Institut Mines-Télécom

Link Budget 4G

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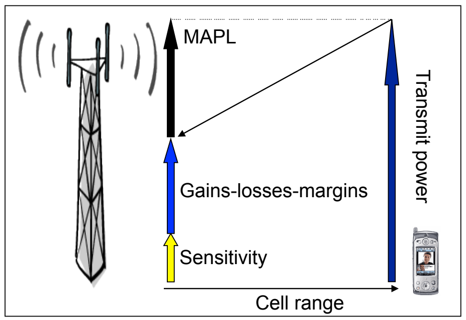
Plan du cours

Introduction

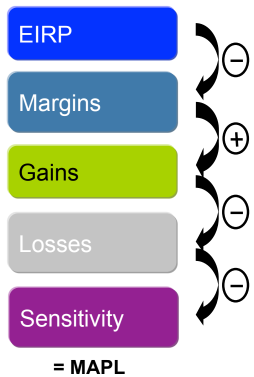
- **Problem formulation :**
  - Dimensionning a cellular network: How many BSs do we need to cover a given area characterized by some radio propagation parameters and traffic demand?
  - Capacity of a cellular network: How many users can the network serve? With which quality of service?
  - Coverage: What is the cell range?
  - Deploiement: Which radio techniques can we use to increase coverage or capacity?
- In this lecture, we are interested in coverage studies thanks to an approximative tool: **the link budget**

Basic concepts
Principles of the link budget

- **Principle**: We start with a power budget from which we substract losses and margins; received power should be higher than the receiver sensitivity.



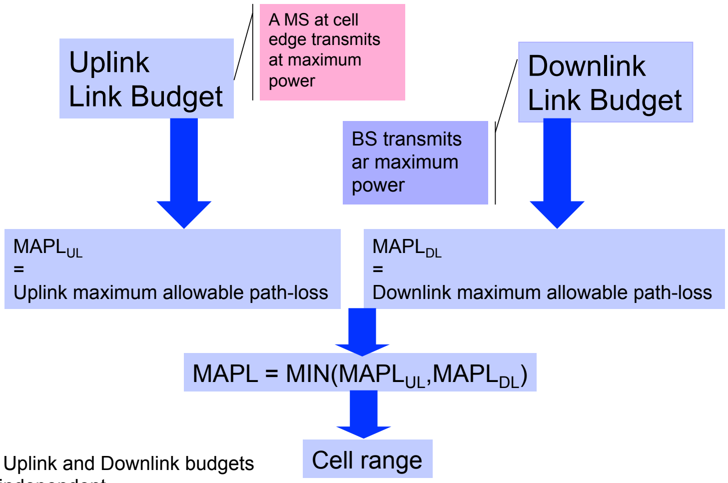
Example: uplink
MAPL = Maximum Allowable Path Loss



Propagation model, e.g. Hata

MAPL [dB] → Cell range [Km]

Basic concepts
Principles of the link budget



NB: Uplink and Downlink budgets are independent

Basic concepts
Principles of the link budget

- **The MAPL is the minimum of the uplink and downlink MAPLs.**
- **To increase coverage, it is needed to identify the limiting link:**
  - Uplink limited: MAPLul < MAPLdl
  - Downlink limited: MAPLdl < MAPLul
- **Coverage extension is done by using appropriate radio techniques:**
  - Uplink limited network:
    - Receive diversity (2 or 4 antennas),
    - Tower Mounted Amplifier (TMA).
  - Downlink limited network:
    - High power amplifier,
    - Transmit diversity,
    - Low loss BS configuration.

Basic concepts
SINR and sensitivity

- **Sensitivity** = minimum power needed to guarantee a certain quality of service or a certain throughput in presence of noise only
- Dedicated channel technologies (UMTS R99, GSM): There is a target SNR or SINR γ^*. Below this threshold, quality of service is not sufficient.
- Shared channel technologies (HSDPA, LTE): Throughput is an increasing function of the SNR/SINR. We deduce from the target throughput at cell edge, the SNR or SINR threshold γ^* to be reached.
- From noise power and SNR threshold, we deduce the sensitivity:

$$\gamma^* = \frac{S}{N} \Rightarrow S = N\gamma^*$$

- In a link budget, co-channel interferences are taken into account in an interference margin.

Basic concepts
SINR and sensitivity

- Reminder on logarithmique scale, dB and dBm
- We use the logarithmic scale to represent signal to (interference plus) noise ratios

$X\_dB = 10 \log_{10}(X\_linear) \Rightarrow X\_linear = 10^{(X\_dB}$

- $SNR_{dB} = 10 \log_{10}(SNR_{linear})$
- The dB milliwatt or dBm:

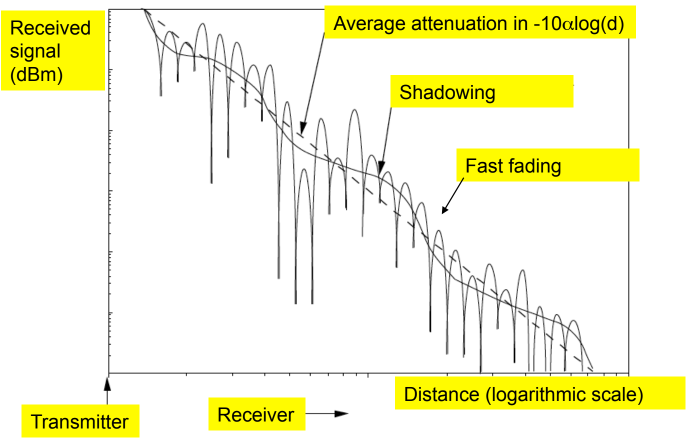
  $P\_dBm = 10 \log_{10}(P\_mW)$.

- Ex: $SNR_{linear} = 2$ <=> $SNR_{dB} = 3$ dB
- Be careful: subscripts are rarely used (but it does not mean that 2 = 3 (!))

10 dB = 10	times
7 dB = 5	times
3 dB = 2	times
0 dB = 1	times
-3 dB = ½	times
-10 dB = 1/10	times
-13 dB = 1/20	times
-17 dB = 1/50	times

Basic concepts
Propagation

- Reminder: The three stage propagation model.



