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CONFERÊNCIA SUJEITA A INSCRIÇÃO
Autónoma TECHLAB
Centro de Investigação em Tecnologias
UNIVERSIDADE AUTÓNOMA DE LISBOA
A QUARTA REVOLUÇÃO INDUSTRIAL
E O
CONTRIBUTO DAS COMUNICAÇÕES 5G
O NOVO PARADIGMA DAS COMUNICAÇÕES 5G
Mário Marques da Silva
COMPUTAÇÃO NA PERIFERIA
Héctor Orrillo
zoom
Departamento de Engenharias e Ciências da Computação
AUTONOMA.PT

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Centro de Investigação em Tecnologias

O Novo Paradigma das Comunicações 5G

Mário Marques da Silva

Associate Professor at Universidade Autónoma de Lisboa

Director of the Department of Sciences and Technologies

Researcher at Instituto de Telecomunicações

mmsilva@autonoma.pt

Reference

- M. Marques da Silva, J. Guerreiro, “On the 5G and Beyond”, MDPI Applied Sciences, 10, 7091, **26 October 2020** (https://www.mdpi.com/2076-3417/10/20/7091)

applied sciences

MDPI

Article

On the 5G and Beyond

Mário Marques da Silva [1,2,*] and João Guerreiro [1,3]

1 Institute of Telecommunications, 1049-001 Lisboa, Portugal; jf.guerreiro@fct.unl.pt
2 Department of Sciences and Technologies, Autonoma University of Lisbon, 1150-293 Lisboa, Portugal
3 Department of Electrical and Computer Engineering, NOVA School of Science and Technology, 825-149 Caparica, Portugal
* Correspondence: mmsilva@autonoma.pt; Tel.: +351-213-177-654

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Featured Application: Introductory Article of the MDPI Special Issue “Transmission Techniques for 5G and Beyond”.

Abstract: This article provides an overview of the fifth generation of cellular communications (5G) and beyond. It presents the transmission techniques of current 5G communications and those expected of future developments, namely a brief study of non-orthogonal multiple access (NOMA) using the single carrier with frequency domain equalization (SC-FDE) block transmission technique, evidencing its added value in terms of spectral efficiency. An introduction to the sixth generation of cellular communications (6G) is also provided. The insertion of 5G and 6G within the Fourth Industrial Revolution framework (also known as Industry 4.0) is also dealt with. Consisting of a change in paradigm, when compared to previous generations, 5G supports a myriad of new services based on the Internet of things (IoT) and on vehicle-to-vehicle (V2V) communications, supporting technologies such as autonomous driving, smart cities, and remote surgery. The new services provided by 5G are supported by new techniques, such as millimeter waves (mm-wave), in addition to traditional microwave communication, and by massive multiple-input multiple-output (m-MIMO) technology. These techniques were not employed in the fourth generation of cellular communications (4G). While 5G plays an important role in the initial implementation of the Fourth Industrial Revolution, 6G will address a number of new services such as virtual reality (VR), augmented reality (AR), holographic services, the advanced Internet of things (IoT), AI-infused applications, wireless brain–computer interaction (BCI), and mobility at higher speeds. The current research on systems beyond 5G indicates that these applications shall be supported by new MIMO techniques and make use of terahertz (THz) bands.

Keywords: 5G; 6G; NOMA; Industry 4.0; massive MIMO; mm-wave; IoT

1. Introduction

The Fourth Industrial Revolution considers the replacement of humans by machines in certain tasks, or the development of new or more efficient tasks. Making use of robots and artificial intelligence, the Fourth Industrial Revolution is already deeply modifying society and organizations [1]. As seen in Figure 1 the Fourth Industrial Revolution comprises other parameters besides robots and artificial intelligence [2]. Robots need to communicate and to sense the environment (using sensors and communications), for which the Internet of things (IoT) is employed (all over the Internet protocol (IP)). The IoT generates massive quantities of data (big data) that will be processed with artificial intelligence to generate knowledge; that is, the data supports human decision-making, as well as decisions made by the robots. [3]. These new technologies will originate a deep modification of society with great impact on the human way of life, as well as on the employment market [4].

Reference

- M. Marques da Silva, R. Dinis, “Power-Ordered NOMA with Massive MIMO for 5G Systems”, MDPI Applied Sciences, 11(8), 3541, **15 April 2021** (https://doi.org/10.3390/app11083541)

applied sciences

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Article

Power-Ordered NOMA with Massive MIMO for 5G Systems

Mário Marques da Silva [1,2,*] and Rui Dinis [1,3]

[1] Instituto de Telecomunicações, 1049-001 Lisboa, Portugal; rdinis@fct.unl.pt
[2] Department of Sciences and Technologies, Universidade Autónoma de Lisboa, 1169-023 Lisboa, Portugal
[3] Faculty of Sciences and Technology, Universidade Nova, 2829-516 Caparica, Portugal
* Correspondence: mmsilva@autonoma.pt

Abstract: The aim of this article is to study the conventional and cooperative power-order Non-Orthogonal Multiple Access (NOMA) using the Single Carrier with Frequency Domain Equalization (SC-FDE) block transmission technique, associated with massive Multiple-Input Multiple-Output (MIMO), evidencing its added value in terms of spectral efficiency of such combined scheme. The new services provided by Fifth Generation of Cellular Communications (5G) are supported by new techniques, such as millimeter waves (mm-wave), alongside the conventional centimeter waves and by massive MIMO (m-MIMO) technology. NOMA is expected to be incorporated in future releases of 5G, as it tends to achieve a capacity gain, highly required for the massive number of Internet of things (IoT) devices, namely to support an efficient reuse of limited spectrum. This article shows that the combination of conventional and cooperative NOMA with m-MIMO and SC-FDE, tends to achieve capacity gains, while the performance only suffers a moderate degradation, being an acceptable alternative for future evolutions of 5G. Moreover, it is shown that Cooperative NOMA tends to outperform Conventional NOMA. Moreover, this article shows that the Maximum Ratio Combiner (MRC) receiver is very well fitted to be combined with NOMA and m-MIMO, as it achieves a good performance while reducing the receiver complexity.

Keywords: NOMA; massive MIMO; SC-FDE; mm-wave; 5G

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1. Introduction

The Fourth Industrial Revolution, comprising the replacement of humans by machines in certain tasks, is originating deep societal, organizational and corporate changes, in areas such as industries, agriculture, mobility (with special focus on autonomous vehicles), home safety and automation, lawyer and medical advice, etc. [1]. These modifications are being carried out making use of technologies, such as robots, artificial intelligence, big data, Internet of Things (IoT) or 3D printing [2]. Appendix A contains a list of acronyms that can be used for clarification.

5G represents a change of paradigm when compared to previous generations. These modifications aim to give a strong contribution, from the cellular communications point of view, to the implementation of the Fourth Industrial Revolution. One important novelty of 5G relies on the implementation of three use cases to provide different services. Moreover, while previous cellular generations comprised communications always established through base stations, 5G allows direct communications (device-to-device), which is especially important to support IoT, widely used, e.g., in smart cities or autonomous vehicles.

As can be seen in Figure 1, 5G communications comprise different groups of use cases in order to support different services: Enhanced Mobile Broadband (eMBB), massive Machine-Type Communications (mMTC) and Ultra Reliable Low Latency Communications (URLLC). These groups of use cases support the concept entitled network slicing, which aims to provide to different users the requirements of the services that are being utilized. For example, autonomous vehicles require communications that are highly reliable and almost real-time, which are supported by URLLC. On the other hand, smart cities require

Reference

- M. Marques da Silva, R. Dinis, G., Martins, “On the Performance of LDPC-Coded Massive MIMO Schemes with Power-Ordered NOMA Techniques”, MDPI Applied Sciences *11*(18), 8684, **17 September 2021**, (https://doi.org/10.3390/app11188684)

applied sciences

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Article

On the Performance of LDPC-Coded Massive MIMO Schemes with Power-Ordered NOMA Techniques

Mário Marques da Silva [1,2,3,*], Rui Dinis [1,3,4] and Gelson Martins [2]

1 Instituto de Telecomunicações, 1049-001 Lisboa, Portugal; rdinis@fct.unl.pt
2 Department of Sciences and Technologies, Universidade Autónoma de Lisboa, 1169-023 Lisboa, Portugal; 30005668@students.ual.pt
3 Autonoma TechLab, 1169-023 Lisboa, Portugal
4 Faculty of Sciences and Technology, Universidade Nova, 2829-516 Caparica, Portugal
* Correspondence: mmsilva@autonoma.pt

Abstract: This article studies the power-ordered Non-Orthogonal Multiple Access (NOMA) techniques associated with Low-Density Parity-Check (LDPC) codes, adopted for use in the fifth generation of cellular communications (5G). Both conventional and cooperative NOMA are studied, associated with Single Carrier with Frequency Domain Equalization (SC-FDE) and massive Multiple-Input Multiple-Output (MIMO). Billions of Internet of Things (IoT) devices are aimed to be incorporated by the Fourth Industrial Revolution, requiring more efficient use of the spectrum. NOMA techniques have the potential to support that goal and represent strong candidates for incorporation into future releases of 5G. This article shows that combined schemes associated with both conventional and cooperative LDPC-coded NOMA achieve good performance while keeping the computational complexity at an acceptable level.

Keywords: NOMA; LDPC; massive MIMO; SC-FDE; 5G

Citation: da Silva, M.; Dinis, R.; Martins, G. On the Performance of LDPC-Coded Massive MIMO Schemes with Power-Ordered NOMA Techniques. *Appl. Sci.* 2021, *11*, 8684. https://doi.org/10.3390/app11188684

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1. Introduction

The Fourth Industrial Revolution consists of the revolution of robots. Artificial intelligence is utilized to support the decision-making of robots, namely, to process a large amount of data (big data) that is generated with high data rate communications and using a wide variety of sensors and Internet of Things (IoT) devices. The Fourth Industrial Revolution is already deeply modifying humans and society in a myriad of areas, such as economy, mobility, housing, teaching, health, agriculture, medical and lawyer counselling, defense, wildlife monitoring, etc. [1,2].

From the communication and IoT point of view, the fifth generation of cellular communications (5G) was designed to offer the services required by the Fourth Industrial Revolution, representing a modification of the paradigm when compared to previous generations. One novelty of 5G relies on the ability to support direct device-to-device communication without requiring a base station, which is needed to support IoT devices required for autonomous vehicles, smart logistics, and smart cities. Moreover, as can be seen from Figure 1, to support different services with the required reliability, 5G is split into three groups of use cases: Enhanced Mobile Broadband (eMBB), massive Machine-Type Communications (mMTC) and Ultra-Reliable Low Latency Communications (URLLC). These three groups support the network slicing concept, which aims to provide diverse requirements for different users. For example, smart cities employ an extremely high number of devices with low power consumption, which is supported by mMTC. On the other side, autonomous vehicles require communication that is highly reliable and almost real-time, which is supported by URLLC.

