5G is fast, 6G will be faster! How does it sound?

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9 Octobre 2025, Télécom Paris

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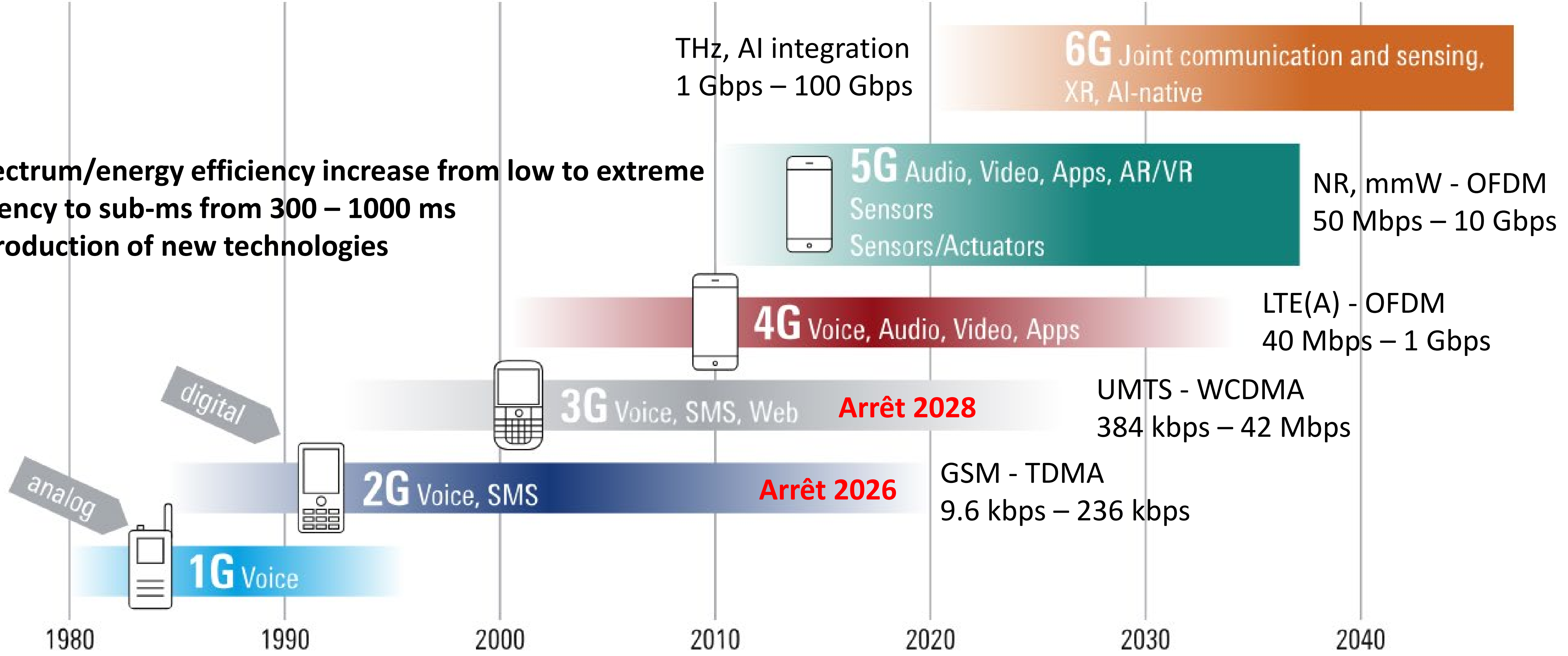
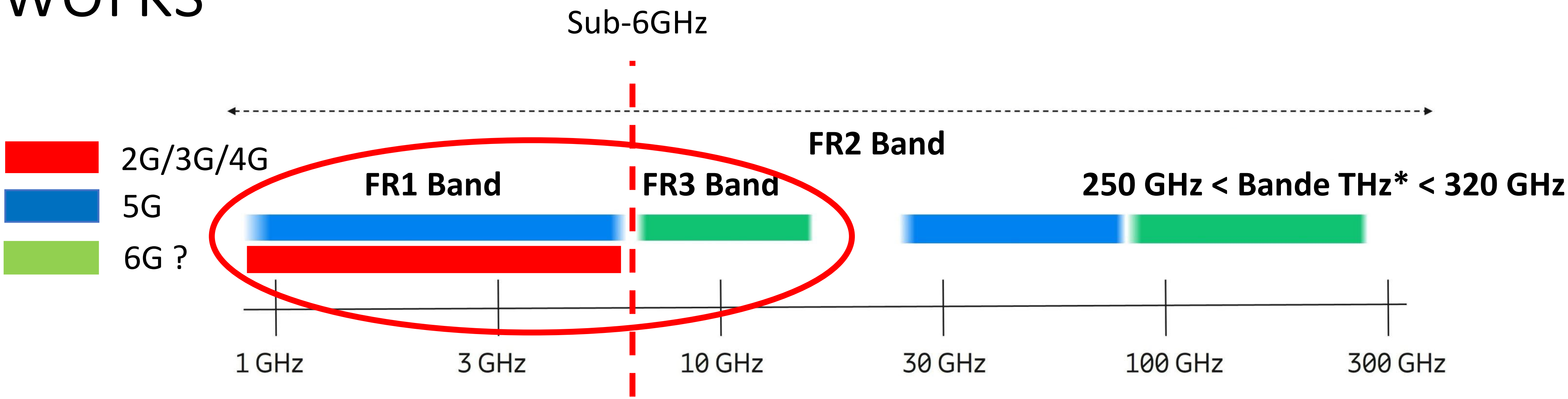
Brief history from 1G to 6G

- **Spectrum/energy efficiency increase from low to extreme**
- **Latency to sub-ms from 300 – 1000 ms**
- **Introduction of new technologies**



https://www.rohde-schwarz.com/

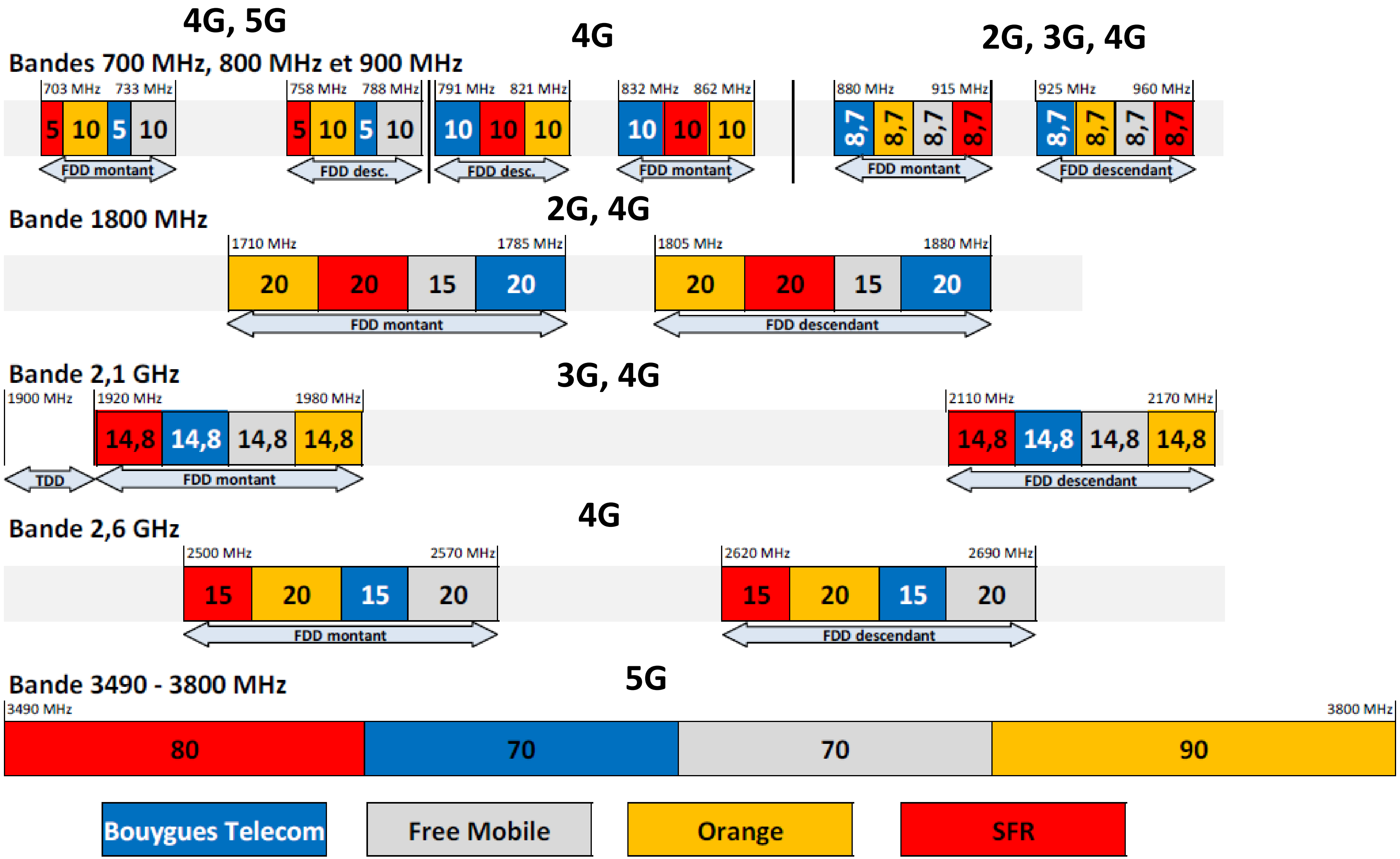
Frequency range for current/future access networks



- Peak speeds of Tbps, reliability (10-9), latency (< 1 ms) with 1 Gbps/m² over a maximum bandwidth of 100 GHz
  - Traffic control and autonomous driving, remote health monitoring services, digital twins, virtual avatars
  - Integration of passive or active Reflective Intelligent Surfaces (RIS) to avoid LOS/NLOS blocking
- High-precision localization and imaging (1 mm in LOS and < 10 cm in NLOS)
  - Integrated or intelligent sensing and communication systems (ISAC)
  - Development of unit technologies for communications systems currently in progress for short-range links in specific industrial scenarios (TIMES6G)

*IEEE 802.15.3d-2017

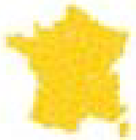
Spectrum Allocation in France (02/2025)



https://www.arcep.fr/

4G/5G

ARCEP regulatory demands

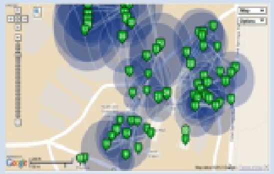
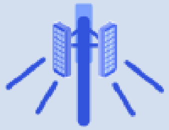
	11-oct-19	31-déc-20	17-janv-22	31-déc-22	11-oct-23	17-janv-24	17-janv-27	08-déc-30
Bande liée à l'obligation[2]	2,6GHz	900MHz 1800MHz 2,1GHz	700MHz 800MHz	900MHz 1800MHz 2,1GHz	2,6GHz	800MHz	700MHz 800MHz	700MHz
Métropole	60% de la population	Passage en THD mobile[1] de 100% des sites hors ZBCB[3] + 75% des sites ZBCB[4]		Passage en THD mobile[1] de 100% des sites	75% de la population	98% de la population	99,6% de la population (800MHz) 98% de la population (700MHz)	99,6% de la population
 Départements métropolitains						90% de la population	95% de la population (800MHz) 90% de la population (700MHz)	95% de la population
 Zone de déploiement prioritaire[5] *(18% de pop et 63% du territoire)*			90% de la population (800MHz) 50% de la population (700MHz)				97,7%[6] de la population (800MHz) 92% de la population (700MHz)	97,7% de la population
Opérateurs	Bouygues Telecom Free Mobile Orange SFR	Bouygues Telecom Free Mobile Orange SFR	Bouygues Telecom Free Mobile (hors 800MHz) Orange SFR	Bouygues Telecom Free Mobile Orange SFR	Bouygues Telecom Free Mobile Orange SFR	Bouygues Telecom Orange SFR	Bouygues Telecom Free Mobile (hors 800MHz) Orange SFR	Bouygues Telecom Free Mobile Orange SFR

https://www.arcep.fr/

5G NR Specifications and Technologies

Aspects	5G NR
Waveform	**OFDM**
Max. Bandwidth	100 MHz (<6 GHz) 1 GHz (>6 GHz)
Subcarrier Spacing	**15**, 30, 60, 120, 240 KHz
Spectrum Occupancy	Up to 98% of BW
Frequency of Operation	**Up to 6 GHz,** ~28 GHz, other mmW bands
Dynamic Analog Beamforming	Supported
Digital Beamforming	Up to 12 streams
Self-contained Subframe	Can be implemented
Channel Coding	Control : LDPC Data: Polar Coding

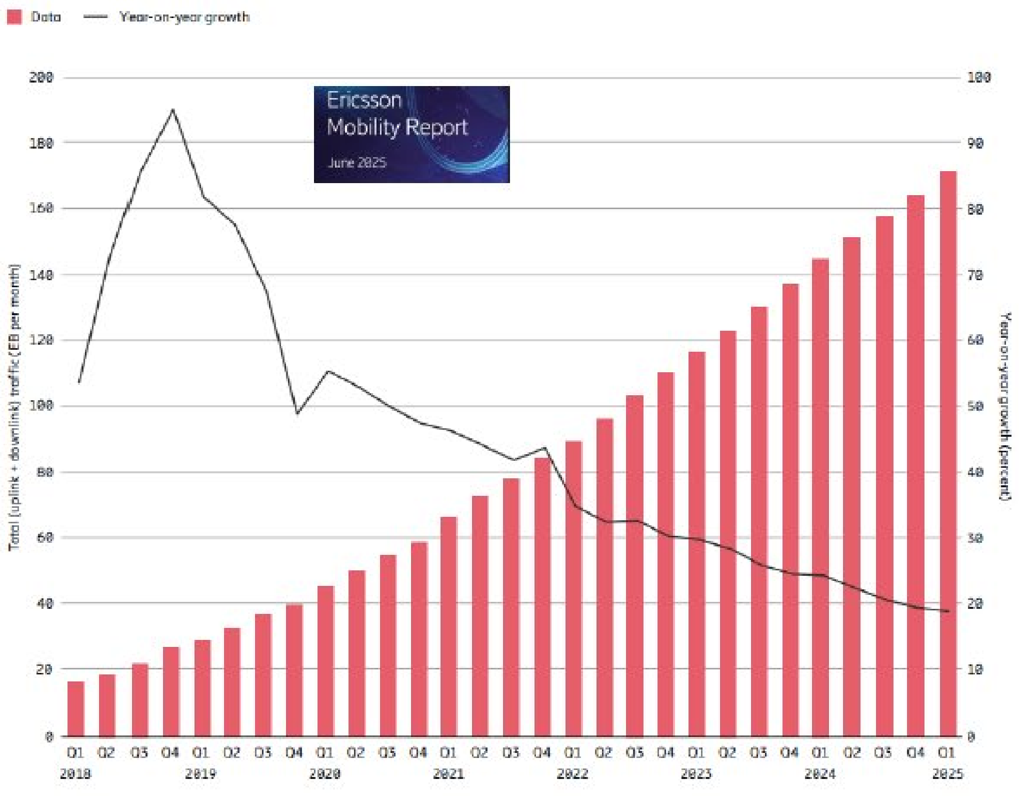
Specifications

Densification	Massive Connexion	Antenna	Spectrum
• Self Backhauling • Energy Efficiency • Interoperability • **Massive MIMO**	• **Massive MIMO** • Long battery life • Protocol optimization • Signaling techniques • Resource allocation	• **Massive MIMO** • Long range • Deep coverage • Antenna packaging and integration	• < 1GHz : IoT, mobile broadband • 1 GHz to 6 GHz : mobile broadband • > 6 GHz : extreme mobile broadband, indoor, backhaul point to point • **Spectral efficiency (Massive MIMO)**
			

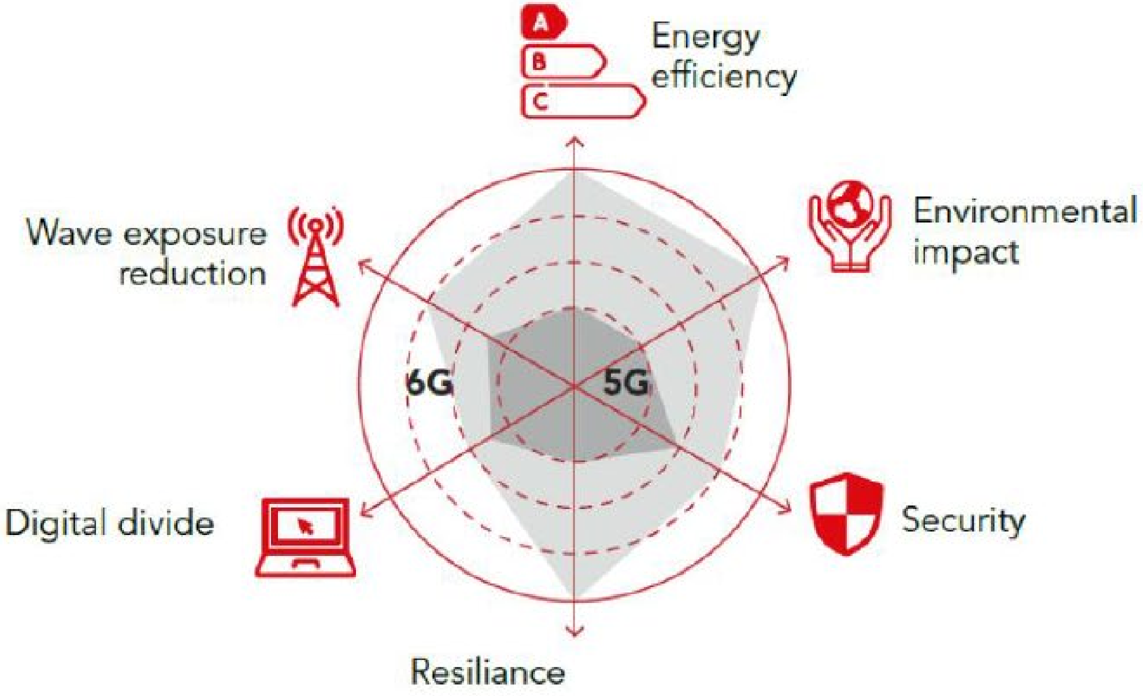
Technologies

6G promises vs. 5G

- Spatial Multiplexing
- Frequency and bandwidth expansion



Note: Mobile network data traffic also includes traffic generated by Fixed Wireless Access services.

