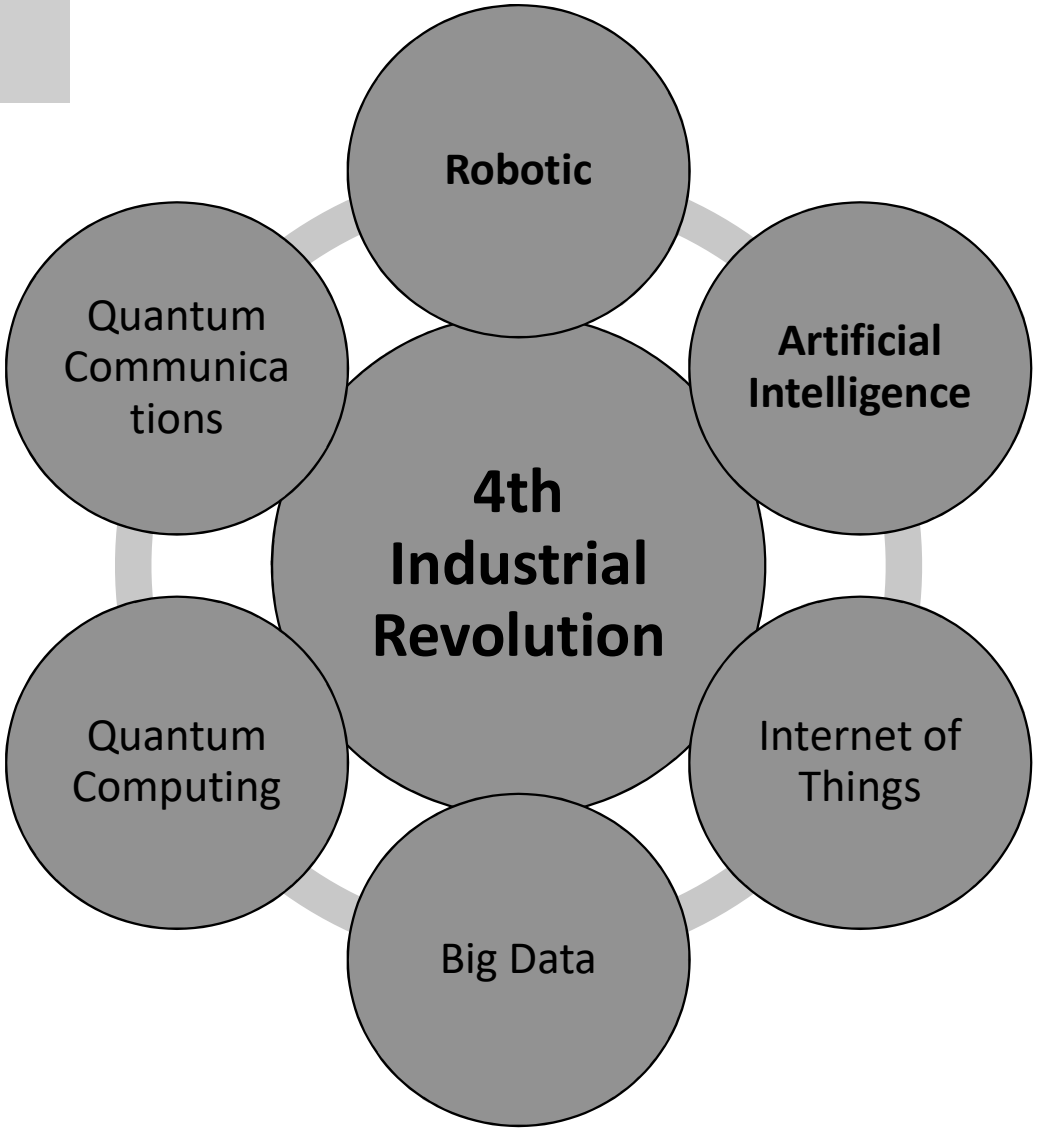
Prof. Doutor Mário Marques da Silva

Prof. Doutor João Guerreiro

Introduction Industry 4.0

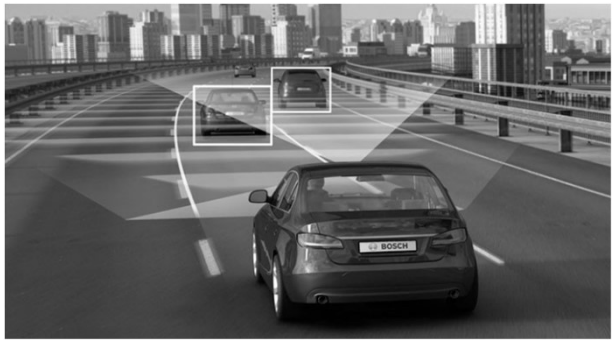


Introduction – The 4th Industrial Revolution

- 5G Cellular Communications (2019/2020)
  - Relates to **Internet of Things** and will support **hiperconnectivity**, generating data **20 times faster** (20 Gb/s) than with 4G, and with a latency 20 times lower. Will support **point-to-point communications (IoT)**, instead of only through a Base Station.

- Big Data
  - Consists of **massive quantity of data**, structured or non-structured, that requires **processing with Artificial Intelligence** to generate **Knowledge**.

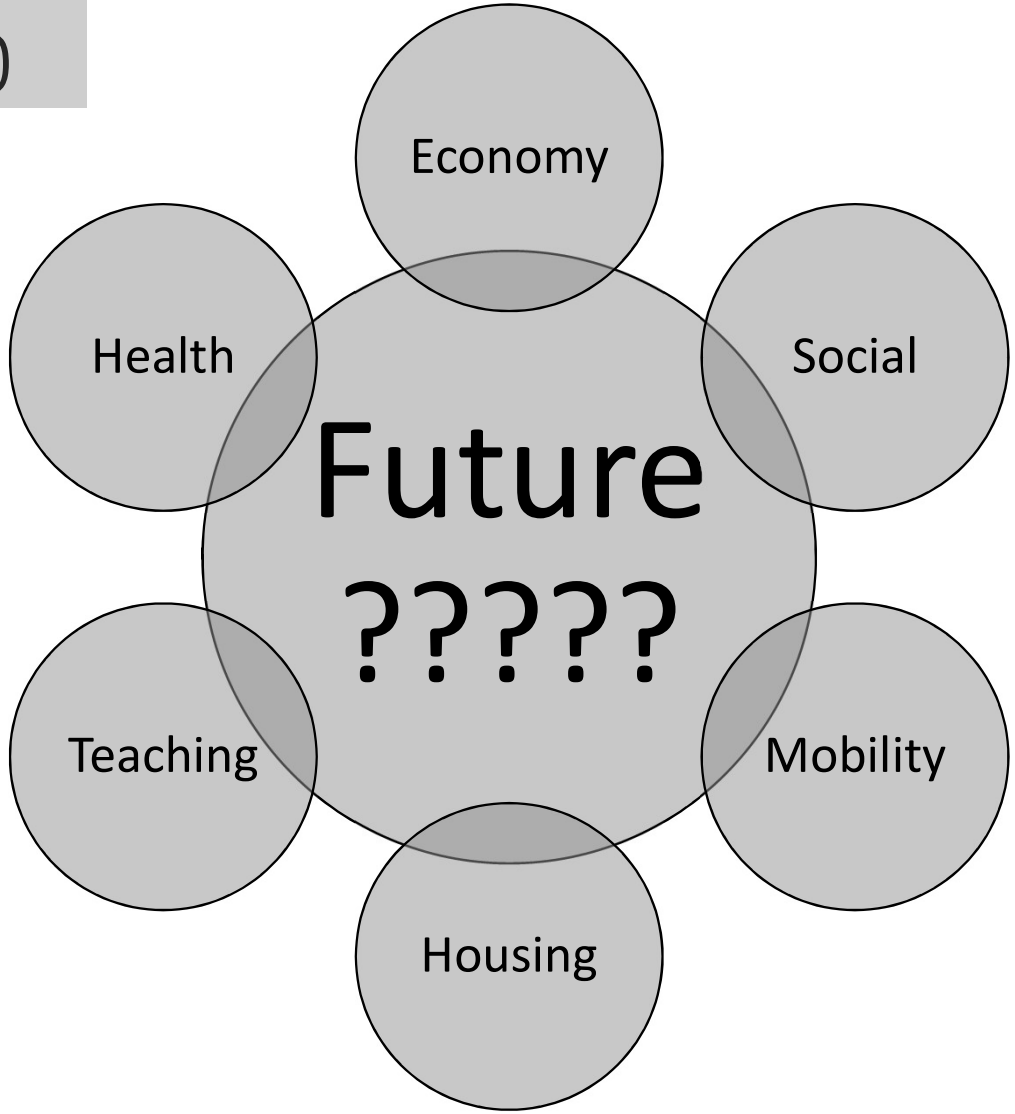
- Robotic and Artificial Intelligence
  - A Robot is used to accomplish a certain task, but requires intelligence → **4th Industrial Revolution**



Introduction – The 4th Industrial Revolution

- Quantum Computing & Communications
  - Moore's Law is not being followed: The speed of microprocessors duplicates every 2 years.
  - Gilder's Law is not being followed: "the total bandwidth of communication systems triples every twelve months".
  - Quantum Computing & Communications relates with the principles of Quantum Mechanics:
    - "Entaiglement"
    - Quantum Duality

Introduction Industry 4.0



Introduction Industry 4.0

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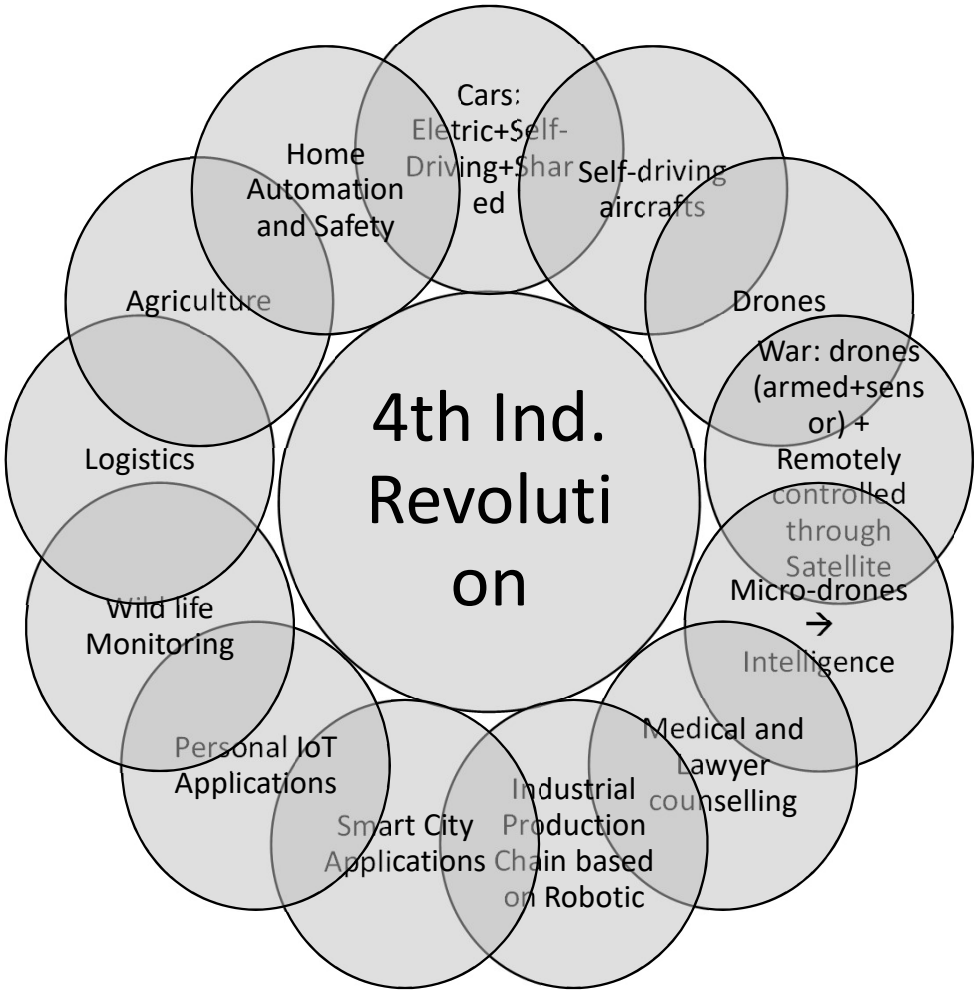

Tecnologia dá resposta a questões como **educação, investigação científica** (feita por computadores), **indústrias, alimentação, mobilidade (veículos elétricos, autónomos e partilhados), smart cities, habitação/casas inteligentes, defesa, ou gestão de recursos**.

