Prof. Doutor Mário Marques da Silva

Prof. Doutor João Guerreiro

Outline

- Evolução das Comunicações Celulares
- As Comunicações 5G, suas diferenças
- Técnicas de Transmissão de Suporte ao 5G
  - MIMO e Massive MIMO
  - Técnicas de Transmissão por Blocos (Prof. João Guerreiro)

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  - Técnicas de Transmissão por Blocos

Evolução das Comunicações Celulares
Suporte a Serviços Disponibilizados

- 1G (FDMA) – Analógica (voz)
- 2G (TDMA) – GSM – Digital, Introdução dos Dados e do Roaming
- 3G (WCDMA) – UMTS – Acesso à Internet
- 4G (OFDM) – VTC (estático, difícil equalização)
- 5G (OFDM) – VTC (on the move), Condução Autónoma, Comunicações ponto-a-ponto (IoT), Realidade Virtual, Inteligência Artificial, etc.

- Normalizado em normas 3GPP da ETSI, tendo sido adotado pela ITU-T
- Liderança das Normas Celulares Europeias

Evolution of Cellular Systems and the New Paradigm of 4G

- First generation of cellular networks (1G) were analogue (around 1980), with a myriad of cellular systems without interoperability (FDMA).
- Global System for Mobile Communications (GSM) is a 2G system (1992), using TDMA, with higher capacity, reliability, performance and interoperability (roaming).
- Universal Mobile Telecommunication System (UMTS) is a 3G system (1999), based on WCDMA (3GPP release 99).
- Long Term Evolution (LTE) is a "3.9G system" (2010), based on OFDM, MIMO, and all-over-IP (3GPP release 8 & 9).
- LTE-Advanced is a 4G system (2014) that aims to accommodate higher bandwidths, spectrum efficiency, lower delays and higher network capacity (3GPP release 10,11 & 12).
  - ITU renamed it as IMT-Advanced.

FDD	WCDMA	HSPA	HSPA+	LTE	LTE/IMT Advanced
TDD	TD-SCDMA[1]	TD-HSDPA	TD-HSUPA	TD-LTE	
Deployment	2003	2006/8	2008/9	2010	2014
3GPP Release	99	5/6	7	8/9	10/11/12
Downlink data rate	384 kbps	14.4 Mbps(*)	28 Mbps(*)	>160 Mbps(+)	1 Gbps nomadic; 100 Mbps mobile
Uplink data rate	128 kbps	5.76 Mbps(*)	11 Mbps(*)	>60 Mbps(+)	500 Mbps nomadic; 50 Mbps mobile
Switching	Circuit + Packet Switching	Circuit + Packet Switching	Circuit + Packet Switching	IP based (Packet Switching)	IP based (Packet Switching)
Transmission Technique	WCDMA/TD-SCDMA	WCDMA/TD-SCDMA	WCDMA/TD-SCDMA	Downlink: OFDMA Uplink: SC-FDMA	Downlink: OFDMA Uplink: SC-FDMA
MIMO	No	No	Yes	Yes	Yes
Multihop Relay	No	No	No	No	Yes
Adaptive Modulation and Coding	No	Yes	Yes	Yes	Yes
Cooperative Systems	No	No	No	No	Yes
Carrier Aggregation	No	No	No	No	Yes

(*) Peak data rates; (+) Assuming 20 MHz bandwidth and 2x2 MIMO

Evolution from 3G Systems into LTE

- 3G systems is composed of different evolutions (WCDMA, HSPA, HSPA+), specified by 3GPP releases.
- While GSM was based on TDMA, the 3G uses WCDMA:
  - This evolution allowed a rate improvement from few dozens of kbps up to 384 kbps for the downlink and 128 kbps for the uplink.
  - These rates were improved in the following updates, achieving 28 Mbps in the downlink of HSPA+ (3GPP release 7).
- To face emergent services, LTE (3GPP release 8) supports 160 Mbps in the downlink, and faster in its release 9 (MIMO systems).
- The LTE can be viewed as a "3.9G" cellular system.
- LTE uses OFDMA, MIMO, base station cooperation, adaptive modulation and coding, all-over IP concept, and dynamic spectrum allocations.
- The LTE introduced Evolved Multimedia Broadcast and Multicast Service (eMBMS), which aims to use spectrum-efficient multimedia services, by transmitting data over a common radio channel.

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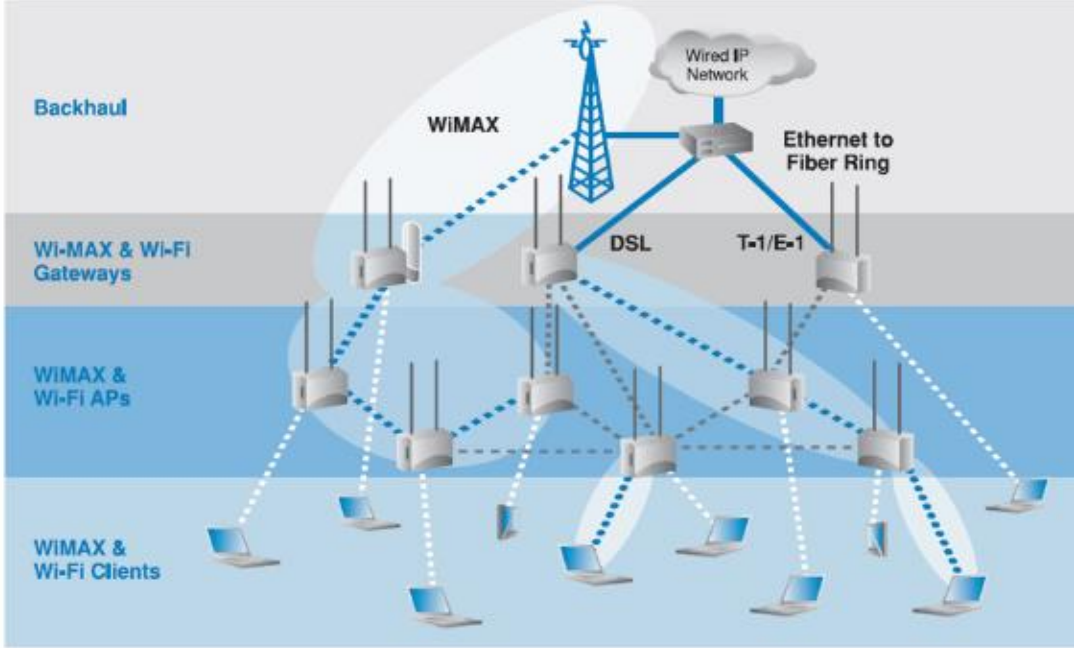
IEEE 802.16 Protocol (WiMAX)

- IEEE 802.16 (WiMAX) allows fixed and mobile wireless access:
  - Mobile: provides wireless Internet access to the last mile, with a range of up to 10 kilometers (alternative to ADSL or cable modem).
  - Fixed: can also be viewed as a backhaul for IEEE 802.11, cellular BS, or mobile WiMAX.
- The initial version of WiMAX, was updated:
  - IEEE 802.16-2004 (IEEE 802.16d), only specified the fixed interface of WiMAX, without providing any support for mobility.
  - IEEE 802.16-2005 (IEEE 802.16e), consists of an amendment to the previous version, introducing mobility, handover and roaming (includes MIMO).
  - IEEE 802.16j introduced multi-hop Relay, increasing throughput by a factor 3 to 5, and to extend the coverage.
  - IEEE 802.16m aimed to reach all the IMT-Advanced requirements, including wider bandwidths (100 MHz), adaptive and advanced TDMA/OFDMA access, advanced relaying techniques, advanced MIMO, adaptive modulation schemes, scheduling, etc.