Agenda

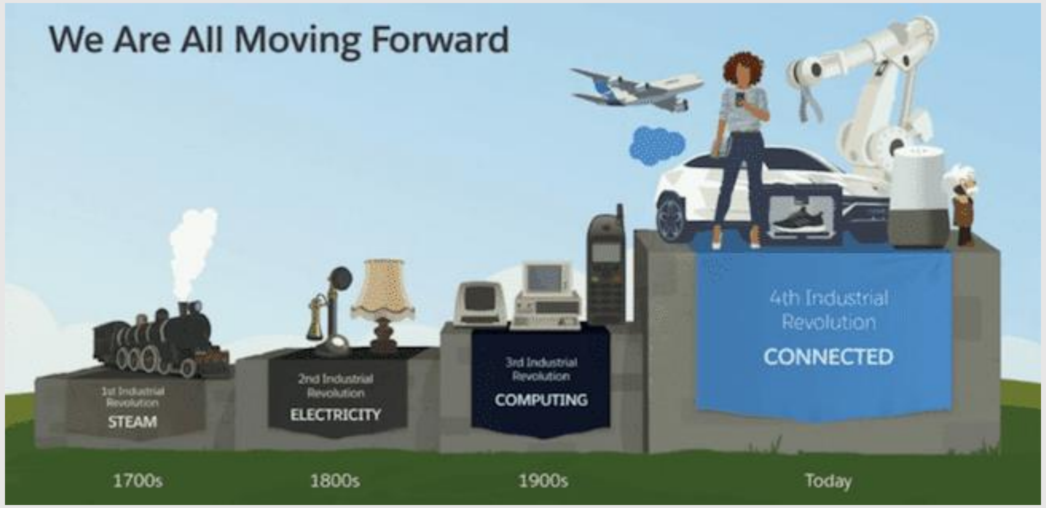
1. The Digital Transformation
2. 5G Communications
3. Future Evolutions & NOMA
4. 6G Communications

Agenda

1. **The Digital Transformation**
2. 5G Communications
3. Future Evolutions & NOMA
4. 6G Communications

1. The Digital Transformation

What is "Digital Transformation"?

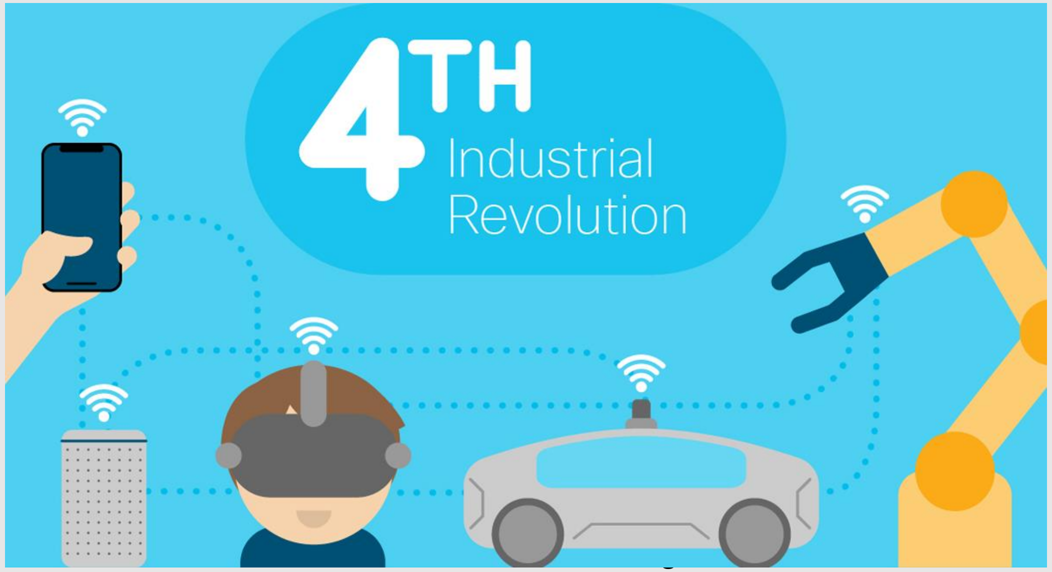


- Analog Electronics (Fourties)
- Phase 1: Digital Electronics (Eighties)
- Phase 2: All-over-IP

3rd Industrial Revolution

Information Age

- **Phase 3: Automation** || 4rd Industrial Revolution (ecology vs technology – strategy of EU) – *Knowledge Age*



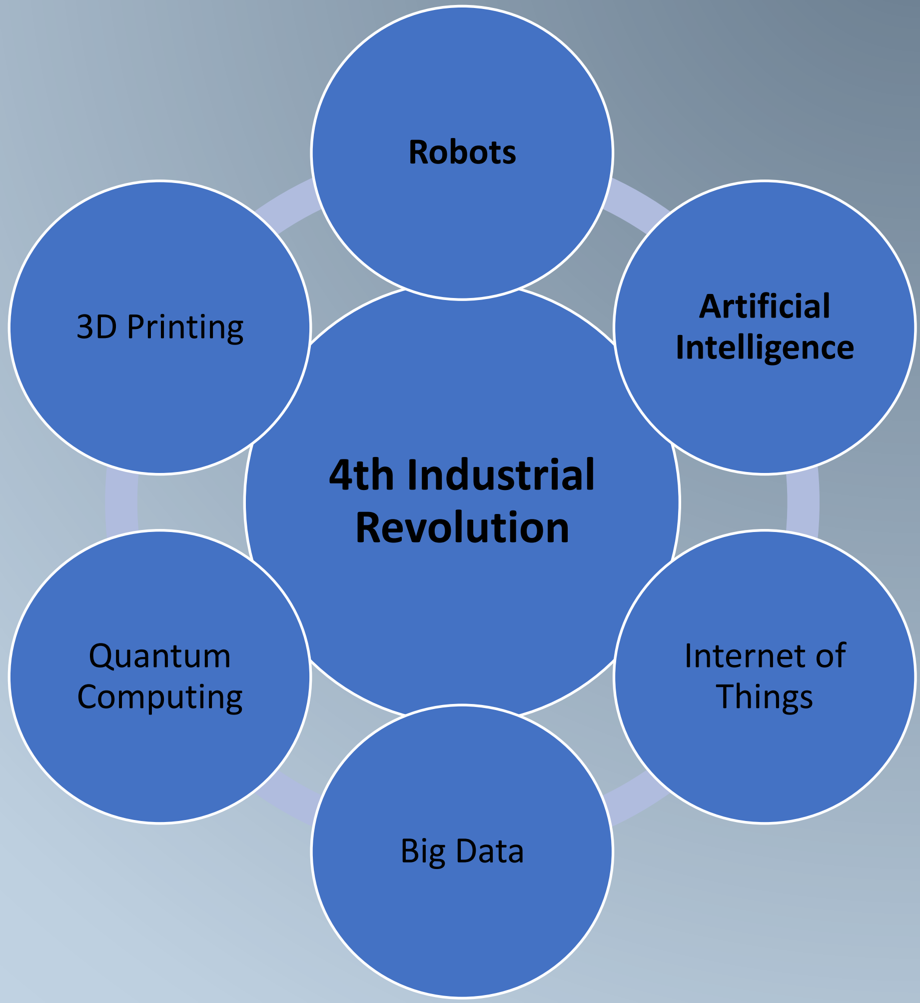
1. The Digital Transformation

The **4th Industrial Revolution** is characterized by the **massive use of Robots**, as well as **Artificial Intelligence, Big Data, Internet of Things, 3D Printing, Quantic Computing**.

More **eficiente use of the Resources**.

These technologies potentiate the **replacement of Humans by Robots** in diferent areas.

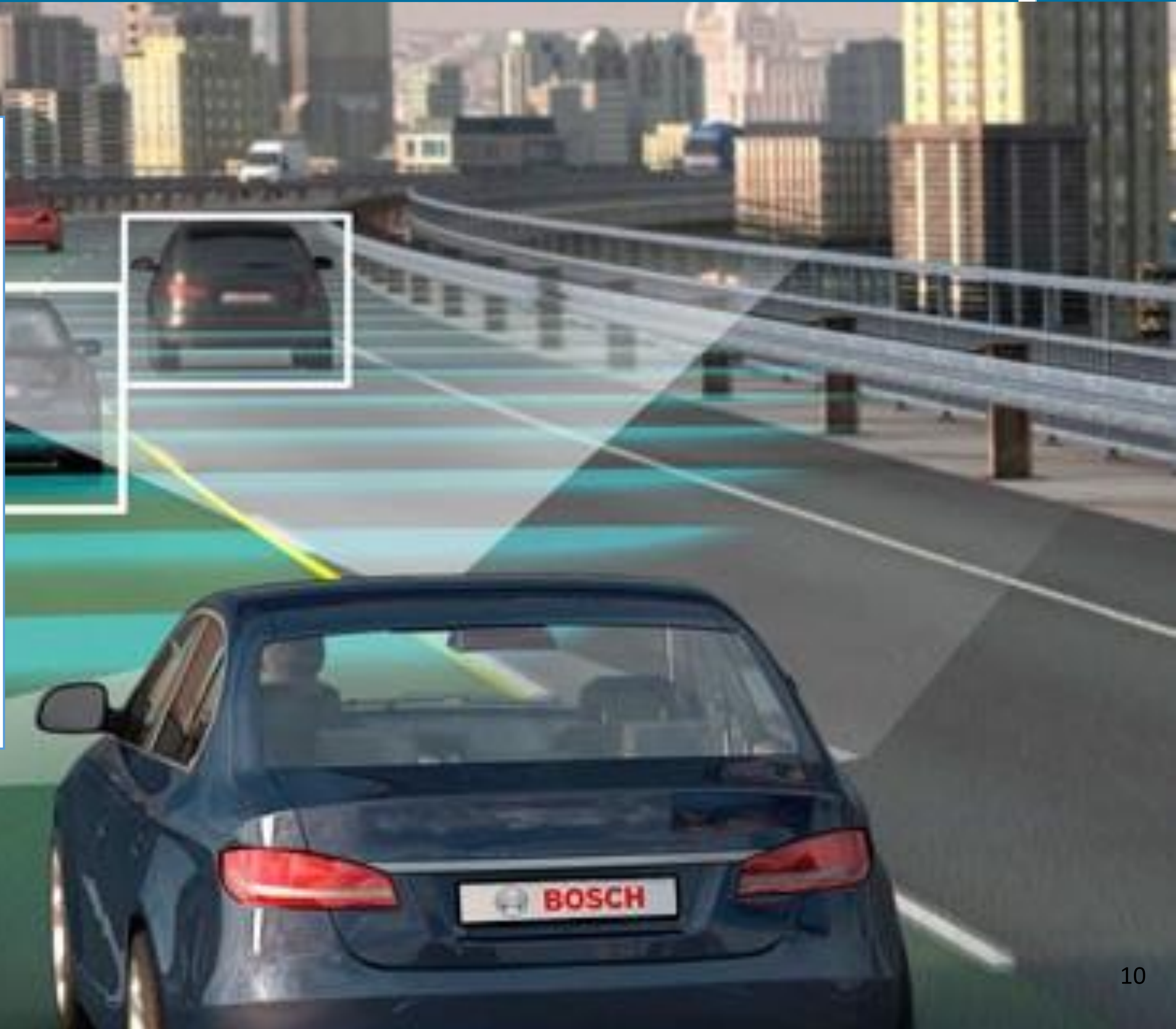
- **Some Jobs disappear, others are created**, requiring a great human **adaptation** to this new **Paradigm**.
- **Knowledge Age – routine decisions (or their support) are implemented by machines.**
  - **Scientific, technical and human skills**, critical thinking, emotional intelligence, abstract thinking, became more important assets than tangible goods.