Consequências da 4ª Revolução Industrial

Emprego: trabalhar menos horas com mais qualidade e mais competências. Algumas profissões serão substituídas por máquinas (trabalhos rotineiros ou mesmo de aconselhamento, como jurídico ou médico [inteligência artificial: Watson da IBM]).

Eficiência vs Liberdade: acesso a informação: cartões bancários, telemóveis, os ISPs, via verde, passes sociais, redes sociais, Google, Apple, etc.; câmaras de videovigilância (cidade Chinesa)

Eficiência vs desumanização das Relações: estão as pessoas efetivamente mais próximas? Um processo que era gerido com 3 cartas é agora gerido com muitas dezenas de mails, com informação pouco estruturada. **Alguns de nós tornam-se escravos da tecnologia, em vez desta ser facilitadora. Sempre em multi-contacto com pormenores, mas as relações humanas reais perdem-se, crianças viciadas em jogos que não intereagem [ex: fortnite --- qual será o futuro destas crianças???], acesso a muita informação, mas sempre de forma superficial, etc.**

Diminuição das Desigualdades: Smart Phones a 10 USD estão a chegar aos países mais pobres do mundo, eliminando as assimetrias. Massificação das tecnologias e da informação…

Introduction – The 4th Industrial Revolution

- Self-Driving Cars
  - **In the Future (15 years) Mobility will be with cars: 1) Electric; 2) Self-Driving; 3) Shared.**
- Self-driving Aircrafts
- Medical and Lawyer counselling
- Cirurgies with Robots
- Functional Drones and War
  - War with Drones, armed and with sensors, controlled through satellite, remotely operated from other parts of the globe
  - Micro-drones → Intelligence
- Industrial Production Chain based on Robotic
- Automatic Translation
- Facial Reconnaissance
- Intelligent Houses (including vacuum machines, etc.)
- Personalized marketing in the Internet
- **The shape of the Robot is not an issue. The future of Robot comprises a shape adapted to its functionality. Ex: Self-Driving Car.**

Aplicações da Robótica / Inteligência Artificial

- Implicações Sociais:
  - Existem receios de que a 4ª Revolução Industrial traga Desemprego
  - Semelhante antecipação ocorreu com as anteriores Revoluções Industriais, nomeadamente com a 3ª (Revolução da Informação -> Tecnologias de Informação e Comunicação)
  - Na realidade, parece-me que os receios que se anteveem funcionarão para aqueles que não se preparam para o "novo paradigma", i.e., **desaparecerão alguns empregos e aparecerão outros**.
  - Implicará que estejamos **atentos** e nos **adaptemos**. Para aqueles que não se adaptam à nova realidade, existirão **consequências laborais, e sociais**.
  - Mas BIG BROTHER (hoje já somos controlados com telemóveis, cartões de crédito, passes sociais, via verde, **Google**, Facebook, Instagram, iPhone, etc.): câmaras espalhadas pelo território, com reconhecimento facial, podem saber tudo sobre nós (com histórico), mas também localizar criminosos em poucos minutos. Cidade Chinesa já oferece sistema de recompensa por pontos, pela cidadania, que é monitorizada e avaliada pelas câmaras associadas a IA → eficiência vs liberdade / proteção dos dados pessoais
- Implicações Económicas:
  - Existirão ganhos de eficiência para as pessoas e organizações (como empresas), tal como com as anteriores Revoluções Industriais (razão para a sua implementação). No entanto, tal como na área social, implica uma readaptação ao novo Paradigma. A forma concreta de posicionamento da organização face à 4ª Revolução Industrial depende do tipo de empresa…..
- Implicações Jurídicas:
  - A lei vai atrás da tecnologia, com algum atraso e com muitas lacunas.
  - E a IA substituirá o aconselhamento jurídico.

A Humanidade Tecnológica

- 3ª Revolução Industrial versus 4ª…
- A 4ª Revolução Industrial trará alterações de paradigma para a humanidade, através de desenvolvimentos na Robótica, Inteligência Artificial, Internet das Coisas, Big data, Computação e Comunicações Quânticas, entre outras.
- A tecnologia tem servido para desenvolver tarefas de forma mais eficiente, para substituir o homem em tarefas rotineiras ou para desenvolver tarefas inovadoras.
- Tecnologia dá resposta a questões como **educação, investigação científica** (feita por computadores), **indústrias, alimentação, mobilidade (veículos elétricos, autónomos e partilhados), smart cities, habitação/casas inteligentes, defesa, ou gestão de recursos**.
- Mas a **escrita manual** e a **tabuada mental** estão a perder-se e a **dislexia** está a aumentar --- tudo isto com **implicações no cérebro humano**.
- Quais as ameaças e oportunidades?
- Tem o homem hoje mais tempo disponível do que tinha antes? Tem melhor qualidade de vida? É a sociedade mais justa, equilibrada e eficiente?
- Estamos a aproximarmo-nos da sabedoria de Salomão?
- Está o homem mais feliz ou a tornar-se escravo das tecnologias? Depende de cada um de nós…
- Funciona a tecnologia como facilitadora das vontades humanas, da sociedade e do mundo, facilitando o amor, a compreensão, a alegria ou o conforto?
- As tecnologias são ferramentas, facilitando a forma de comunicar. As motivações de Maslow mantêm-se…
- Em termos futuros, receamos os robôs superinteligentes, mas trabalhamos arduamente para os construir.

A Humanidade Tecnológica

- Qual o futuro para a humanidade em consequência da robotização?
  - **Emprego:** trabalhar menos horas com mais qualidade e mais competências. Algumas profissões serão substituídas por máquinas (trabalhos rotineiros ou mesmo de aconselhamento, como jurídico ou médico [inteligência artificial: Watson da IBM]).
  - **Eficiência vs Liberdade** (acesso a informação: cartões bancários, telemóveis, os ISPs, via verde, passes sociais, redes sociais, Google, Apple, etc.; câmaras de videovigilância – Exemplo da cidade Chinesa)
  - **Eficiência vs desumanização das Relações**: estão as pessoas efetivamente mais próximas? Um processo que era gerido com 3 cartas é agora gerido com muitas dezenas de mails, com informação pouco estruturada. **Alguns de nós tornam-se escravos da tecnologia, em vez desta ser facilitadora. Sempre em multi-contacto com pormenores, mas as relações humanas reais perdem-se, crianças viciadas em jogos que não intereagem [ex: fortnite --- qual será o futuro destas crianças???], acesso a muita informação, mas sempre de forma superficial, etc.**
  - **Diminuição das Desigualdades:** Smart Phones a 10 USD estão a chegar aos países mais pobres do mundo, eliminando as assimetrias. Massificação das tecnologias e da informação…
- A tecnologia torna muita gente escrava das máquinas, mas por outro, combate a pobreza, a doença e a ignorância.
- Qual o futuro da humanidade tecnológica? Dentro de cada ser humano há bondade e maldade, luz e trevas, paz e guerra.
- Mas o resultado final depende da forma como é utilizada, que pode ser para o bem ou para o mal ---» Chefe Índio… porque há homens bons e maus? Todos temos o bem e o mal dentro de nós. Qual ganha? Aquele que tu alimentares. É o livre arbítrio.
- Existem guerras entre os povos, entre as pessoas e no interior de cada um.
- O futuro da tecnologia depende dos homens e da sociedade (bem sobre o mal)… e de uma visão de Longo Prazo, em detrimento de curto prazo (plantar as sementes para os nossos netos).
- Necessário Regulação e Regulamentação, mas também uma atitude colaborativa, em vez de meramente competitiva.
- Tal como a bomba atómica, a tecnologia errada nas mãos erradas pode ser altamente destrutiva. Com a diferença que a tecnologia tende a ser mais fácil de desenvolver do que a bomba atómica (tratado de não proliferação de armas nucleares).
- A melhor invenção de todos os tempos foi o "Ser Humano" e todas as espécies. E são estas que têm que ser preservadas e potenciadas.

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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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.

- 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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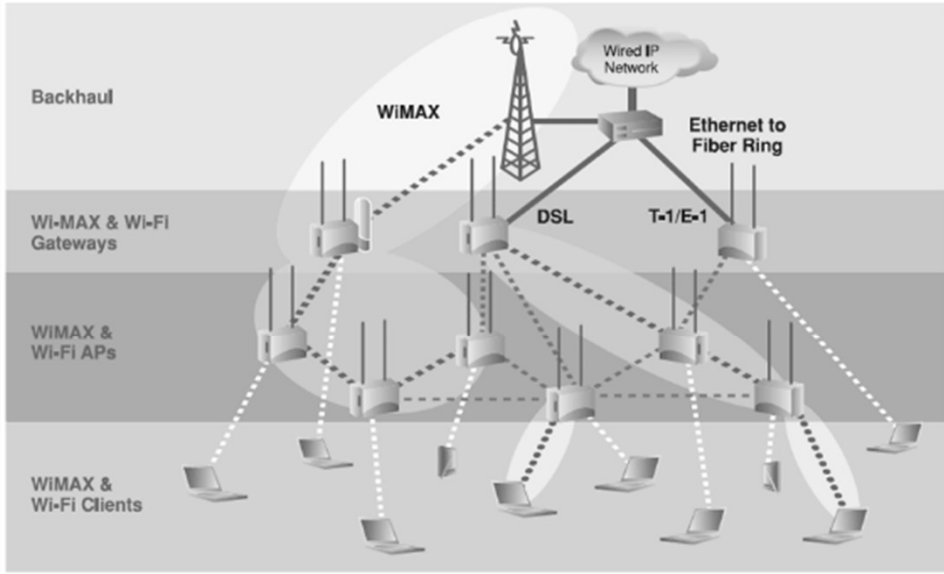
IEEE 802.16 Protocol (WiMAX)