LTE-Advanced and IMT-Advanced

- 4G aims to support the emergent multimedia and collaborative services.
- The LTE-Advanced (standardized by 3GPP release 10, 11 & 12) is a 4G system, supporting 1 Gbps nomadic access and 100 Mbps vehicular (in the downlink, whose values are halved in the uplink), achieved with:
  - Carrier aggregation (up to 20 MHz), supporting bandwidths up to 100 MHz.
  - Advanced antenna systems (single-user 8x8 MIMO [downlink] and 4x4 MIMO [uplink], and multi-user MIMO).
  - Multi-hop Relay.
  - Advanced Inter-Cell Interference Cancellation.
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  - Multi-resolution Techniques (ex: hierarchical constellations, MIMO).
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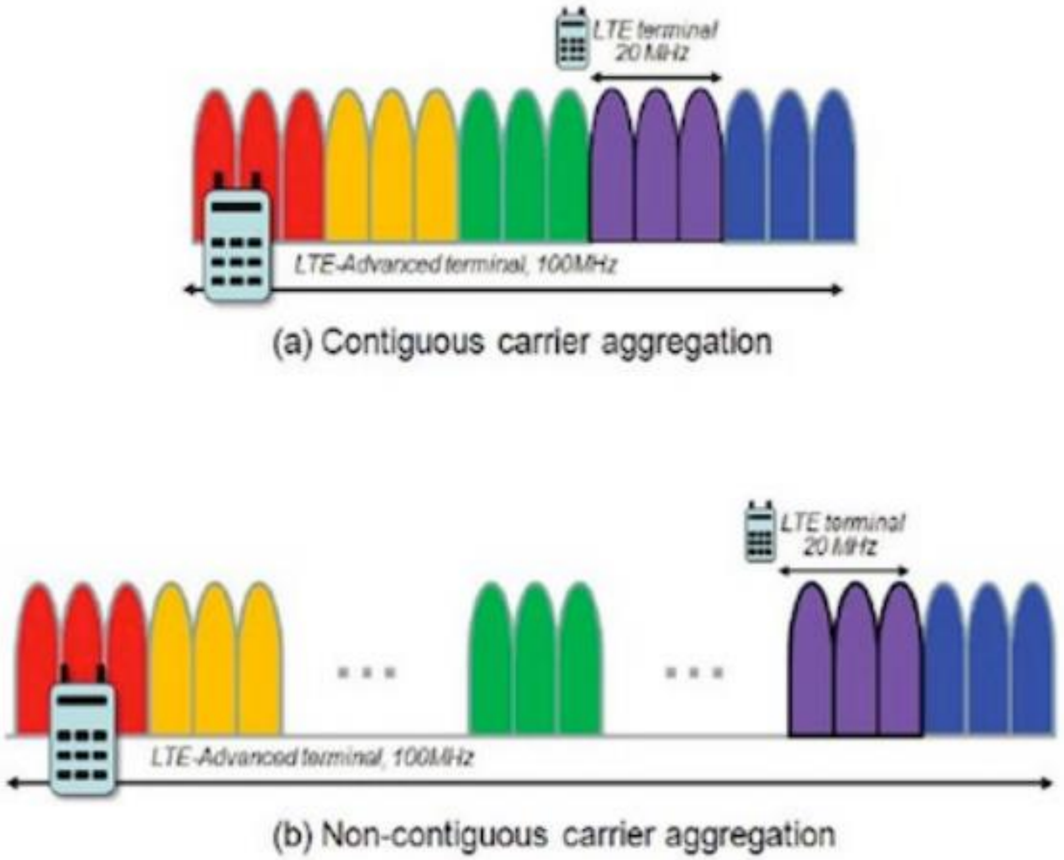

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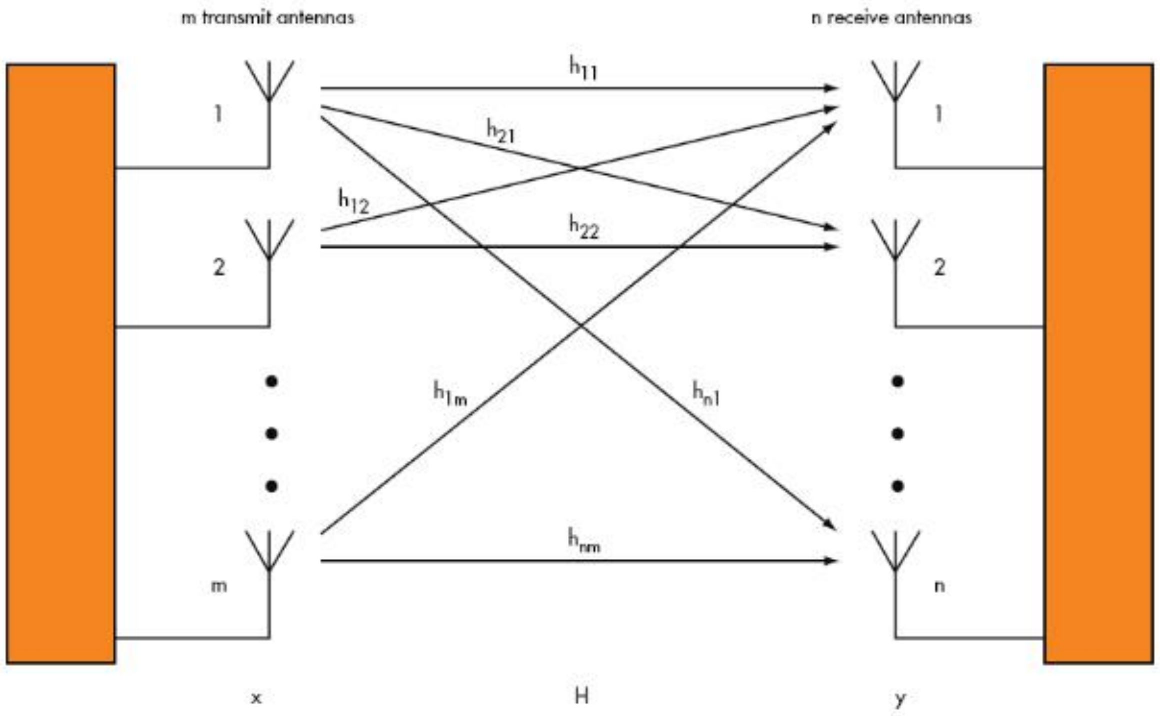

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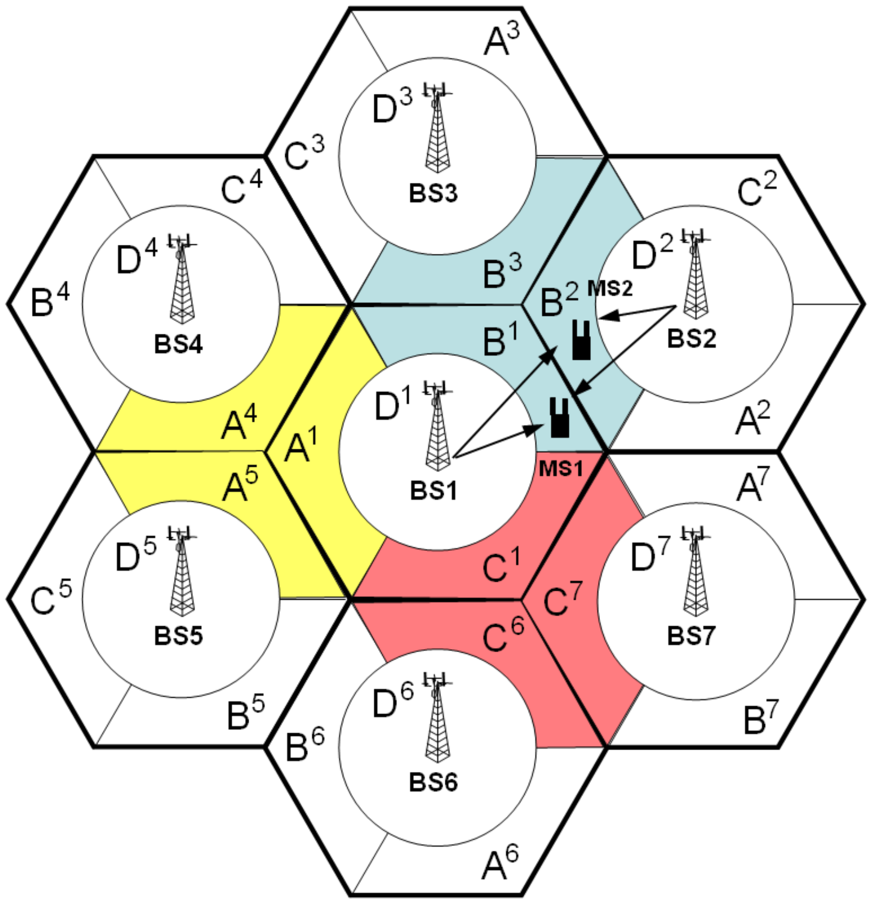
Base Station Cooperation

Mitigates Path Loss, Shadowing, Inter-cell Interference
Increases SNR



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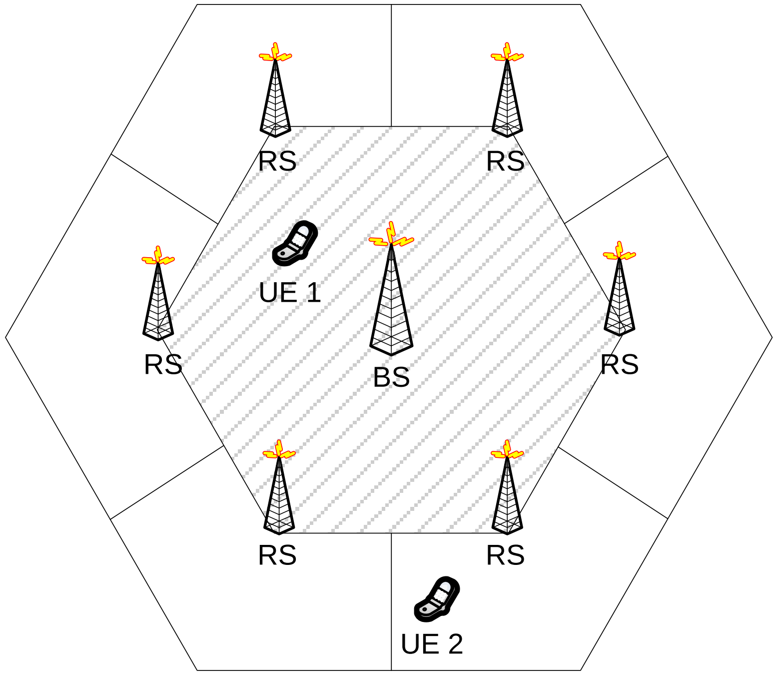
Multi-Hop Relay