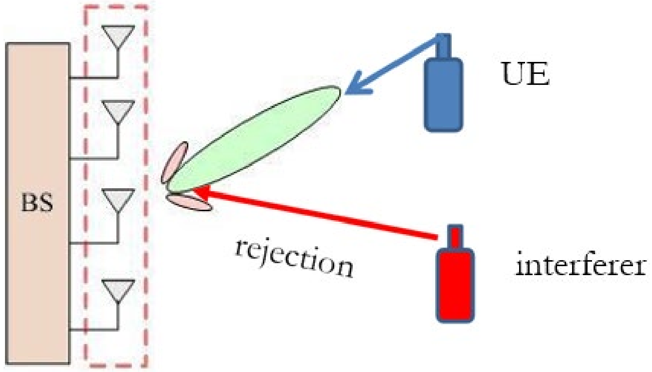


The promise of 6G lies in enabling the AI revolution, guaranteeing seamless connectivity for all, and strengthening resilience from everyday life to component sourcing.

MIMO Techniques (4G)

Smart antennas

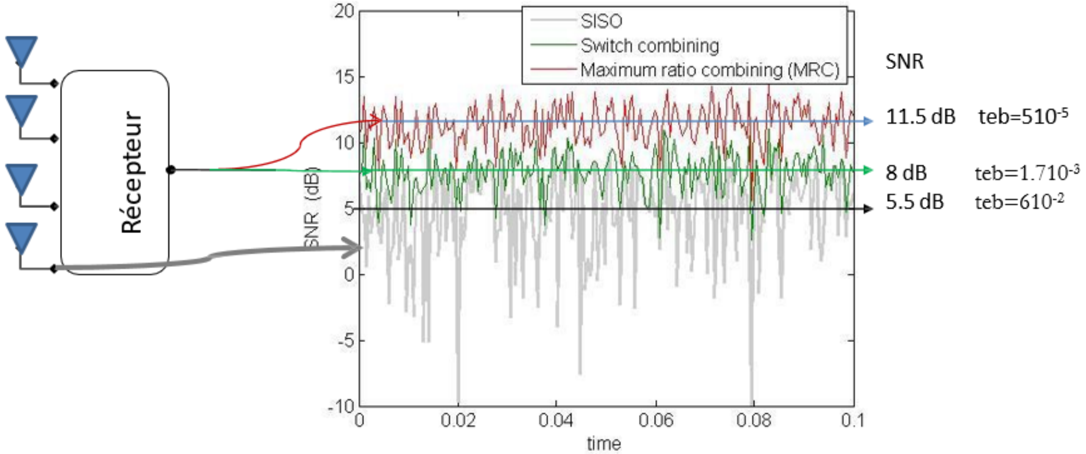
- Beamforming
- Spatial diversity
- Spatial Multiplexing

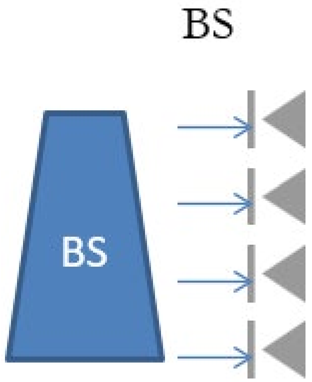


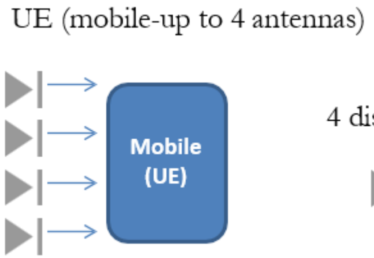
Low to no MPC:
Reduce multi-user interference or focus energy toward specific direction or user.
Well adapted to SDMA

When MPC exist:
Increase the robustness of the communication: BER ↓ ou SNR↑

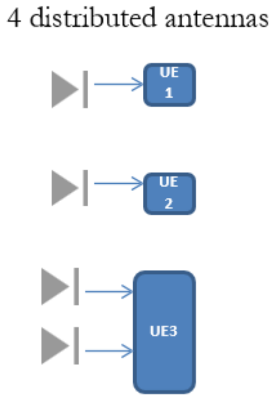
High density of MPC:
↑Cell capicity or throughput





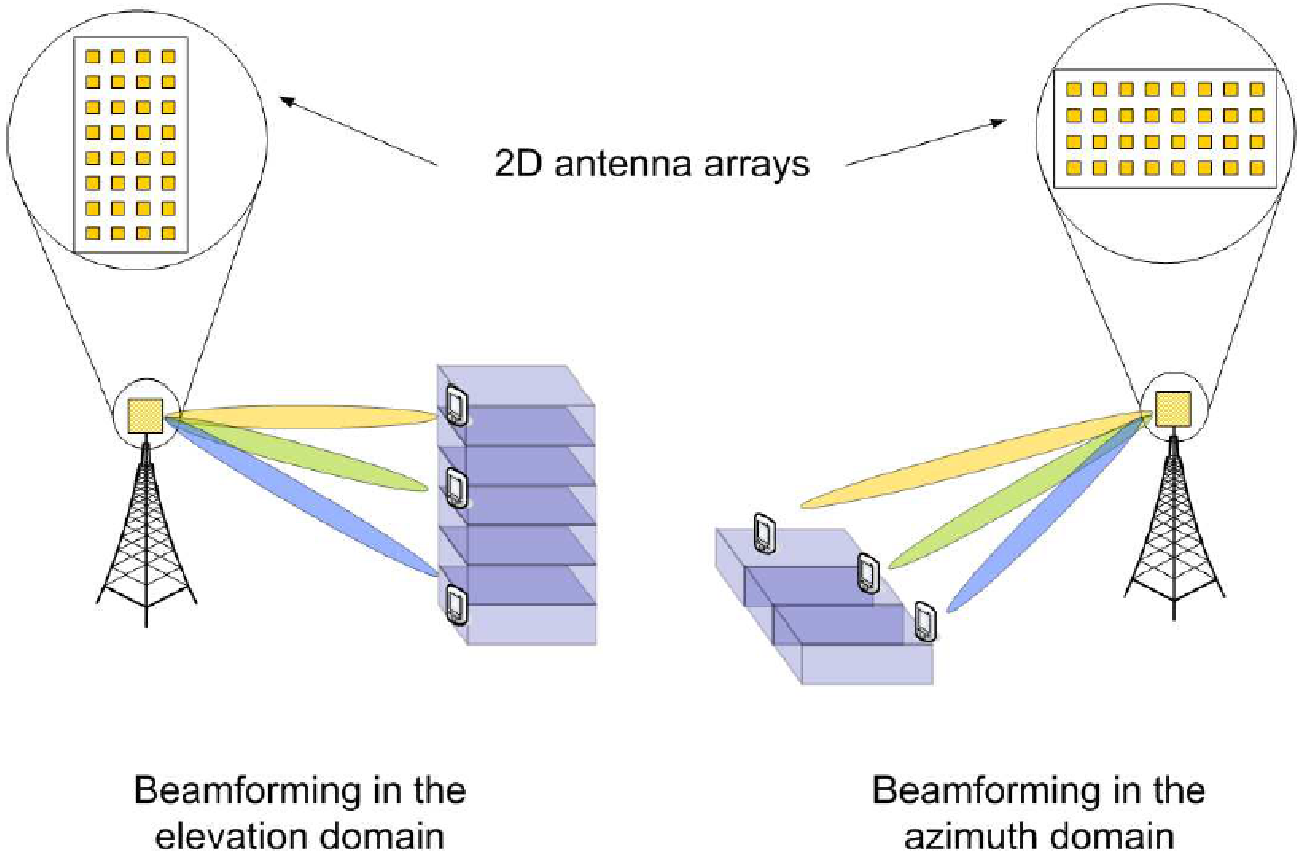


SU-MIMO



MU-MIMO

Massive MIMO (5G)

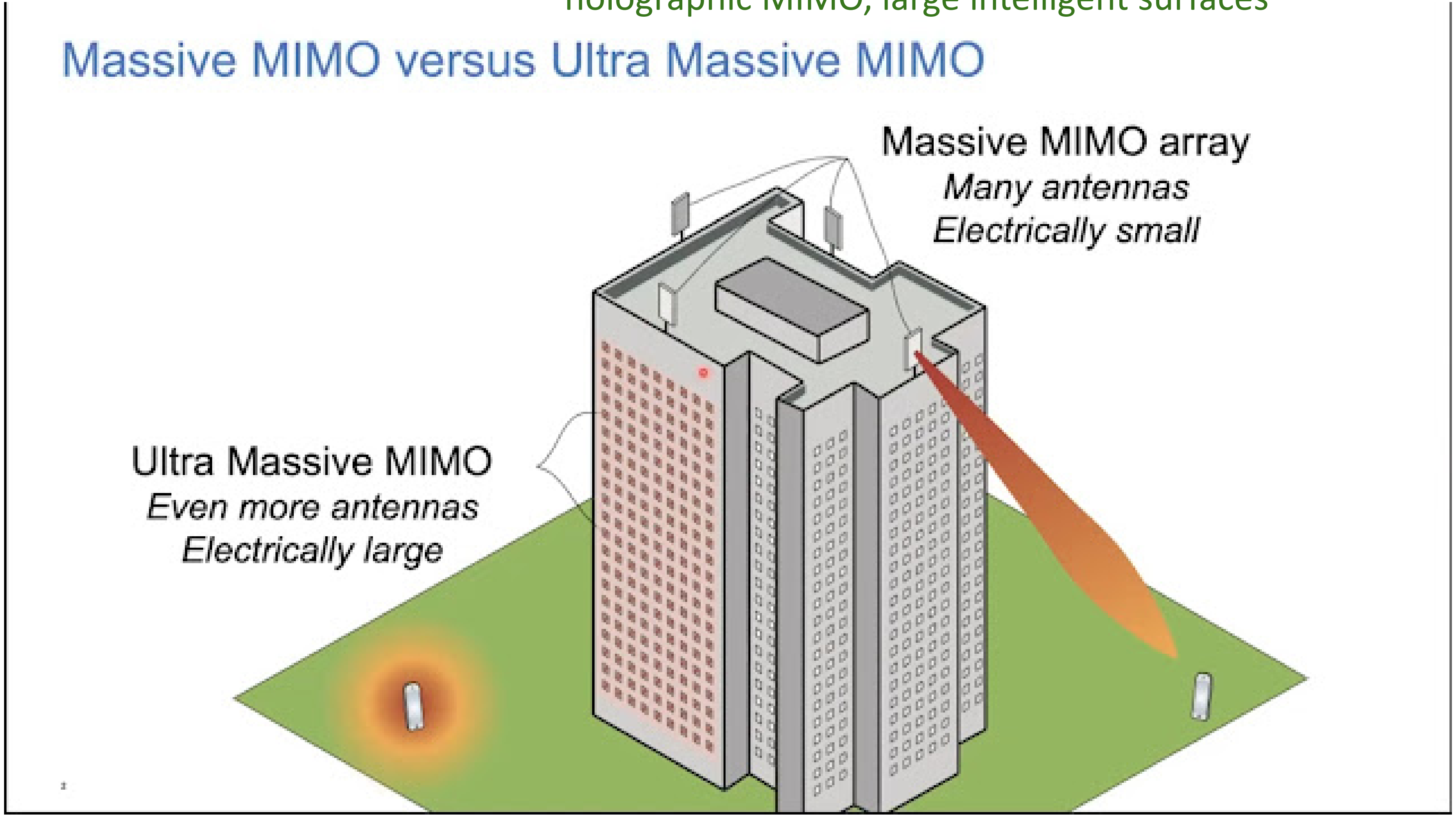


Main Advantages:

- Reduced Inter-user Interference
- Increased Spectral Efficiency
- Energy Efficiency
- Large array gains
  - Channel Hardening
  - High link reliability
  - Focus in small regions of space
  - Simple linear signal processing (ZF)
  - Efficient diversity & Multiplexing techniques in favorable propagation scenarios (rich MPC)

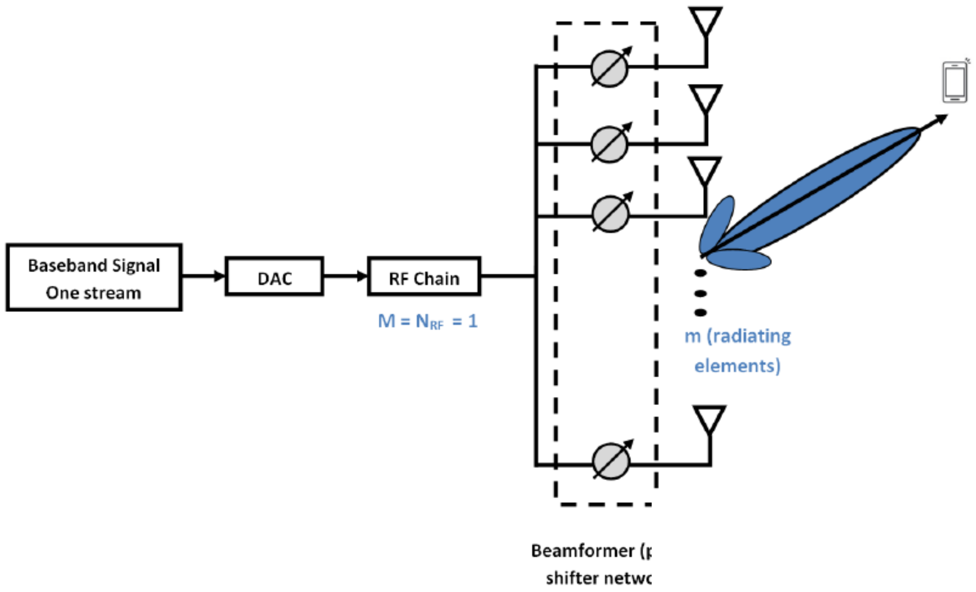
Ultra-Massive MIMO (6G)

holographic MIMO, large intelligent surfaces

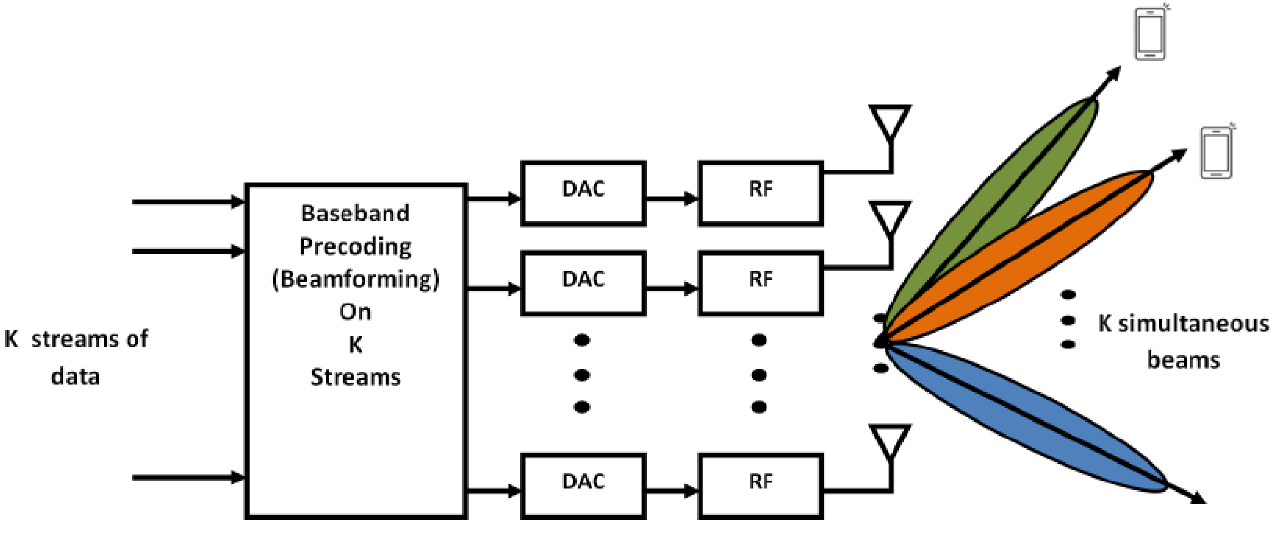


https://www.free6gtraining.com/2020/11/can-ultra-massive-mimo-deliver-terabits.html