- 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:
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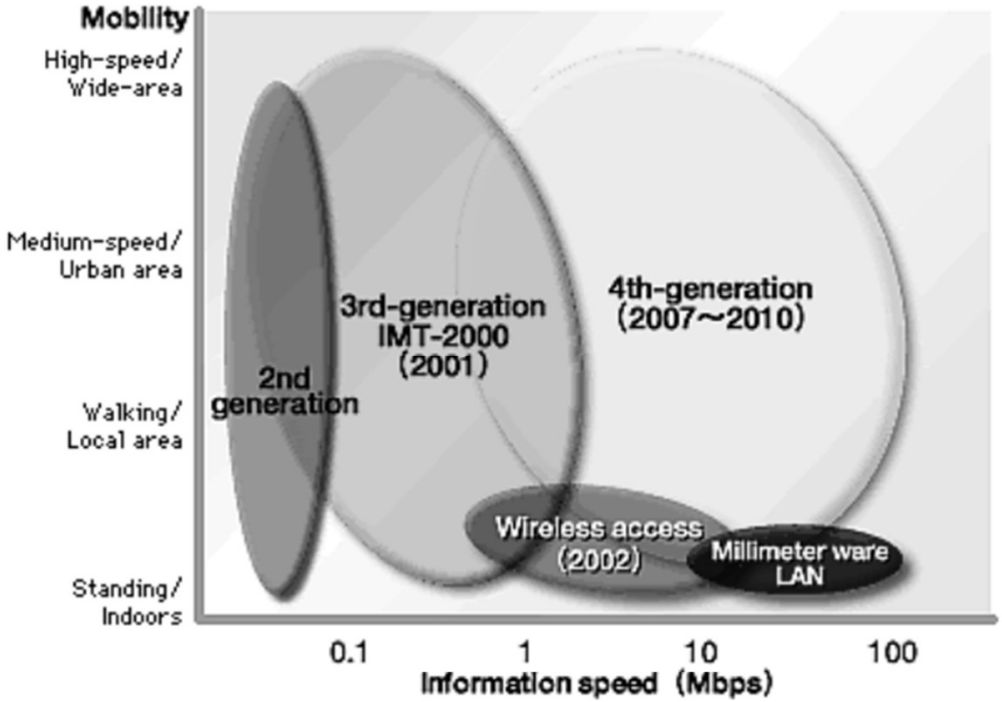

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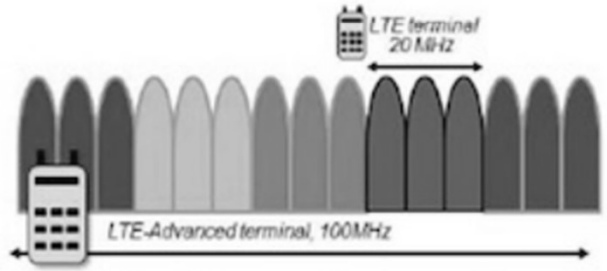
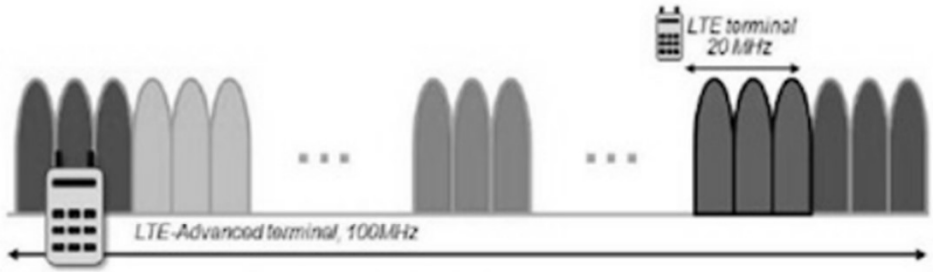


(a) Contiguous carrier aggregation



(b) Non-contiguous carrier aggregation

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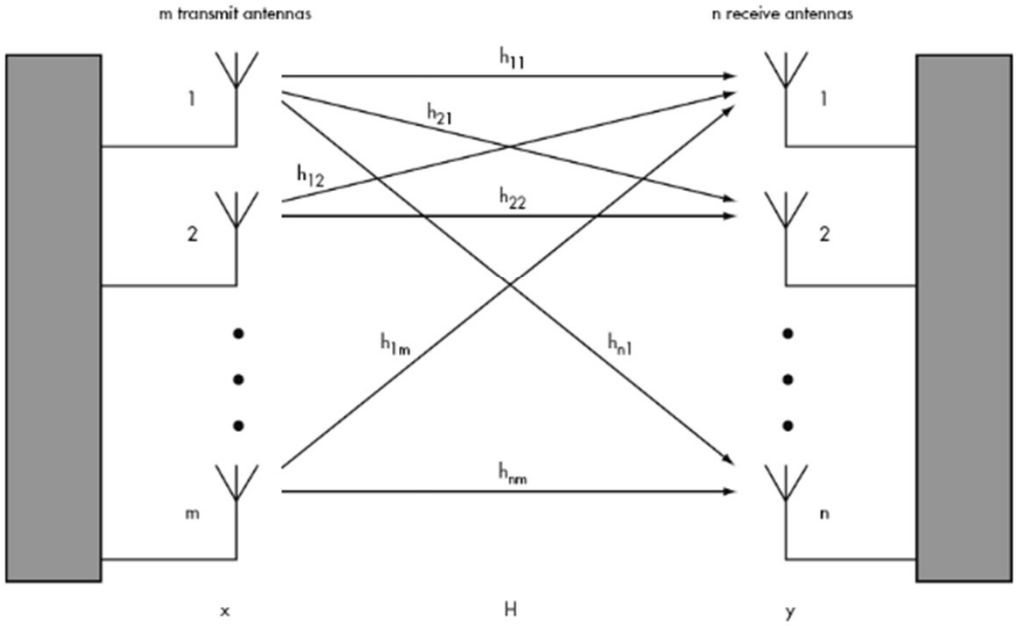

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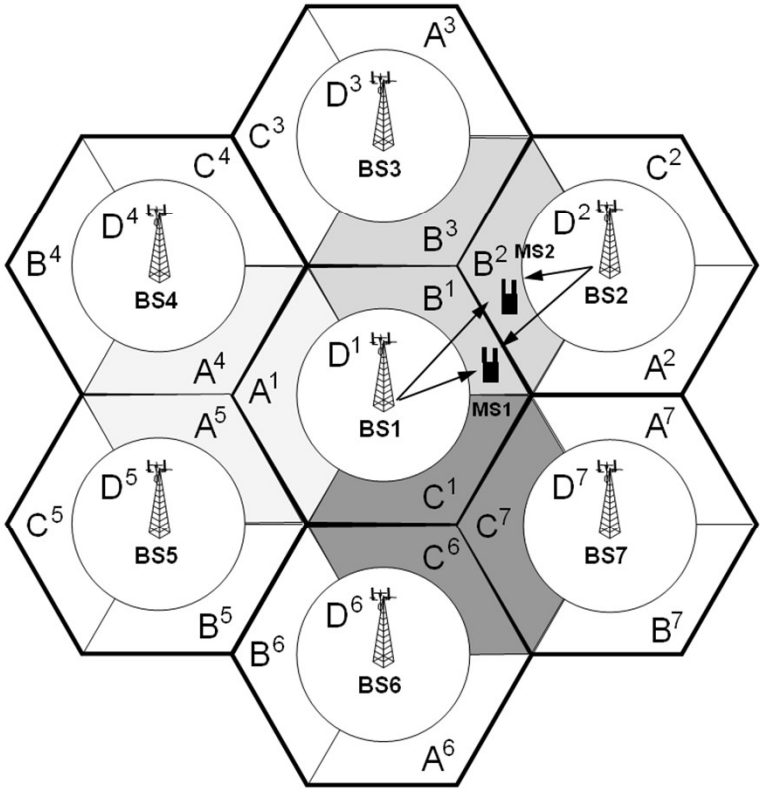
Base Station Cooperation

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



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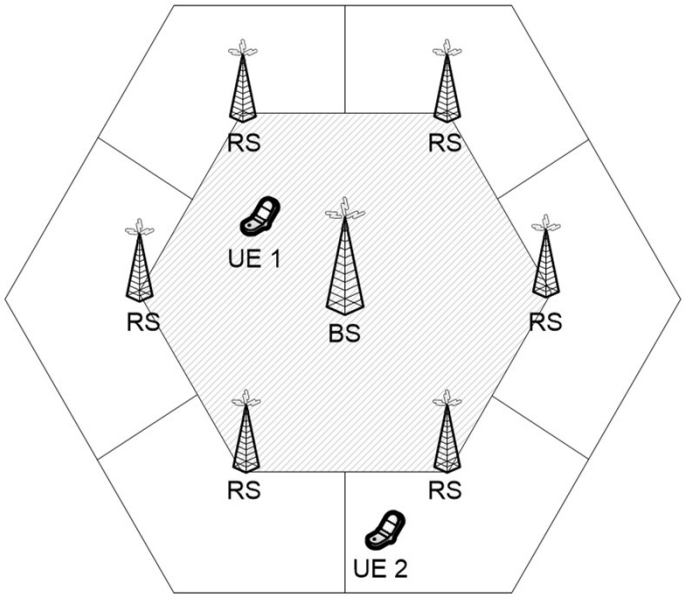
Multi-Hop Relay

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



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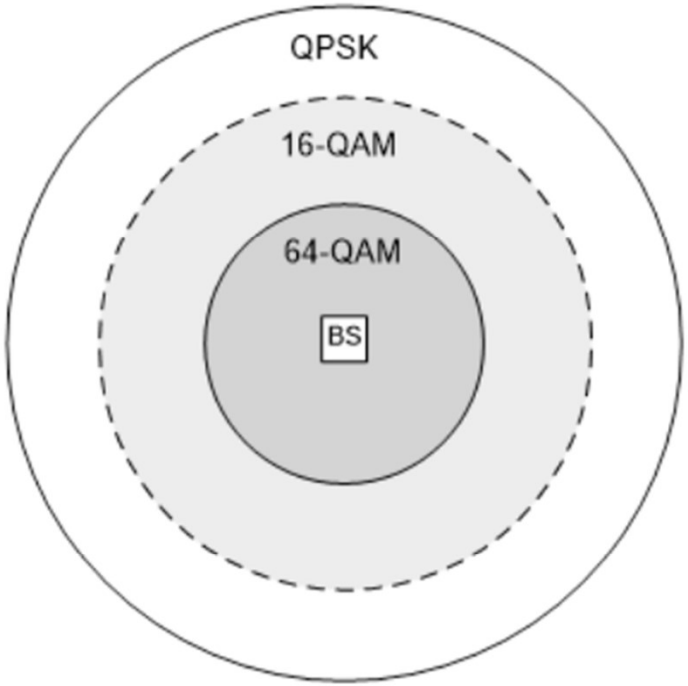
  - Advanced Base Station Cooperation (ex: Macro Diversity).
  - Multi-resolution Techniques (ex: hierarchical constellations, MIMO).
- LTE-Advanced was ratified by the ITU as an IMT-Advanced.