Mitigates Path Loss, Shadowing, Inter-cell Interference
Increases SNR



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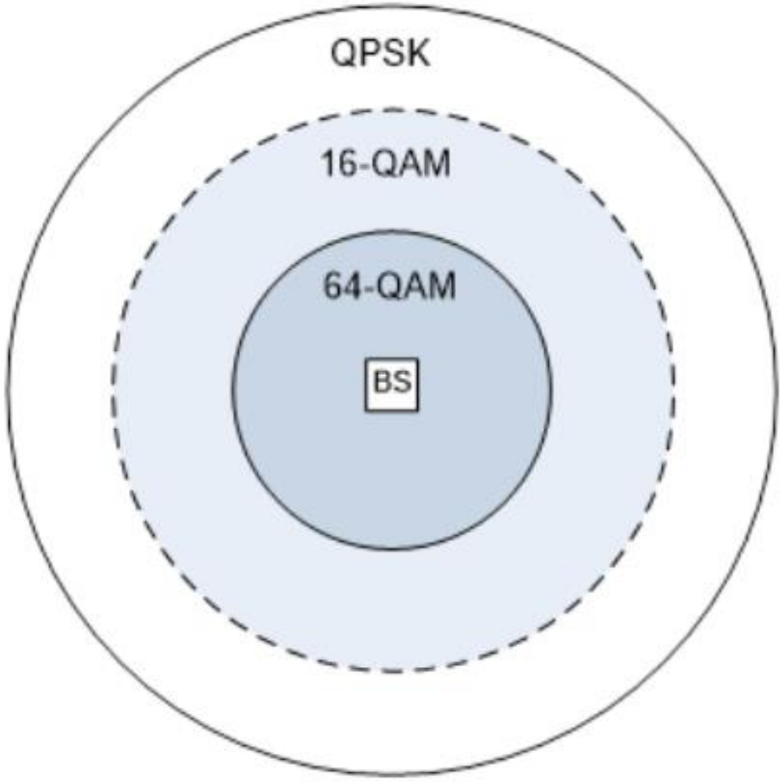

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As Comunicações 5G, suas diferenças

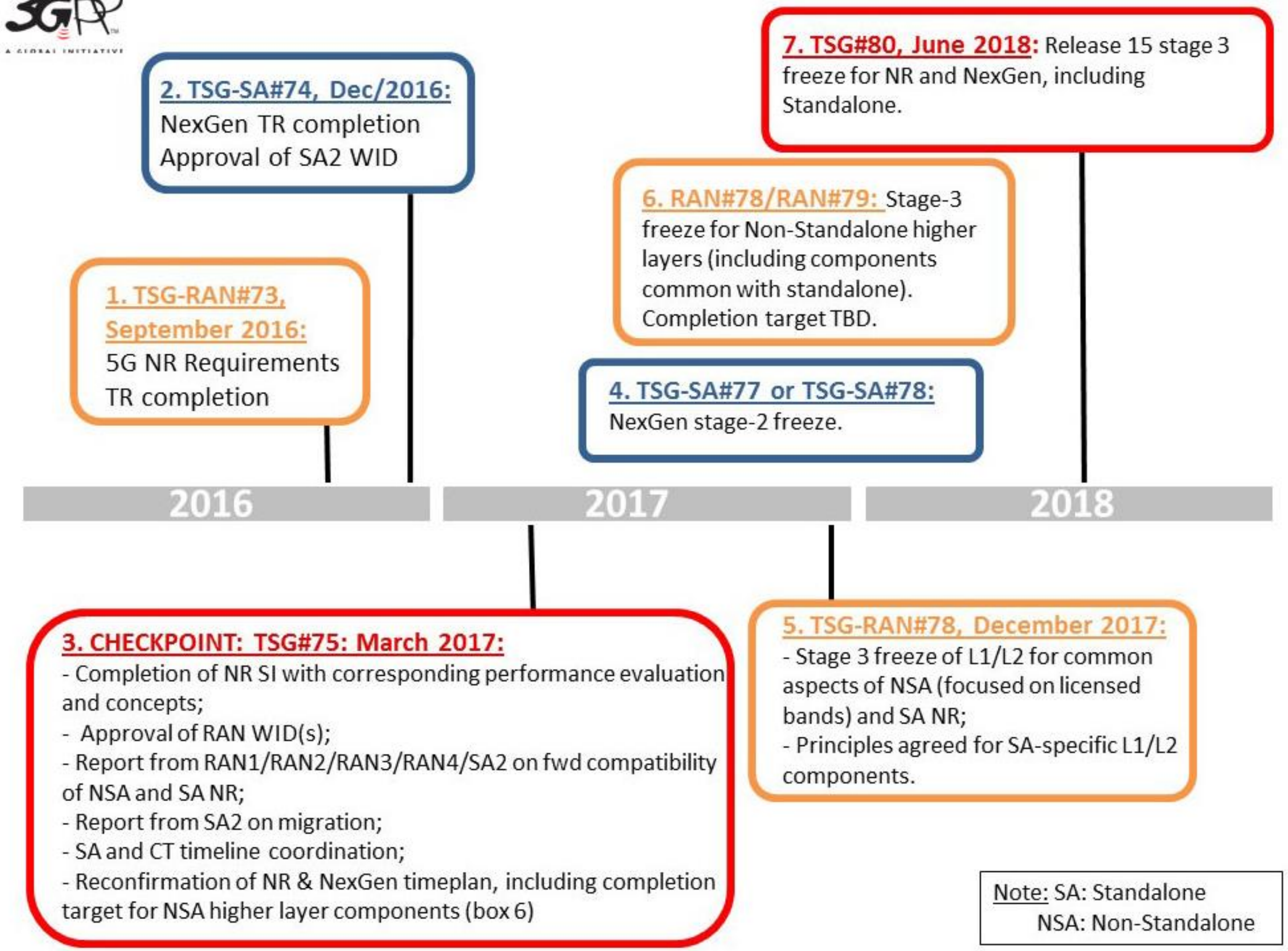
- 5G systems (2020) are aimed to achieve:
  - Higher throughputs (1 to 10 Gbps)
  - Lower Latency (0,5-1 ms latency)
  - Higher Capacity
  - Better Spectral Efficiency
- 3GPP Release 15 (from ETSI)
  - Covers: 1-Radio Access Network; 2-Services and Systems Aspects; 3-Core Network and Terminals
  - ITU-T will standardize 5G as IMT-2020
- Data, data, data… (High Speed).
- 5G will support: VTC on the move, real-time communications, augmented reality, support of self-driving cars, machine-to-machine communications, etc.
- Both infrastructure centralized architecture and device-to-device communication (to support IoT, MANET, and Security Application)
- Massive MIMO schemes involving several tens or even hundreds of antenna elements are expected to be central technologies for 5G systems

New Paradigm of 5G

- Support of new and emerging services
- Increase of data rates (10 Gb/s) and lower delays
- Increase of offer tends to originate an increase of demand => new services will come

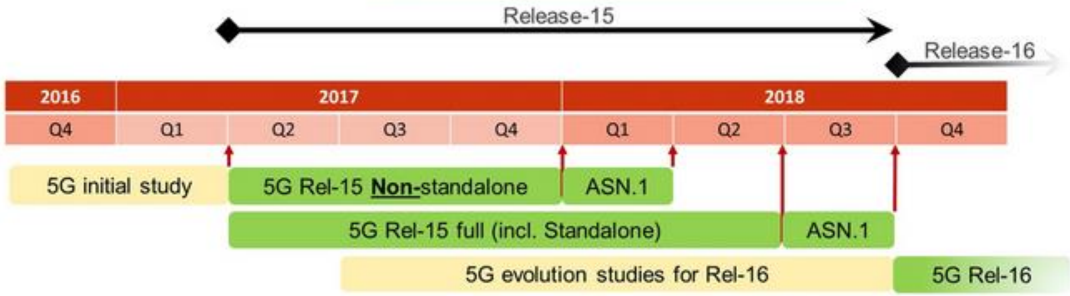
5G main Requirements:

- **Transmission Rates: 10 Gbps** nomadic and 1 Gbps on the move in **downlink** (halved in the uplink).
- **Latency: 0,5 ms for tactile interaction**.
- **Capacity:** targets can be as high as **15 Tbps/km2** with **250 000 users/km2** for indoor hotspots such as office environments.
- **Spectral Efficiency**
  - Downlink 30bit/s/Hz - services require more in the downlink
  - Uplink 15bit/s/Hz - uplink is the bottleneck, due to lower Tx Power, and lower number of Tx antenas, …