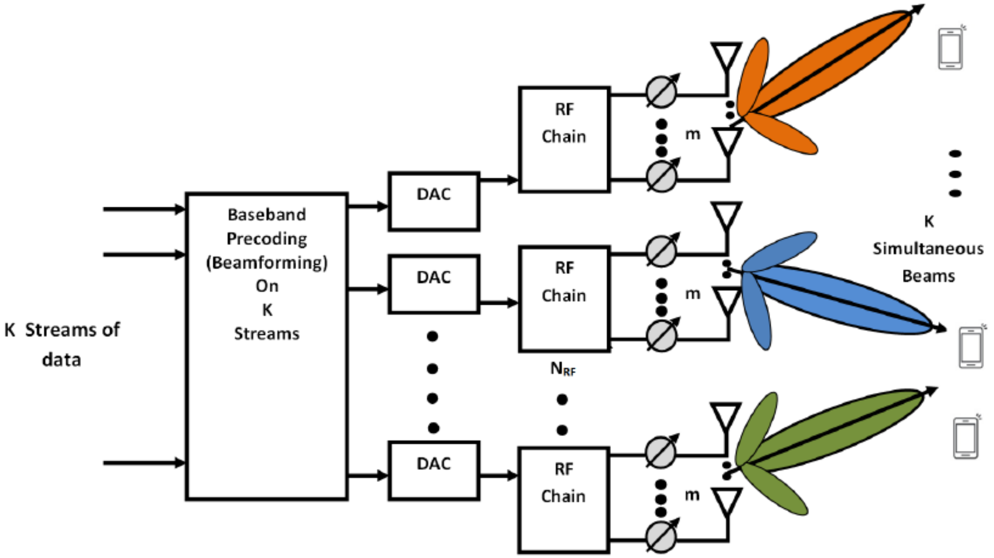
Massive MIMO Beamforming Architecture



Analog Architecture

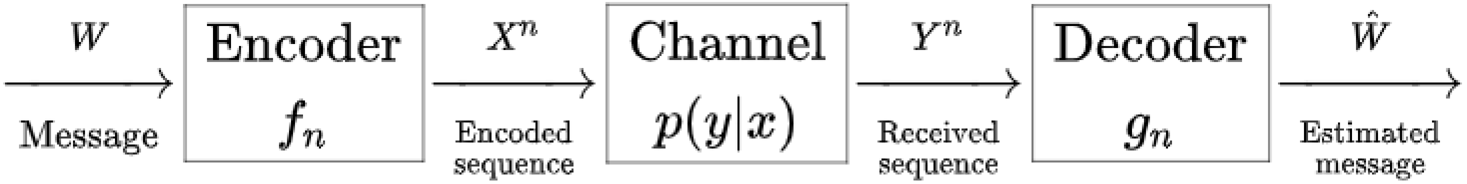


Fully Digital Architecture



Hybrid Architecture

Shannon Capacity



- Defined as the maximum Mutual Information of channel $C = \max_{f} I(X;Y)$
- Maximum error-free data rate a channel can support
- Theoretical limit
- Capacity in AWGN

Power

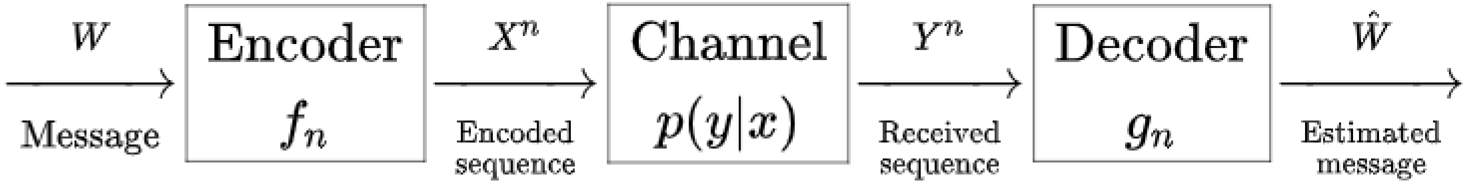
$$C = B.log_2(1 + SNR) = B.log_2\left(1 + \frac{P}{N_0 B}\right)$$

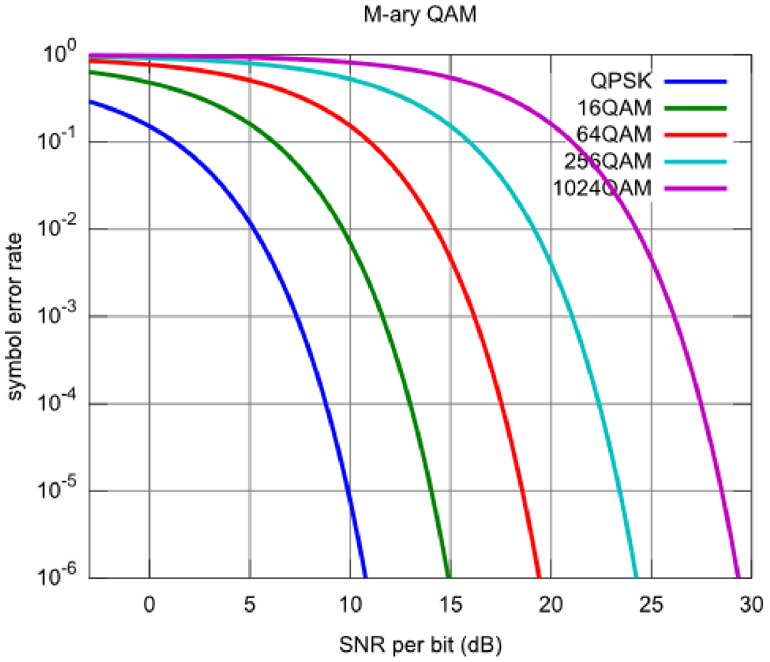
Bandwidth

2G: 200 kHz
3G: 5 MHz
4G: Up to 40 MHz
5G: up to 90 MHz

Noise PSD

Shannon Capacity





3 bits/sym.
4 bits/sym.
6 bits/sym.
8 bits/sym.
10 bits/sym.

$$C = \max_f I(X;Y)$$

Power

$$C = B.log_2(1 + SNR) = B.log_2\left(1 + \frac{P}{N_0 B}\right)$$

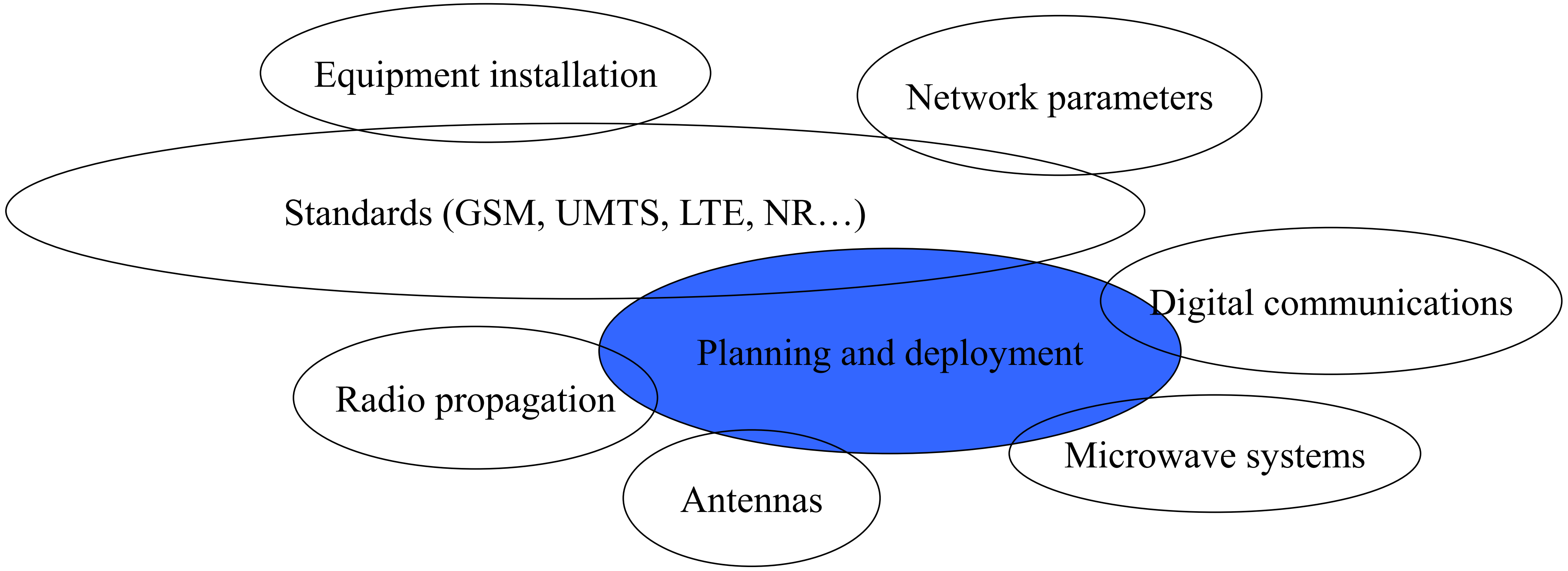
Bandwidth

2G: 200 kHz
3G: 5 MHz
4G: Up to 40 MHz
5G: up to 90 MHz

Noise PSD

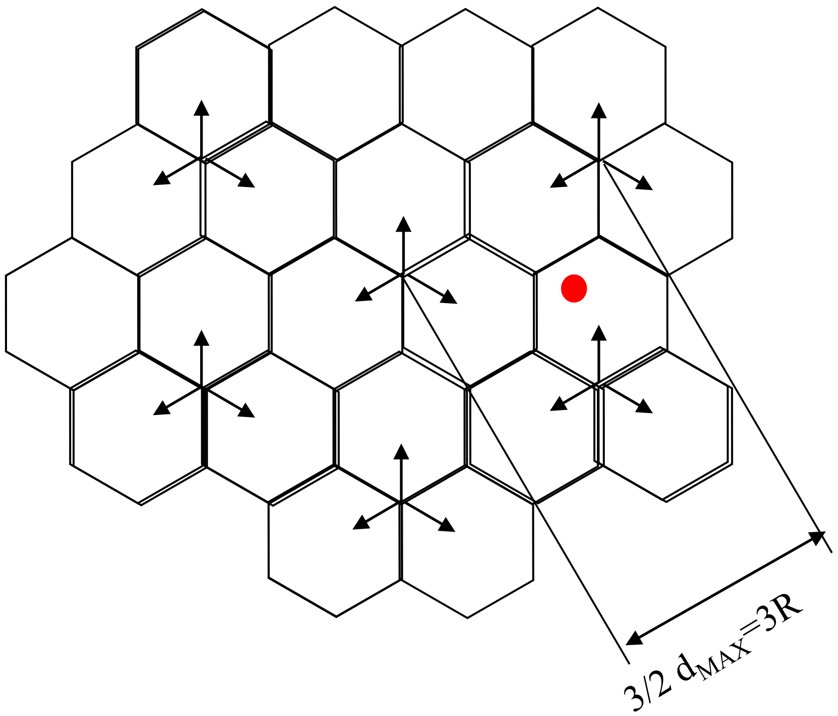
How operators deploy networks?

- Deployment of equipment's (access network) on a certain number of cells according to a marketing business plan and regulation.
- Ensure adequate **coverage** AND **capacity** AND **quality**



Hexagonal Architecture

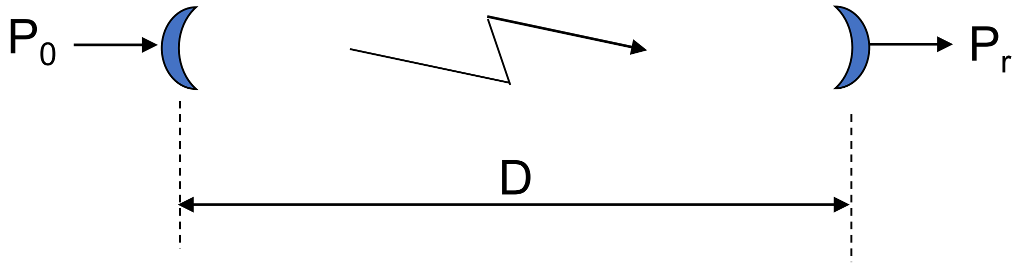
Intersites distance in the tri-sectorized sites case:



- Received Power
- SNR
- Interference
- Throughput
- Handover

How do you determine cell size?

Free Space Propagation – Friis Formula



Free space formula :

(Friis formula)

$$(P_r)_W = G_r.\left(\frac{\lambda}{4\pi D}\right)^2.G_t.(P_0)_W$$

where $\lambda = \dfrac{c}{f}$

dB or dBm ⇩ $10\mathrm{Log}_{10}(.)$ or $10\mathrm{Log}_{10}(./0{,}001)$

$$(P_r)_{dBm} = (G_r)_{dBi} + 10\mathrm{Log}_{10}\left(\frac{\lambda}{4\pi D}\right)^2 + (G_t)_{dBi} + (P_0)_{dBm}$$

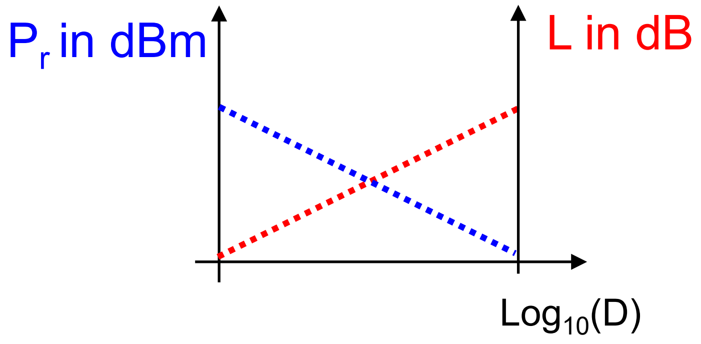
Free Space Propagation – Friis Formula

Free Space Losses (FSL) :

or Line Of Sight Pathloss

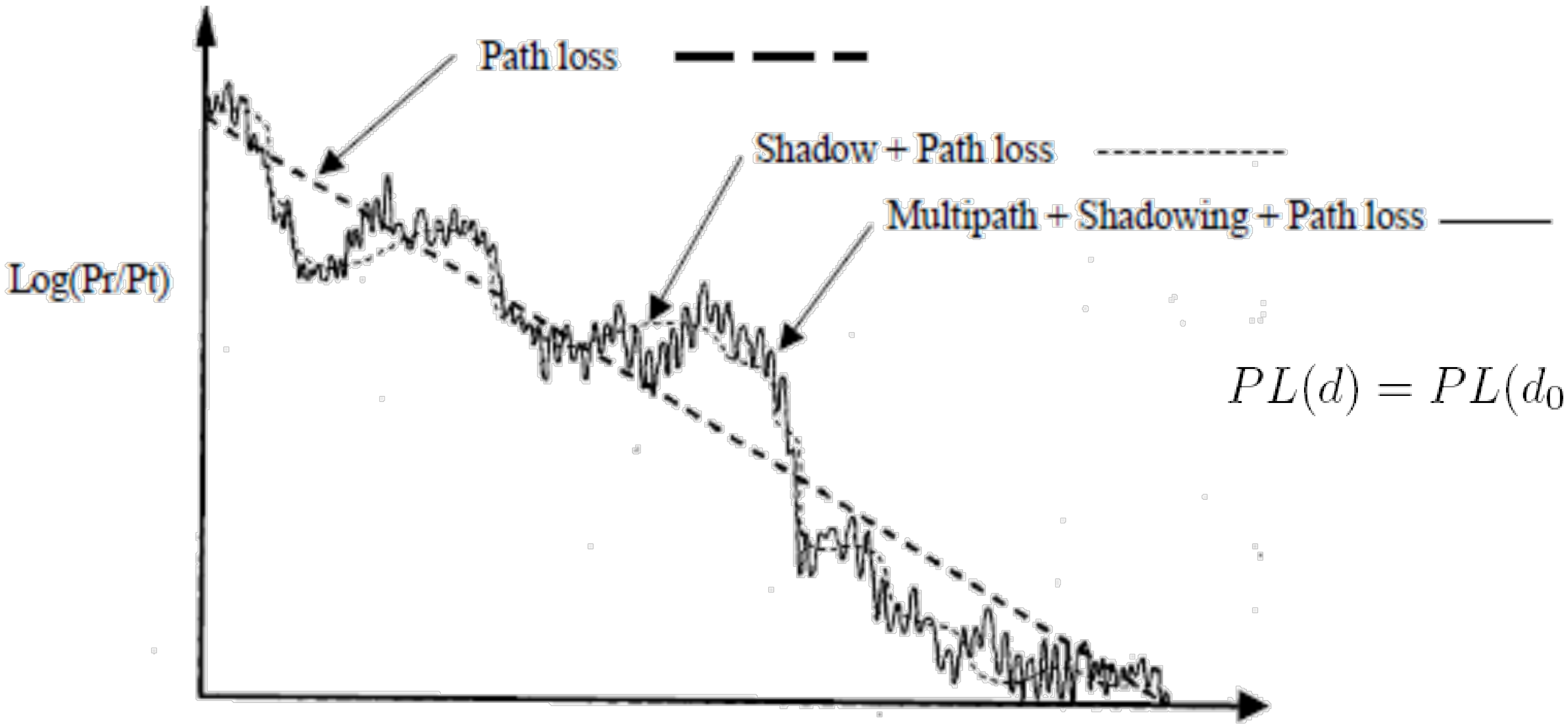
$$L = \frac{1}{\left(\frac{\lambda}{4\pi D}\right)^2}$$

$$(L)_{dB} = 10\mathrm{Log}_{10}(L) = 32.4 + 20\mathrm{Log}_{10}(f)_{MHz} + 20\mathrm{Log}_{10}(D)_{km}$$



Friis formula : $$(P_r)_{dBm} = (G_r)_{dBi} - (L)_{dB} + (G_t)_{dBi} + (P_0)_{dBm}$$

In more details: Narrowband Analysis



Gain as a function of distance Tx - Rx

$$PL(d) = PL(d_0) + 10n \cdot log\left(\frac{d}{d_0}\right) + \chi_\sigma$$

Empirical/semi-empirical path loss models (Hata, Cost231-Hata, Okumura-Hata, Walfish-Ikegami)

GSM Downlink (DL) Link Budget

Pedestrian 2W in urban environment with 2 TRX

	Limited Coverage outdoor	Excellent Coverage window indoor	Excellent Coverage deep indoor
BS Tx power	**43**	**43**	**43**
Combiner loss	**3**	**3**	**3**
Feeder + jumper Loss	**3**	**3**	**3**
BS Antenna Gain	**17**	**17**	**17**
BTS EIRP	**54**	**54**	**54**
Body Loss	**3**	**3**	**3**
MS Antenna Gain	**0**	**0**	**0**
MS Rx sensitivity	**-102**	**-102**	**-102**
Log-normal margin	**7**	**7**	**7**
Mobility margin	**6**	**6**	**6**
Penetration margin	**0**	**12**	**21**
Engineering threshold	**-86**	**-74**	**-65**
Maximum Allowable PathLoss	**140**	**128**	**119**

Cell Size Computation

$$L_x = L_0 + 10\gamma Log(D) = L(D=1km) + 10\gamma Log(D_{km})$$

Ex : L = 126,4 + 35Log(D) in urban areas (GSM 900)

$$L_{MAX} = MAPL = L_0 + 10\gamma Log(D_{MAX})$$

Cell size : $D_{MAX} = 10^{\left(\frac{MAPL - L_0}{10\gamma}\right)}$

Outdoor : $d_{MAX} = 10^{\left(\frac{140-126.4}{35}\right)} = 2.5\ km$

Indoor : $d_{MAX} = 10^{\left(\frac{128-126.4}{35}\right)} = 1.11\ km$

Daylight window : $d_{MAX} = 10^{\left(\frac{124-126.4}{35}\right)} = 854\ m$

Deep indoor : $d_{MAX} = 10^{\left(\frac{119-126.4}{35}\right)} = 614\ m$

Propagation Phenomena

- In urban areas, indoors: Presence of multiple reflections and diffractions on obstacles between Tx and Rx and in their vicinity. In this course, we therefore assume that the size of the obstacles is greater than λ. We can thus apply geometric optics, for example ray theory or image theory => What about measurements?
- A large number of possible paths between Tx and Rx with different propagation phenomena come into play.