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

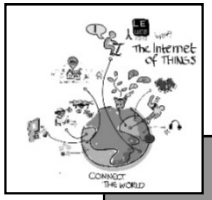
Introduction: 5G Communications

5G systems (2019/20) are aimed to achieve [as compared to 4G]:

- Higher throughputs (1-20 Gbps)
- Lower Latency (0,5-1 ms)
- Higher Capacity
- Better Spectral Efficiency

3GPP Release 15 and 16 (from ETSI):

- Covers: 1-Radio Access Network; 2-Services and Systems Aspects; 3-Core Network and Terminals
- ITU-T is expected to standardize 3GPP Release 15/16 (5G) as IMT-2020

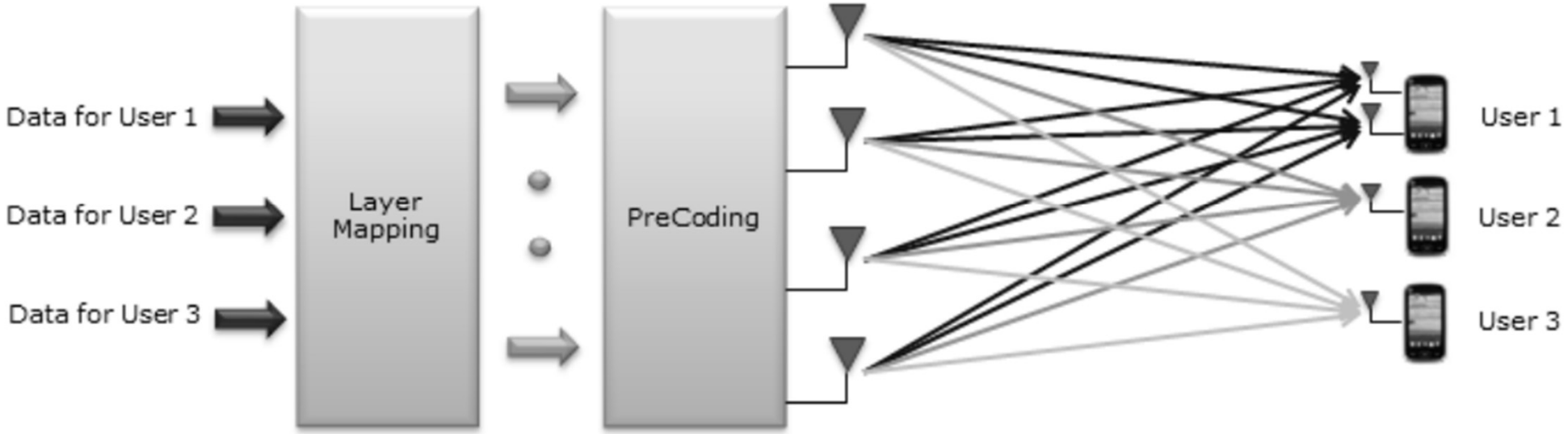


Support of new and Emergent Services:

- **VTC on the Move**
- Real-Time Communications
- Augmented Reality
- **Support of Self-Driving Cars**
- **Machine-to-machine communications** (IoT and Security Apps) – in addition to infrastructure centralized architecture

Massive MIMO schemes involving several hundreds or even thousands of antenna elements are expected to be central technologies for 5G systems

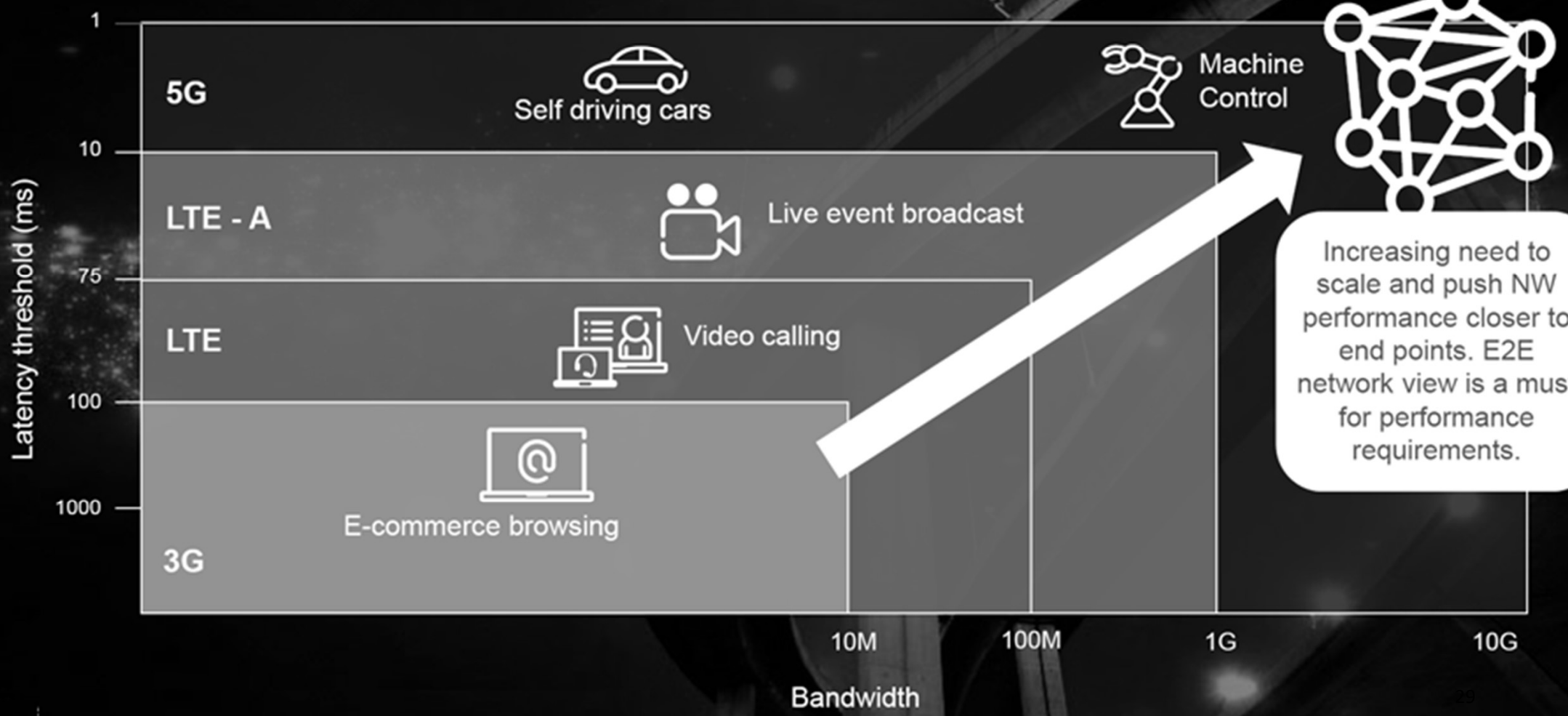
Introduction: 5G Communications



New Paradigm of 5G

- Support of new and emerging services
- Increase of data rates (20 Gb/s) and lower delays
- Increase of offer tends to originate an increase of demand => new services will come