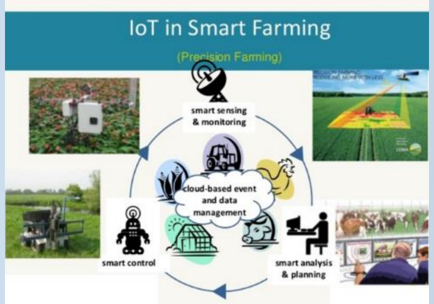
1. The Digital Transformation

4th Industrial Revolution

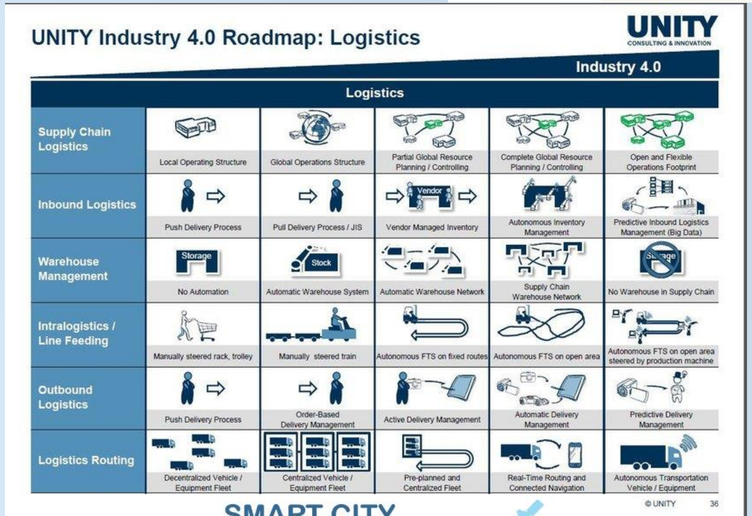
- **Massive IoT & 5G**
  - **5G is disruptive:** not only higher throughputs and lower latency - Introduction of **Machine-to-Machine Communications - point-to-point (IoT)**, instead of through Base Station.
  - Speeds up to **20 times higher** (20 Gb/s) & latency 10 times lower (than 4G).
- **Big Data**
  - Consists of the generation of **massive quantity of data**, structured or not, which can be processed by **Artificial Intelligence** to generate **Knowledge**.
- **Robotic & Artificial Intelligence**
  - A robot moves, but has also to **make decisions** → **Artificial Intelligence**



1. The Digital Transformation



Higher dependency from Cybersecurity, but with new Cybersecurity Solution



UNITY Industry 4.0 Roadmap: Logistics

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Industry 4.0

Logistics					
Supply Chain Logistics	Local Operating Structure	Global Operations Structure	Partial Global Resource Planning / Controlling	Complete Global Resource Planning / Controlling	Open and Flexible Operations Footprint
Inbound Logistics	Push Delivery Process	Pull Delivery Process / JIS	Vendor Managed Inventory	Autonomous Inventory Management	Predictive Inbound Logistics Management (Big Data)
Warehouse Management	No Automation	Automatic Warehouse System	Automatic Warehouse Network	Supply Chain Warehouse Network	No Warehouse in Supply Chain
Intralogistics / Line Feeding	Manually steered rack, trolley	Manually steered train	Autonomous FTS on fixed routes	Autonomous FTS on open area	Autonomous FTS on open area steered by production machine
Outbound Logistics	Push Delivery Process	Order-Based Delivery Management	Active Delivery Management	Automatic Delivery Management	Predictive Delivery Management
Logistics Routing	Decentralized Vehicle / Equipment Fleet	Centralized Vehicle / Equipment Fleet	Pre-planned and Centralized Fleet	Real-Time Routing and Connected Navigation	Autonomous Transportation Vehicle / Equipment

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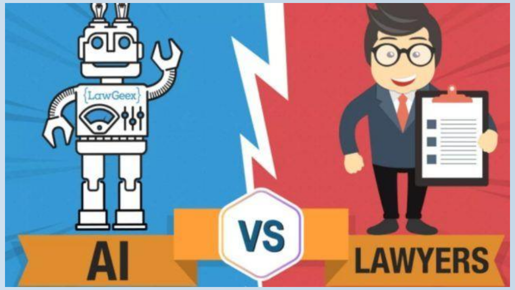
Under the Skin Surveillance



1. The Digital Transformation

Employability Post 4th Industrial Revolution (OECD):

- Automation **affects mainly industry and agriculture**, but trade and services are also vulnerable to automation;
- About **14% of existing jobs in OECD are highly automated**, while **32% of jobs can suffer a main change** on the way they are done;
- Higher risk is associated to **jobs with higher level of routines, lower skills and lower incomes**;
- **Younger people who enter the job market are more vulnerable to automation** than jobs developed by more experienced people;
- **Lower risk** is applicable to jobs related to **creation, maintenance and administration of technologies**, **creative intelligence, organizational manipulation, social intelligence**;
- **Not all the jobs technically automated will disappear**. Moreover, **other jobs will be created**, predicting that **employability will continue to rise**.

1. The Digital Transformation

Artificial Intelligence

- Invented in 1956 (R&D)
- Bursted recently by:
  - **Increase of Processing Power**
  - **Increase of Data (Big Data) that can be used by Learning Algorithms**
  - Development of areas such as Neural Networks or Reinforcement Learning

  - Data: "The Petrol of XXI Century"

  - Sub-delegation in Machines to Decide:
    - **Ethical Issue** (Send or not to Prison? Kill or not to kill?)
    - Machines should have "awareness" of "good or evil"
    - Algorithms to take into account the **Awareness / Impact of Decisions** (not only to decide), considering factors such as **Altruísm & Empathy** .
    - **Altruísm & Empathy** had determinant impact in the survival and prosperity of humans.

Environment vs Technology

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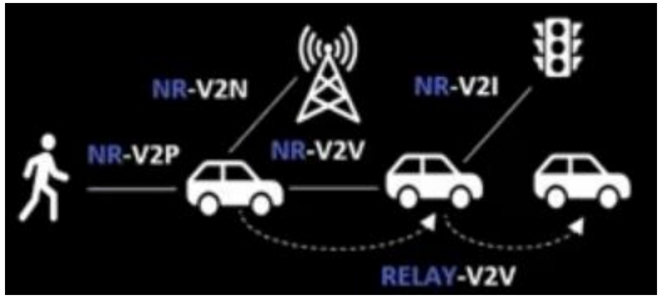
- **Technologies** link with **Climate & Environment**, because they allow:
  - Generation of **renewable energies**
  - **More eficiente use of resources**
    - **Mobility**
    - **Energy**
    - **Industry**
    - **Smart Cities**
    - **Telework**
    - **eLearning**
    - **Robotis**
- Digital Transformation → Energetic Transformation → Ecological Transformation
- Transformations bursted by COVID-19 crisis.

Autonomous Vehicles

- **IoT** and, specifically **5G, is importante in the transition to the 4th Industrial Rev.**, namely for the implementation of **Autonomous Driving**, with the option **V2V** of high data rate and low latency (uRLLC).
- V2X (V2V+V2I+V2P+V2N).
- 5G, namely using **millimeter Waves** of order 60 GHz in V2V, allows the rapid sharing of huge quantities of data, such as **position, direction, speed, point origin and destination, surrounding traffic**, etc.
- **Car-sharing** is bursted by **Autonomous Vehicles**
- **Future**: Use a car of others (shared) or buy and share (investment)
- **Advanced Security, more efficient use of Resources, lower consumption (+green) & Remote Control of Vehicles**



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2. **5G Communications**
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2. 5G Communications

Evolution of Cellular Communica tions

1G (FDMA) – Analog (voice)

2G (TDMA) – GSM – Digital, Introduction of data and Roaming

3G (WCDMA) – UMTS – Internet Access

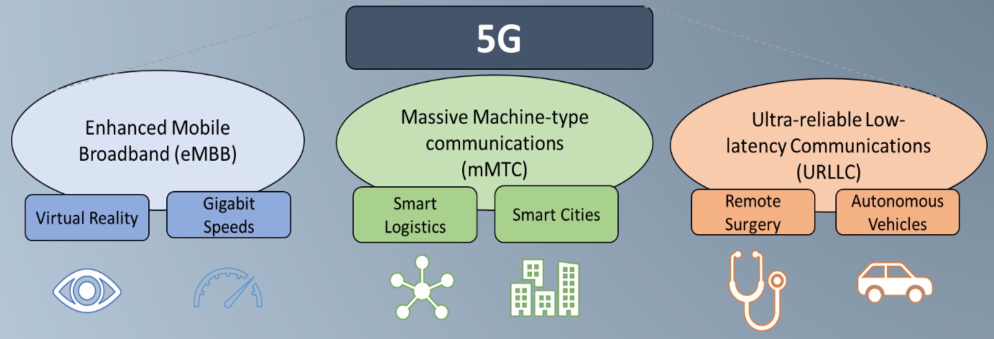
4G (OFDM) – VTC (static, hard to equalize)

5G (OFDM) – Machine-machine Comm, VTC (on the move), Autonomous Driving, Point-to-point Comms (IoT), Virtual Reality, Artificial Intelligence, etc.

Leadership of European Standards in Cellular Networks

2. 5G Communications

- **Disruptive:** Not only **higher speeds**, but **increased Capacity** (massive IoT) and **lower lattencies** (autonomous vehicles or remote surgeries)
- **Massive MIMO, Millimeter Waves & V2V**
- **Capacity:** Up to **15 Tbps/km2** Indoor environment.
- **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, …



Internet of Things

- **Main Differences:** 3 Use Cases – Improved Resilience of services (Network Slicing, ex: Virtual Reality, autonomous vehicles & smart cities):
  - (1) Normal + Higher Speed;
  - (2) Terminal-to-Terminal → Internet of Things & Security (Tetra)
    - [2.1] Sensitive to delay and very reliable (Communication & Sensors) → Edge Computing
    - [2.2] Smart Cities) → one million devices per square kilometer, and each device should have up to 10 years of autonomy or more [ITU]