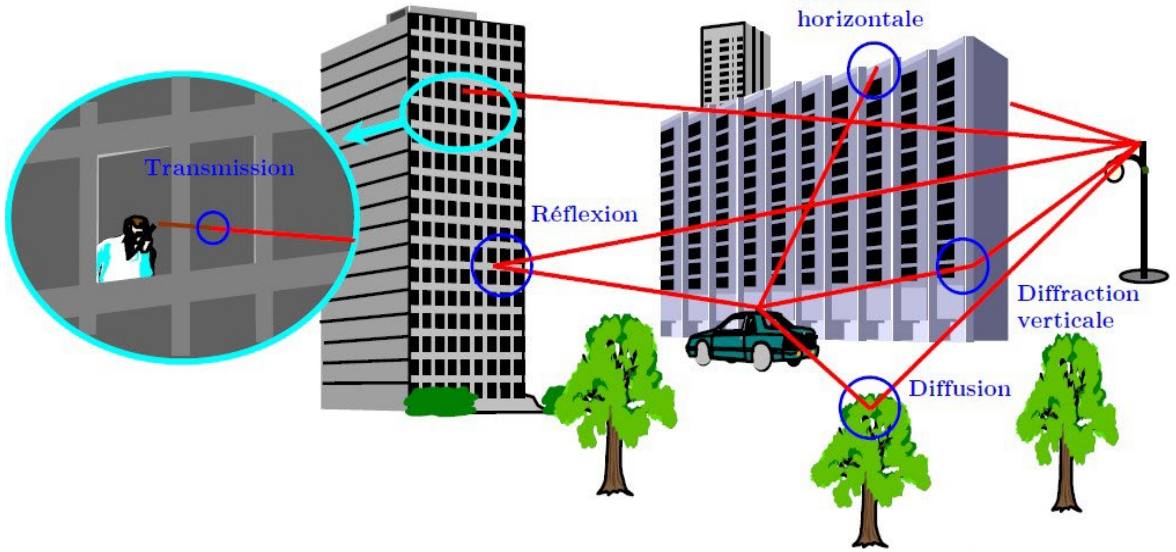


Figure 1-2 : Exemple de propagation multi-trajets en milieu urbain

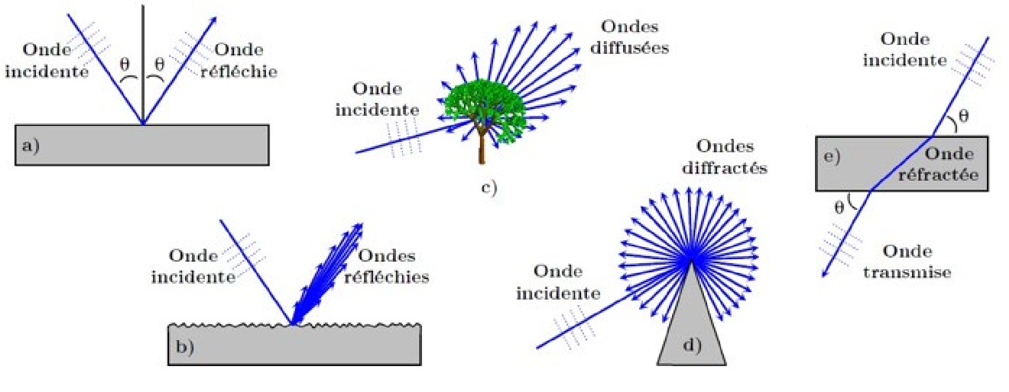
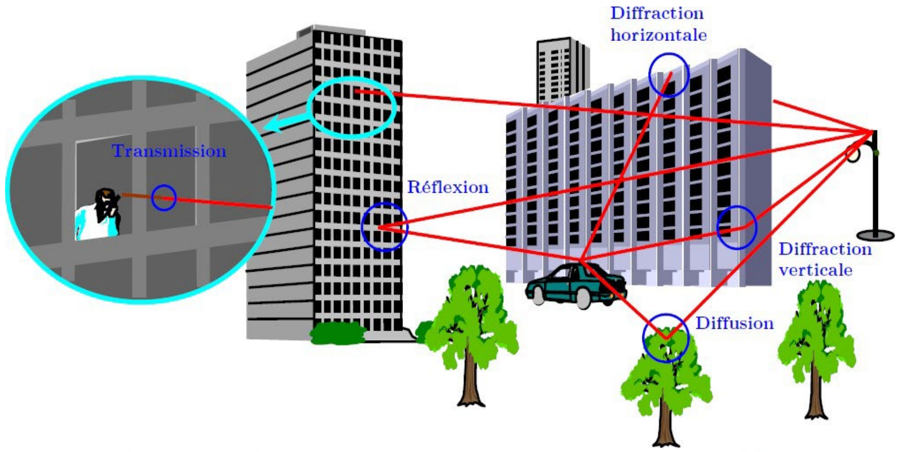


Figure 1-1 : Principales interactions macroscopiques entre onde et obstacle
a) Réflexion spéculaire b) Réflexion diffuse c) Diffusion d) Diffraction e) Transmissions

PhD Thesis Patrice Pajusco,2011

Wideband Analysis



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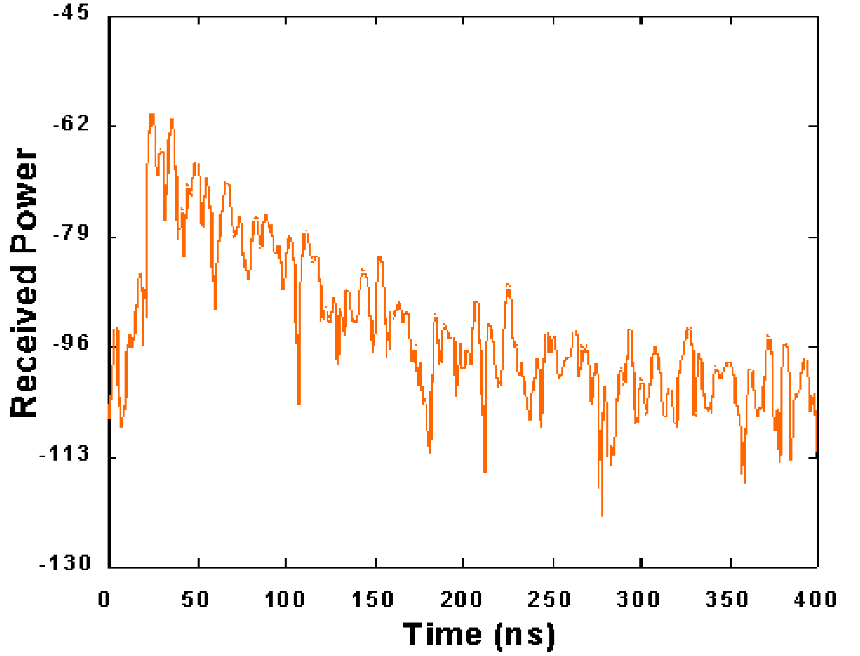
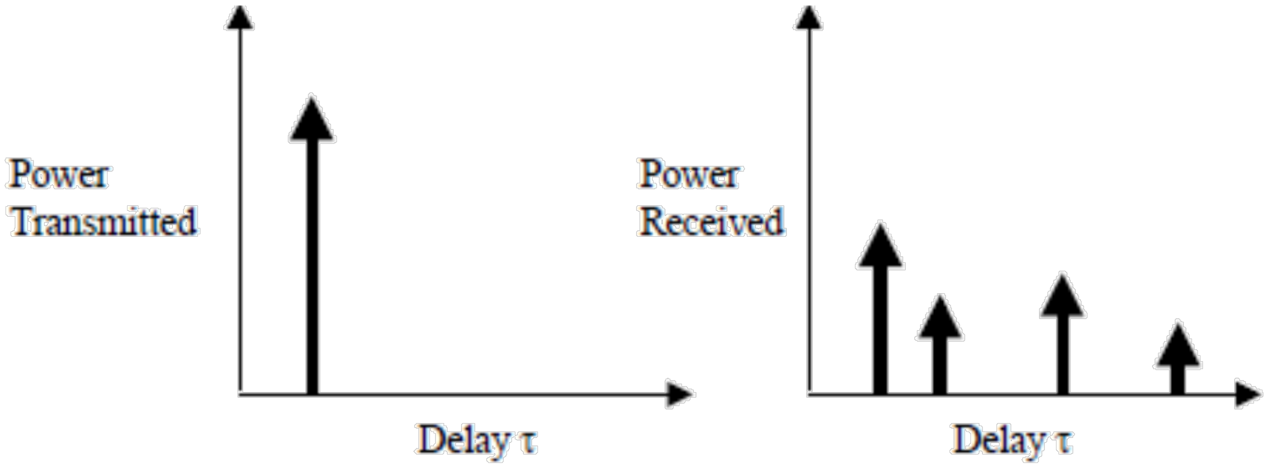
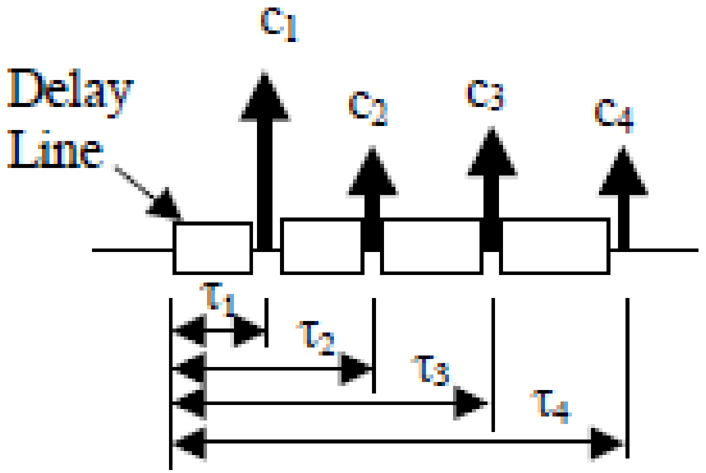




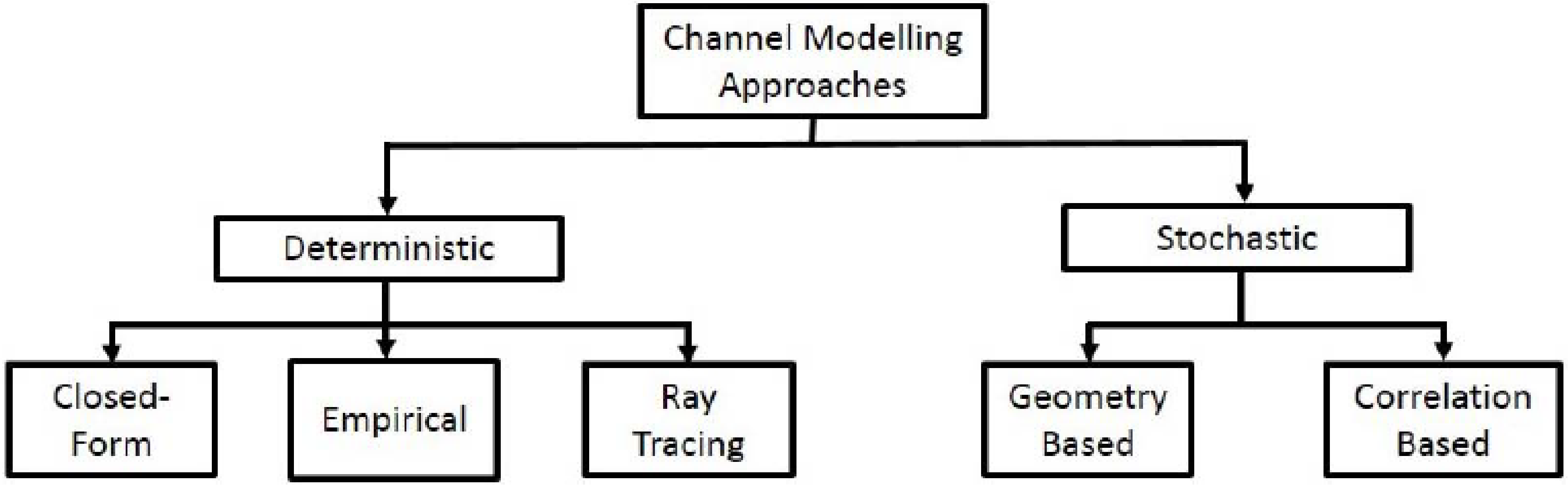


Why do we need to "understand" the channel?

- Develop deployment tools and then interpret the results (and sometimes even incidents observed on the network).
- Enables the development of models that, when introduced into simulators, make it possible to estimate the performance of a communication chain before defining standards (optimizing coding algorithms, modulation, diversity techniques, the most suitable multi-antenna techniques, etc.).
- **Need to characterize the propagation channel in order to develop models that will reproduce these characteristics**

Atoll, Forsk

Channel modeling



NEED MEASUREMENTS!

- Deterministic models
  - based on ray theory and diffraction theory. It takes into account the phenomena of reflection and diffraction. The problem is to find all possible paths between Tx and Rx
- Stochastic models
  - From the channel modeling point of view, it considers the channel as a superposition of a finite MPC number whose parameters are drawn from statistical distributions.