Basic concepts
Propagation

- **In link budgets:**
  - Average attenuation (path-loss): We use an empirical model
  - Shadowing: Taken into account by a shadowing margin in the computation of the MAPL
  - Fast fading: Usually taken into account in the sensitivity (except in UMTS R99), which is computed from link level simulations including fast fading models

Basic concepts
Propagation

- Path-loss: Difference in dB between transmit and received power
- We use empirical models coming from extensive measurement campaigns and that depends only on a small set of parameters characterizing the environment
- Some models:
  - **Okumura-Hata**: measurements performed in Tokyo in 1968, 150-1500 MHz, distances between 1 and 10 Km, urban areas, suburban areas, open areas
  - **COST231-Hata**: 1999, extends Okumura-Hata model to 1500-2000 MHz
  - **COST231-Walfish-Ikegami**: distances between 20 m and 5 Km, 800-2000 MHz, LOS and NLOS
- There are other models for indoor propagation, micro-cells, below roof top antennas, etc.

Basic Concepts
Propagation

- Okumura-Hata model for 150-1500 MHz :

$$L = A + B\log_{10} R - C$$

With:

$$A = 69.55 + 26.16\log_{10} f - 13.82\log_{10} h_b$$

$$B = 44.9 - 6.55\log_{10} h_b$$

$$C = \begin{cases} 3.2(\log_{10}(11,75f))^2 - 4.97 & \text{(Urban)} \\ 2(\log_{10}(f/28))^2 + 5.4 & \text{(Suburban)} \\ 4.78(\log_{10} f)^2 - 18.33\log_{10} f + 40.94 & \text{(Rural)} \end{cases}$$

f in MHz

R in km

h_b in m

Basic concepts
Propagation

- COST231-Hata model for 1500-2000 MHz (urban environment) :

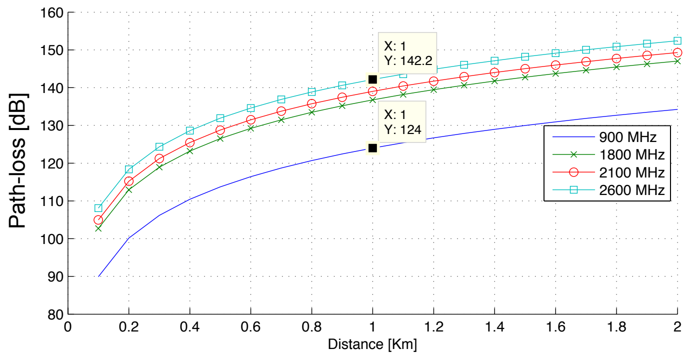
$$L = A + B\log_{10} R - C$$

With:

$$\begin{aligned} A &= 46.3 + 33.9\log_{10} f - 13.82\log_{10} h_b \\ B &= 44.9 - 6.55\log_{10} h_b \\ C &= (1.1\log_{10} f - 0.7)h_m - (1.56\log_{10} f - 0.8) - 3 \\ f &\text{ in } \mathrm{MHz} \\ R &\text{ in } \mathrm{km} \\ h_b &\text{ in } \mathrm{m} \\ h_m &\text{ in } \mathrm{m} \end{aligned}$$

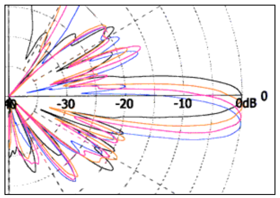
Basic concepts
Propagation

- Example in urban environment: 18 dB difference at 1 Km between 900 and 2600 MHz, few differences between 2100 and 2600 MHz.



Basic concepts
Antennas, diversity and sectorization

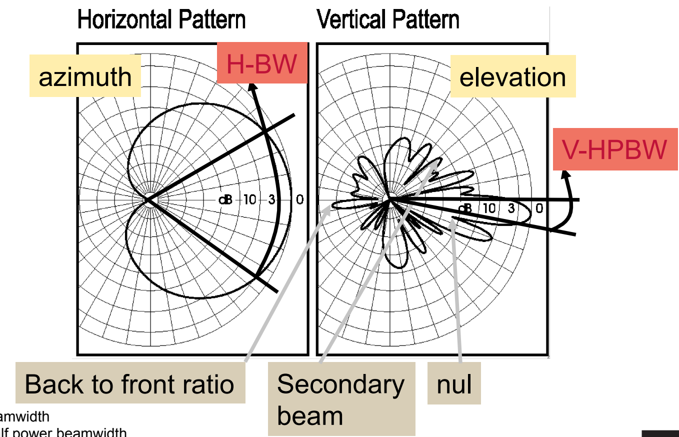
- **Main characteristics of an antenna (reminder):**
  - Frequency band
  - Horizontal beamwidth (in °),
  - Vertical beamwidth (in °),
  - Gain (in dBi),
  - Polarisation (horizontal, vertical)
  - Height (rarely more than 2 m),
  - Electrical or mecanical tilt (in °).



Antenna tilt

Basic concepts
Antennas, diversity and sectorization

- Antenna pattern

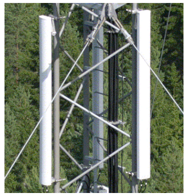


HBW: Horizontal beamwidth
V-HPBW: Vertical half power beamwidth

Basic concepts
Antennas, diversity and sectorization

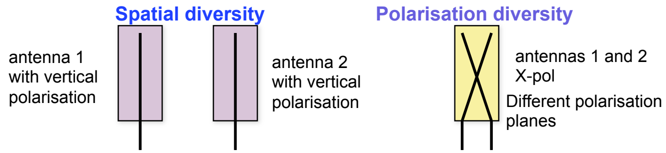
- The gain depends on the height, the frequency band and the capacity of the antenna to focus energy in a given direction.
- Typical antenna gains:

Spectrum	Omni	Tri-sectorized
Low bands (700 — 900 MHz)	12 dBi	16 dBi
Intermediate bands (1.3 – 2.3 GHz)	13 dBi	18 dBi
Higher bands (2.5 – 2.6 GHz)	14 dBi	19 dBi



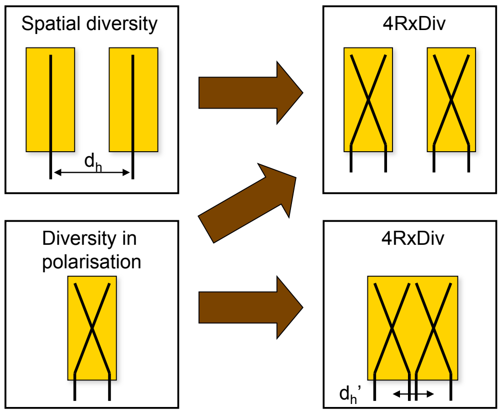
Basic concepts
Antennas, diversity and sectorization