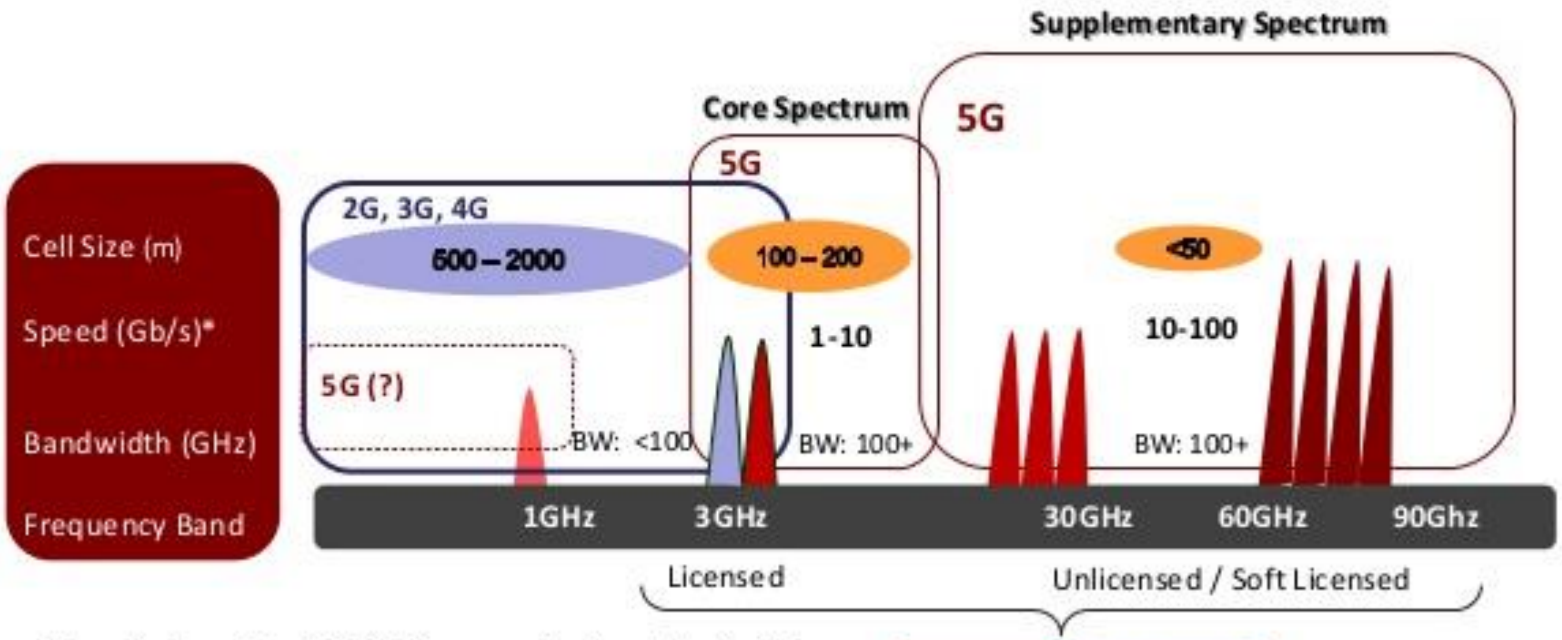


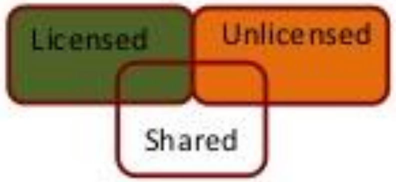
5G NR timeline

- Overall timeline had been agreed at RAN#75 in March/2017
- This time plan still holds
- RAN#77 took some key measures to ensure timeline is met



5G & Spectrum





- ✓Best use of low (below 6Ghz) & high frequencies (mmWave) - Sub 6GHz as core spectrum, mmWave (10-100 GHz) for ultra dense access & backhaul, Supplementary Services
- ✓Ideally 100+ MHz channel bandwidth
- ✓Dynamic Spectrum Allocation
- ✓Coordinated Shared Access
- ✓ Use of temporal & local availability of spectrum
- ✓Carrier Aggregation

Spectrum remains a challenge for 5G and for the wireless industry

Dr Shahram G Niri, July 2014

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HOW TO ACHIEVE 5G?

- Massive MIMO (instead of conventional MIMO)
- Base Station Cooperation
- Multi-hop Relay
- All-over IP
- Adaptive Modulation and Coding
- Multi-Resolution Techniques
- OFDM and other block Transmission Techniques
- Carrier Agreggation
- Etc.
- All properly selected and criteriously combined.

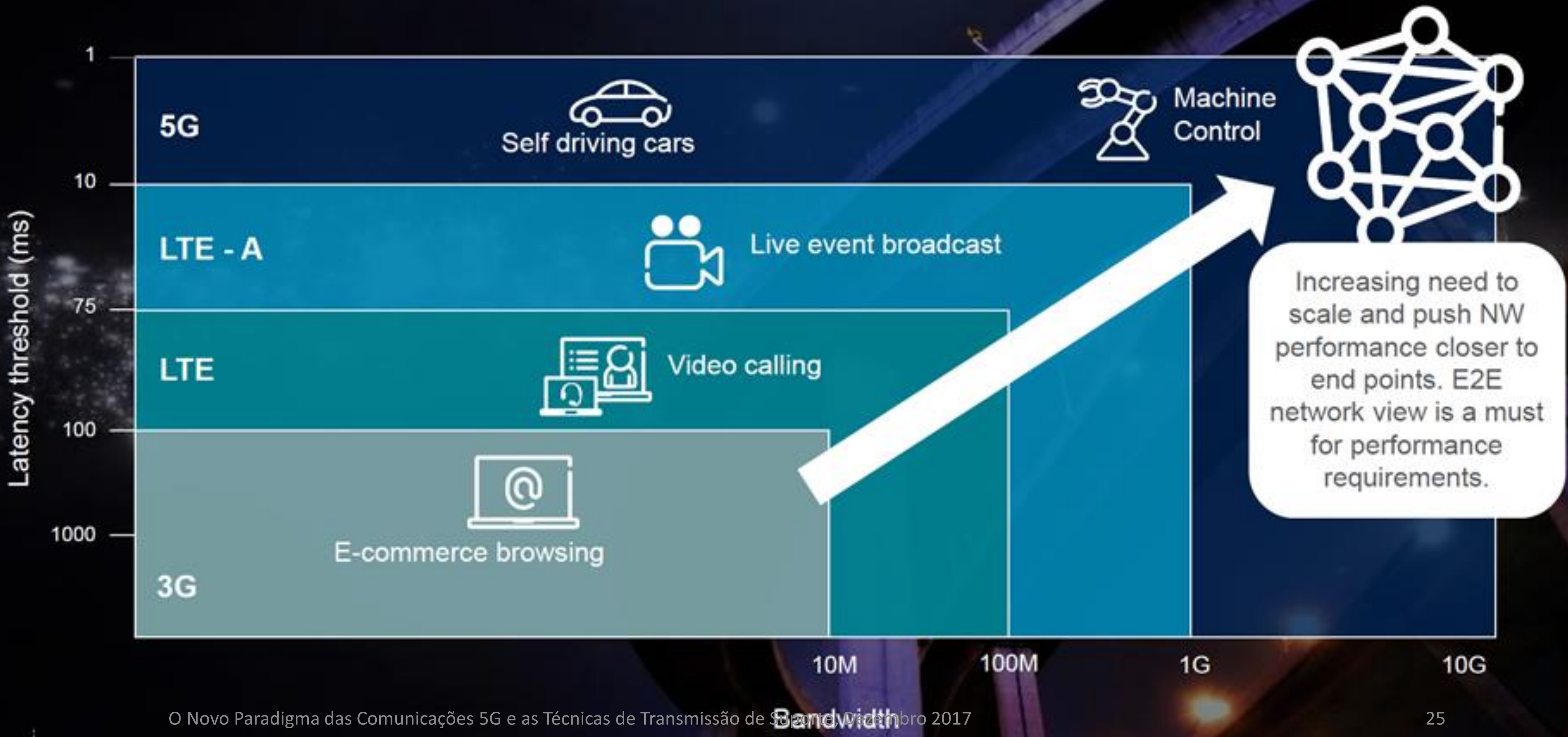
Massive MIMO

- Hundreds or Thousands of Tx and Rx Antennas
- Complexity grows exponentially => Signal Processing
- mm-Wave facilitates m-MIMO, as distance between antennas is reduced.