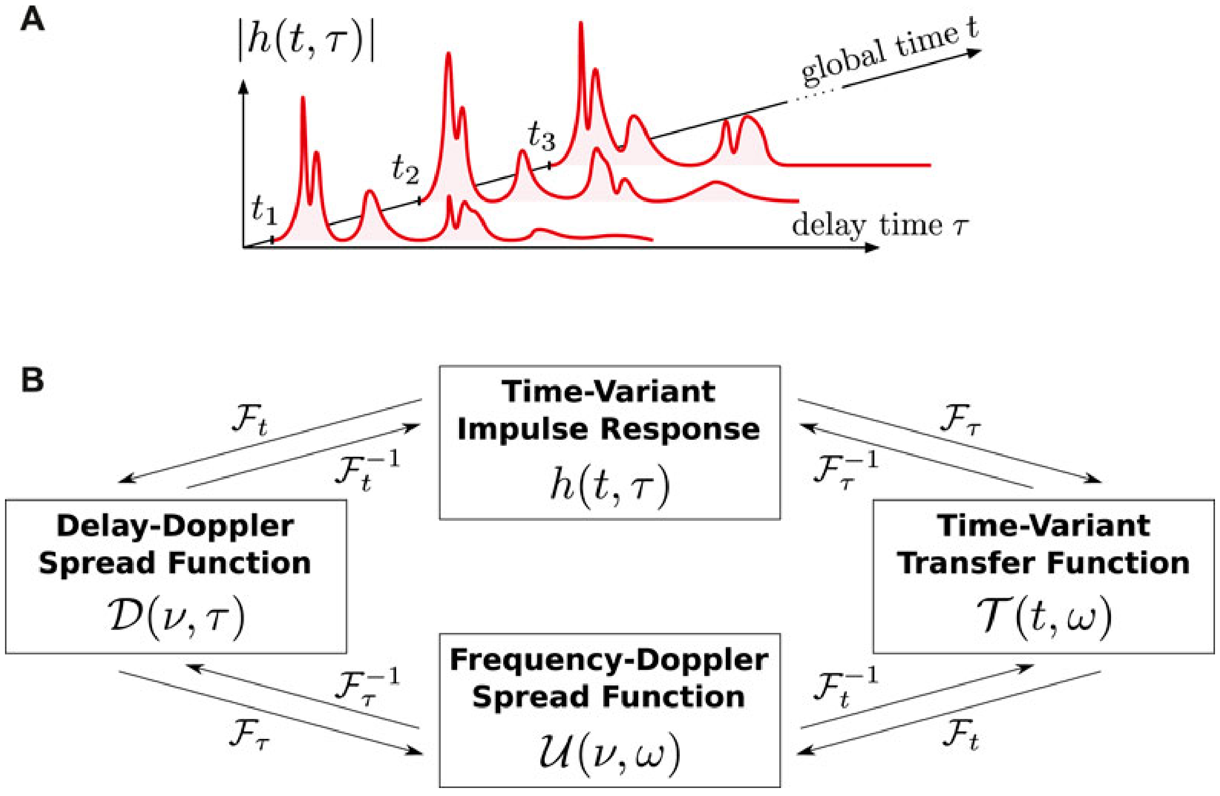
Multidimensional Channel Sounding

- High-quality radio technique to measure the time-varying channel seen as a filter
  - Digital radio metrology

$$h(t, \tau, \varphi_T, \varphi_R)$$

$$h(k.\Delta t, l.\Delta\tau, m.\Delta\varphi_T, n.\Delta\varphi_R)$$

Mobility Wideband Tx Array Rx Array



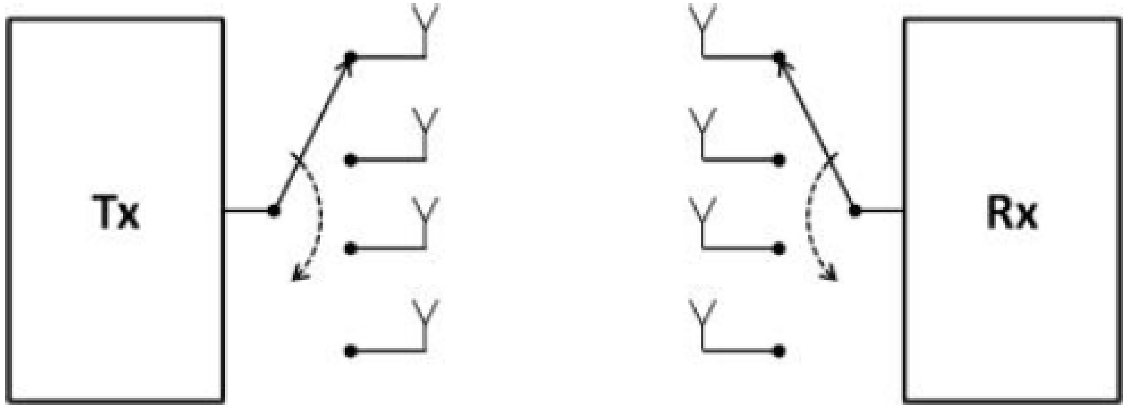
Bello Functions

Channel Sounder Signal

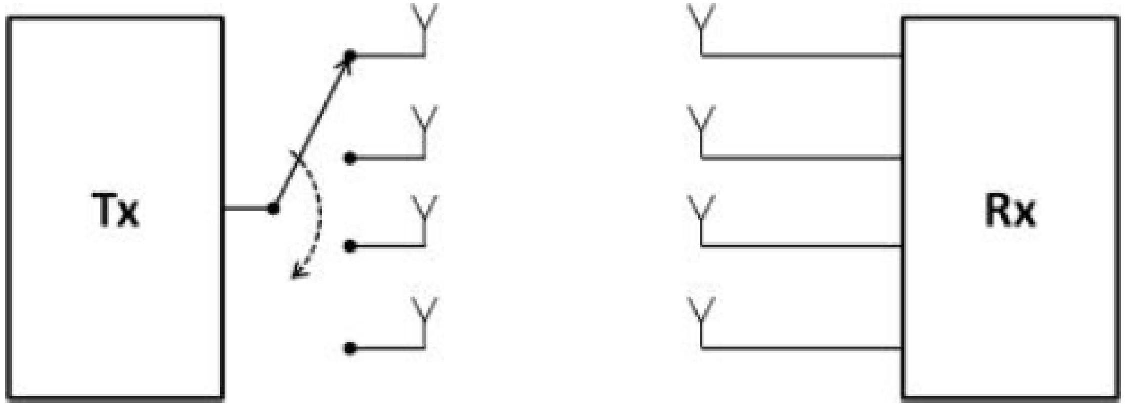
- Pseudo-random sequence with maximum length
  - Constant envelop with no PAPR (Peak to Average Power Ratio)
  - Requires high sampling frequency for receiver and antialiasing filters
  - CIR obtained through sliding correlation using matched filter
  - Post-process often realized using programmable digital devices (DSP, FPGA)

- Chirp or multi-carrier sequence
  - Signal whose frequency increases (or decreases) linearly over band B during a time interval T
  - Heterodyne detector or matched filter can be used for receiver
  - Needs a data acquisition system with large bandwidth
  - Specific multi-carrier signal to obtain low PAPR values (like Chu-Zadoff in 4G)

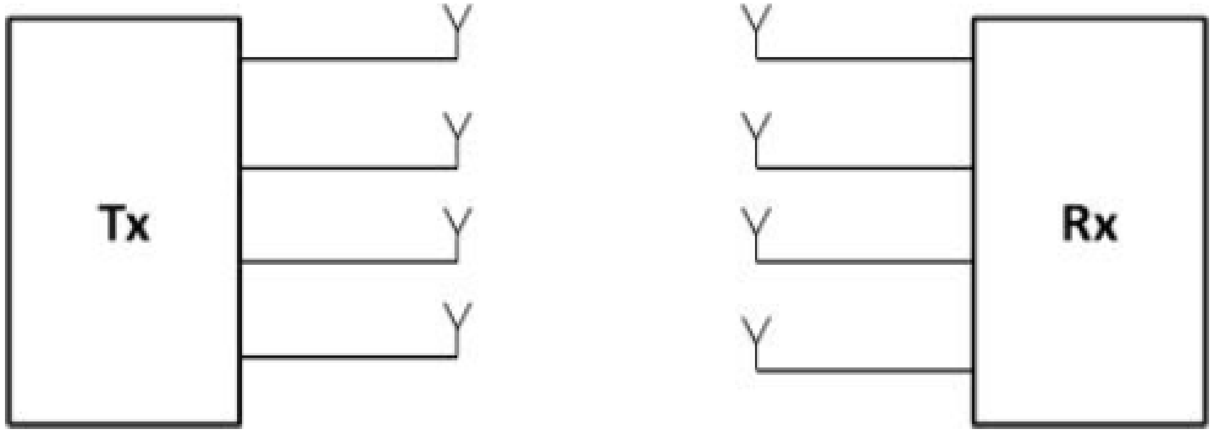
Port Switching Approaches



Full Tx and Rx Switching $T_H = 2(\tau_{Max}).M_t.N_r$



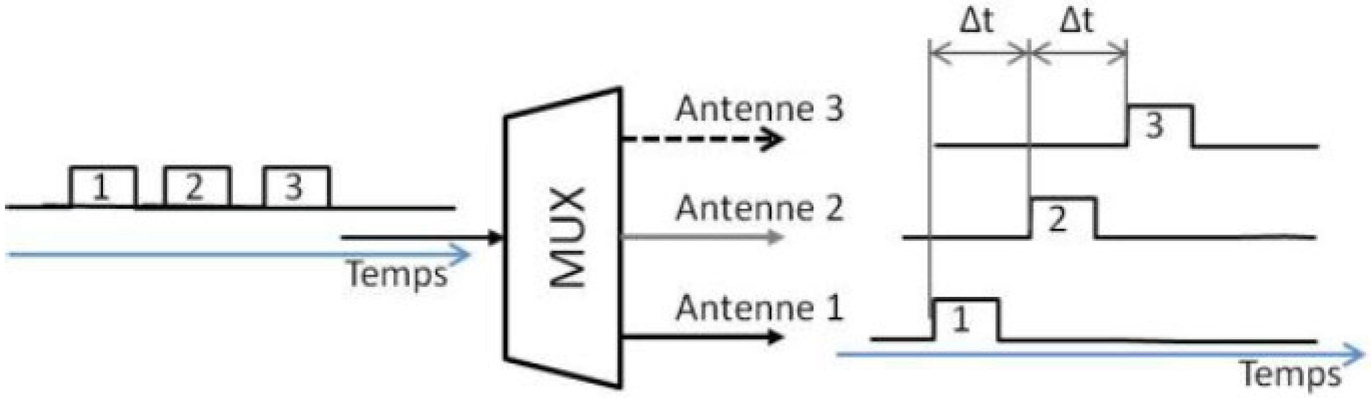
Tx Switching and // Rx $T_H = 2(\tau_{Max}).M_t$



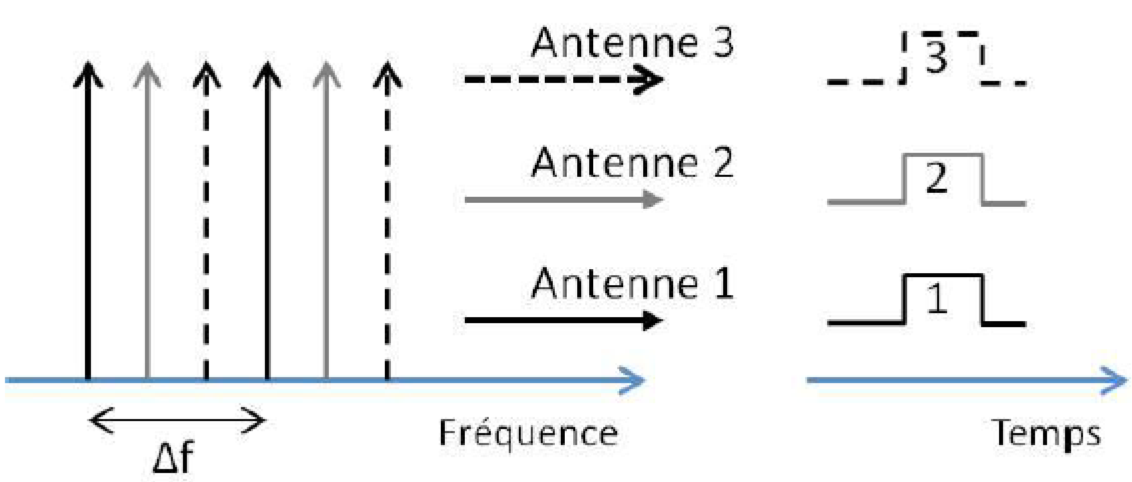
Fully // Architecture $T_H = 2(\tau_{Max})$

T_H must be faster than the coherence time of the channel!

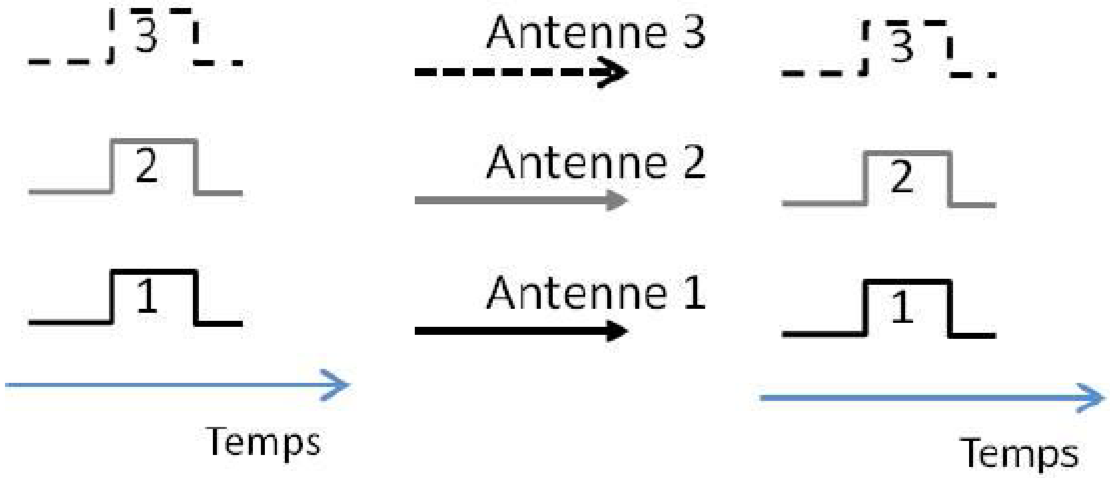
Multiplexing Techniques



1 - Time Multiplexing



2 - Frequency Multiplexing



3 - Code Multiplexing with pseudo-random codes

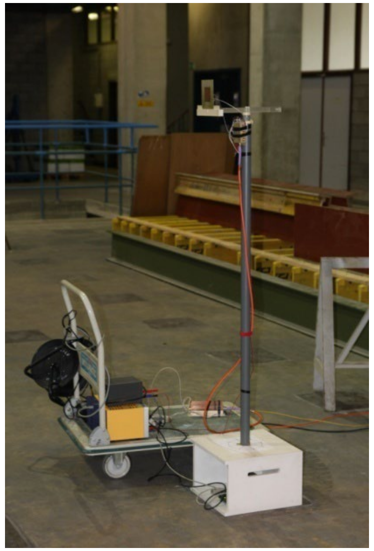
Example of Sounder: Commercial VNA

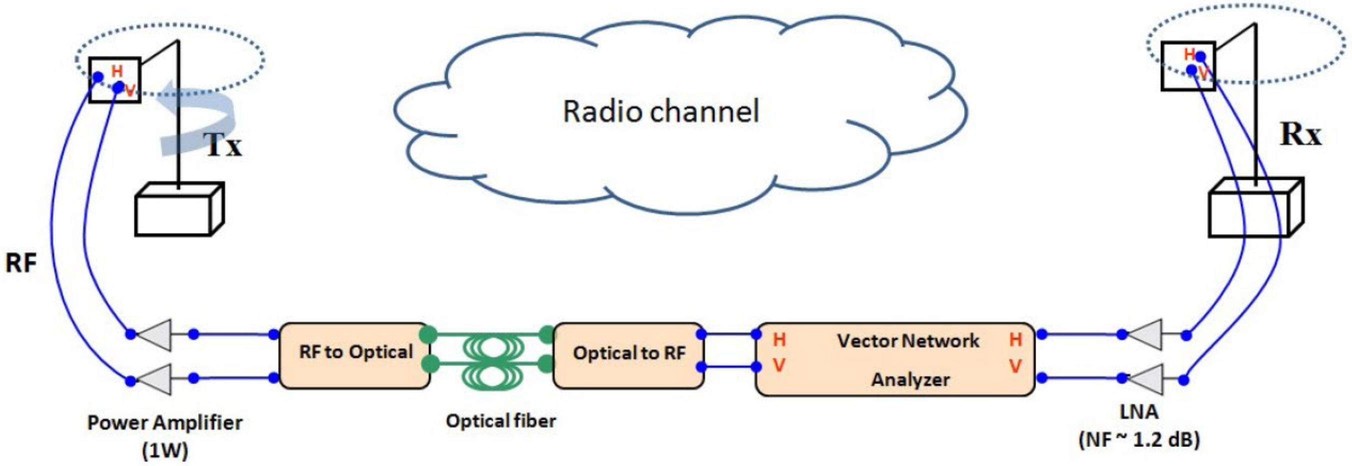
- Vector Network Analyzer: "Poor's man tool"
  - Originally used to measure quadrupoles with high-quality multiport analysis
  - Single reference rubidium clock ($10^{-11/12}$ ppm)
  - Supports large set of frequencies, bandwidth, number of frequency points (up to THz)
  - High dynamic range > 100 dB
  - Slow measurement (static scenarios)
  - No mobility support
  - Only few ports available
    - Indoor scenarios with small Tx – Rx distance
    - Need controlled switching driver

ZVA 67 for mmW measurements

Virtual Channel Sounder

- Virtual Sounding (VNA)
  - Architecture TELICE (Agilent E5071C < 8.5 GHz)
    - Indoor & outdoor characterization @ 1.35 GHz
  - Architecture UPTC (R&S ZVA67 < 325 GHz)
    - 60 GHz, 94 GHz, 300 GHz indoor characterization





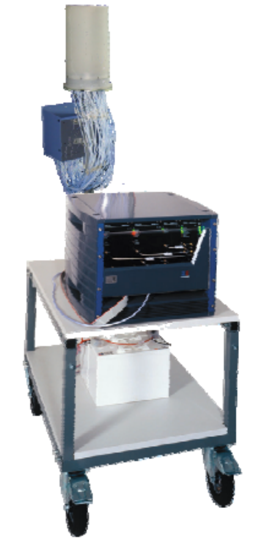
Architecture of the TELICE virtual sounder

Example of Sounder: PropSound – Elecktrobit

Table 2-2 Propsound^{TM} characteristics

Propsound Property	**Range of values**
RF bands	1.7 - 2.1, 2.0 - 2.7, 3.2 - 4.0, 5.1 - 5.9 GHz
Sustained measurement rate	Up to 30,000 CIR/s (code length: 255 chips)
Maximum cycle (snapshot) rate	1500 Hz
Chip frequency	up to 100 Mchips/s
Available code lengths	31 - 4095 chips (M-sequences)
Number of measurement channels	up to 8448
Measurement modes	SISO, SIMO, MIMO
Receiver noise figure	better than 3 dB
Baseband sampling rate	up to 2 GSamples/s
Spurious IR free dynamic range:	35 dB
Transmitter output	up to 26 dBm (400 mW), adjustable in 2 dB steps
Control	Windows notebook PC via Ethernet
Post processing	MATLAB package
Synchronisation	rubidium clock with stability of 10^{-11}

Pseudo-random sequence



Trasmitter with a trolley.