- Receive diversity reduces the effects of fast fading by combining different correlated signals.
- **Spatial diversity**: Two or more antennas are physically separated horizontally or vertically. The visual impact is significant. Important gains in LOS: this solution is adapted to rural environments.
- **Polarisation diversité**: Antennas have different polarisation planes. Solution more adapted to urban environments.
- **Typical gains** : 3dB (2RxDiv), 6dB (4RxDiv)



Basic concepts
Antennas, diversity and sectorization

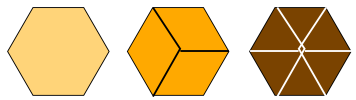
- **Evolutions towards 4RxDiv :**



- **Spatial constraints**
  - $d_h > 20\lambda = 3m$
  - for f = 2GHz
  - $\lambda = c/f = 15cm$
- **[Laiho02] recommands:**
  - $d_h = 1,5m$
  - $d_h' = 0,3m$

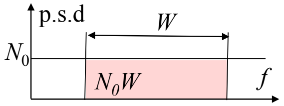
Basic concepts
Antennas, diversity and sectorization

- **Sectorization: increase the number of sectors per site**
- **Impact on the dimensionning:**
  - Antenna gain is increased (example at 900 MHz)
    - 1 sector : 360°/12dBi
    - 3 sectors : 65°/16dBi
    - 6 sectors : 33°/18dBi
  - Increased capacity (densification)
- **There is a need for more hardware modules**
  - Antennas
  - Amplifiers
  - Processing capacity
- One can genrally observe a degradation of the average cell SINR when the number of sectors increases



Basic concepts
Thermal noise and noise factor

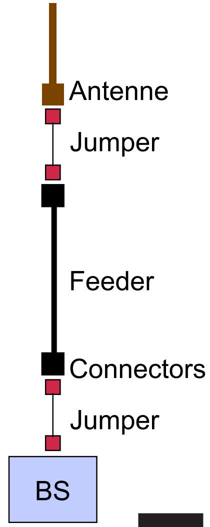
- **Noise power (N)** = Thermal (or background) noise x receiver noise factor
- **Thermal noise** (***background noise***)
  - N_0 = -174 dBm/Hz = 10 log(kT), psd (power spectral density)
  - k = 1.38066 10^{-23} J/K (Boltzmann constant), T = 290 K
  - Noise power in the band: $N_0\, W$ = -174 +10 Log(W)
- **Noise factor of the receiver**
  - Noise introduced by the components of the reception chain
  - Typical value: NF = 5dB (BS) NF = 8dB (UE)



$$N = N_0 W \cdot NF$$

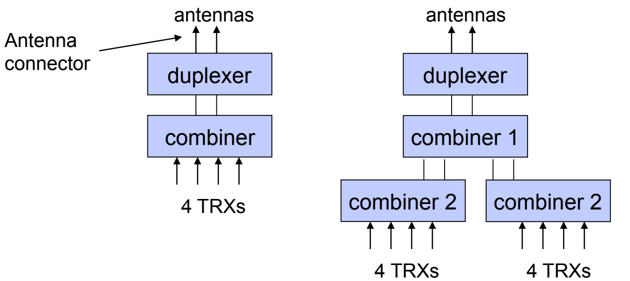
Basic concepts
Cable losses

- **Cable losses**: feeder, jumper, connectors
- The feeder is at the interface between the antenna and the BS.
- **The feeder** is a thick rigid cable whose attenuation depends on feeder type and length and on the frequency band.
  Example : LCF 7/8'' 900 MHz 3.7dB/100m
- **The jumper** is a flexible cable which is used at both ends of the feeder. His losses are greater.
  Example : 0.15dB/1m
- **The connectors** link different cables together.
  They introduce additional losses.
- Some other components are needed if the feeder is shared (diplexer) or if the site is shared (filters).



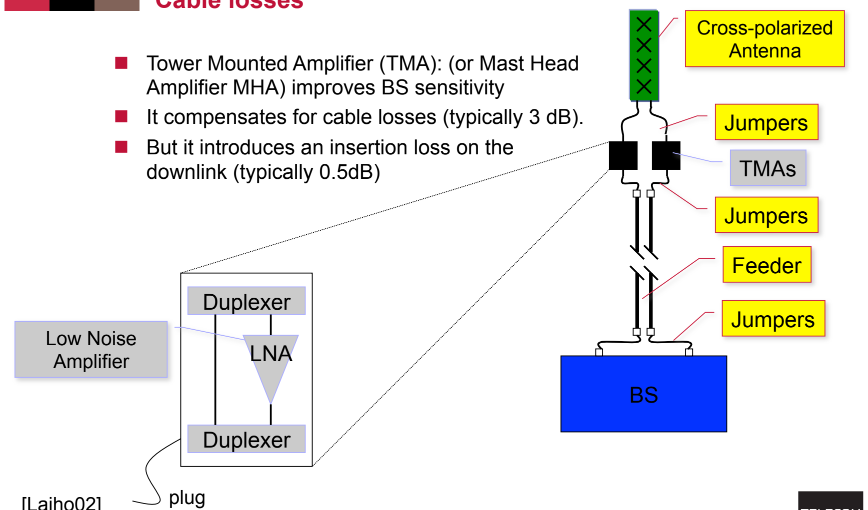
Basic concepts
Cable losses

- Duplexer: an electronic device used to combine or separate transmission and reception on the same frequency band
- Combiner : an electronic device to combine or separated several frequencies in the same band



Basic concepts
Cable losses

- Tower Mounted Amplifier (TMA): (or Mast Head Amplifier MHA) improves BS sensitivity
- It compensates for cable losses (typically 3 dB).
- But it introduces an insertion loss on the downlink (typically 0.5dB)

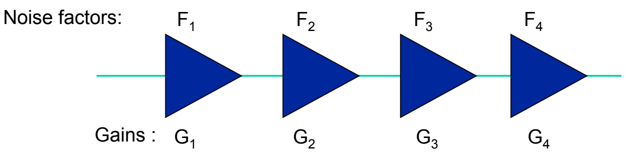


[Laiho02]

Basic concepts
Cable losses

- Noise factor reduction: the global noise factor of a cascade of active and passive components is given by the Friis formula:

$$NF = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 G_2} + \frac{NF_4 - 1}{G_1 G_2 G_3} + \dots$$



- The number of stages depends on the site architecture
- Typically: TMA – Feeder – Connectors – BS (if jumpers are neglected)
- TMA impact is often modeled by the suppression of cable and connectors losses on the uplink: interesting for high antennas