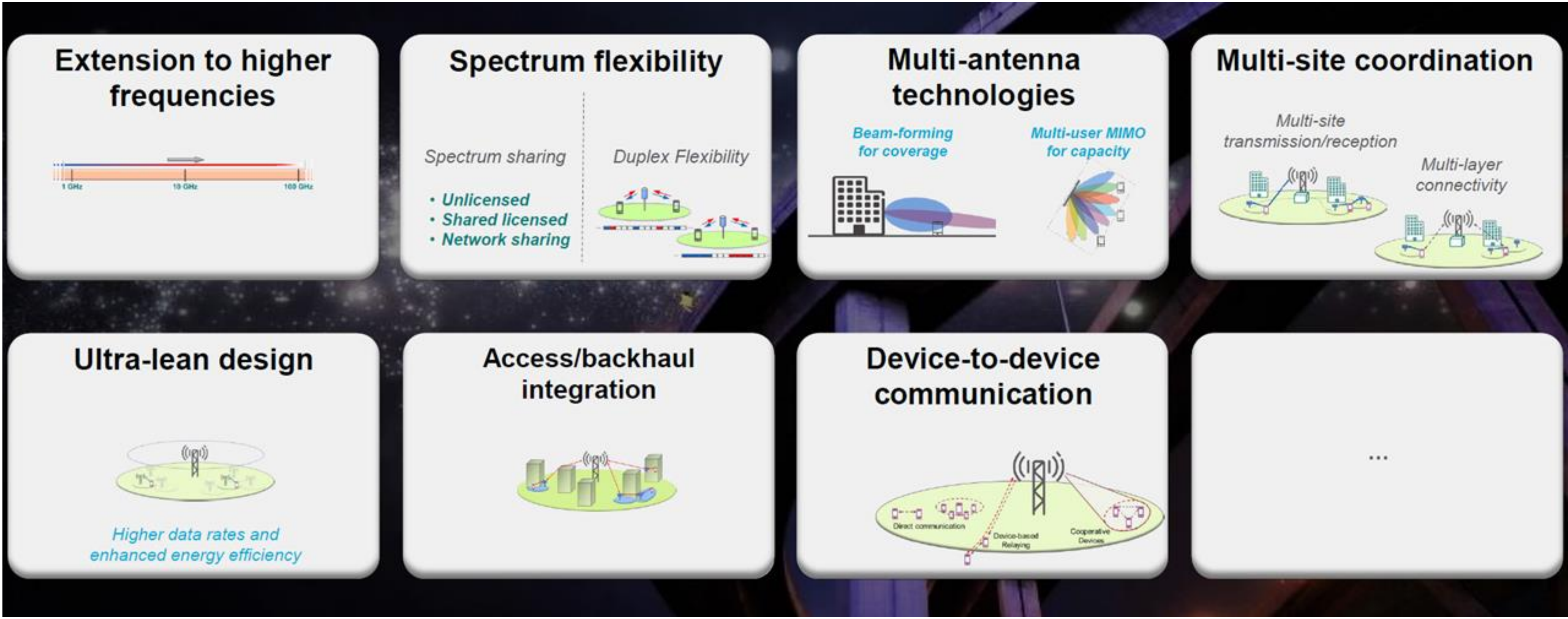
mm-Wave and Massive MIMO

- mm-Wave communications (30-300GHz - EHF) are expected to be a crucial part of 5G systems due to their increased channel coherence bandwidth, as compared to centimeter Wave. These systems use carrier frequencies of 30 - 70 GHz, where we have large unoccupied bandwidth.
  - Ex: IEEE802.11ad uses 2.16 GHz of BW in 60 GHz band (ISM band), supporting up to 7 Gbps.
- Moreover, the distance between antennas is reduced, facilitating a higher number of antennas elements (Massive MIMO)
- However, mm-Wave suffers from high path loss and rain and oxygen absorption.

LATENCY & BANDWIDTH



5G Key Elements – Transmission Techniques



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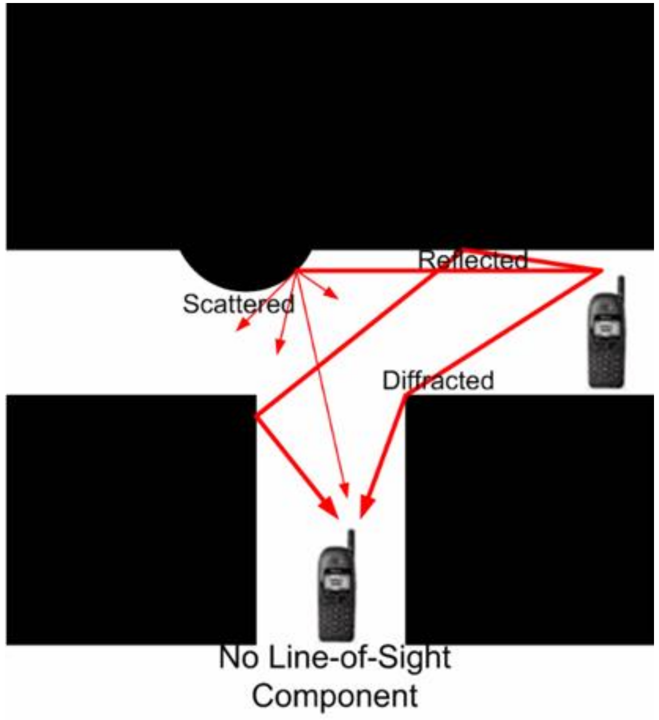
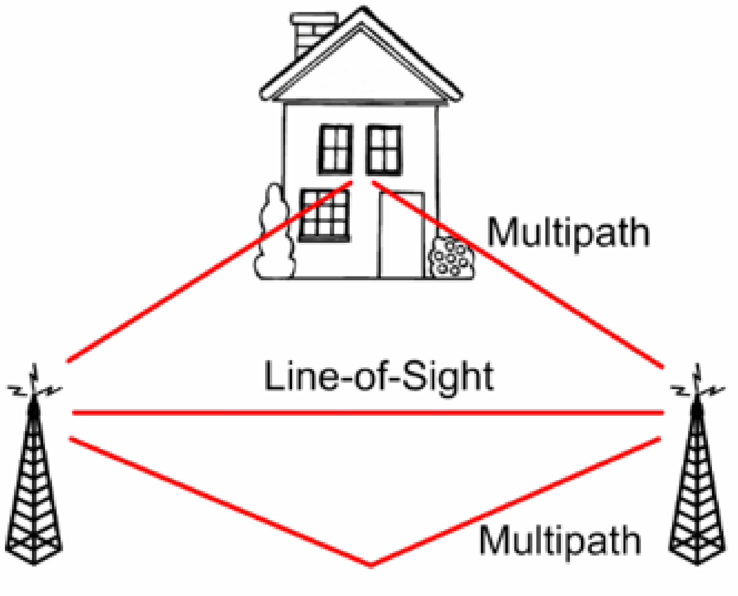
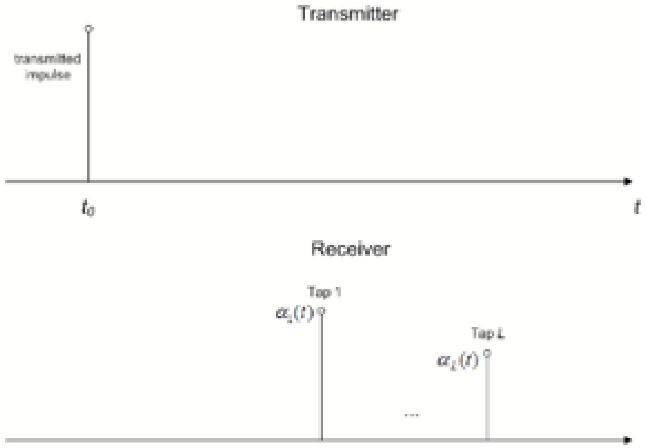
Multipath Interference
Intersymbol Interference



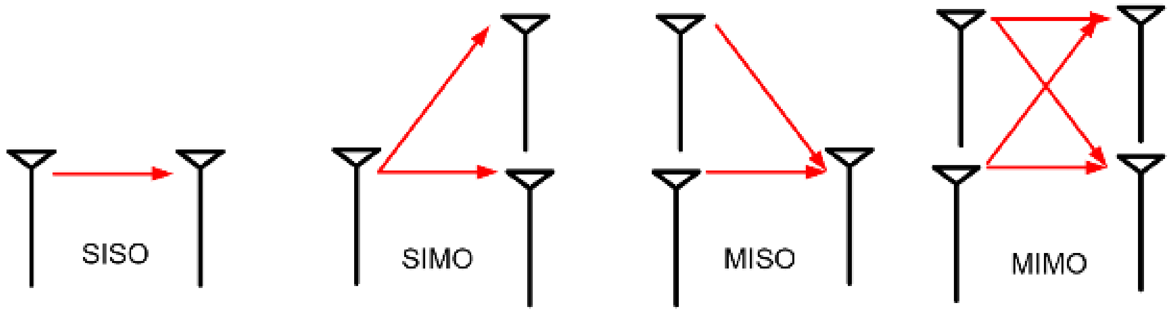




- **Higher Signal Bandwidth corresponds to higher Intersymbol Interference**
- **This is not only a matter of Spectrum**