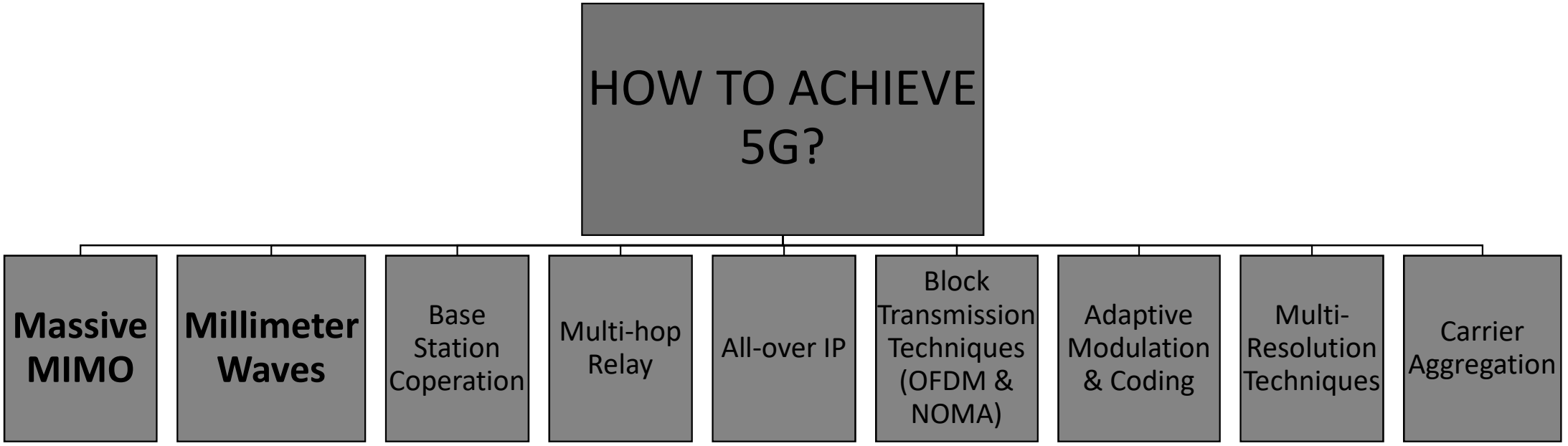
LATENCY & BANDWIDTH



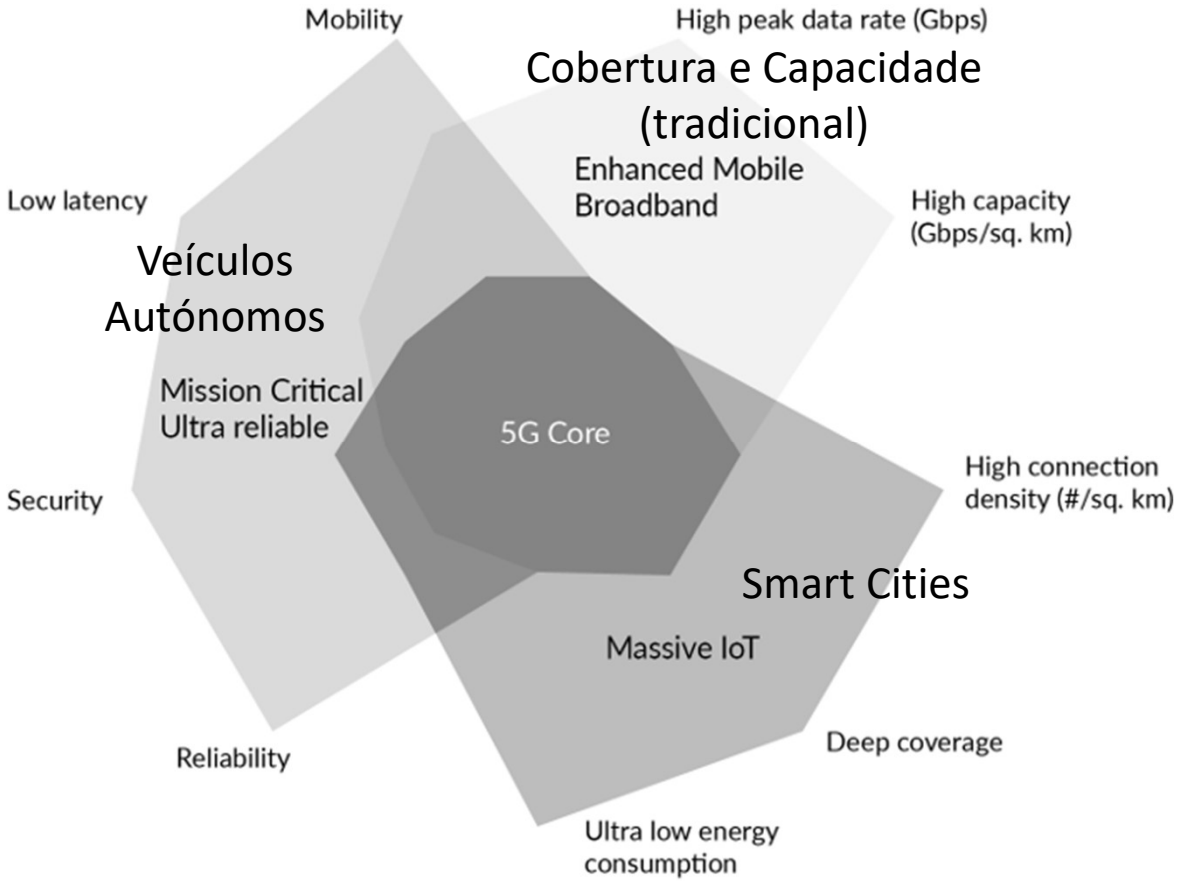
Introduction: 5G Communications

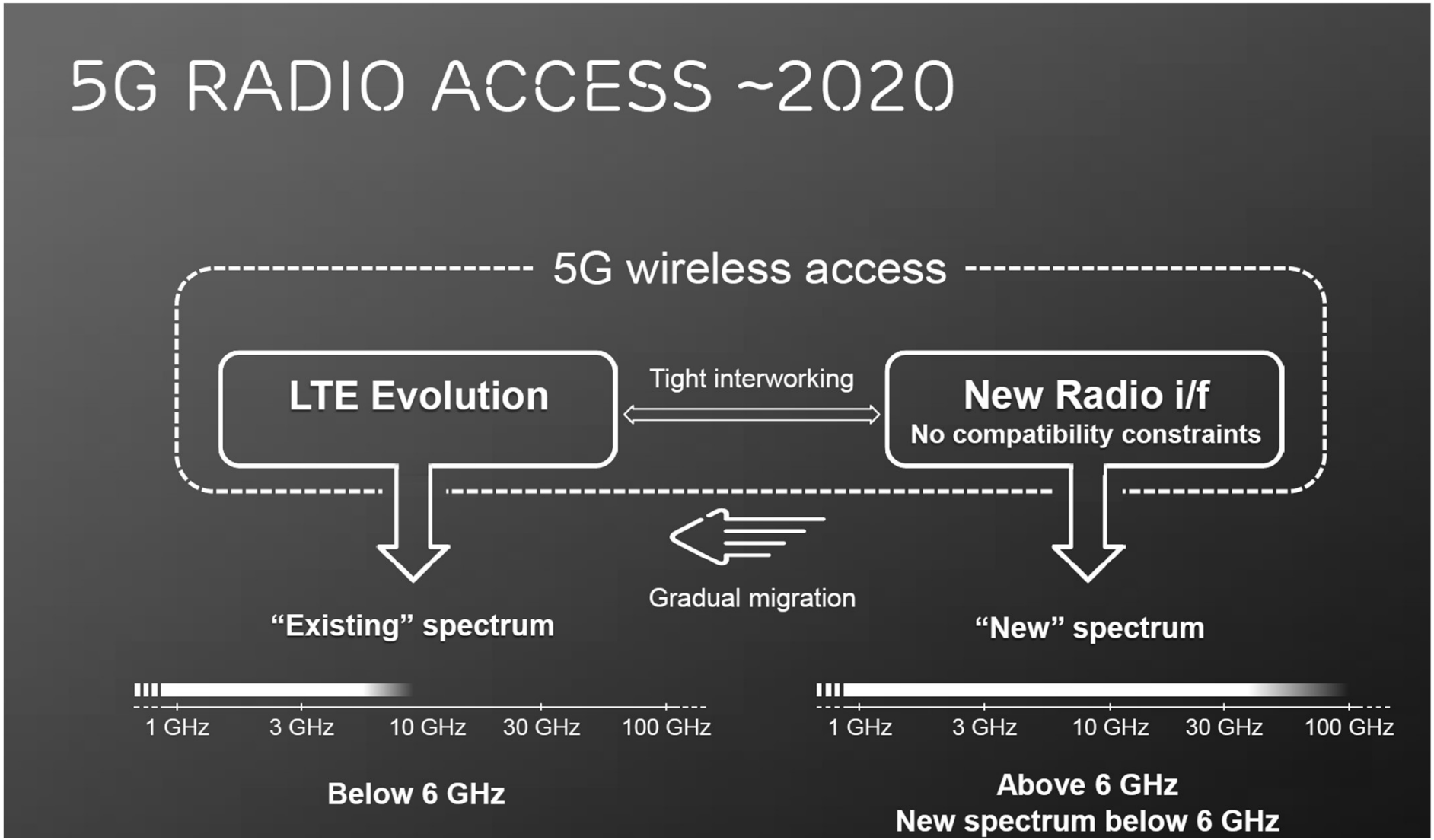
- **Transmission Rates: 20 Gbps** nomadic and 1 Gbps on the move in **downlink** (halved in the uplink).
- **Latency: 0,5 ms for tactile interaction**.
- **Capacity:** targets can be as high as **15 Tbps/km2** with **250 000 users/km2** for indoor hotspots such as office environments.
- **Spectral Efficiency**
  - 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, …

Introduction: 5G Communications

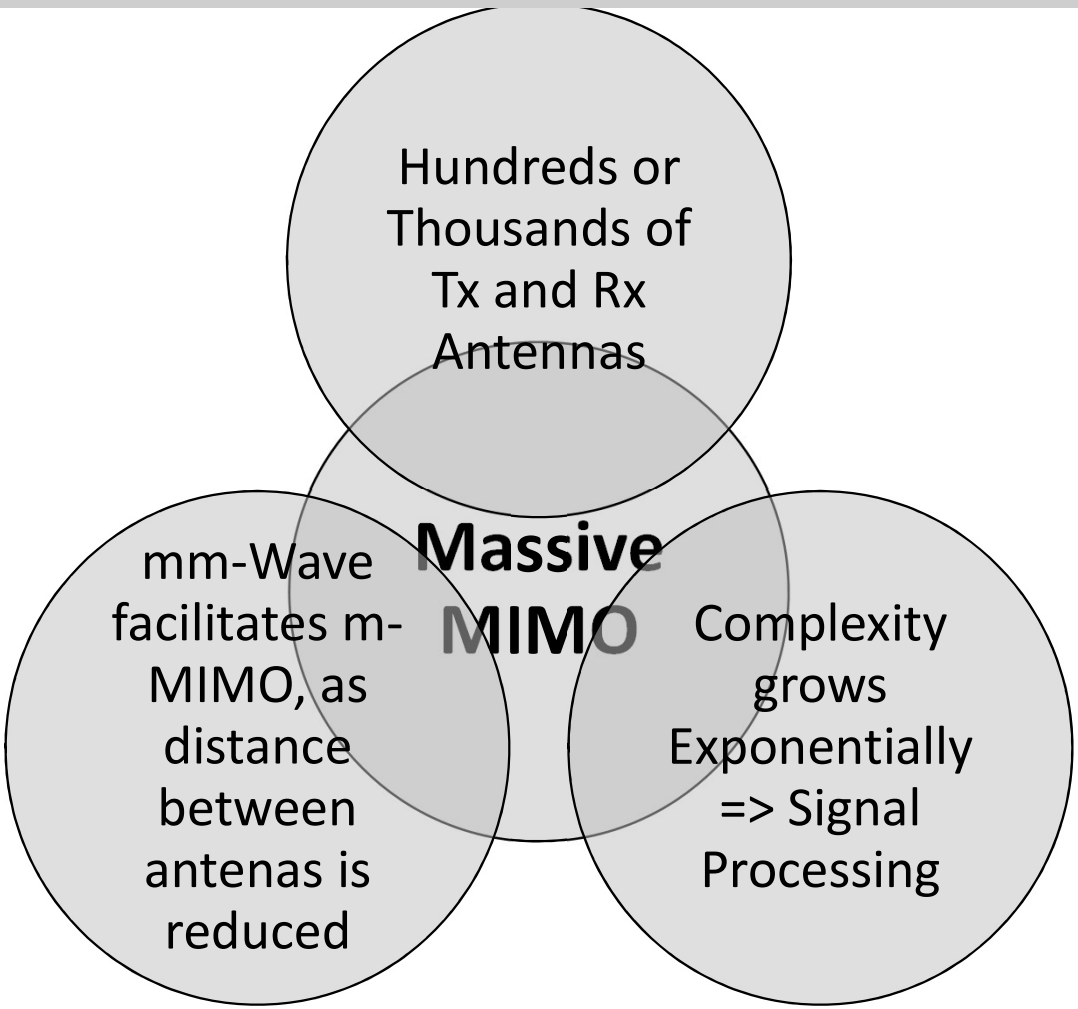


Introduction: 5G Communications




5G RADIO ACCESS ~2020
5G wireless access
LTE Evolution
Tight interworking
New Radio i/f
No compatibility constraints
Gradual migration
"Existing" spectrum
"New" spectrum
1 GHz
3 GHz
10 GHz
30 GHz
100 GHz
1 GHz
3 GHz
10 GHz
30 GHz
100 GHz
Below 6 GHz
Above 6 GHz
New spectrum below 6 GHz

Introduction: 5G Communications



Introduction: 5G Communications

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. – E.g.: IEEE802.11ad uses 2.16 GHz of BW in **60 GHz band** (ISM band), supporting up to 7 Gbps.

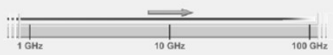
The **distance between antennas is reduced**, facilitating a higher number of antenna elements (Massive MIMO)

However, mm-Wave suffers from high path loss and rain and oxygen absorption.

5G KEY ELEMENTS

Ericsson_GBF_Still_44

Extension to higher frequencies



Spectrum flexibility

Spectrum sharing

- ***Unlicensed***
- ***Shared licensed***
- ***Network sharing***

Duplex Flexibility

Multi-antenna technologies

Beam-forming for coverage

Multi-user MIMO for capacity

Multi-site coordination

Multi-site transmission/reception

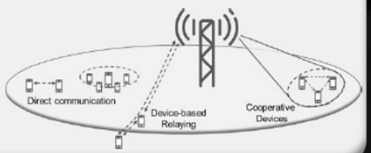
Multi-layer connectivity

Ultra-lean design

Higher data rates and enhanced energy efficiency

Access/backhaul integration

Device-to-device communication



...

Conclusions

- 5G is expected by 2020, supporting the following improvements, as compared to 4G:
  - Transmission Rates 20 times higher (20 Gb/s for nomadic access)
  - Latency 10 times lower (0,5-1 ms)
  - Point-to-point communications (similar to TETRA, p.e.), supporting Internet of Things, Virtual Reality and Self Driving Cars.

- Supported in Massive-MIMO.
- Incorporating millimetric Waves (with higher coherence bandwidth) which also facilitates the implementation of Massive-MIMO **(in Research)**.
- Other techniques, such as Base-Station Cooperation, Multi-Hop Relay, Multi-Resolution Techniques, Block Transmission Techniques (e.g., OFDM), Carrier Agreggation, AMC, etc., also contribute to support the improvement of 5G **(in Research)**.