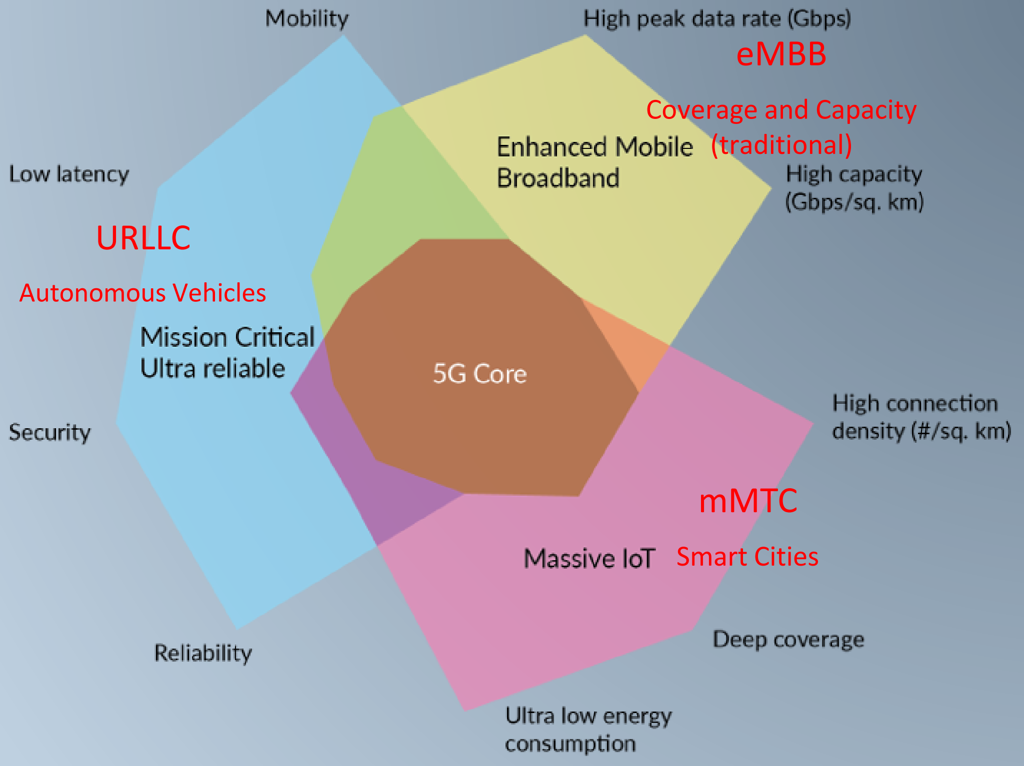
Capabilities	5G		4G
Peak Data Rates	eMBB	20 Gb/s (downlink)	1 Gb/s (downlink)
Experienced Data Rates		100 Mb/s (downlink)	10 Mb/s(downlink)
Mobility Speed		500 km/h	350 Km/h
Connection Density	mMTC	1 million devices per Km^2	100,000 devices per Km^2
Latency	URLLC	1 ms	10 ms

Roadmap to 5G Communications

Phases of 3GPP Standardization for 5G:

1. [2018] **3GPP Release 15:** Improvement of 4G (eMBB), with increased speeds and IoT support, in Non-standalone (NSA) Mode & Standalone (SA) [Radio Access, Core & Transport Networks]
2. [2020] **3GPP release 16:** Implementation of the other two uses cases: mMTC & URLLC, new Air Interface (5G New Radio [SA]), Network Slicing (splitting services in different uses cases/QoS), etc -> Services Resilience.
3. [2022] **3GPP Release 17:** Several improments to 5G, as improvement to URLLC, Network Slicing, improved capacity, remote control of vehicles, etc.

- Phased Implementation and differentiated by different Countries and Operators.



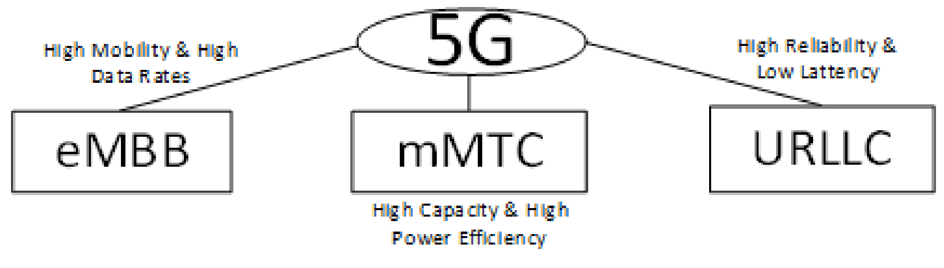
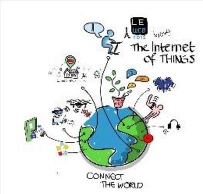


FIGURE 1 THE THREE GROUPS OF USE CASES OF 5G

2. 5G Communications

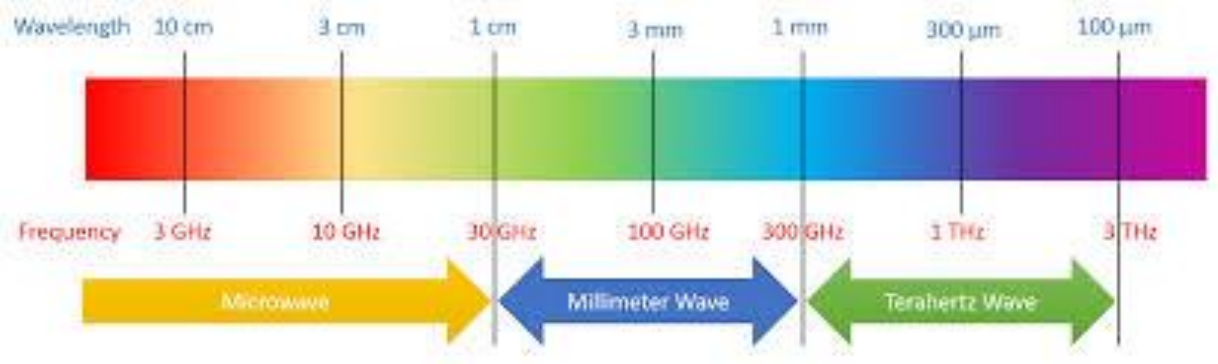
5G systems (2019/20) are aimed to achieve [as compared to 4G]:

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

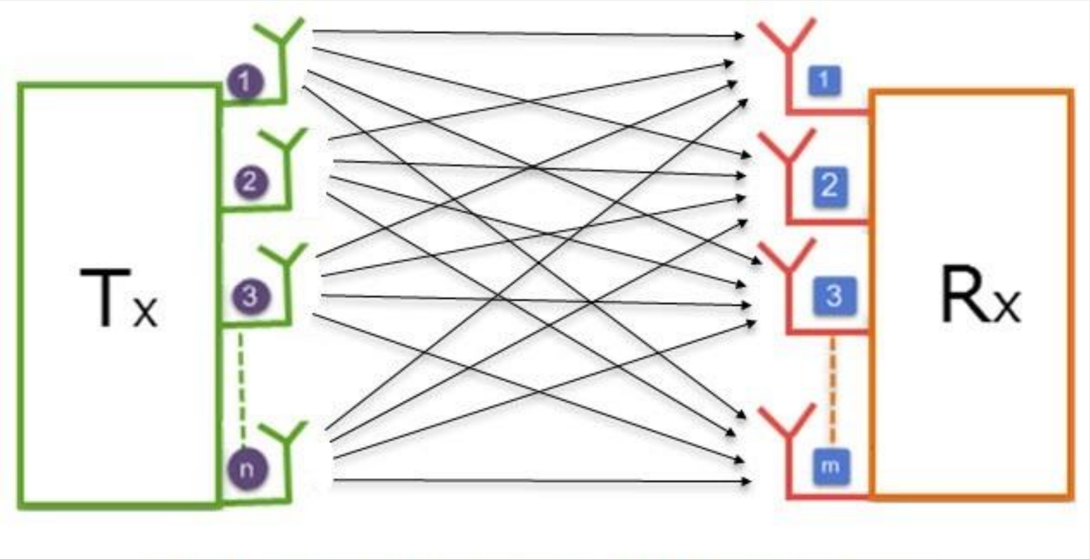


Support of new and Emergent Services:

- **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

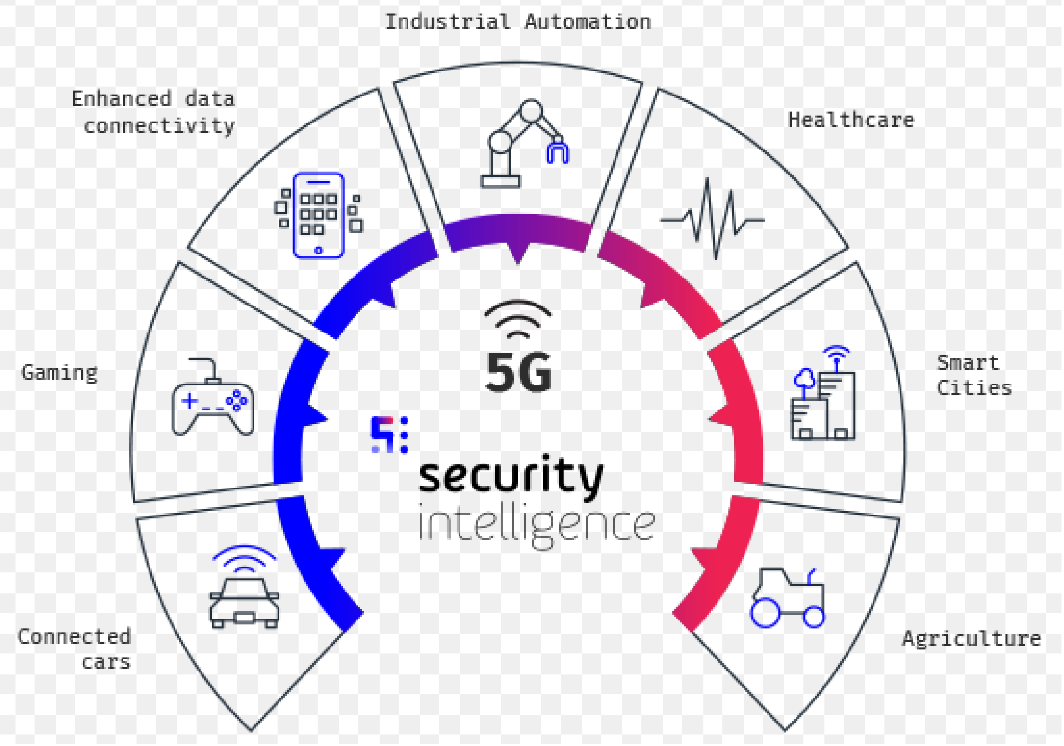


Millimeter Waves & Massive MIMO schemes involving several hundreds of antenna elements are expected to be central technologies for 5G systems



5G – Security Aspects:

1. Vulnerabilities from the Cybersecurity point of view;
2. Human Exposure from Electromagnetic Radiations;
3. Utilization of 5G Communications by Forces and Security Services (e.g., replacing TETRA).