Receiver with a trolley.

Example of Sounder: RUSK – TUI-FAU (Medav GMBH), Ge

Stacked Polarimetric Uniform Circular Patch Array (SPUCPA4x24)

Table 2-5 Key features of the Medav RUSK TUI-FAU channel sounder.

RUSK TUI-FAU Sounder Property	**Range of values**
RF bands	5…6 GHz
Max. meas. data storage rate	(2x)*160 Mbyte/s
Test signal	Multi Carrier Spread Spectrum Signal (MCSSS)
Sequence length (defines maximum excess delay)	256 – 8192 spectral lines, depending on IR length
Number of measurement channels	up to 65536 (2^{16})
Measurement modes	SISO, SIMO, MIMO
Sampling frequency	640 MHz at Tx and Rx
Spurious free IR dynamic range	48 dB
Transmitter output	up to 33 dBm (2 W),
Propagation delay resolution	4.17 ns (1/bandwidth)
Impulse response length	0.8 µs – 25.6 µs
RF sensitivity	-88 dBm
Control	Windows PC
Post processing	MATLAB package
Synchronisation	rubidium clock with stability of 10^{-10}

Multi-carrier sequence

Port Switching Scheme

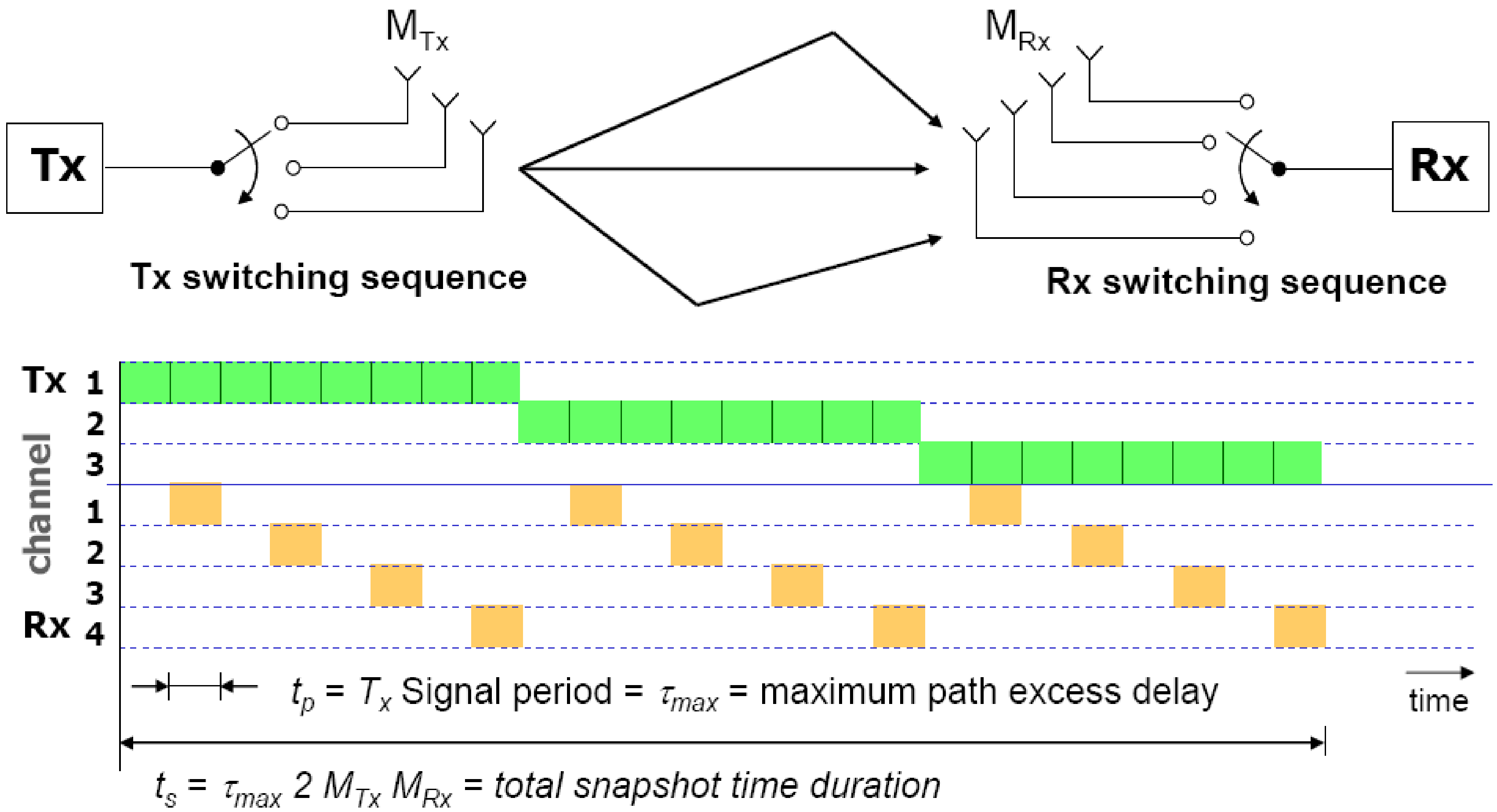
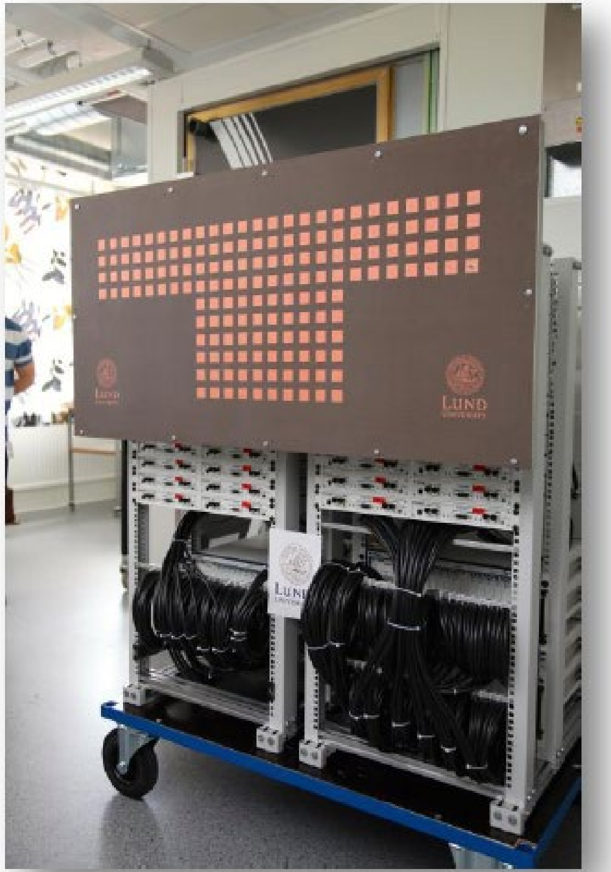
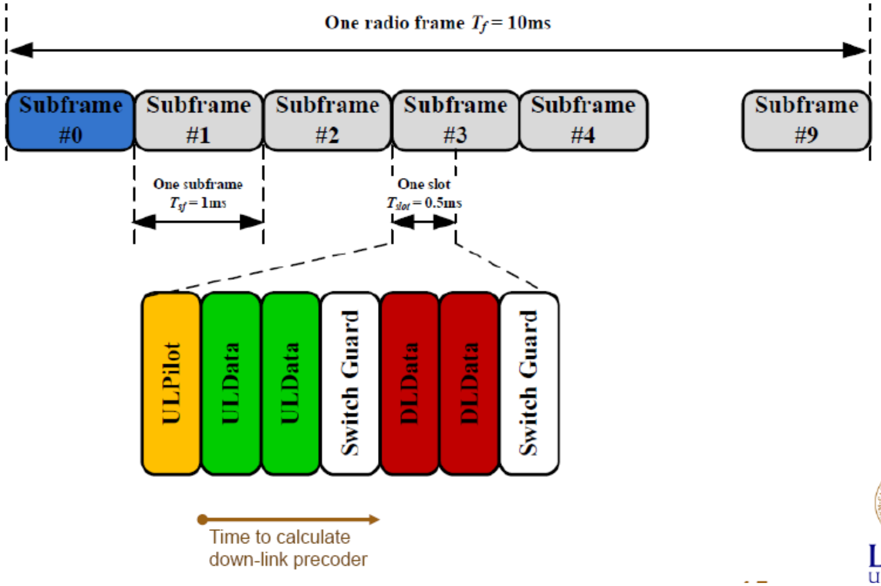


Figure 3-2: MIMO sounder switching time frame.

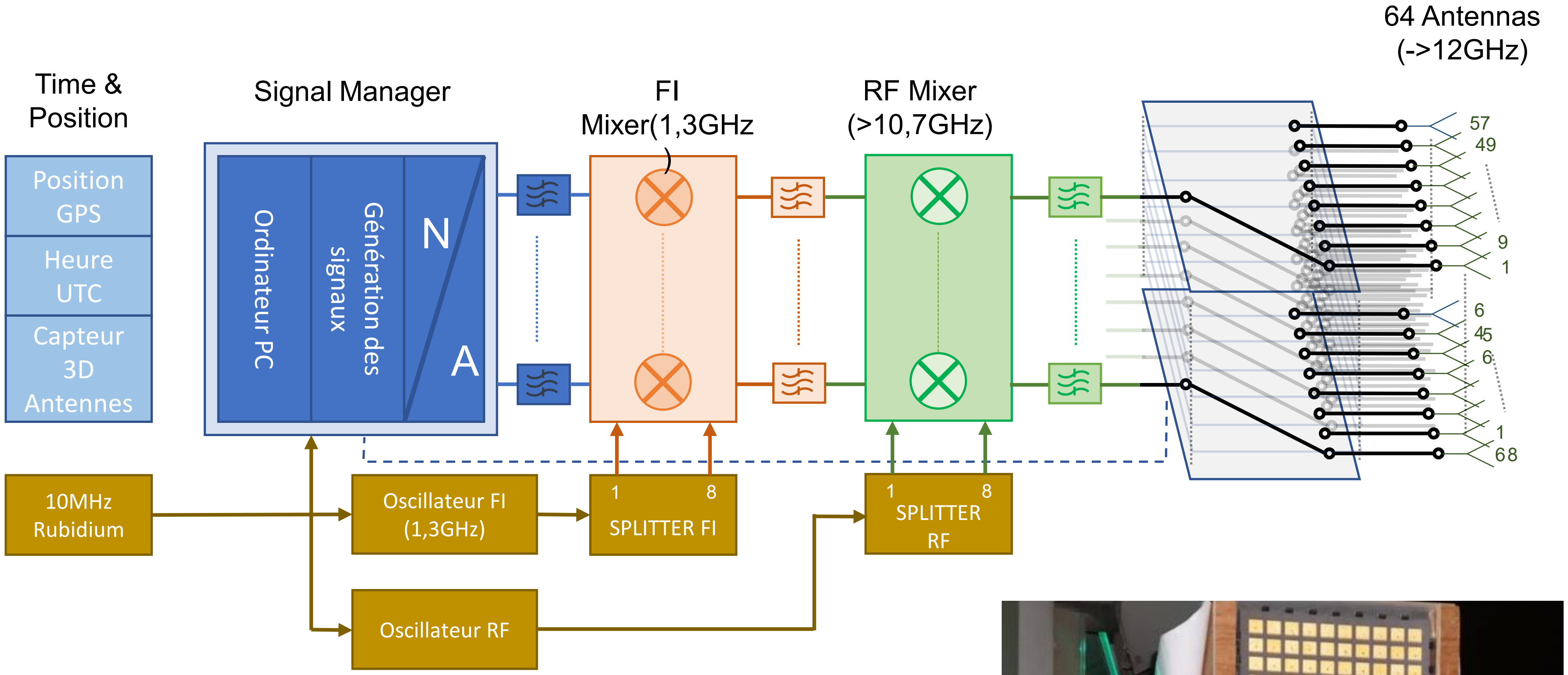
Rusk Channel Sounder (MEDAV)

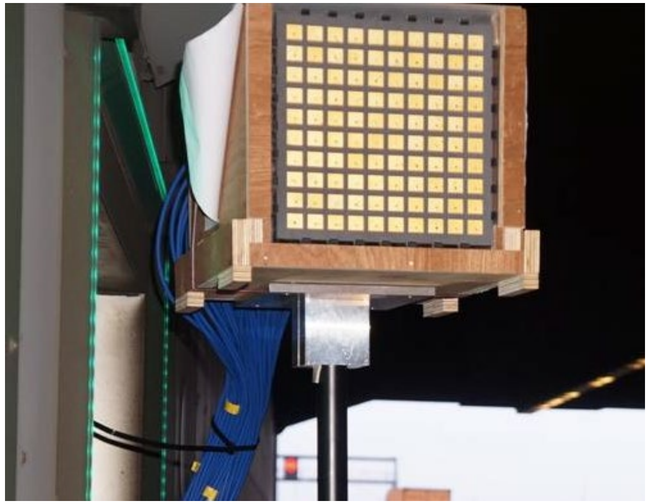
Channel Sounder: Massive MIMO Lund Univ.





Massive MIMO ULille Sounder: MaMIMOSA





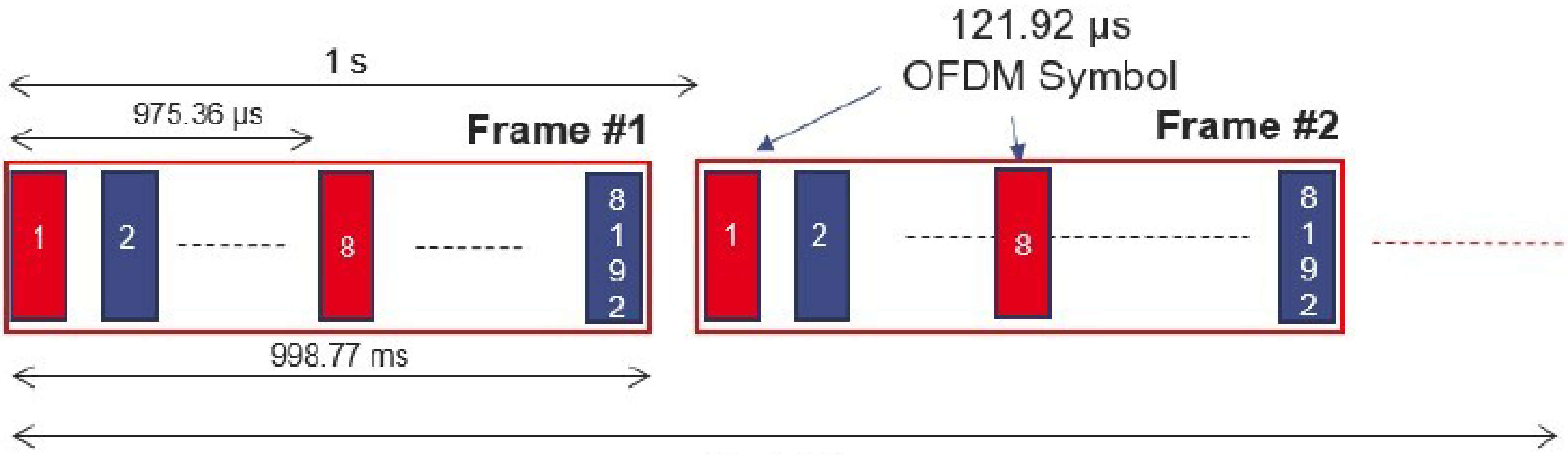
Emitter Massive MIMO 2-> 12GHz

Multi-carrier sequence

Massive MIMO ULille Sounder: MaMIMOSA

Signal en bande de base		Radio Fréquence	
Multiplexage	IFDM	Frequencies	**1.35 GHz / 5,89GHz**
Used sub carrier	6560	Bandwidth	**80 MHz**
Outputs	**8**	N_{Tx} (switched mode)	**8 (16 ou 64)**
N subcarrier / output	**820**	Power / Tx	0.001 to 1 W
Delta frequency	**97.7 kHz**	N_{Rx}	**16**
Symbol duration	81.92 µs	AGC Dynamic	63 dB
Caractéristiques de sondage			
CIR*	**10.24 µs**	CIR Résolution	12.5 ns
Max CIR*	**50 M**	Matrice H(16,16,1024) Matrice H(16,64,1024)	1 Mo 4 Mo

What is the quantity of channels measured?



$H(f,t)$ of size $(M_T.M_R.M_f.M_s.M_F)$

DOD (64)

DOA (16)

Delay (818)

Symbols (8192)

Frames (Drive)

What can we extract from the measured channels?