[Laiho02]

Basic concepts
Cable losses

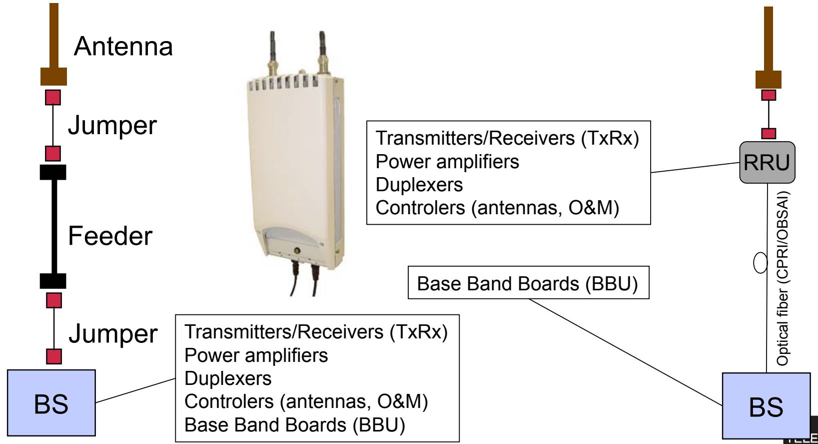
- **Example of computation of the noise factor:**
  - NB: passive components have a noise factor equal to their loss
  - Typical gain of a TMA: 12dB
  - Typical noise factor of a TMA : 2dB

Component	Gain	Noise factor
TMA	12dB	2dB
Feeder	-2dB	2dB
Connectors	-0.3dB	0.3dB
BS	-	3dB

- Without TMA: NF = 5.3dB
- With TMA: NF = 2.4dB
- Gain brought by the TMA: 2.9dB

Basic concepts
Cable losses

- RRU (Remote Radio Unit) or RRH (Remote Radio Head): allows to move certain functions of the BS in a module close to the antenna



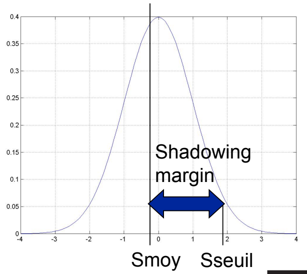
Basic concepts
Margins

- **Main margins:**
  - Shadowing margin
  - Fast fading margin (for UMTS)
  - Indoor penetration margin (loss)
  - Interference margin
  - Body losses

- **Body losses:** losses introduced by the head of the user when he is in a phone call. Recommanded figure is 3 dB [GSM03.30]. 0dB for visiophonie or data services.

Basic concepts
Margins

- **Shadowing margin:** shadowing is modeled by a log-normal distribution; the shadowing margin ensures that the signal level is above the sensitivity in the whole cell with a probability of 90% - 95%.
- **Shadowing margin depends on the standard deviation of the log-normal**
- **Standard deviation depends on the environment:**
  - Close to 8 dB in dense urban,
  - Close to 6 dB in rural.
- **Two approaches:**
  - On the whole cell area,
  - On the cell border.



Basic concepts
Margins

- **Shadowing (in dB)** is modeled by a normal distribution (with zero mean and standard deviation σ which is typical of the environment)
  - One wants to ensure a coverage at (1-Pout)% of the cell
  - or alternatively a coverage at (1-Pout)% at cell edge
  - In urban areas, (1-Pout)=95% or more
  - In rural areas, (1-Pout)=90% or more
- **Propagation model**
  - Path-loss plus shadowing has a Gaussian distribution in dB
  - With mean: A+Blog(r)
  - With variance: σ^2

$$Att(r) = PL(r) + s = A + B\log(r) + s$$
$$E[Att] = A + B\log(r)$$
$$E[Att^2] = \sigma^2$$

[Viterbi94]

Basic concepts
Margins

- We look for the shadowing margin K_s
- We compute the probability to overcome this margin at distance r

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{+\infty} e^{-t^2/2} dt$$

$$Q(x) = \tfrac{1}{2} erfc(x/\sqrt{2})$$

$$\begin{aligned} P_{out}(r) &= \Pr(s + PL(r) > PL(R) + K_s) \\ &= \Pr(s > K_s - B\log(r/R)) \\ &= \frac{1}{\sqrt{2\pi}} \int_{\frac{K_s - B\log(r/R)}{\sigma}}^{+\infty} e^{-t^2/2} dt \\ &= Q\left(\frac{K_s - B\log(r/R)}{\sigma}\right) \end{aligned}$$

[Viterbi94]

Basic concepts
Margins

- At cell **border**: r=R $\quad P_{out}(R) = Q\left(\frac{K_s}{\sigma}\right)$ (**Jakes formula**)
- With a constraint of 90% coverage at cell border (Pout(R)=0.1) and σ=8dB, the margin is 7.8dB
- To avoid **ping-pong effect**, the UE may leave the cell beyond R, r=aR :

$$P_{out}(aR) = Q\left(\frac{K_s - B\log(a)}{\sigma}\right)$$

- Example: with a=1.1 and B=35, the margin should be 9.3dB
- In **average** over the cell:

$$\overline{P}_{out} = \frac{1}{\pi R^2} \int_0^R P_{out}(r) 2\pi\, r dr$$

$$\overline{P}_{out} = 2\int_0^1 Q\left(\frac{K_s - B\log(t)}{\sigma}\right) t dt$$

[Viterbi94]

Basic concepts
Margins

- Computation of the shadowing margin with the Jakes formula:

$$K_s = \sigma Q^{-1}(P_{out})$$

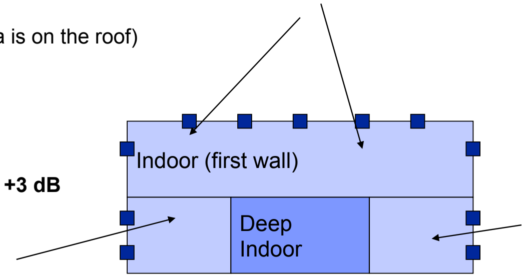
- With:

1-Pout	Margin [dB] / sigma [dB]
0,9	1,28
0,95	1,64
0,99	2,33

Basic concepts
Margins

- **Penetration margin:** losses due the propagation across walls and windows; to be taken into account if we want to cover indoor or inside cars.