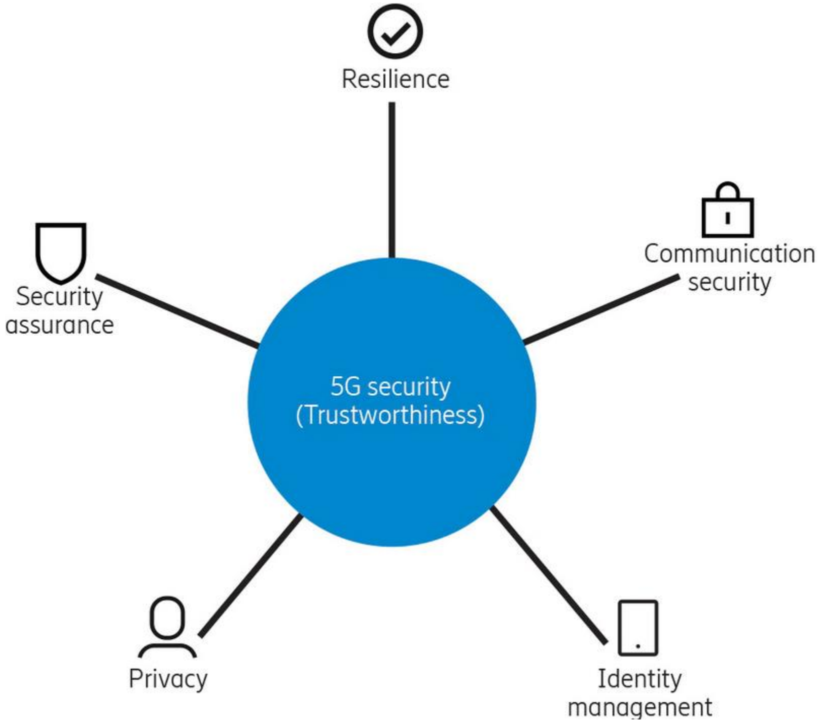


2. 5G Communications

5G Security Aspects:

1 - Vulnerabilities from the Cybersecurity point of view:

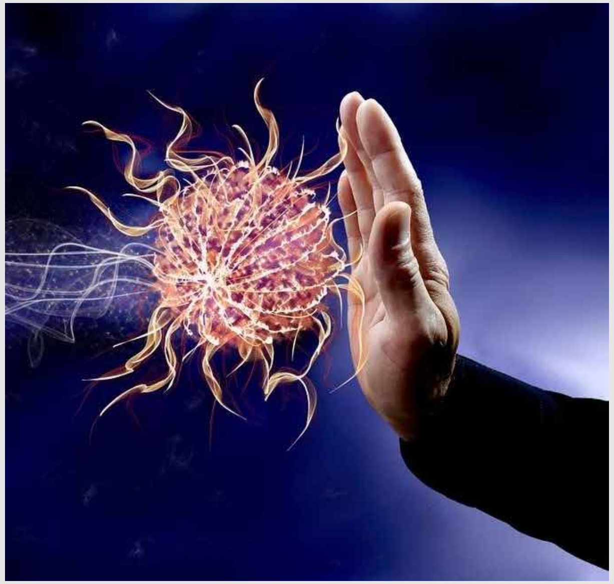
- 5G connects billions of IoT devices. While PCs tend to be secure (Firewalls, anti-vírus, etc.), such concern is normally not taken into account in the majority of IoT devices developed by external entities but interconnected through 5G (WebCams, Smart TVs, Loudspeakers, refrigerators, smart lockers, Vehicles [autonomous]). These **devices act as an input** to 5G network, allowing reaching other devices.
- The extremely high number of 5G devices, with lower latencies and higher bandwidths, make monitorization of cyber attacks more difficult → Rethink Security.
- The extremely high number of IoT devices supported by 5G makes IPv4 address spacing unsufficient. 5G is typically associated with IPv6, where IPSec is embedded using Authentication Header (AH) or Encapsulation Security Payload (ESP).
  - AH: Protects from attacks against Authenticity and Integrity.
  - ESP: Protects from attacks against Confidentiality
- What happens within the MANUFACTURER CLOUD? Which kind of data is stored, and for which purposes?



2. 5G Communications

5G Security Aspects:

2 - Human Exposure to Electromagnetic Radiations



- Special concern with millimeter waves due to extremely high Propagation losses.
- Existing legislation, based on studies, protects humans from Electromagnetic radiations:
  - Recommendation ITU-T. K-Series, "5G technology and human exposure to RF EMF," 2017
  - International Commission on Non-Ionizing Radiation Protection. Guidelines for limiting exposure to Electromagnetic Fields (100 kHz to 300 GHz), Health Physics 2020, 118(5), pp.483-524
  - Electronic Communications Committee (ECC), within the European Conference of Postal and Telecommunications Administrations (CEPT), Recommendation (02)04 (https://docdb.cept.org/download/d9aa1d17-0482/REC0202.PDF)
  - 1999/519/EC: Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz) (https://op.europa.eu/en/publication-detail/-/publication/9509b04f-1df0-4221-bfa2-c7af77975556/language-en)

2. 5G Communications

5G Security Aspects:

2 - Utilization of 5G Communications by Forces and Security Services (e.g., replacing TETRA)

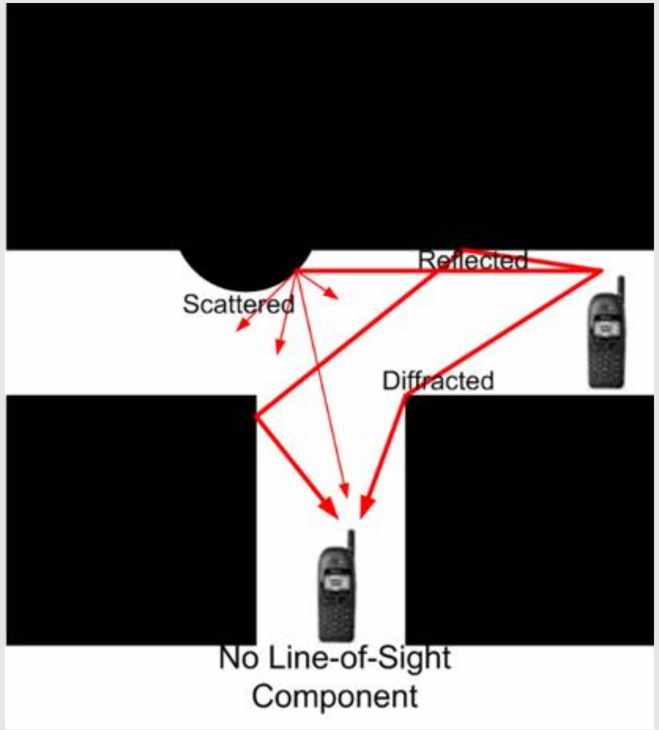
- TETRA is still a 2G System (very low data rates, used by policies, militaries, firefighters, etc.).

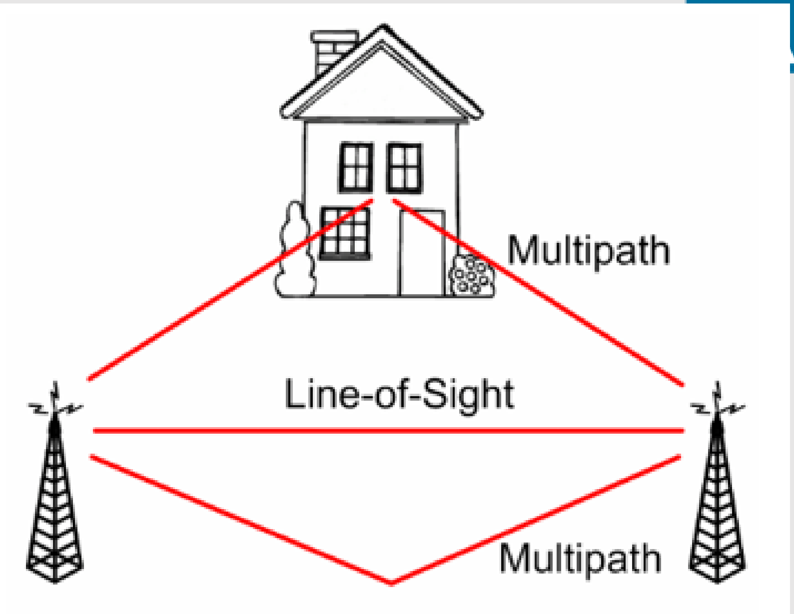
- Some Comms Requirements used by Security Forces:
  - ComSec (authenticity, integrity, confidentiality): IPv6: 5G OK
  - Direct mode of Operation [w/ relay]: Device-to-device Communication (without Base Station): 5G OK
  - Multicast & Broadcast: 5G OK
  - Priority of calls and fast setup

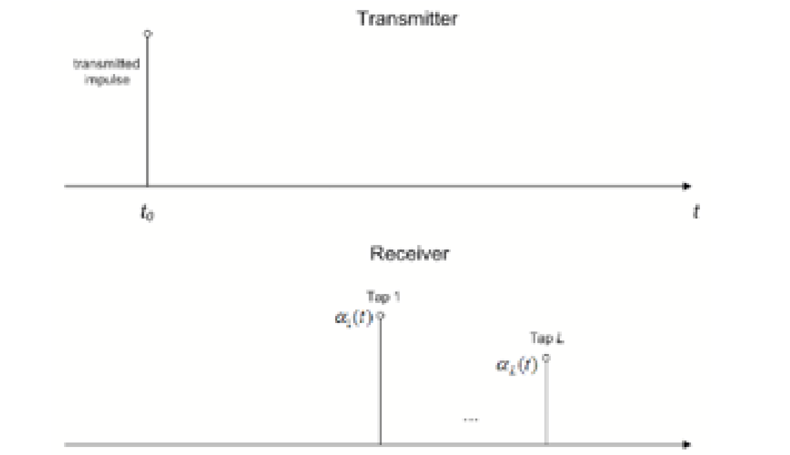
- 5G can also be used as a private network, such as Logistic Centers or Forces & Security Services.

- Network Slicing can be employed to reserve resources in public 5G network for creating private networks

- Virtualization and Software Defined Network (SDN), used in 5G, facilitates the customization of network, adapting to specific requirements.



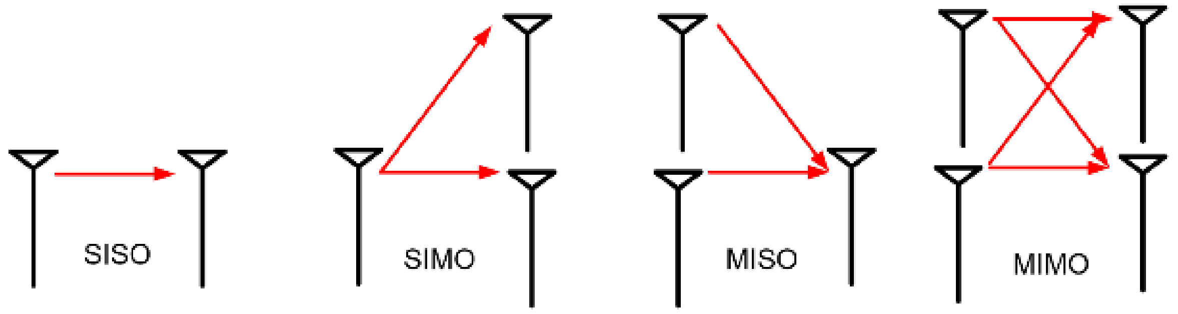




- **Higher Signal Bandwidth corresponds to higher Intersymbol Interference**
- **This is not only a matter of Spectrum**

MIMO Systems

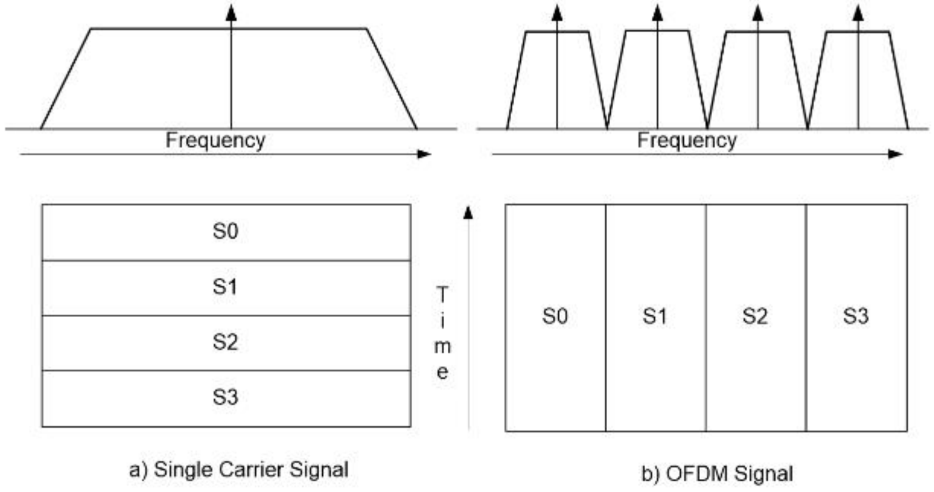
- The basic concept behind Multiple Input Multiple Output (MIMO) techniques relies on exploiting the multiple propagation paths of signals between multiple transmit (Input) and multiple receive (Output) antennas.
- In the case of frequency selective fading channel, different symbols suffer interference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