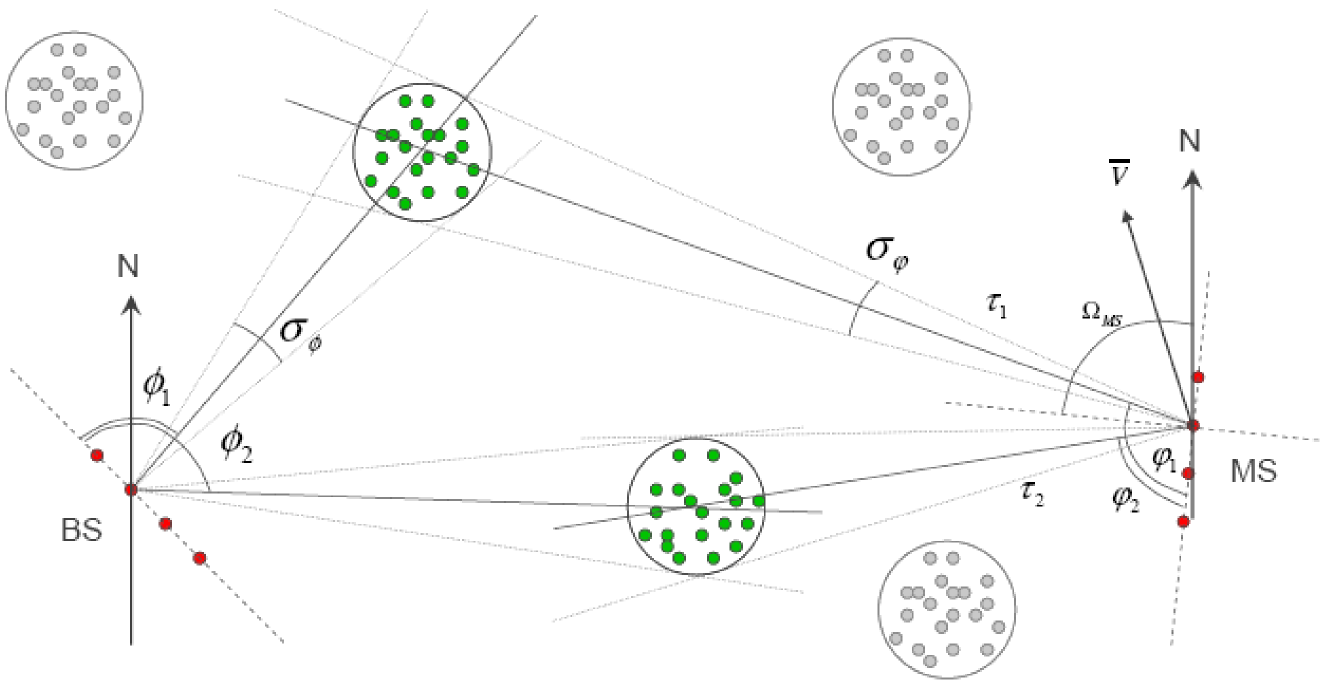


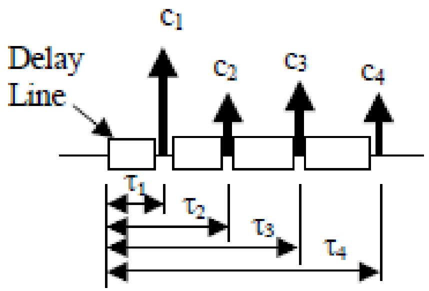
Figure 3-4. Single link.

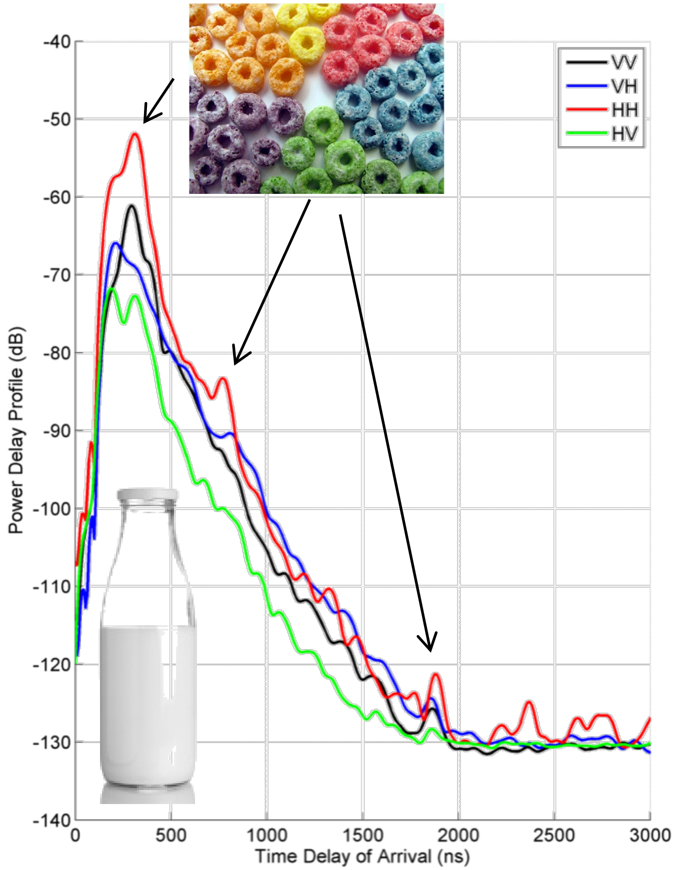
WINNER 2 Channel Model MIMO Single link

Urban micro-cell

Scenarios		B1 LOS	B1 NLOS
Delay spread (*DS*) $\log_{10}$([s])	μ	-7.44	-7.12
	σ	0.25	0.12
AoD spread (*ASD*) $\log_{10}$([°])	μ	0.40	1.19
	σ	0.37	0.21
AoA spread (*ASA*) $\log_{10}$([°])	μ	1.40	1.55
	σ	0.20	0.20
Shadow fading (*SF*) [dB]	σ	3	4
K-factor (*K*) [dB]	μ	9	N/A
	σ	6	N/A
Cross-Correlations *	*ASD* vs *DS*	0.5	0.2
	ASA vs *DS*	0.8	0.4
	ASA vs *SF*	-0.5	-0.4
	ASD vs *SF*	-0.5	0
	DS vs *SF*	-0.4	-0.7
	ASD vs *ASA*	0.4	0.1
	ASD vs *K*	-0.3	N/A
	ASA vs *K*	-0.3	N/A
	DS vs *K*	-0.7	N/A
	SF vs *K*	0.5	N/A
Delay distribution		Exp	Uniform ≤800ns
AoD and AoA distribution			
Delay scaling parameter r_τ		3.2	—
XPR [dB]	μ	9	8
	σ	3	3
Number of clusters		8	16
Number of rays per cluster		20	20
Cluster *ASD*		3	10
Cluster *ASA*		18	22
Per cluster shadowing std ζ [dB]		3	3
Correlation distance [m]	*DS*	9	8
	ASD	13	10
	ASA	12	9
	SF	14	12
	K	10	N/A

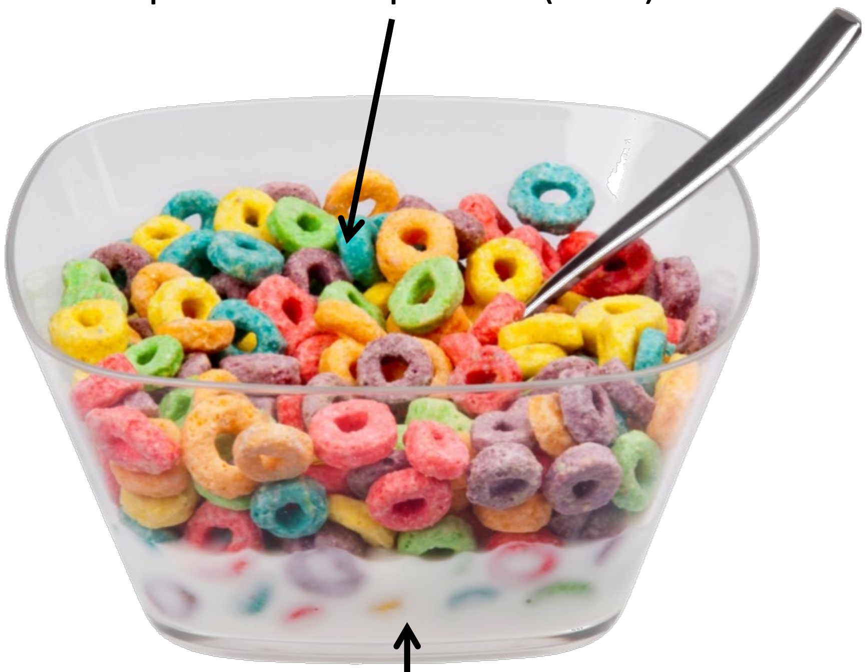
How do we extract MPC information?





Example of polarimetric PDP measured

Specular component (SMC)



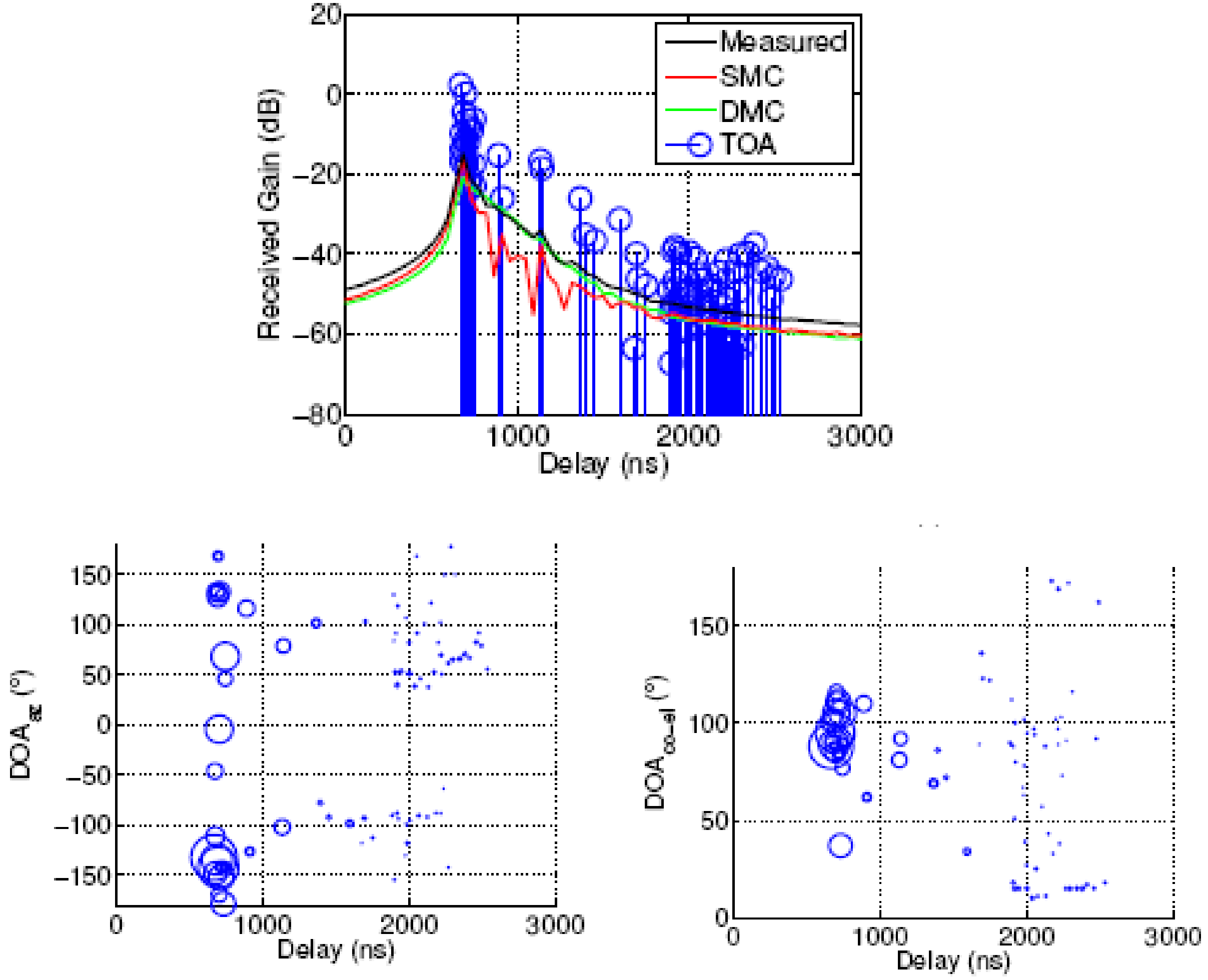
DMC component (diffuse + low specular SNR)

$$p(\mathbf{x}|\theta_{sp}, \mathbf{R}(\theta_{dan})) = \frac{1}{\pi^M det(\mathbf{R}(\theta_{dan}))} e^{-(x-\mathbf{s}(\theta_{sp}))^H \cdot \mathbf{R}(\theta_{dan})^{-1} \cdot (x-\mathbf{s}(\theta_{sp}))}$$

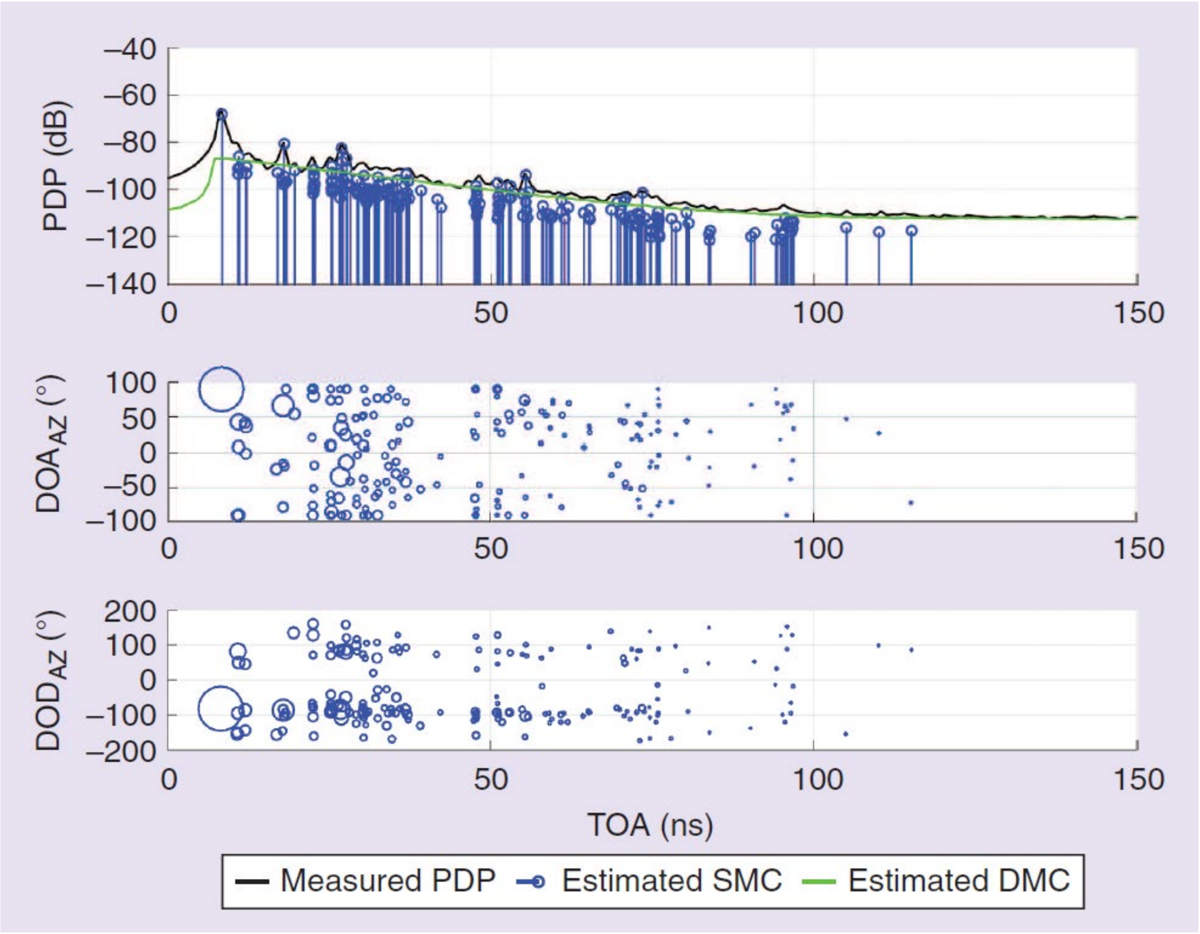
PhD Thesis, A. Richter 2005

Example from measured Channels

@ 1.35 GHz



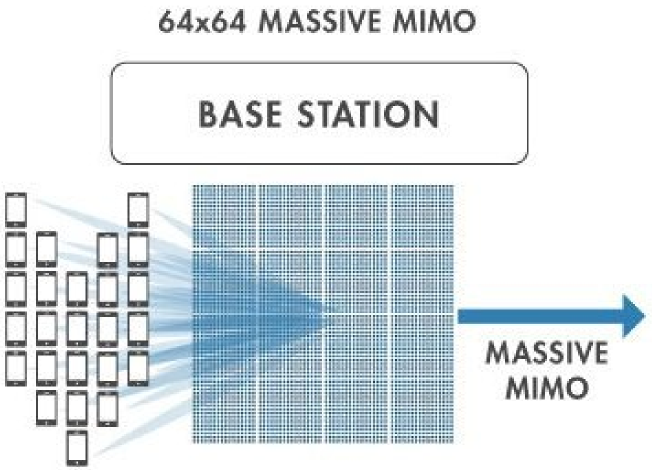
@ 60 GHz



M.-T. Martinez-Ingles *et al.*, *IEEE Antennas Wireless Propag. Lett.*, 2014

What about new networks for 6G?