- Cars without a kit: ~ 7 dB
- Cars with a kit: 0 dB (antenna is on the roof)
- **Indoor (first wall) :**
  - Dense urban: ~ 18 dB
  - Urban: ~ 15 dB
  - Rural: ~ 10-12 dB
- **Deep indoor (second wall): +3 dB**



Basic concepts
Margins

- **Interference margin**: Link budget is based on the computation of the sensitivity in presence of noise. To take into account co-channel interference, we add an interference margin.

- UMTS: the interference margin depends on load
- LTE and GSM: the interference margin is computed thanks to system simulations

LTE Link Budget
General parameters

- Operation bands: the standard has defined several frequency bands for the FDD mode (around 700, 800, 900, 1400, 1800, 2100, 2600 MHz).
  - Typical bands in Europe: 800, 900, 1800, 2100, 2600 MHz
  - Typical bands in US: 700, 1700, 2100 MHz

- Bandwidths: radio resources are organized in PRB (Physical Radio Block) made of 12 sub-carriers of 15 KHz and 7 OFDM/SC-FDMA symbols.

Bandwidth	1,4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
Sub-carriers	72	180	300	600	900	1200
PRB	6	15	25	50	75	100

LTE Link Budget
Transmission modes

- **There are 7 Transmission modes**
  - TM1 : SIMO (single antenna port)
  - TM2 : MIMO/TxDiv (transmit diversity)
  - TM3 : MIMO/SM-OL (open loop spatial multiplexing)
  - TM4 : MIMO/SM-CL (closed loop spatial multiplexing)
  - TM5 : MU-MIMO (multi-user MIMO)
  - TM6 : Beamforming CL (losed-loop)
  - TM7 : Beamforming
- For transmission modes TM3 to TM6 good radio conditions are required. TM7 is not always available.
- Modes TM1 et TM2 are backup solutions to be considered in the link budget.
- Transmit diversity provides a typical gain of 3dB.
- If two power amplifiers are used (a typical deploiement approach), then 3 addition dB gain should be considered.

LTE Link Budget
Link adaptation

- Mapping between data rate and SNR: A data rate is targeted at cell edge. The mapping between data rate and SNR can be obtained as follows:
  - **Link level simulations**: A target BLER (Block Error Rate) is set, for example 10%. Transmission and reception chains are simulated for different modulation and coding schemes (MCS) and channel profiles and BLER vs SINR curves are obtained. The combinations SNR/MCS at BLER=10% provides the data rate vs SNR mapping.
  - **Approximated Shannon formula**: It is a fitting of the data rate vs SNR curve obtained by simulations. Example:

$$C = \alpha W \log_2\left(1 + \frac{SNR}{\beta}\right)$$

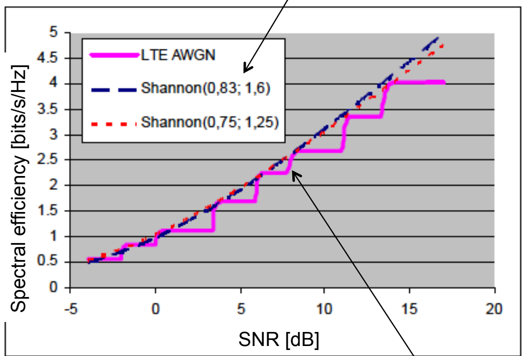
Another example:

$$C = \begin{cases} 0 & \text{si } SNR < SNR_{min} \\ \alpha W \log_2(1 + SNR) & \text{si } SNR_{min} \le SNR \le SNR_{max} \\ C_{max} & \text{si } SNR > SNR_{max} \end{cases}$$

LTE Link Budget
Link adaptation

- Example 1 [Mogensen07] :

α et β

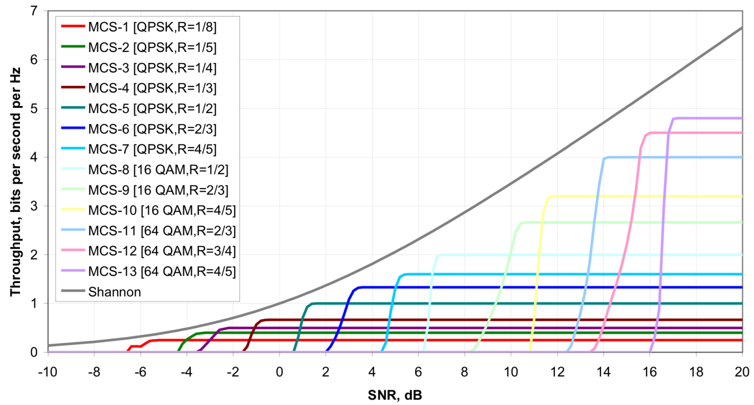


QPSK: 1/6, 1/3, 1/2, 2/3
16QAM: 1/2 , 2/3, 3/4
64QAM: 1/2 , 2/3, 3/4, 4/5

Downlink, TU10

LTE Link Budget
Link adaptation

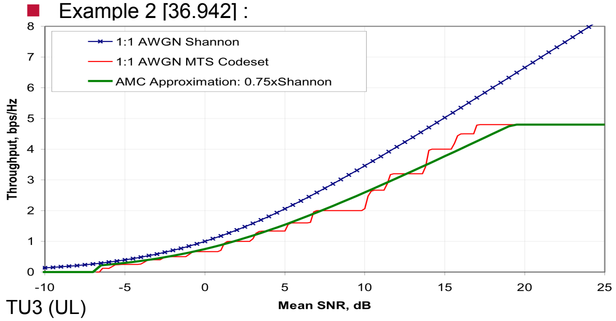
- Example 2 [36.942] :



TU10 (DL)

LTE Link Budget
Link adaptation

- Example 2 [36.942] :



TU10 (DL), TU3 (UL)

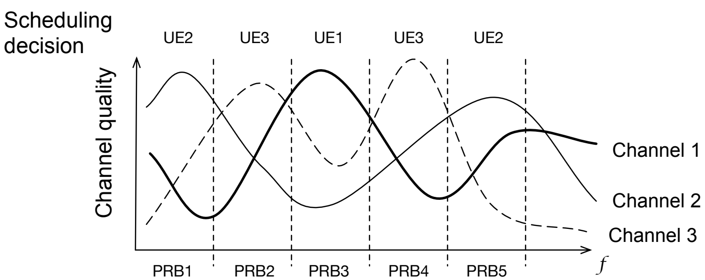
	DL	UL	Note
α	0,6	0,4	Implementation loss
SNRmin	-10 dB	-10 dB	QPSK 1/8 (DL) 1/5 (UL)
SNRmax	22 dB	15 dB	64QAM 4/5 (DL) 16QAM ¾ (UL)
Cmax/W	4,4 bits/s/Hz	2,0 bits/s/Hz	