MIMO Systems

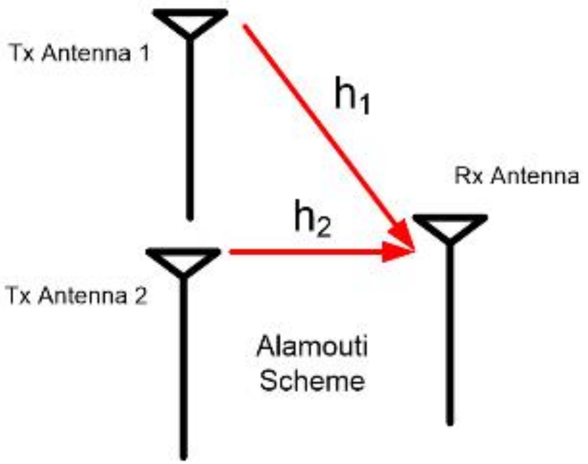
- The basic concept behind Multiple Input Multiple Output (MIMO) techniques relies on exploiting the multiple propagation paths of signals between multiple transmit (Input) and multiple receive (Output) antennas.
- In the case of frequency selective fading channel, different symbols suffer interference from each other, whose effect is usually known as Intersymbol Interference (ISI). This effect tends to increase with the increase of the symbol rate. MIMO systems can be employed to mitigate ISI. The antenna spacing must be larger than the coherence distance to ensure independent fading across different antennas.
- The various configurations are referred to as Single Input Single Output (SISO), Multiple Input Single Output (MISO), Single Input Multiple Output (SIMO) or Multiple Input Multiple Output (MIMO).
- MIMO architectures can be used for combined transmit and receive diversity (performance improvement), as well as for the parallel transmission of data or spatial multiplexing.
- MIMO schemes are implemented based on multiple-antenna techniques, which can be of different forms:
  - Space-time block coding
  - Multi-layer transmission
  - Space division multiple access
  - Beamforming



Multiple Antennas Configurations

Space-Time Coding

- Space-time block coding (STBC) is essentially a MISO system. Nevertheless, the use of receive diversity makes it a MIMO, which corresponds to the most common configuration for this type of diversity.
- STBC based schemes focus on achieving a performance improvement through the exploitation of additional diversity, while keeping the symbol rate unchanged.
  - Open loop transmit diversity schemes achieve diversity without previous knowledge of the Channel State Information (CSI) at the transmitter side.
  - On the contrary, closed loop transmit diversity requires knowledge about the CSI at the transmitter side.
- Space-time block coding, also known as Alamouti scheme, is the most known open loop technique.
- With STBC, symbols are transmitted using an orthogonal block structure, enabling simple decoding algorithm at the receiver.



$$\begin{array}{c|cc} & \multicolumn{2}{c}{\text{time} \rightarrow} \\ \hline \text{space (antenna)} \downarrow & a_1 & a_2 \\ & -a_2^* & a_1^* \end{array}$$

$$\tilde{A}_1 = \left[Y_1 H^{(1)*} + Y_2^* H^{(2)} \right] \beta$$

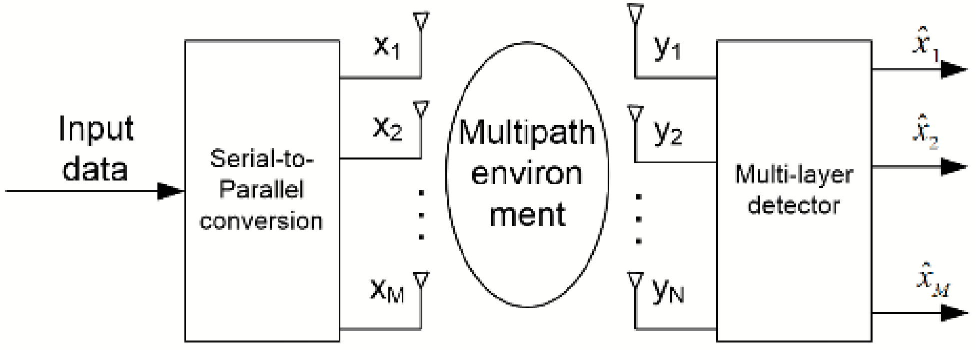
$$\tilde{A}_2 = \left[Y_2 H^{(1)*} - Y_1^* H^{(2)} \right] \beta$$

$$\beta = \left[\sum_{m=1}^{2} \left| H_l^{(m)} \right|^2 \right]^{-1}$$

$$\tilde{A}_{2l-j} = \overbrace{A_{2l-j} \sum_{m=1}^{M} \left| H_l^{(m)} \right|^2 \beta}^{\text{Desired Symbol}} + \overbrace{N_{2l-j}^{eq}}^{\text{Noise Component}} \qquad j = 0,1$$

Multi-Layer Transmission

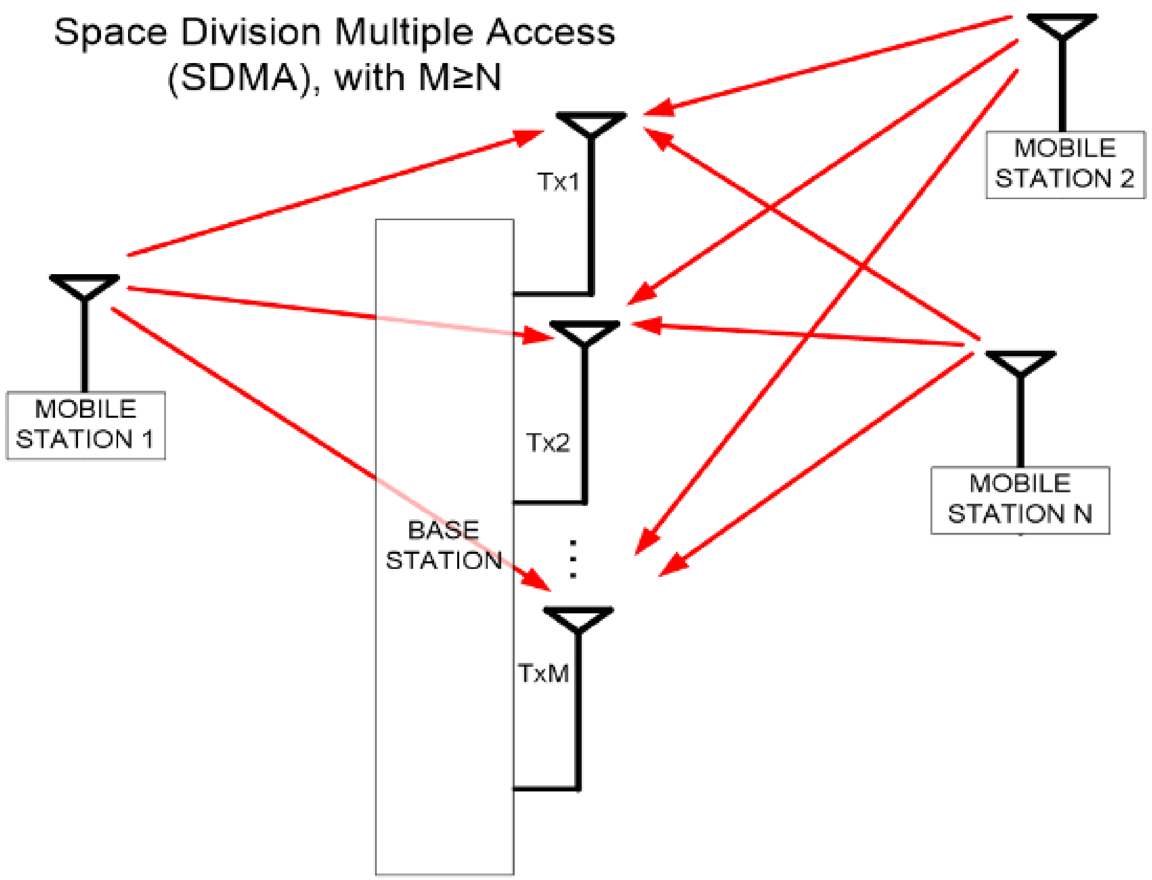
- The goal of multi-layer MIMO relies on achieving higher data rates, in a given bandwidth, whose increase rate corresponds to the number of transmit antennas.
- The symbols stream is split in a serial to parallel converter into the several transmit antennas, and each transmit antenna sends a lower symbol rate.
- The reconstruction of the original symbol stream is made at the receiver side, typically using the nulling algorithm.
  - This requires that the number of receive antennas must be equal to or higher than the number of transmit antennas.
- The increase of symbols rate is achieved by "steering" the receive antennas to each one of the transmit antennas, in order to receive the corresponding data stream.
- Detector employed in Multi-Layer MIMO:
  - Linear Detectors: decorrelator and MMSE
  - Sub-optimal Detectors: SIC or V-BLAST (SIC with the decorrelator or with the MMSE)
  - Optimal Detector: MLSE