- Increased transmission rates result from the optimized conjugation of different transmission techniques.

Porquê 5G?

5G, uma rede para todos os serviços

Enhanced MBB

Experiência MBB/Media em todo o lado a qualquer instante

Desafios: maximizar QoS em indoor, outdoor ou mobilidade

Aplicações: video UHD, broadcast, VoLTE e novas formas de social media

Massive IoT

Comunicação massiva entre sensores, veículos, habitações etc.

Desafios: segurança, sustentabilidade, integração e escalabilidade

Aplicações: indústria automóvel, smart-home, smart-cities, etc.

Human Interaction

Comunicação contextual entre humanos e IoT

Desafios: privacidade, real-time, mobilidade, sustentabilidade

Aplicações: saúde, educação, gaming, realidade aumentada, etc.

Mission Critical

Comunicação crítica entre máquinas e/ou pessoas

Desafios: segurança, mobilidade, contexto legal, latência/real-time

Aplicações: controlo remoto máquinas, industria 4.0, smartgrids, segurança pública, etc.

2. TSG-SA#74, Dec/2016:
NexGen TR completion
Approval of SA2 WID

7. TSG#80, June 2018: Release 15 stage 3 freeze for NR and NexGen, including Standalone.

6. RAN#78/RAN#79: Stage-3 freeze for Non-Standalone higher layers (including components common with standalone). Completion target TBD.

1. TSG-RAN#73, September 2016:
5G NR Requirements TR completion

4. TSG-SA#77 or TSG-SA#78:
NexGen stage-2 freeze.

2016 | 2017 | 2018

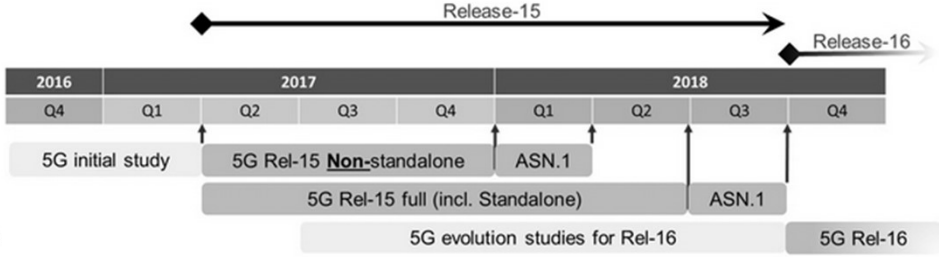
3. CHECKPOINT: TSG#75: March 2017:
- Completion of NR SI with corresponding performance evaluation and concepts;
- Approval of RAN WID(s);
- Report from RAN1/RAN2/RAN3/RAN4/SA2 on fwd compatibility of NSA and SA NR;
- Report from SA2 on migration;
- SA and CT timeline coordination;
- Reconfirmation of NR & NexGen timeplan, including completion target for NSA higher layer components (box 6)

5. TSG-RAN#78, December 2017:
- Stage 3 freeze of L1/L2 for common aspects of NSA (focused on licensed bands) and SA NR;
- Principles agreed for SA-specific L1/L2 components.

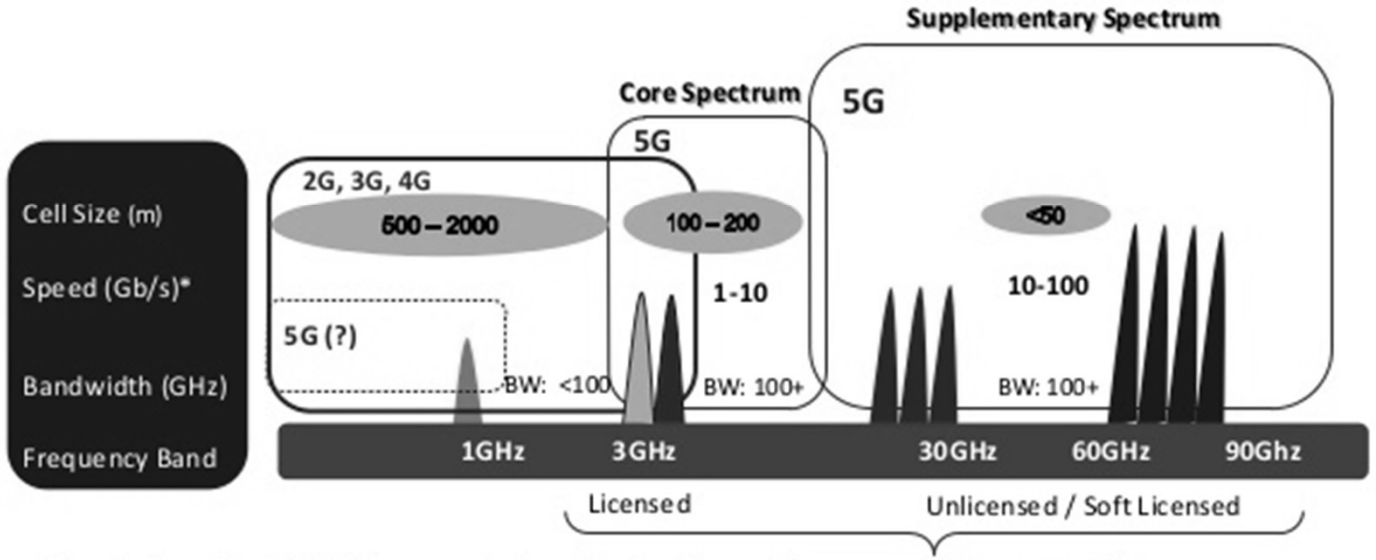
Note: SA: Standalone
NSA: Non-Standalone

5G NR timeline

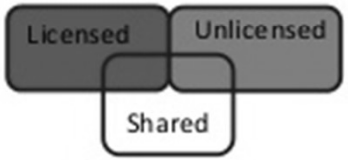
- Overall timeline had been agreed at RAN#75 in March/2017
- This time plan still holds
- RAN#77 took some key measures to ensure timeline is met



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

15

Outline

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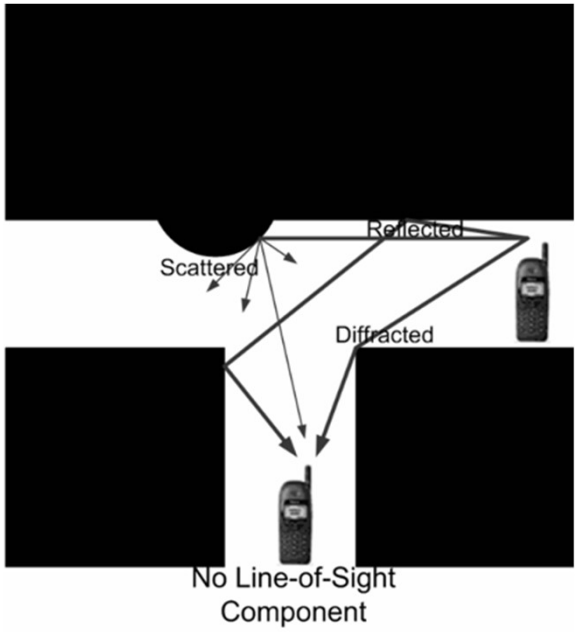
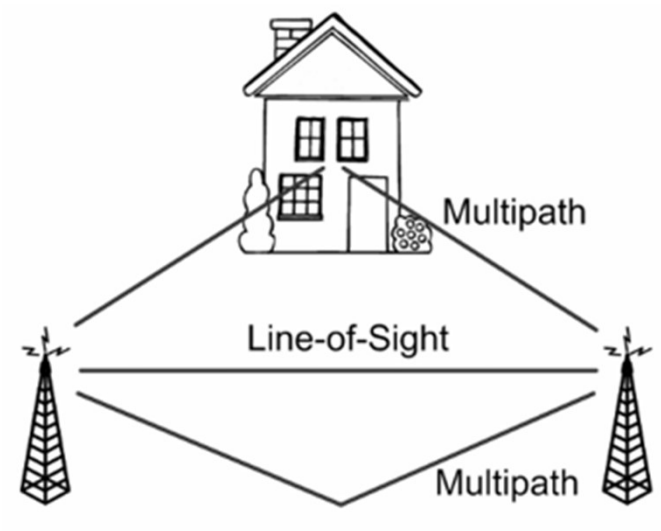
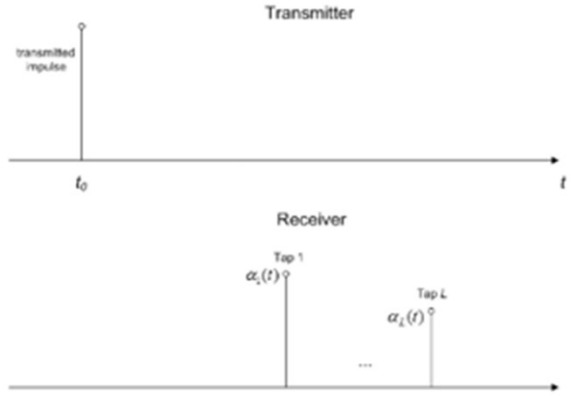
Multipath Interference
Intersymbol Interference



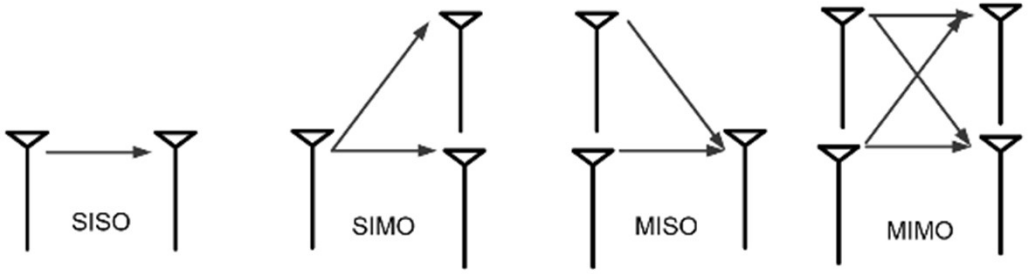




- **Higher Signal Bandwidth corresponds to higher Intersymbol Interference**
- **This is not only a matter of Spectrum**

MIMO Systems

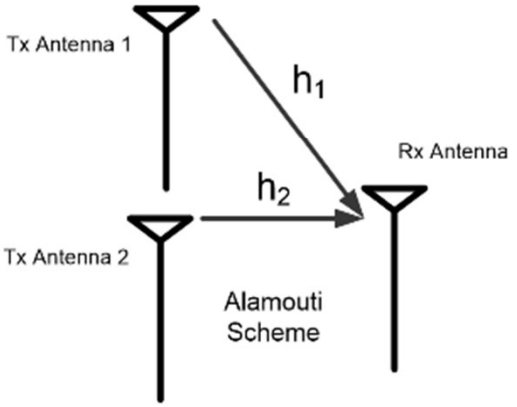
- The basic concept behind Multiple Input Multiple Output (MIMO) techniques relies on exploiting the multiple propagation paths of signals between multiple transmit (Input) and multiple receive (Output) antennas.
- In the case of frequency selective fading channel, different symbols suffer interference 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

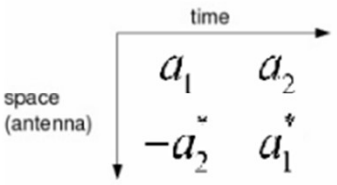


Multiple Antennas Configurations

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.