LTE Link Budget
Link adaptation

- **Channel models for fast fading:** the standard has defined 3 new channel models [36.104]
  - Enhanced Typical Urban (**ETU**): 9 paths, large delay spread, urban environment and large cells
  - Enhanced Vehicular A (**EVA**): 9 paths, intermediate delay spread, urban environment and large cells
  - Enhanced Pedestrian A (**EPA**): 7 paths, low delay spread, indoor environment and small cells

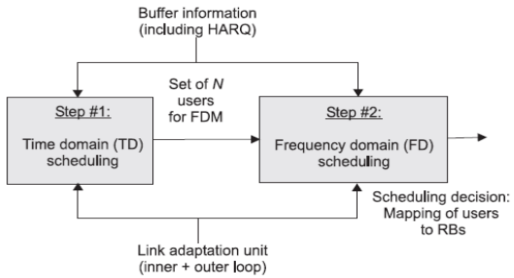
LTE Link Budget
Scheduling

- Scheduling: Dynamic allocation of radio resources to UEs in frequency and time domains.
- Accounting for the channel state in these two domains increases system performance.
- Principle of the scheduling in the frequency domain.



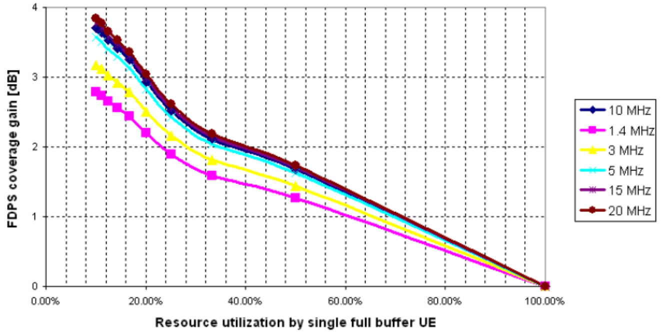
LTE Link Budget
Scheduling

- **Example of scheduling algorithm [NSN11]** taking into account the channel variations:
  - The TD part selects N users based on delay constraints, buffer size, number of retransmissions, priorities, etc
  - The FD part allocates RBs according to a PF criterion (Proportional Fairness).

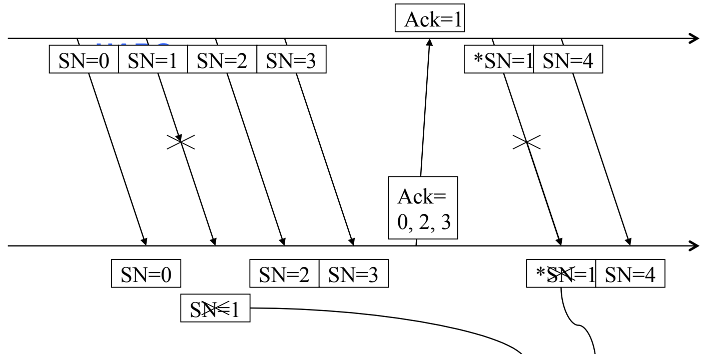


LTE Link Budget
Scheduling

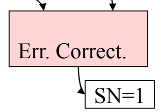
- Examples [NSN11] of gains obtained with FDPS with respect to Round Robin (RR).
- Gains are higher when:
  - Bandwidth is large
  - The number of users is large



LTE Link Budget
HARQ



- On this example: From two erroneous versions of the same block, one can recover the original information.
- HARQ brings a gain in term of time diversity



LTE Link Budget
Downlink

Parameters	
Cell edge throughput [Mbps]	1,0
Carrier frequency [MHz]	2600,00
Bandwidth [MHz]	10,00
Spectral efficiency parameter 1	1,25
Spectral efficiency parameter 2	0,75
eNB antenna height [m]	30,00
UE antenna height [m]	1,50
Coverage probability	0,99
Shadowing standard deviation [dB]	8,00
Load	1,00
Number of HARQ retransmissions	4,0
Transmission	
Transmit power per antenna [dBm]	46,00
Number of transmit antennas	2,00
eNB total transmit power [dB]	49,01
eNB antenna gain [dBi]	19,00
Cables and connectors losses [dB]	1,30
TMA insertion loss [dB]	0,50
EIRP [dBm]	66,21
Reception	
Required SINR [dB]	-9,17
Thermal noise density [dBm/Hz]	-174,00
Noise power [dBm]	-104,00
UE noise factor [dB]	8,00
UE antenna gain [dBi]	0,00
Antenna diversity gain [dB]	3,00
Scheduling gain [dB]	3,00
HARQ gain [dB]	6,02
Protocol overhead [%]	29,00
Protocol overhead [dB]	1,49
Sensitivity [dBm]	-115,70
Margins	
SIRmin [dB]	-3,00
Interference margin [dB]	1,20
Shadowing margin [dB]	18,64
Body loss [dB]	0,00
Indoor penetration margin [dB]	20,00
Total margins [dB]	39,84
Cell range	
MAPL [dB]	142,07
Environment	Urbain
Hata A	141,65
Hata B	35,22
Correction factor	-2,94
Cell range [Km]	0,85

Target data rate at cell edge

Spectrum efficiency parameters

Antenna heights used in the propagation model

Reliability: used for shadowing margin and SIRmin

Shadowing standard deviation used in Jakes formula for the shadowing margin computation

Load = proportion of used radio resources (used in the computation of the interference margin)

HARQ retransmissions add a diversity gain

LTE Link Budget
Downlink

Parameters	
Cell edge throughput [Mbps]	1,0
Carrier frequency [MHz]	2600,00
Bandwidth [MHz]	10,00
Spectral efficiency parameter 1	1,25
Spectral efficiency parameter 2	0,75
eNB antenna height [m]	30,00
UE antenna height [m]	1,50
Coverage probability	0,99
Shadowing standard deviation [dB]	8,00
Load	1,00
Number of HARQ retransmissions	4,0
Transmission	
Transmit power per antenna [dBm]	46,00
Number of transmit antennas	2,00
eNB total transmit power [dB]	49,01
eNB antenna gain [dBi]	19,00
Cables and connectors losses [dB]	1,30
TMA insertion loss [dB]	0,50
EIRP [dBm]	66,21
Reception	
Required SINR [dB]	-9,17
Thermal noise density [dBm/Hz]	-174,00
Noise power [dBm]	-104,00
UE noise factor [dB]	8,00
UE antenna gain [dBi]	0,00
Antenna diversity gain [dB]	3,00
Scheduling gain [dB]	3,00
HARQ gain [dB]	6,02
Protocol overhead [%]	29,00
Protocol overhead [dB]	1,49
Sensitivity [dBm]	-115,70
Margins	
SIRmin [dB]	-3,00
Interference margin [dB]	1,20
Shadowing margin [dB]	18,64
Body loss [dB]	0,00
Indoor penetration margin [dB]	20,00
Total margins [dB]	39,84
Cell range	
MAPL [dB]	142,07
Environment	Urbain
Hata A	141,65
Hata B	35,22
Correction factor	-2,94
Cell range [Km]	0,85