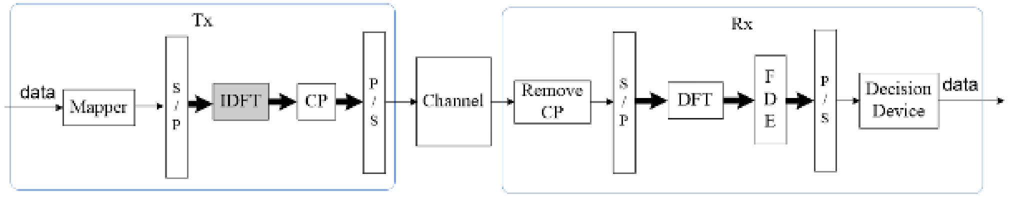
Multiple Antennas Configurations

OFDM

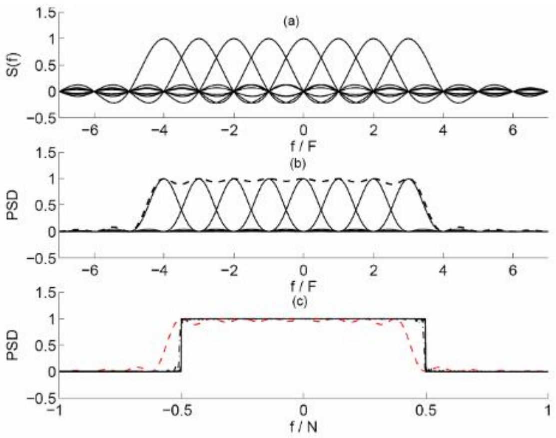
- Orthogonal Frequency Division Multiplexing (OFDM) is a transmission technique adopted by many high data rate communication systems such as IEEE 802.11n and IEEE 802.16e, being suitable for frequency selective fading channels.
- OFDM technique splits the symbols into several lower rate streams, which are then transmitted in orthogonal parallel sub-carriers. As a consequence, the symbol period is increased, making the signal less sensitive to ISI. To avoid interference between sub-carriers, the several streams are transmitted in orthogonal sub-carriers.
- To further improve the capabilities to combat ISI, it is added a cyclic prefix to each sub-stream, being removed at the receiver side, and each stream is independently subject to equalization.
- OFDM signals are commonly generated by computing the N-point IFFT, where the input of the IFFT is the frequency domain representation of OFDM signal. The output of the IFFT is the time domain representation of the OFDM signal, the N-point IFFT out is defined as a useful OFDM symbol. This "time domain" OFDM signal is composed of N sub-carriers.



Spectrum of a) Single Carrier signal versus b) OFDM signal



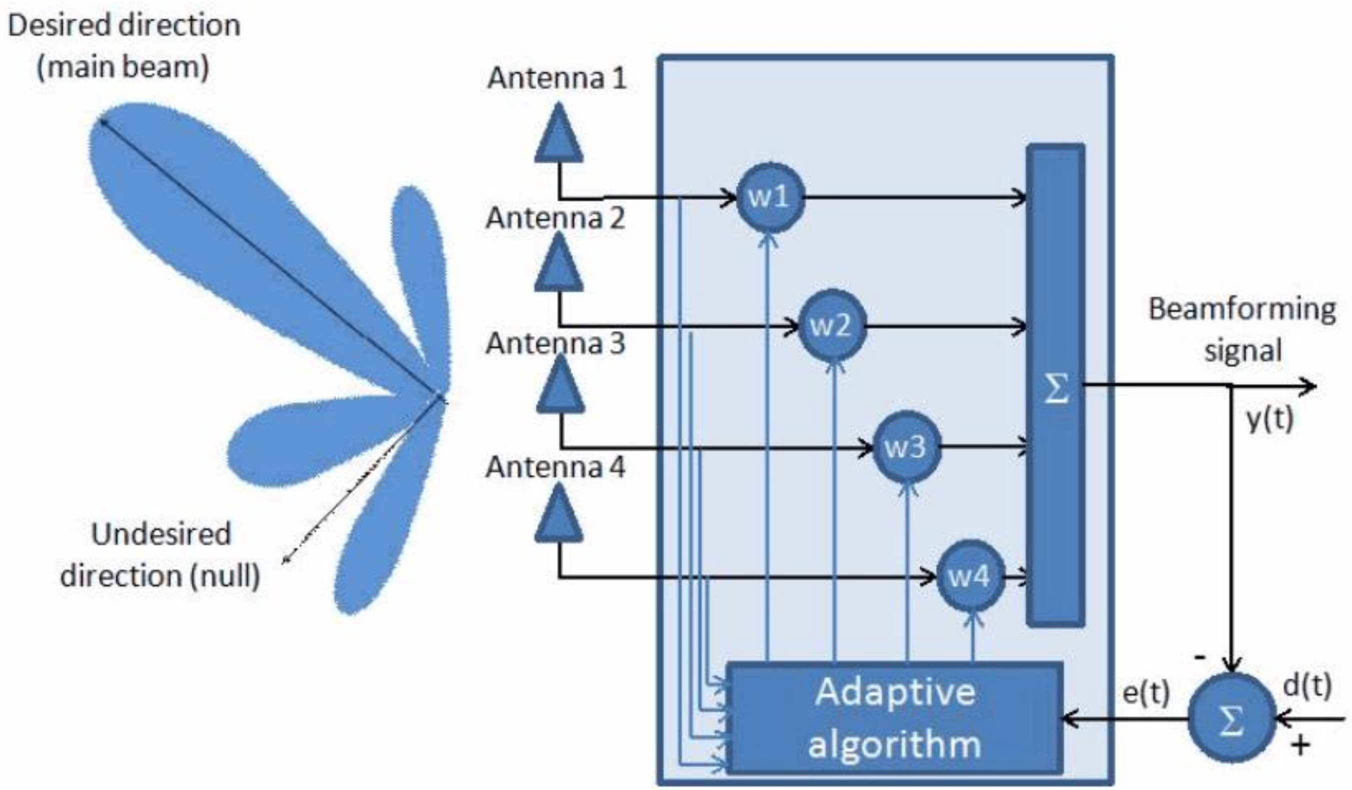
Generic transmission chain for OFDM



Transmitted OFDM signal: (a) individual sub-carriers; (b) PSD of sub-carriers and envelope; (c) PSD of envelope signal

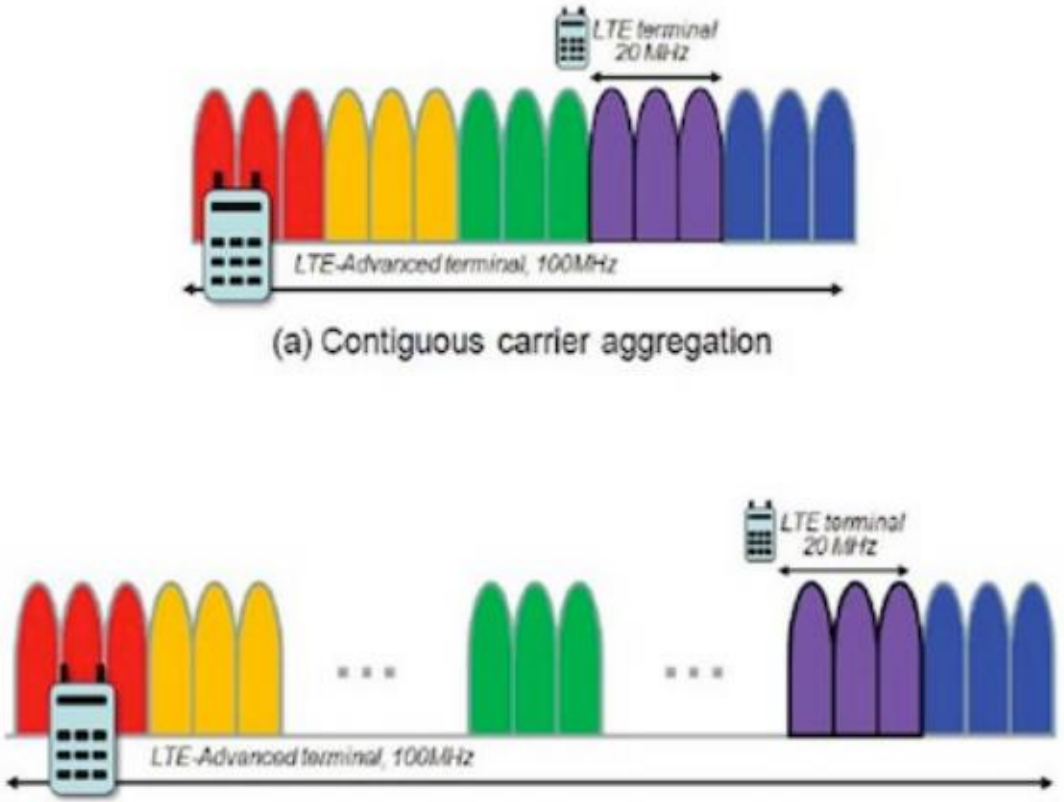
Beamforming

- 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.



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.
  - 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.