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

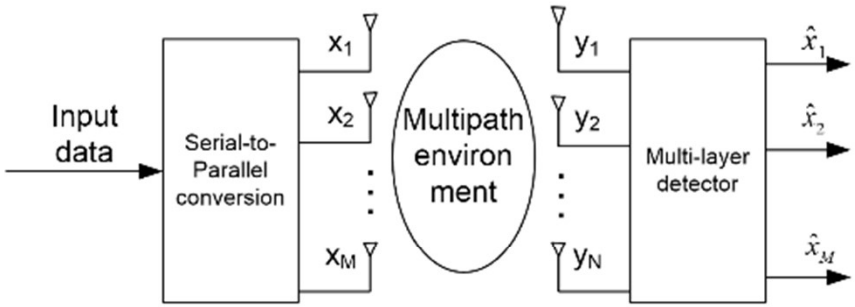
$$\tilde{A}_2 = \left[Y_2 H^{(1)*} - Y_1^* H^{(2)} \right] \beta$$

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

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

Multi-Layer Transmission

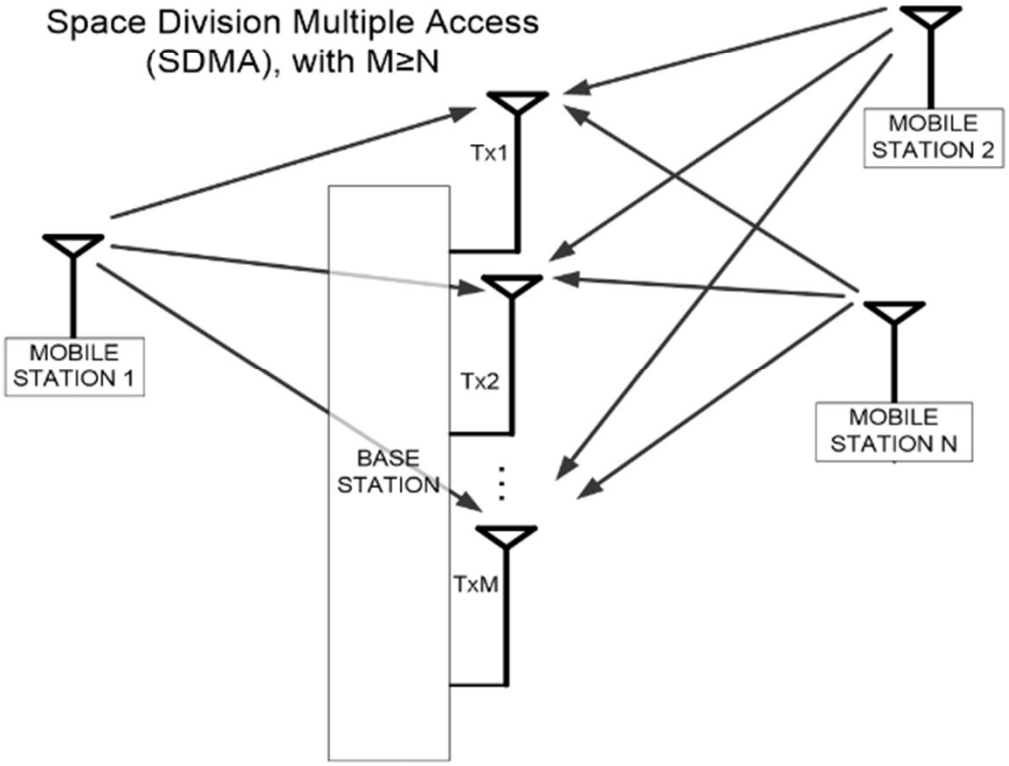
- The goal of multi-layer MIMO relies on achieving higher data rates, in a given bandwidth, whose increase rate corresponds to the number of transmit antennas.
- The symbols stream is split in a serial to parallel converter into the several transmit antennas, and each transmit antenna sends a lower symbol 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

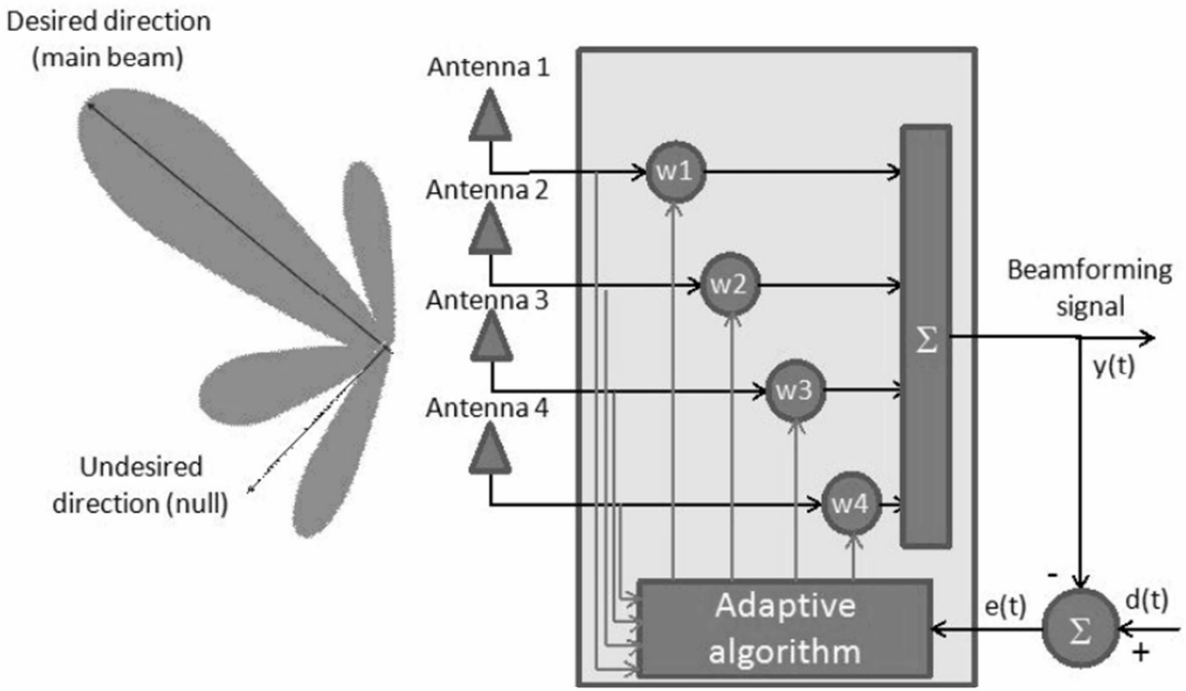
- Space Division Multiple Access (SDMA) relies on improving the capacity (more users per cell), while keeping the spectrum allocation unchanged.
  - SDMA is a technique that allows multiple users exploiting spatial diversity as a multiple access technique, while using the same spectrum.
- Both SDMA and 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

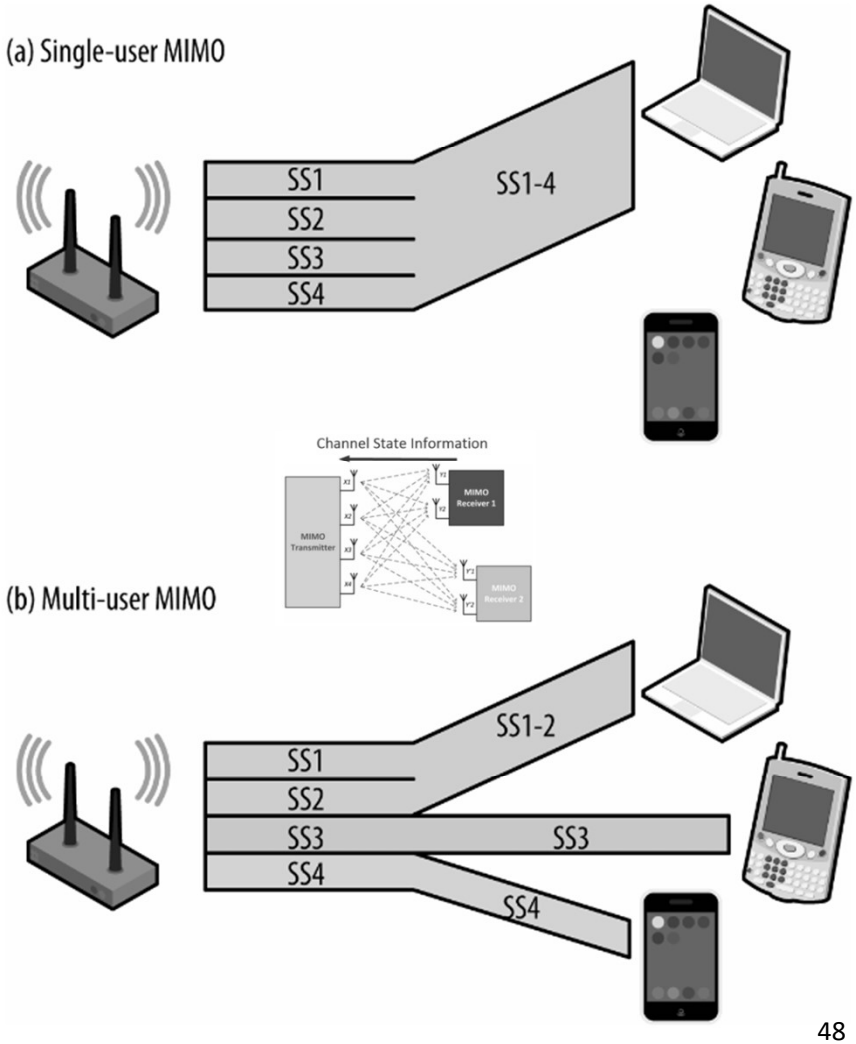
Beamforming

- 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.