2 transmit antenna, transmit diversity mode

Total transmit power = Power per antenna + 10Log(#antennas)

Antenna gain depends on the frequency band and on the sectorization (here: tri-sectorized sites)

EIRP = Total transmit power + Antenna gain – Cable losses –TMA insertion loss

LTE Link Budget

Downlink

Parameters	
Cell edge throughput [Mbps]	1,0
Carrier frequency [MHz]	2600,00
Bandwidth [MHz]	10,00
Spectral efficiency parameter 1	1,25
Spectral efficiency parameter 2	0,75
eNB antenna height [m]	30,00
UE antenna height [m]	1,50
Coverage probability	0,99
Shadowing standard deviation [dB]	8,00
Load	1,00
Number of HARQ retransmissions	4,0
Transmission	
Transmit power per antenna [dBm]	46,00
Number of transmit antennas	2,00
eNB total transmit power [dB]	49,01
eNB antenna gain [dBi]	19,00
Cables and connectors losses [dB]	1,30
TMA insertion loss [dB]	0,50
EIRP [dBm]	66,21
Reception	
Required SINR [dB]	-9,17
Thermal noise density [dBm/Hz]	-174,00
Noise power [dBm]	-104,00
UE noise factor [dB]	8,00
UE antenna gain [dBi]	0,00
Antenna diversity gain [dB]	3,00
Scheduling gain [dB]	3,00
HARQ gain [dB]	6,02
Protocol overhead [%]	29,00
Protocol overhead [dB]	1,49
Sensitivity [dBm]	-115,70
Margins	
SIRmin [dB]	-3,00
Interference margin [dB]	1,20
Shadowing margin [dB]	18,64
Body loss [dB]	0,00
Indoor penetration margin [dB]	20,00
Total margins [dB]	39,84
Cell range	
MAPL [dB]	142,07
Environment	Urbain
Hata A	141,65
Hata B	35,22
Correction factor	-2,94
Cell range [Km]	0,85

SINR obtained from the target data rate and the spectral efficiency formula

In LTE, UEs have two receive antennas

Typical figure obtained by silmulation (depends on the number of UEs and the bandwidth)

HARQ Gain = 10LOG(#HARQ transmissions)

Common channels overhead

S = SINR + N + NF – Gains + Protocol overhead

LTE Link Budget

Downlink

- Target SINR: Inversion of the approximated Shannon formula giving the spectral efficiency as a function of the SINR

$$SNR_{target} = 10\log_{10}(\beta(2^{\frac{C_{target}}{\alpha W}} - 1))$$

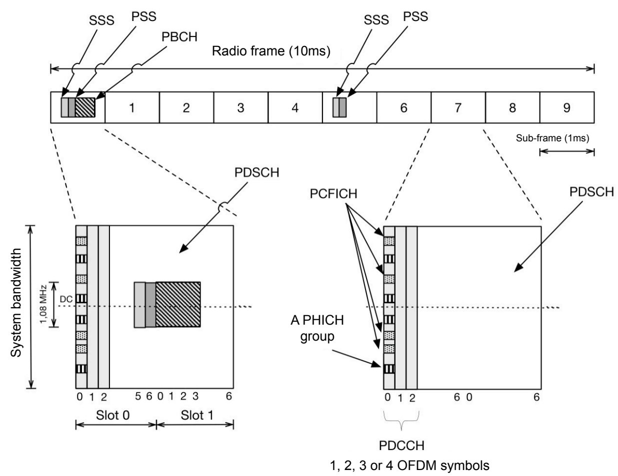
LTE Link Budget

Downlink

- Protocol overhead: Due to the transmission of PDCCH, SSS/PSS, PBCH and Reference Signals (RS).
  - Smaller is the bandwidth, higher is the overhead
  - Order of magnitude: 30%
  - Example: 30% induces a power loss of 10LOG(1-0.3)=-1,5 dB
- PDCCH: 1, 2, or 3 (or 4 for 1,4 MHz) OFDM symbols per sub-frame
- PBCH: 4 OFDM symbols x 72 sub-carriers in the second slot of each frame
- SSS/PSS: 4 OFDM symbols x 62 sub-carriers per frame
- RS: 4 (1 antenna), 8 (2 antennas) or 12 (4 antennas) RE per RB

LTE Link Budget

Downlink



LTE Link Budget

Downlink

- Orders of magnitude:

BW [MHz]	DL Overhead (%)
1,4	34
3	31
5	30
10	29
15	29
20	29

LTE Link Budget

Downlink

Parameters	
Cell edge throughput [Mbps]	1,0
Carrier frequency [MHz]	2600,00
Bandwidth [MHz]	10,00
Spectral efficiency parameter 1	1,25
Spectral efficiency parameter 2	0,75
eNB antenna height [m]	30,00
UE antenna height [m]	1,50
Coverage probability	0,99
Shadowing standard deviation [dB]	8,00
Load	1,00
Number of HARQ retransmissions	4,0
Transmission	
Transmit power per antenna [dBm]	46,00
Number of transmit antennas	2,00
eNB total transmit power [dB]	49,01
eNB antenna gain [dBi]	19,00
Cables and connectors losses [dB]	1,30
TMA insertion loss [dB]	0,50
EIRP [dBm]	66,21
Reception	
Required SINR [dB]	-9,17
Thermal noise density [dBm/Hz]	-174,00
Noise power [dBm]	-104,00
UE noise factor [dB]	8,00
UE antenna gain [dBi]	0,00
Antenna diversity gain [dB]	3,00
Scheduling gain [dB]	3,00
HARQ gain [dB]	6,02
Protocol overhead [%]	29,00
Protocol overhead [dB]	1,49
Sensitivity [dBm]	-115,70
Margins	
SIRmin [dB]	-3,00
Interference margin [dB]	1,20
Shadowing margin [dB]	18,64
Body loss [dB]	0,00
Indoor penetration margin [dB]	20,00
Total margins [dB]	39,84
Cell range	
MAPL [dB]	142,07
Environment	Urbain
Hata A	141,65
Hata B	35,22
Correction factor	-2,94
Cell range [Km]	0,85