(a) Contiguous carrier aggregation

(b) Non-contiguous carrier aggregation

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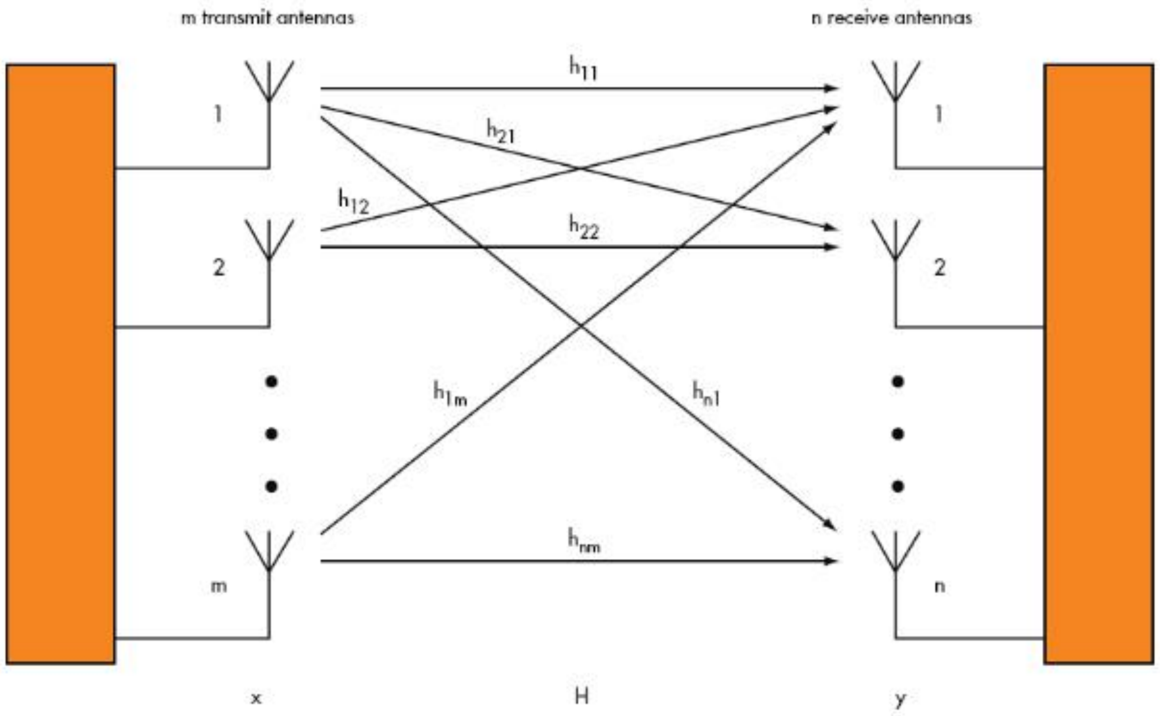

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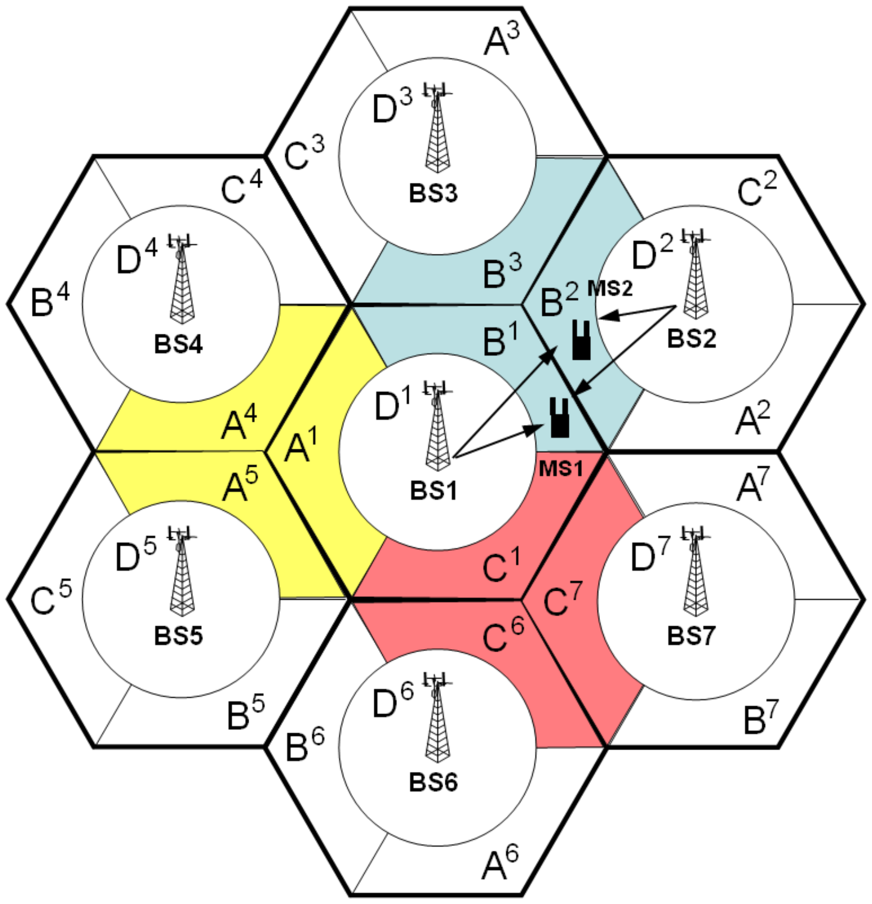
Base Station Cooperation

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



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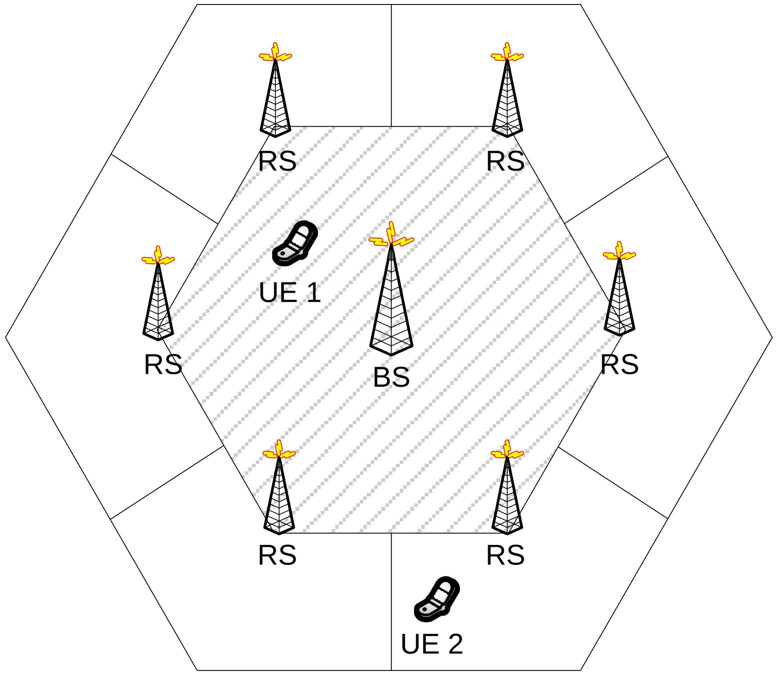
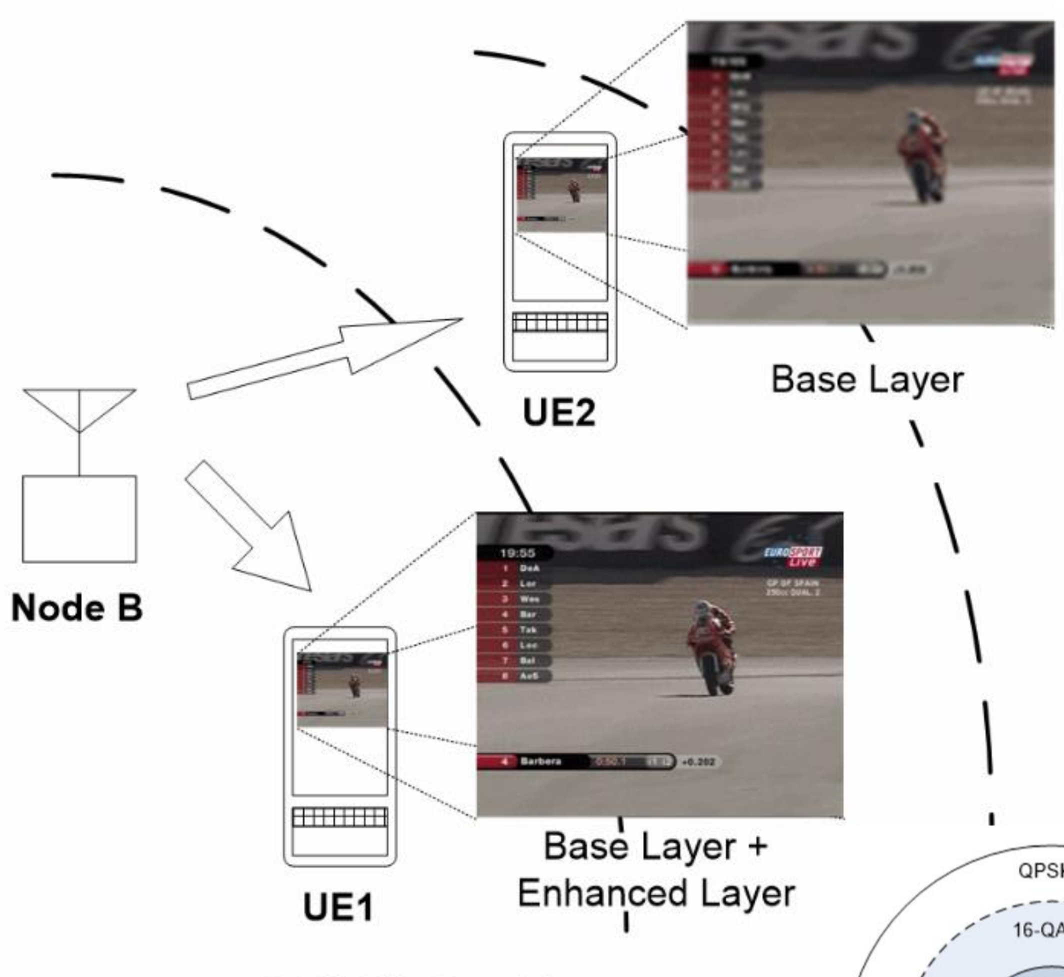
Multi-Hop Relay

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

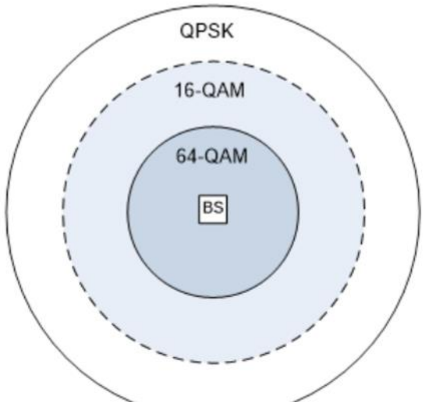


Multi-Resolution Tx Techniques

- With Multimedia Broadcast and Multicast Service (MBMS), it makes sense to have two or more classes of bits with different error protection, to which different streams of information can be mapped.
- Depending on the propagation conditions, a given user can attempt to demodulate only the more protected bits or also the other bits that carry the additional information.
- Using non-uniformly spaced signal points in hierarchical modulations we modify the different error protection levels.
- Multi-resolution techniques are interesting for applications where the data being transmitted is scalable, that is, it can be split into classes of different importance.
- Multi-resolution in a broadcast cellular system deals with source coding and transmission of output data streams.
- Scalable video, provides a base layer for minimum requirements, and one or more enhancement layers to offer improved quality at increasing bit/frame rates and resolutions.