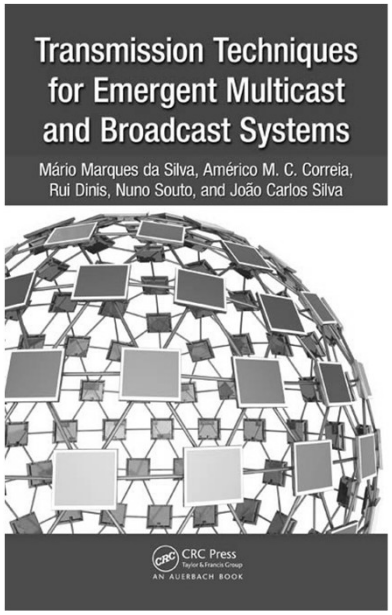


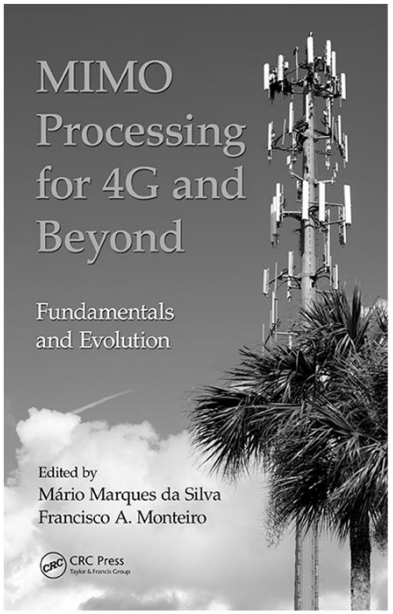
Conclusions

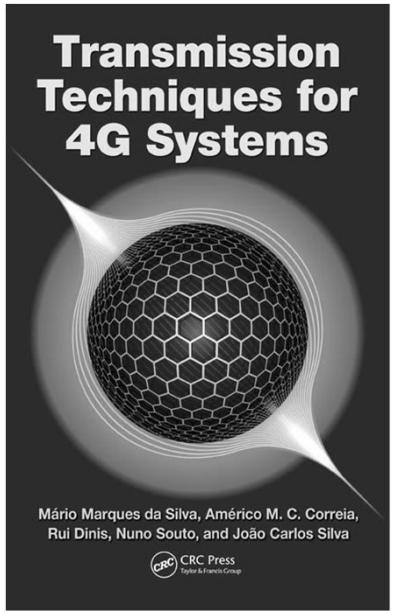
- As Comunicações 5G são esperadas a partir de 2019/20, com algumas inovações sobre 4G:
  - Ritmos de transmissão 20 vezes superiores (20 Gb/s acesso nomádico)
  - Atrasos 20 vezes inferiores (0,5-1 ms)
  - Comunicações diretas terminal-terminal (tal como o TETRA, p.e.), suportando Internet of Things, 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, 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.


Transmission Techniques for Emergent Multicast and Broadcast Systems
Mário Marques da Silva, Américo M. C. Correia, Rui Dinis, Nuno Souto, and João Carlos Silva
CRC Press
AN AUERBACH BOOK


MIMO Processing for 4G and Beyond
Fundamentals and Evolution
Edited by
Mário Marques da Silva
Francisco A. Monteiro
CRC Press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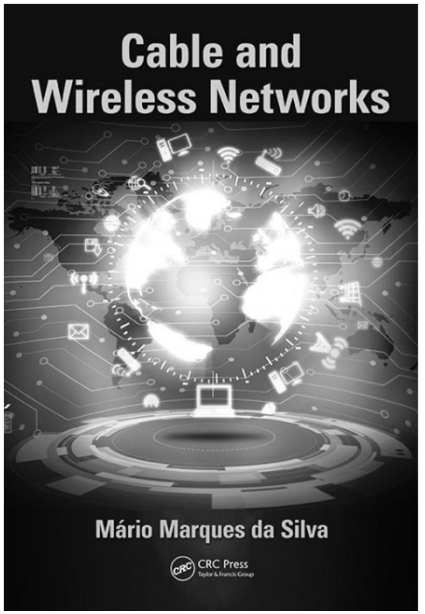
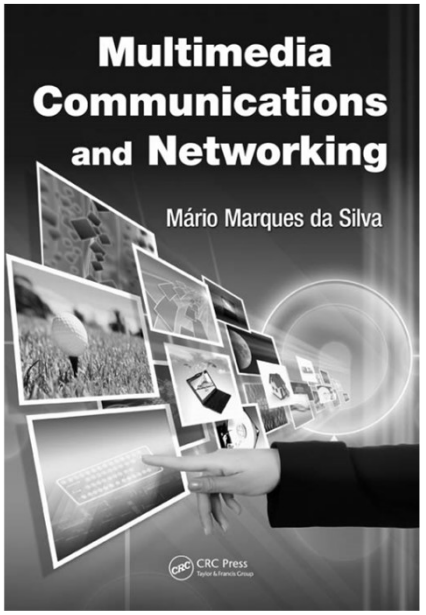

Cable and Wireless Networks
Mário Marques da Silva
CRC Press


Multimedia Communications and Networking
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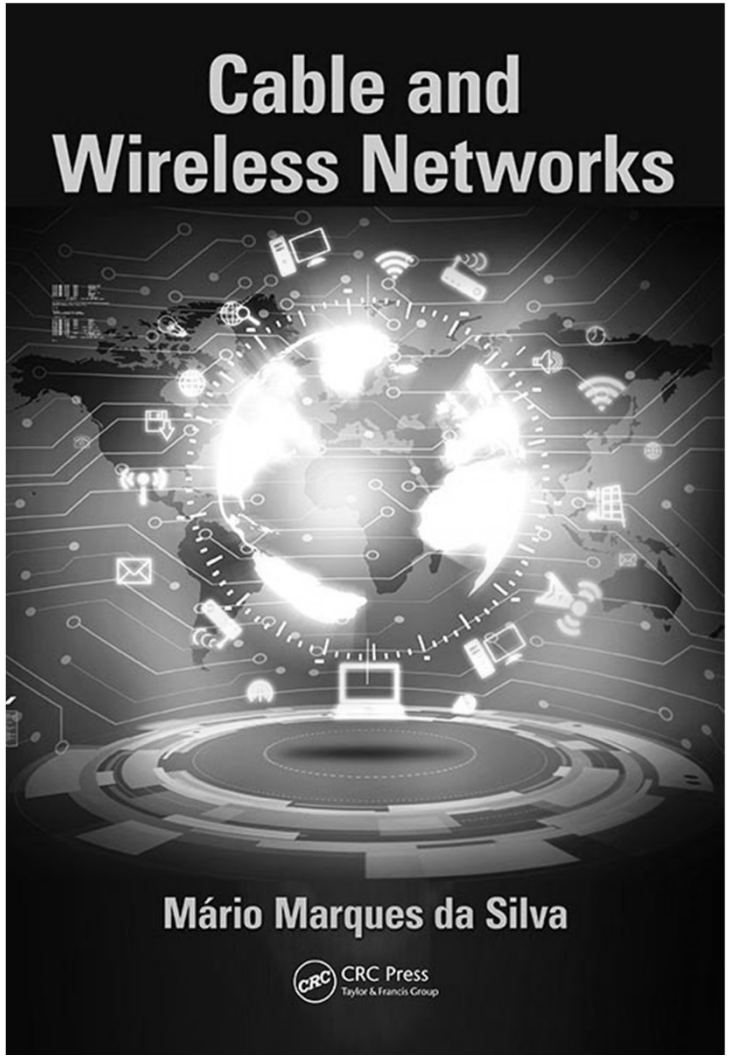
CRC Press

Book: cable and wireless networks: Theory & practice (crc Press)



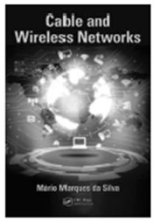
Book: cable and wireless networks: Theory & practice (crc Press)

NEW

EMONA Information Sheet

Wireless Textbook: Theory & Practice with TIMS

Emona TIMS experiment platforms support the practical component of a new wireless textbook by renowned author and educator, Professor Mario da Silva.



Cable and Wireless Networks: Theory and Practice - ISBN: 978-1-49-874681-6 - aimed at undergraduate and graduate readers, is a comprehensive textbook covering wireless communications and networking security. It demonstrates the fundamentals of communications, identifies the key components of networks and communication systems, and covers many key aspects concerning the development and understanding of current and emergent services.

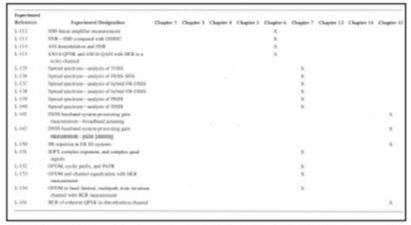
This wide-ranging textbook combines theory along with hands-on exercises which utilise the EMONA TIMS and ETT-101 range of equipment. Thorough coverage is given to emergent and current topics into a single source, enabling students to develop deeper understanding of these systems' interconnections.

The Author of the book, **Mário Marques da Silva** is an associate professor and the director of the Department of Sciences and Technologies at Universidade Autónoma de Lisboa, Lisbon, Portugal. His research interests include networking and mobile communications, namely Internet protocol (IP) technologies and network security, block transmission techniques, interference cancellation, MIMO systems, and software-defined radio. He is a Cisco certified instructor, a member of the IEEE and AFCEA, and reviewer for several international scientific IEEE journals and conferences.

Prof Mario da Silva has also written and co-authored numerous titles, including 'Multimedia Communications and Networking', 'Transmission Techniques for 4G Systems', 'MIMO Processing for 4G and Beyond: Fundamentals and Evolution' and more..

INTEGRATED HANDS-ON LAB EXERCISES

ETT-101 Lab Exercises at the end of each chapter and the APPENDIX listing TIMS-301C experiments



ABOVE : Illustration of the seven page Appendix, tabulating advanced TIMS experiments (Experiment Reference) against textbook chapters.

LEFT : LAB EXERCISES at the end of each chapter reference experiments from the four ETT-101 Lab Manuals.

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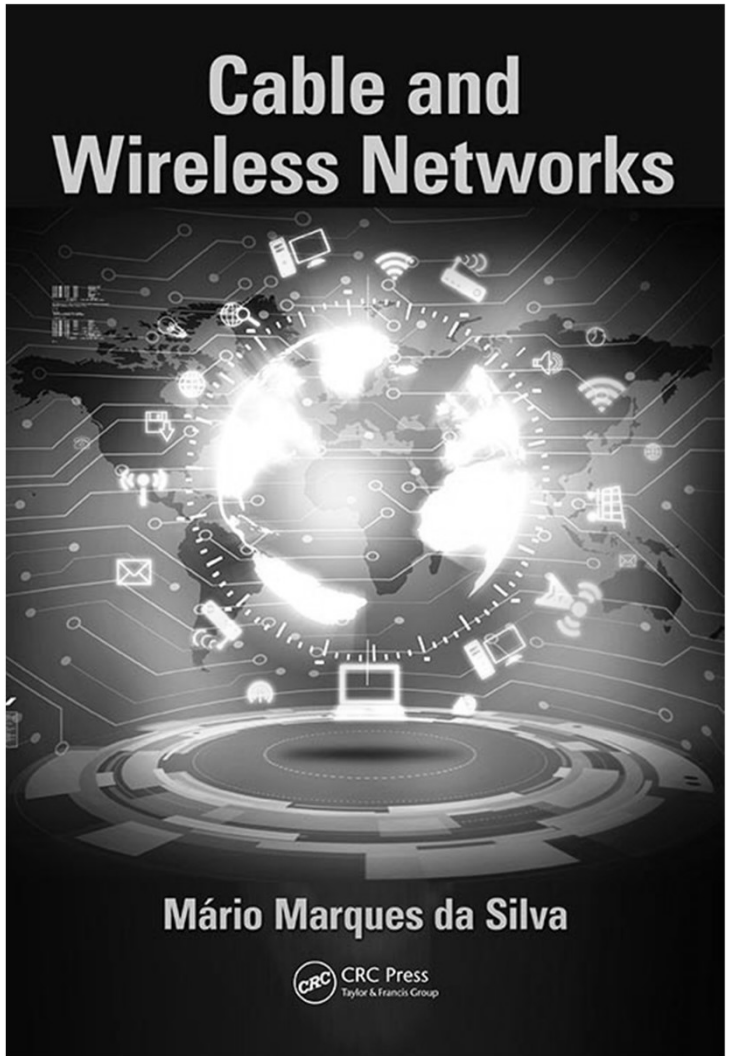

THANK YOU