MI = -10LOG(1-load*SINR/SIRmin)

Jakes Formula

Margins = MI + Shadowing + Body loss + Penetration

LTE Link Budget

Downlink

- Interference margin: One obtains by simulation the SIRmin as a function of the coverage required reliability. One then deduces the interference margin from SIRmin and from the target SINRas follows:

$$SINR = \frac{S}{\eta I + N} = \frac{1}{\frac{\eta}{SIR_{min}} + \frac{1}{SNR}}$$

$$MI = \frac{SNR}{SINR}$$

$$MI = \frac{1}{1 - \eta \frac{SINR}{SIR_{min}}}$$

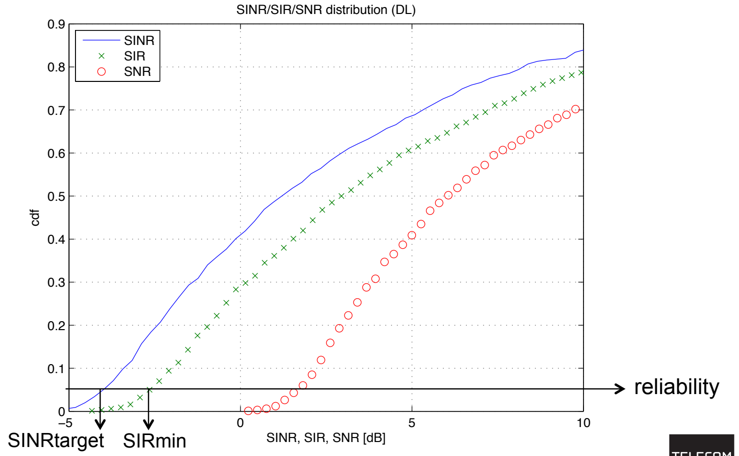
hb (m) / SIRmin DL (dB)	0,9	0,95	0,99
30	-1,3	-2	-3
45	-1,5	-2,1	-3,1
55	-1,6	-2,2	-3,2

Note 1 : SIRmin depends only on the propagation model and on the required reliability
Note 2 : withCOST231-Hata, SIRmin depends only on B (i.e., on hb) and on the reliability

LTE Link Budget

Downlink

- Example: urban environnment, hb=55m, reliability = 0,95



LTE Link Budget
Uplink

Parameters	
Cell edge throughput [Mbps]	0,500
Number of allocated PRBs	50,0
Carrier frequency [MHz]	2600,00
Bandwidth [MHz]	10,00
Spectral efficiency parameter 1	1,25
Spectral efficiency parameter 2	0,75
eNB antenna height [m]	30,00
UE antenna height [m]	1,50
Coverage probability	0,95
Shadowing standard deviation [dB]	8,00
Load	1,00
Number of HARQ retransmissions	4,0
Transmission	
Transmit power per antenna [dBm]	24,00
Number of transmit antennas	1,00
UE total transmit power [dBm]	24,00
UE antenna gain [dBi]	0,00
EIRP [dBm]	24,00
Reception	
Required SINR [dB]	-11,81
Thermal noise density [dBm/Hz]	-174,00
Noise power [dBm]	-104,46
eNB noise factor [dB]	2,00
eNB antenna gain [dBi]	19,00
Cable losses [dB]	3,00
Antenna divezrsity gain [dB]	3,00
Scheduling gain [dB]	3,00
HARQ gain [dB]	6,02
TMA gain [dB]	3,00
Protocol overhead [%]	24,00
Protocol overhead [dB]	1,19
Sensitivity [dBm]	-138,10
Margins	
SIRmin [dB]	-1,30
Interference margin [dB]	0,40
Shadowing margin [dB]	13,12
Body loss [dB]	0,00
Indoor penetration margin [dB]	18,00
Total margins [dB]	31,52
Cell range	
MAPL [dB]	130,58
Environment	Suburbain
Hata A	141,65
Hata B	35,22
Correction factor	0,06
Cell range [Km]	0,49

Only a portion of the whole system bandwidth ca be allocated to UE

Use the bandwidth allocated to UE:
$C = \alpha W_{alloc} \log_2(1+SINR/\beta)$
With W_{alloc} = #PRBx12x15 KHz

Use the bandwidth allocated to the UE:
$N = N_0 W_{alloc}$

LTE Link Budget
Uplink

- Protocol overhead:
  - Reference signals: 1 OFDMA symbol per slot
  - PUCCH: 4 RBs per slot
  - PRACH: 6 RBs per frame (depends on PRACH configuration)
- Orders of magnitude on the uplink:

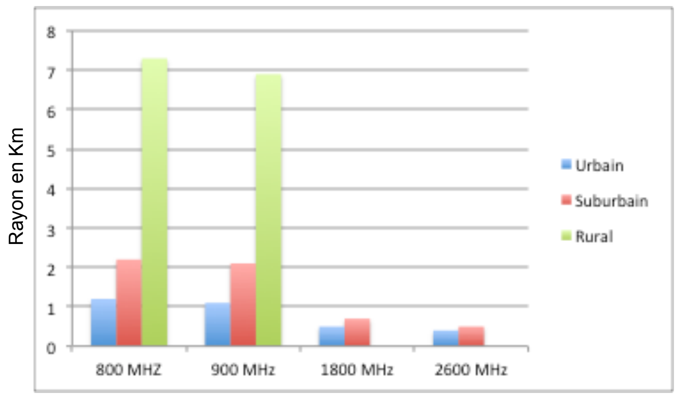
BW [MHz]	UL Overhead (%)
1,4	39
3	32
5	26
10	24
15	23
20	22

LTE Link Budget
Uplink

- Figures of SIRmin (COST231-Hata) on the uplink:

hb (m) / SIRmin UL (dB)	0,9	0,95	0,99
30	-0,1	-1,3	-2,8
45	-0,4	-1,4	-3
55	-0,6	-1,5	-3,1

LTE Link Budget
Typical cell ranges



Conclusion

- **Advantages:**
  - Allows to quickly obtain a first estimate of the cell ranges
  - Quick and simple
- **Limitations of the link budget approach:**
  - Does not accuratly take into account interferences and frequency reuse schemes
  - Does not take into account the dynamics of the system in terms of user traffic

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