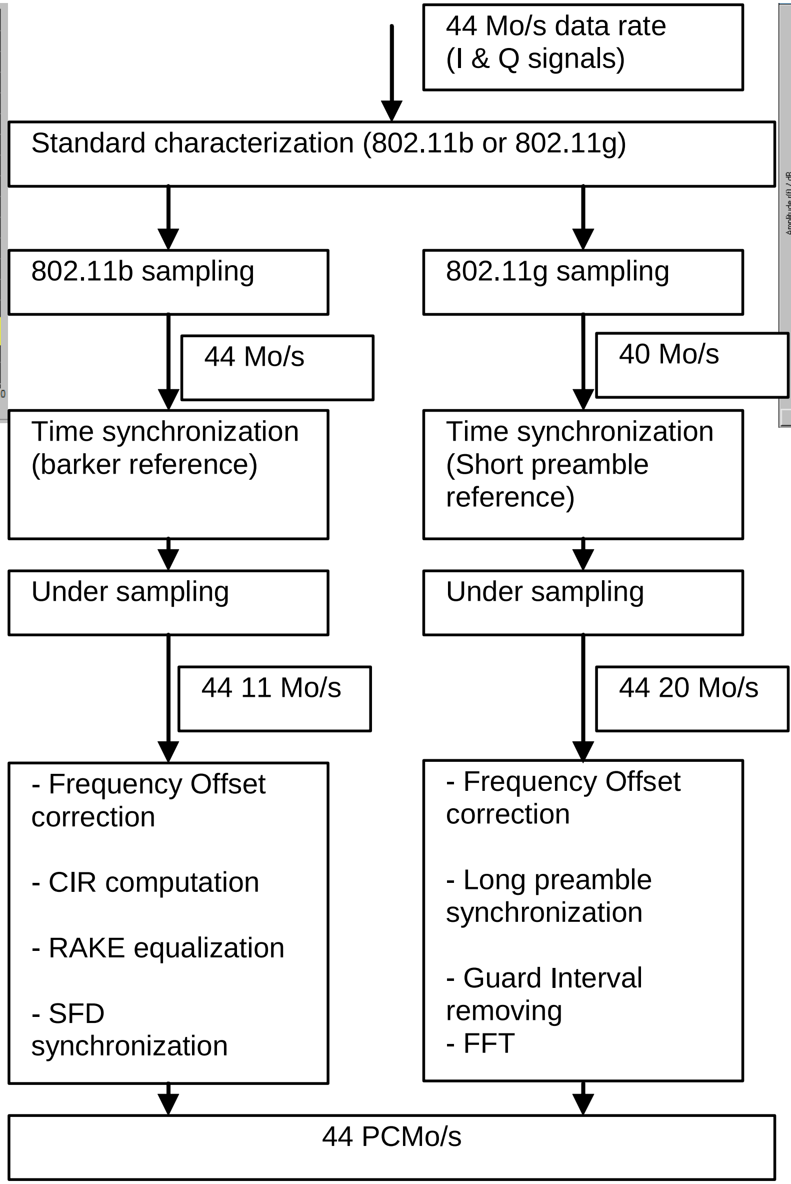
Effective number of bits:

$$ENOB = \frac{SNDR - 1{,}76}{6{,}02}$$

Gain control

- With AGC the average signal level at the A/D converter input is kept almost constant
  - Trade off between AGC and A/D converter dynamic range
- In GSM phone reports received signal strength and ±1 dB relative measurement accuracy is required from -110 dBm to -48 dBm
- In IS-95 CDMA the TX power must follow received signal strength: Pout = -Pin -76 dBm at the input range -104 dBm to -25 dBm (open loop power control, accuracy requirement ±9.5 dB)
- In CDMA RX and TX gain controls should have similar temperature behavior




44 Mo/s data rate
(I & Q signals)
Standard characterization (802.11b or 802.11g)
802.11b sampling
802.11g sampling
44 Mo/s
40 Mo/s
Time synchronization
(barker reference)
Time synchronization
(Short preamble
reference)
Under sampling
Under sampling
44 11 Mo/s
44 20 Mo/s
- Frequency Offset
correction
- CIR computation
- RAKE equalization
- SFD
synchronization
- Frequency Offset
correction
- Long preamble
synchronization
- Guard Interval
removing
- FFT
44 PCMo/s