Generic diagram of the $M \times N$ multi-layer MIMO scheme

SDMA

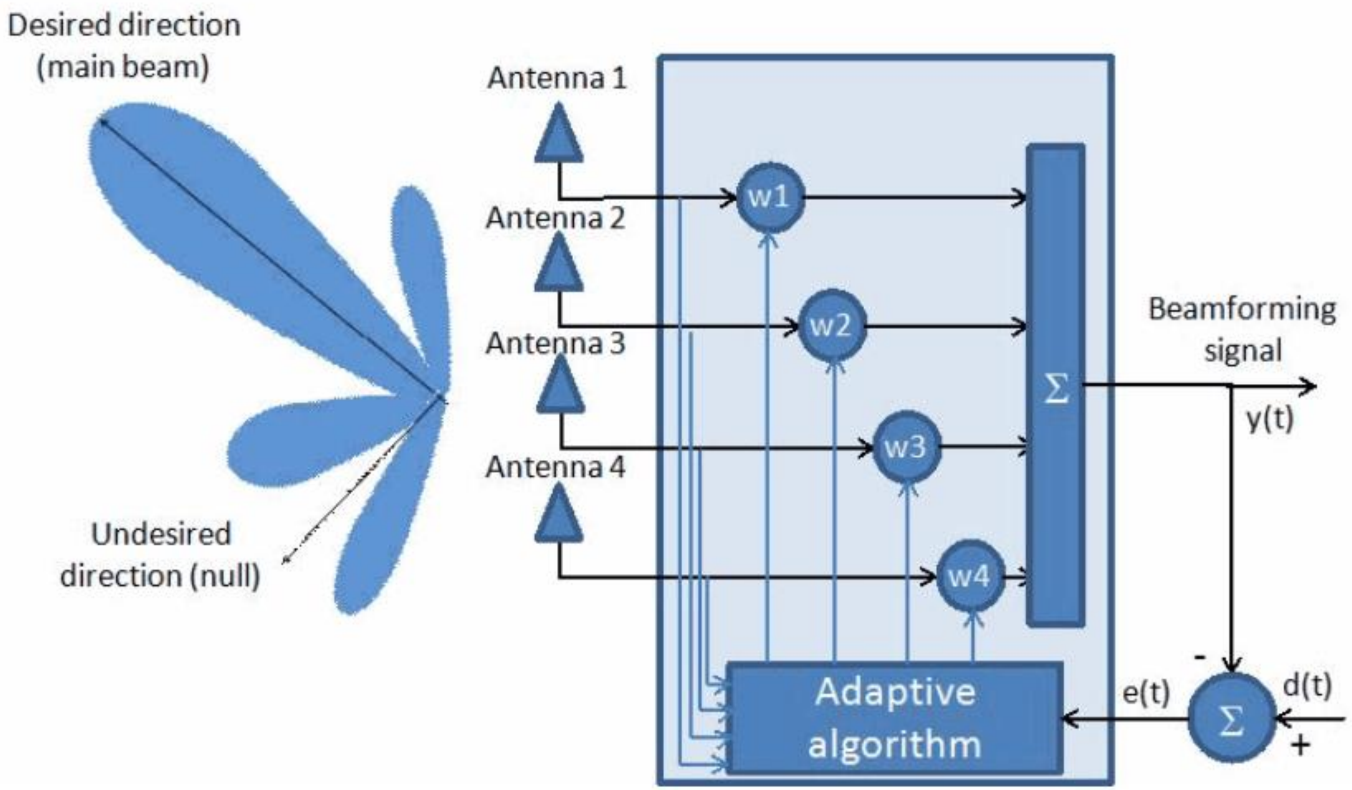
- Space Division Multiple Access (SDMA) relies on improving the capacity (more users per cell), while keeping the spectrum allocation unchanged.
  - SDMA is a technique that allows multiple users exploiting spatial diversity as a multiple access technique, while using the same spectrum.
- Both SDMA and multi-layer transmission belong to the same group, entitled spatial multiplexing.
  - Nevertheless, while in multi-layer transmission an increase of the symbol rate is achieved by considering multiple antennas at the transmitter side, using the SDMA, it is assumed that each transmitter has a single antenna, and the multiple number of receive antennas allow steering the different flows of data corresponding to different users.
  - SDMA is commonly employed in the uplink, where the transmitter (UE) has a single antenna, whereas the receiver (BS) has several antennas.



Example of SDMA scheme applied to the uplink

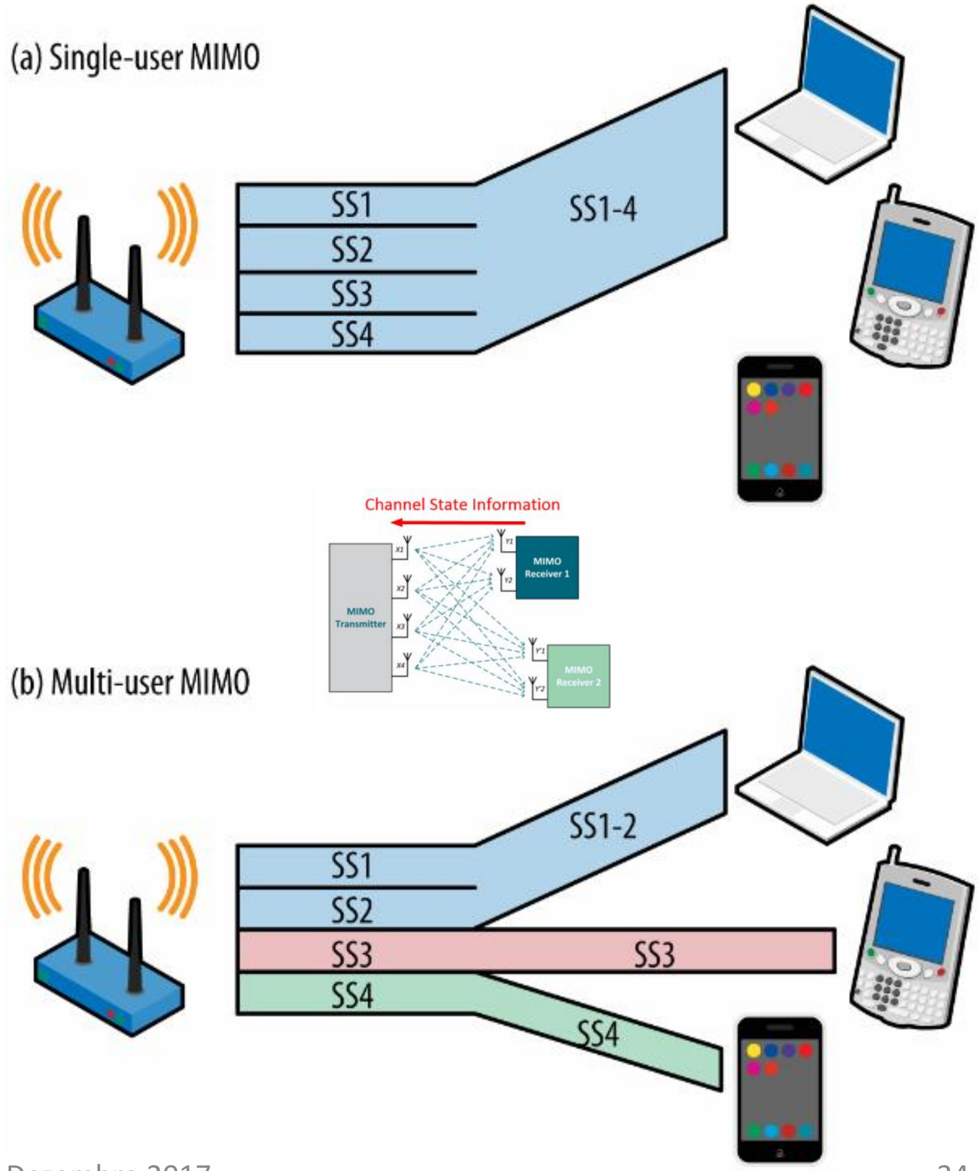
Beamforming

- In space-time block coding and spatial multiplexing MIMO schemes, the antenna elements that form an array are usually widely separated in order to form a transmit diversity array with low correlation among them.
- On the other hand, the beamforming is implemented by antenna array with array elements at the transmitter or receiver being closely located to form a beam.
- The beam is generated with the Uniform Linear antenna Array (ULA).
- The ULA antenna elements spacing is typically half wavelength.
- Beamforming is an effective solution to maximize the SNR, as it steers the transmit (or receive) beam towards the receive (or transmit) antenna.



Multi-User MIMO

- Previous MIMO techniques are single-user MIMO (SU-MIMO). This considers data being transmitted from a single user into another individual user.
- Contrarily, multi-user MIMO (MU-MIMO) sends, simultaneously, multiple streams of data into different users, using the same frequency bands.
- The approach behind MU-MIMO is similar to SDMA. Nevertheless, while SDMA is typically employed in the uplink, the MU-MIMO is widely implemented in the downlink.
- This allows sending different data streams into multiple UE. In this case, instead of performing the nulling algorithm at the receiver side, the nulling algorithm needs to be performed using a pre-processing approach at the transmitter side (BS).
- In MU-MIMO, the number of Tx antennas must be equal to or higher than then number of users.