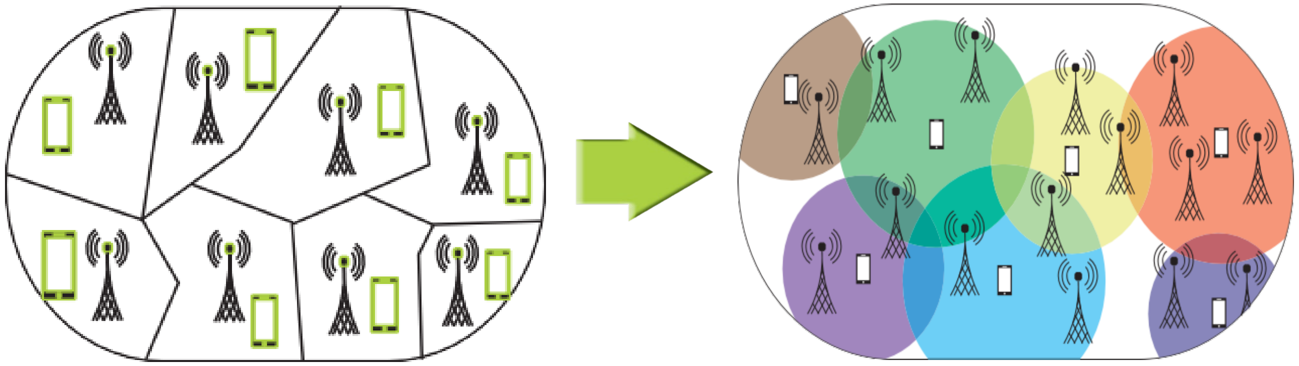
- **Massive Multiple-Input Multiple Output** (mMIMO)



- Spectrum for CF-mMIMO
  - **FR1 (sub-6 GHz)** : moderate attenuation
  - **FR2 (26-28 and 40 GHz)** : increase of capacity

- Distributed **Cell-Free networks** (CF)

Joint Transmission, CoMP, cooperative beamforming…



Conventional cellular networks:
AP-centric networks

5G & Beyond networks:
User-centric Cell-Free networks

\+ **Channel hardening & favorable propagation conditions**

\- **Inter-cell interference**

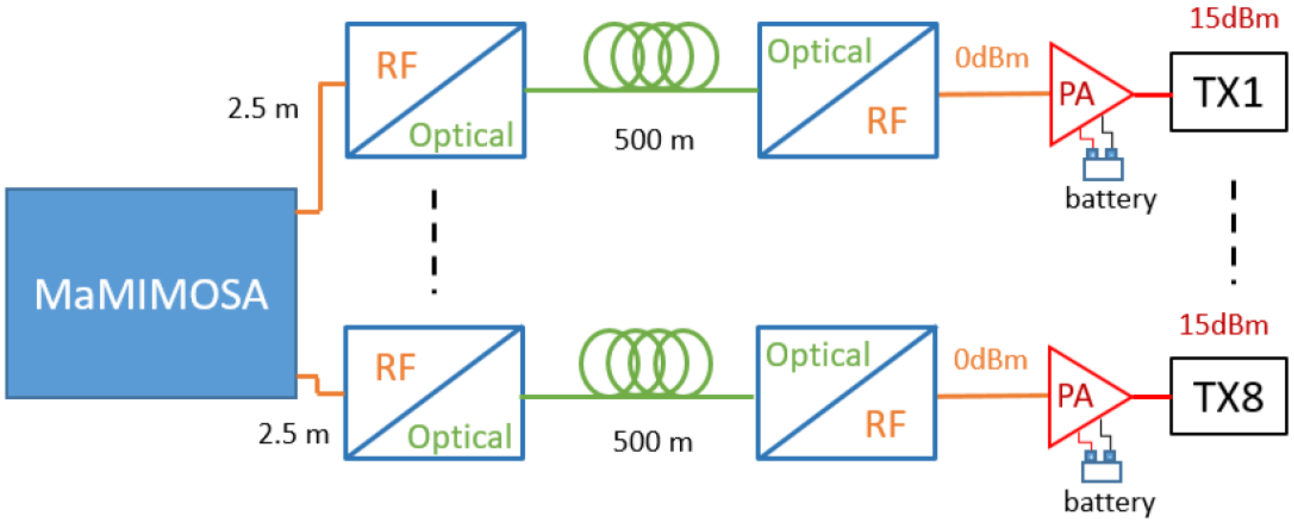
\+ **Larger, uniform SNR with AP selection and clustering algorithms**

CF-mMIMO provides seamless coverage, reduced latency and high throughput

→ promising candidate to fulfill the requirements of **future networks**

MaMIMOSA Distributed Radio Channel Sounding

- Upgrade of the Massive MIMOSA sounder:
  - 64 x 16 real-time sounder with 80 MHz bandwidth @ 5.89 GHz
  - Time-varying MIMO transfer functions computed "on the fly" with no additional post-processing
  - 8 x 16 using 500m-long 8 RF-over-Fiber (RoF) links with 0 dBM output power
  - Power amplifier (PA) on battery to generate 15 dBm output power with 40 dB SNR
  - Potential of *X* AP times *Y*-antenna arrays (*X* times *Y* = 64) to emulate a realistic cell-free network



Measurement campaign: TX & RX Description

TX

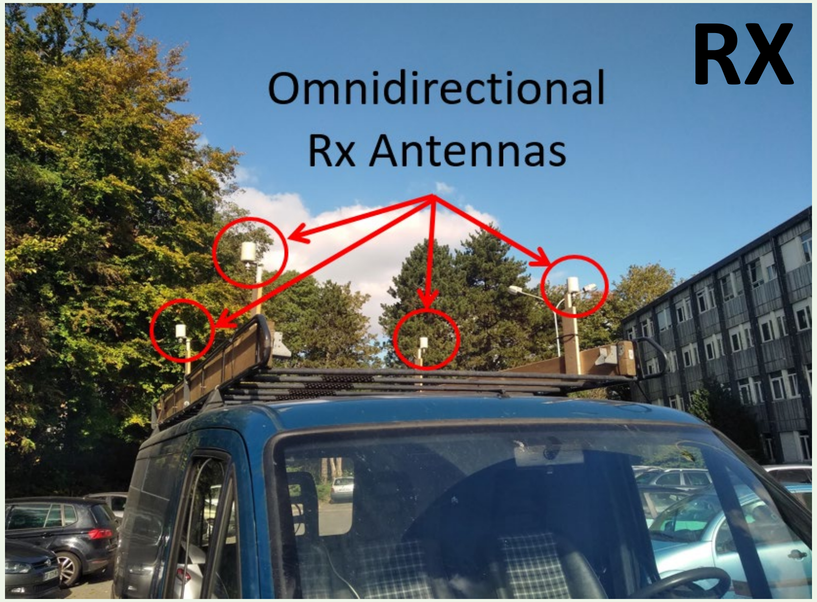
MaMIMOSA TX with 8 RoF links

1 antenna / AP   2 antennas / AP

4 & 8 antennas / AP

Eight 6.5 dBi patch antennas at 2.5 m high with V-Polarization
4 tested AP configurations from fully distributed to fully co-localized network

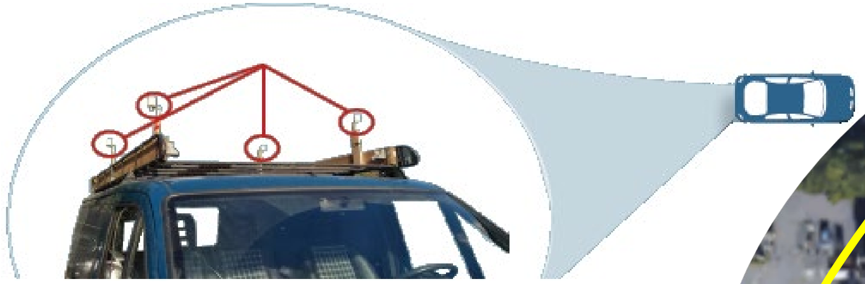
RX



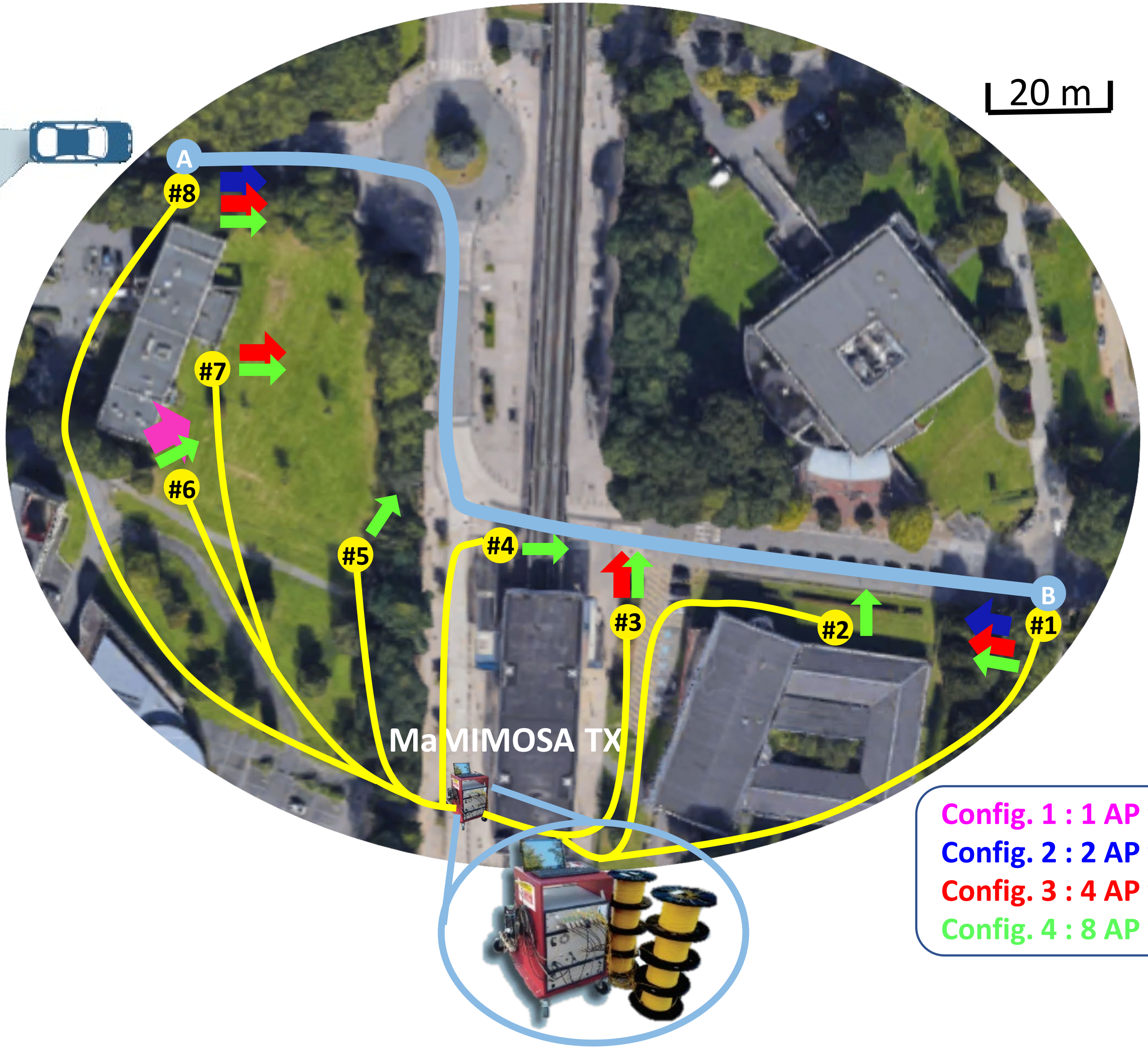
MaMIMOSA RX in van with four 2 dBi EM6116 omnidirectional antennas

- Both TX & RX powered with Li-ion batteries for up to 8 hours of continuous measurements
- Back-to-Back calibration including RoF
- All antennas emit at same time & first detected antenna from RX side starts measuring

Measurement campaign: Investigated Scenario

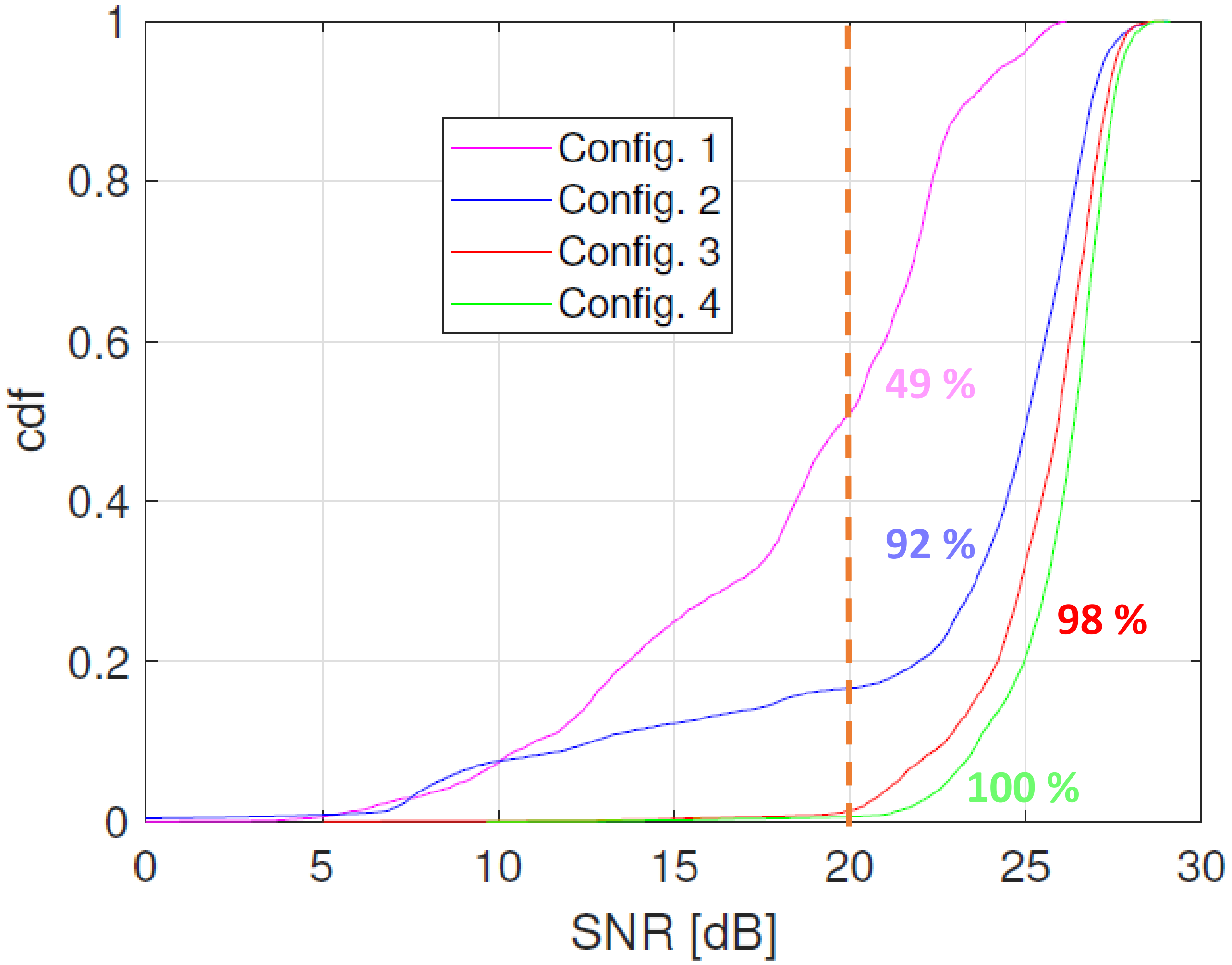


- 35 seconds drive-test from A and B with 25 km/h average speed (275 m distance)
- Up to 8 AP distributed in scenario with ~ 50 m distance between them
- Multiple antenna configurations to compare typical cellular with cell-free network
  - LOS / NLOS shadowing conditions with foliage and buildings
  - SNR distribution over covered area
  - RMS delay spread
  - Path loss characteristics

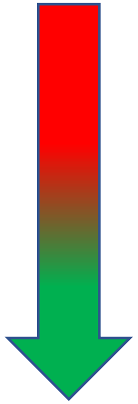


Config. 1 : 1 AP with 8 antennas
Config. 2 : 2 AP with 4 antennas
Config. 3 : 4 AP with 2 antennas
Config. 4 : 8 AP with 1 antenna

Results: SNR ECDF



Fully co-localized network (current)



Fully distributed cell-free network (new)

Config. 1 : 1 AP with 8 antennas
Config. 2 : 2 AP with 4 antennas
Config. 3 : 4 AP with 2 antennas
Config. 4 : 8 AP with 1 antenna

- 100% of SNR values have an SNR > 20 dB for cell-free network compared to 49% with fully co-localized network
- Clear demonstration of the topology benefits even when both LOS/NLOS conditions coexist

First demonstration of a realistic cell-free network (robustness)!

E.P. Simon *et al.*, EUCAP 2023

Summary

- Radio channel sounding is key equipment to assess the characteristics of radio channels:
  - Realistic propagation models for specific use cases are badly needed for
    - Developing robust physical chains with new modulation schemes, processing techniques
    - Deploying current/future networks!
    - Optimize the performance of future networks (optimized capacity does not mean optimized energy efficiency)
- Modern sounders include advanced real-time processing with increasing complexity:
  - Frequency, bandwidth, number of Tx/Rx antennas, embedded processing, switching capabilities and number of RF chains
  - Distributed emitters with multiple antennas for CF-mMIMO networks
- Current problematic:
  - There is no universal sounder => specific use-cases in given scenarios (but in phase with "slicing")
  - Cost of increasing frequency and developing dedicated Tx/Rx RF chains
  - Systems can mostly treat single users with multiple antennas (SU-MIMO)
  - Going full MU-MIMO with distributed emitters AND receivers is missing (we work on that!)
- Acquisition is FAST, measured data is HUGE and post-process TEDIOUS (AI, data-mining)

In the end, 6G will be fast! but sounds very SLOW…

Thank you for your attention !

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