Outline

- Evolução das Comunicações Celulares
- As Comunicações 5G, suas diferenças
- Técnicas de Transmissão de Suporte ao 5G
  - MIMO e Massive MIMO

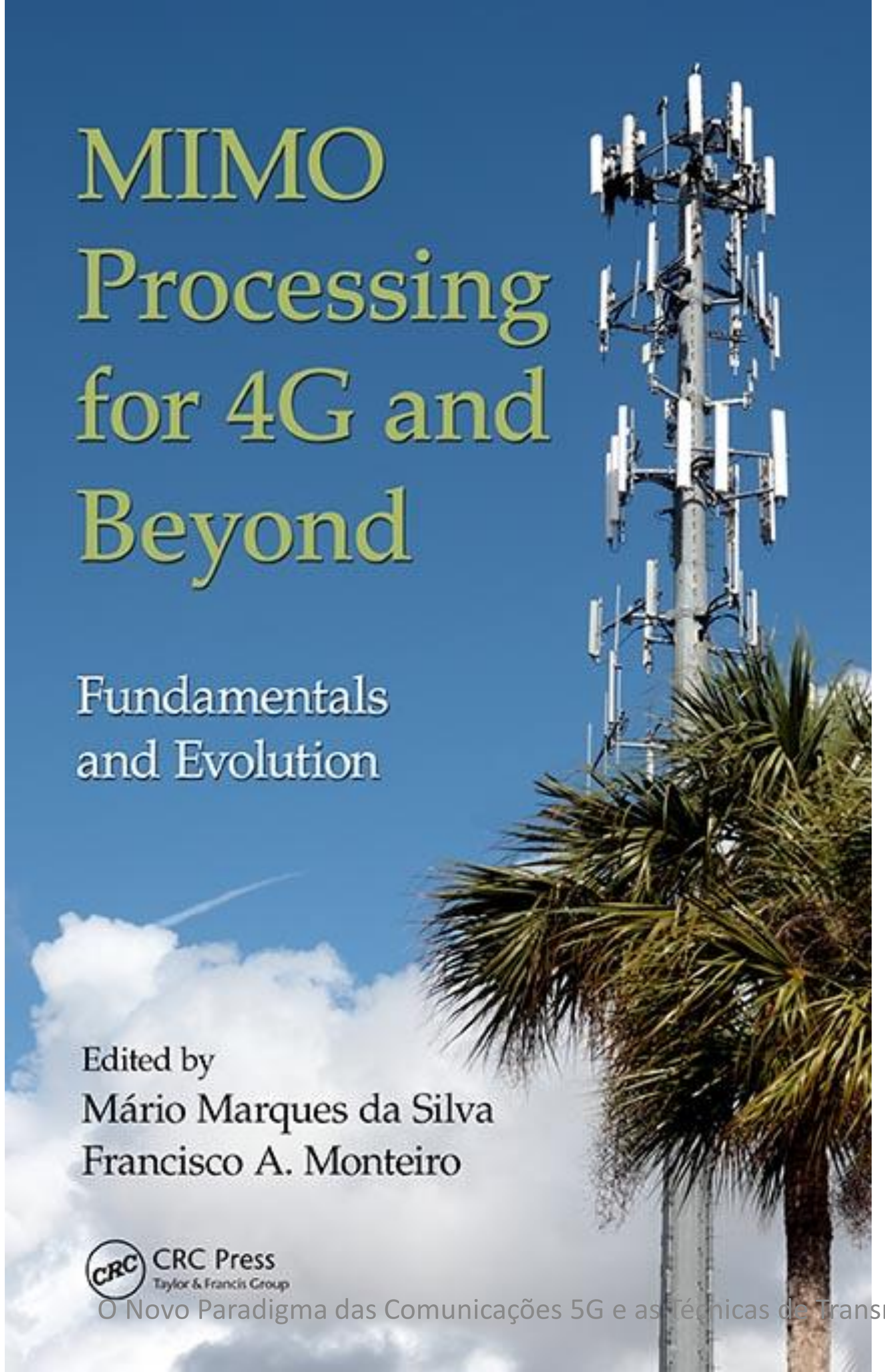
Conclusions

- As Comunicações 5G são esperadas a partir de 2020, com algumas inovações sobre 4G:
  - Ritmos de transmissão 10 vezes superiores (10 Gb/s acesso nomádico)
  - Atrasos 10 vezes inferiores (0,5-1 ms)
  - Comunicações diretas terminal-terminal (tal como o TETRA, p.e.), suportando Internet of Things, Realidade Virtual e Condução Autónoma

- Suportado em Massive-MIMO.
- Incorporação de ondas milimétricas (que têm maior largura de banda) e que facilitam a implementação do Massive-MIMO **(em Investigação)**.
- Outras técnicas, como Base-Station Cooperation, Multi-Hop Relay, Multi-Resolution Techniques, Técnicas de Transmissão por Blocos (e.g., OFDM), Carrier Agreggation, AMC, etc., também contribuem para suportar estas maiores velocidades **(em Investigação)**.

- Aumentos de ritmos de transmissão resultam da conjugação optimizada de multiplas técnicas de transmissão.

Obrigado


MIMO Processing for 4G and Beyond
Fundamentals and Evolution
Edited by
Mário Marques da Silva
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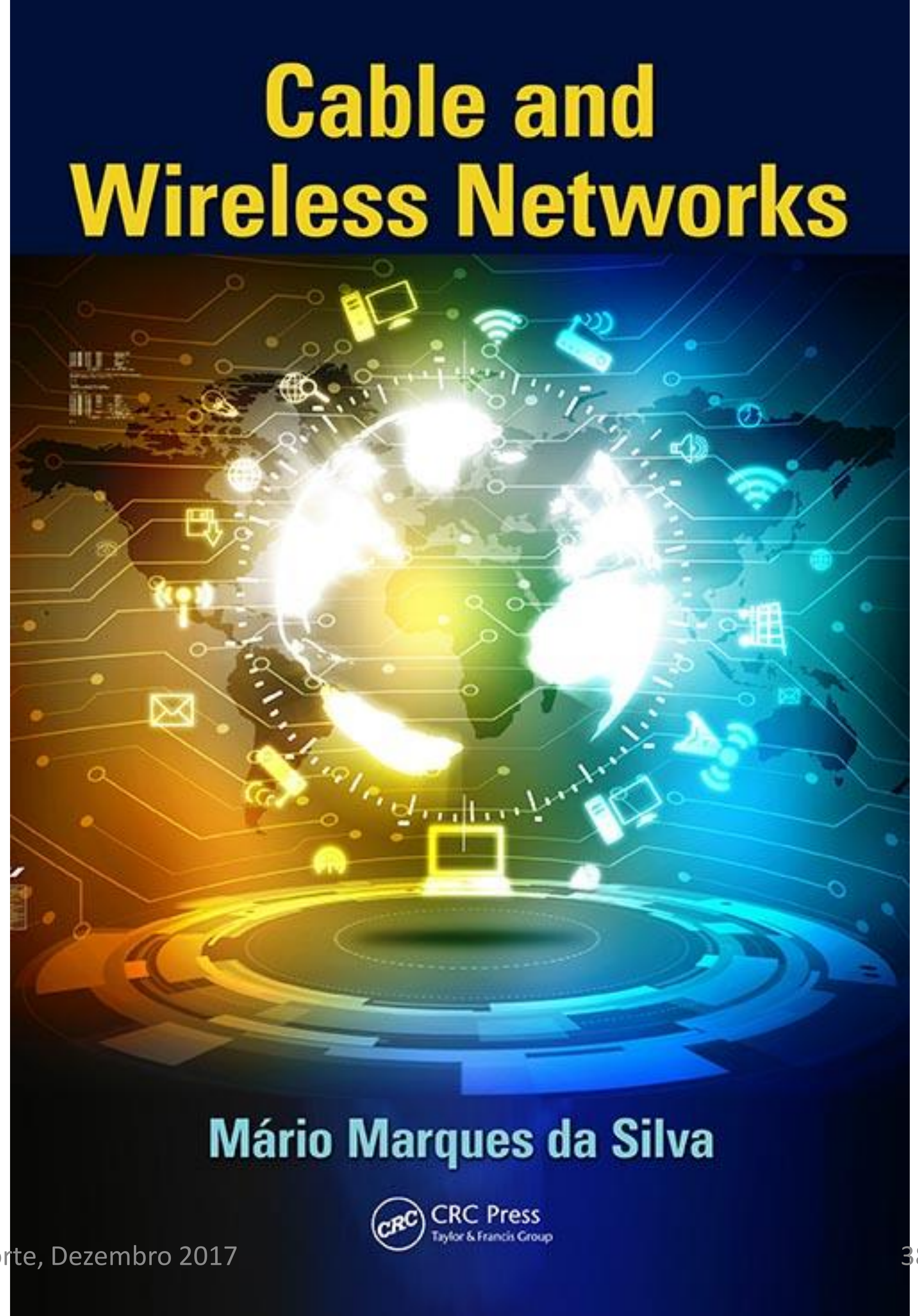
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