Scalable Video Transmission



Agenda

1. The Digital Transformation
2. 5G Communications
3. **Future Evolutions & NOMA**
4. 6G Communications

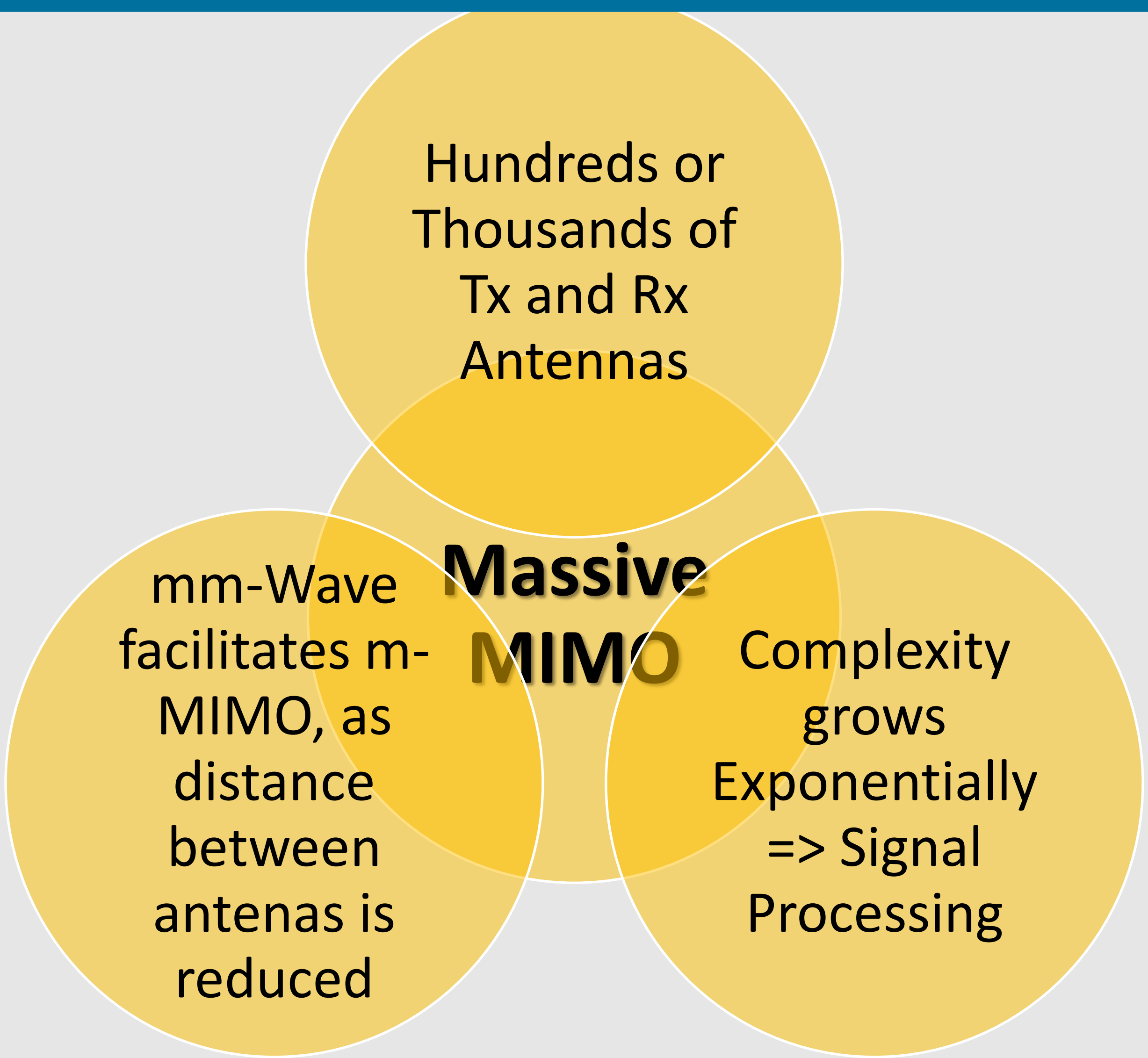
3. Future Evolutions & NOMA

HOW TO ACHIEVE 5G?

- **Massive MIMO**
- **Millimeter Waves**
- Base Station Coperation
- Multi-hop Relay
- All-over IP
- Block Transmission Techniques (OFDM & NOMA)
- Adaptive Modulation & Coding
- Multi-Resolution Techniques
- Carrier Aggregation

O Novo Paradigma das Comunicações 5G

3. Future Evolutions & NOMA



3. Future Evolutions & NOMA

mm-Wave and Massive MIMO

(Large Capacity Gains)

mm-Wave communications (30-300GHz - EHF) are 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.

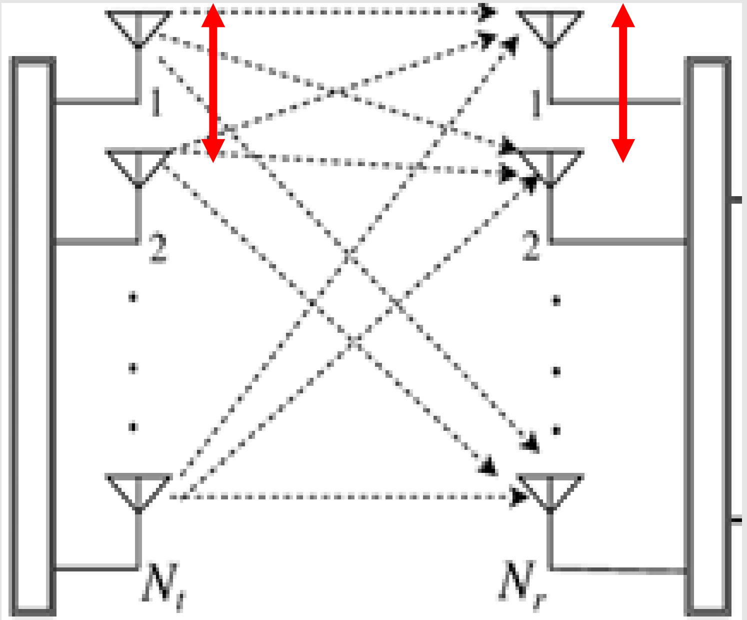
The **distance between antennas is reduced**, facilitating a higher number of antenna elements (Massive MIMO).

Moreover, antennas size are also reduced.

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

Moreover, **higher frequencies present higher propagation path losses.**

5G will overcome this problem with m-MIMO techniques, such as beamforming.



$$c = \lambda \cdot f$$

$$\lambda = c / f$$

$$with\ f = 60\ GHz$$

$$\lambda = \frac{3\times10^8}{60\times10^9} = \frac{1}{200} = 0,005\ m = 5\ mm$$

3. Future Evolutions & NOMA

$$y'_n = y_{u,n} - \sum_{i=1}^{U'} \hat{y}_{i,n} ,$$

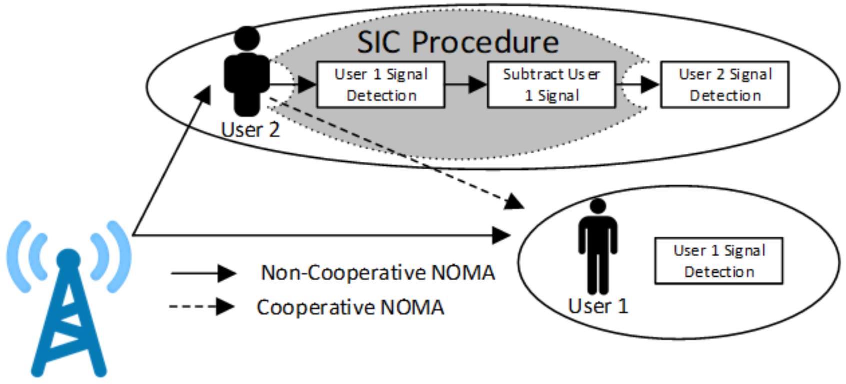


Figure 3 Illustration of NOMA and Cooperative NOMA

NOMA

Non-Orthogonal Multiple Access

- Due to the **near–far problem and power control, the received power of different users suffers variations**.
- By **exploiting different power levels, NOMA aims to serve multiple users sharing spectrum and time**, leading to an **improved spectral efficiency** when compared with OFDMA.
- By employing SIC and detecting users' signals in descending order, NOMA can detect different users that **share the same time and frequency**.
- NOMA leads to a **higher channel capacity**, especially useful in scenarios with extremely high numbers of mobile terminals, such as in 5G use cases with **mMTC or URLLC**.

3. Performance Results

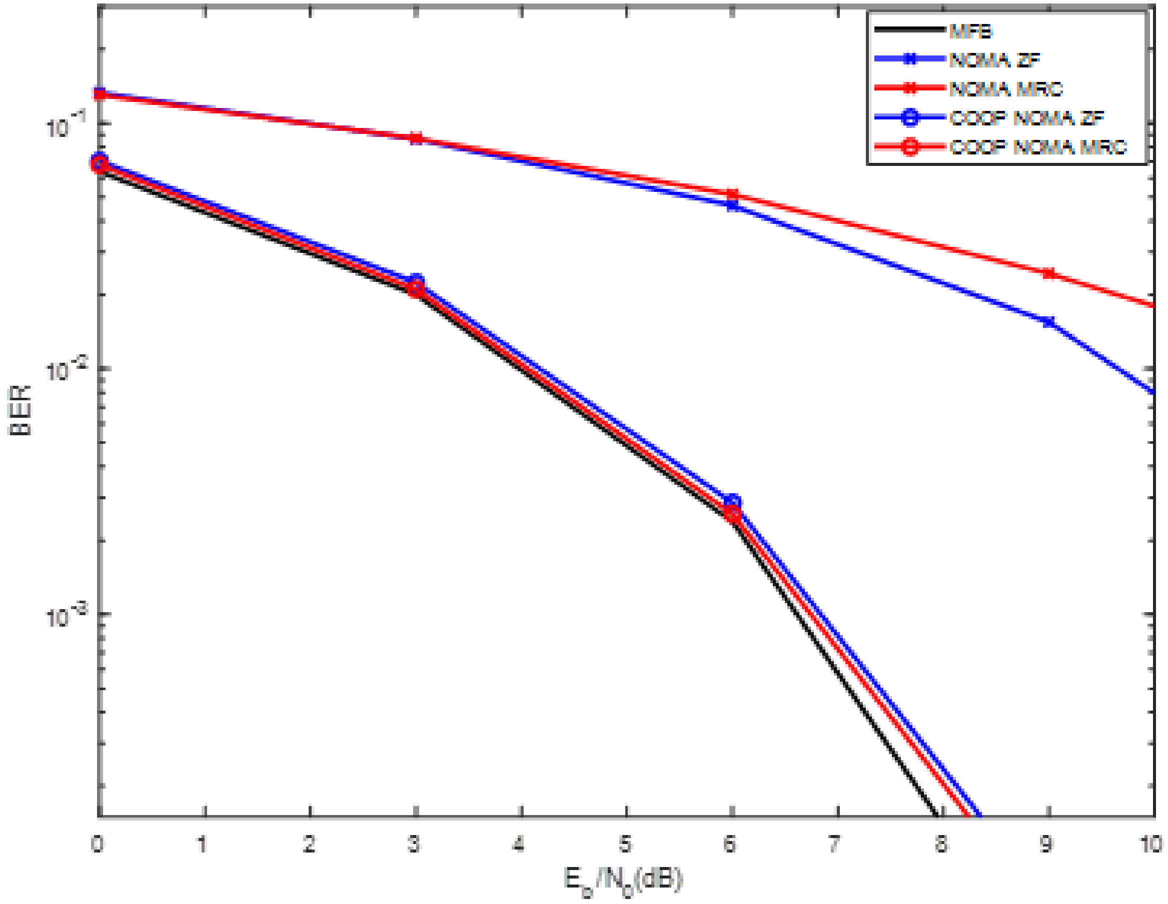


FIGURE 3 – RESULTS FOR 2 NOMA USERS WITH POWERS [1 0.5], 4X32 MIMO

NOMA Simulation Results

3. Performance Results

NOMA Simulation Results

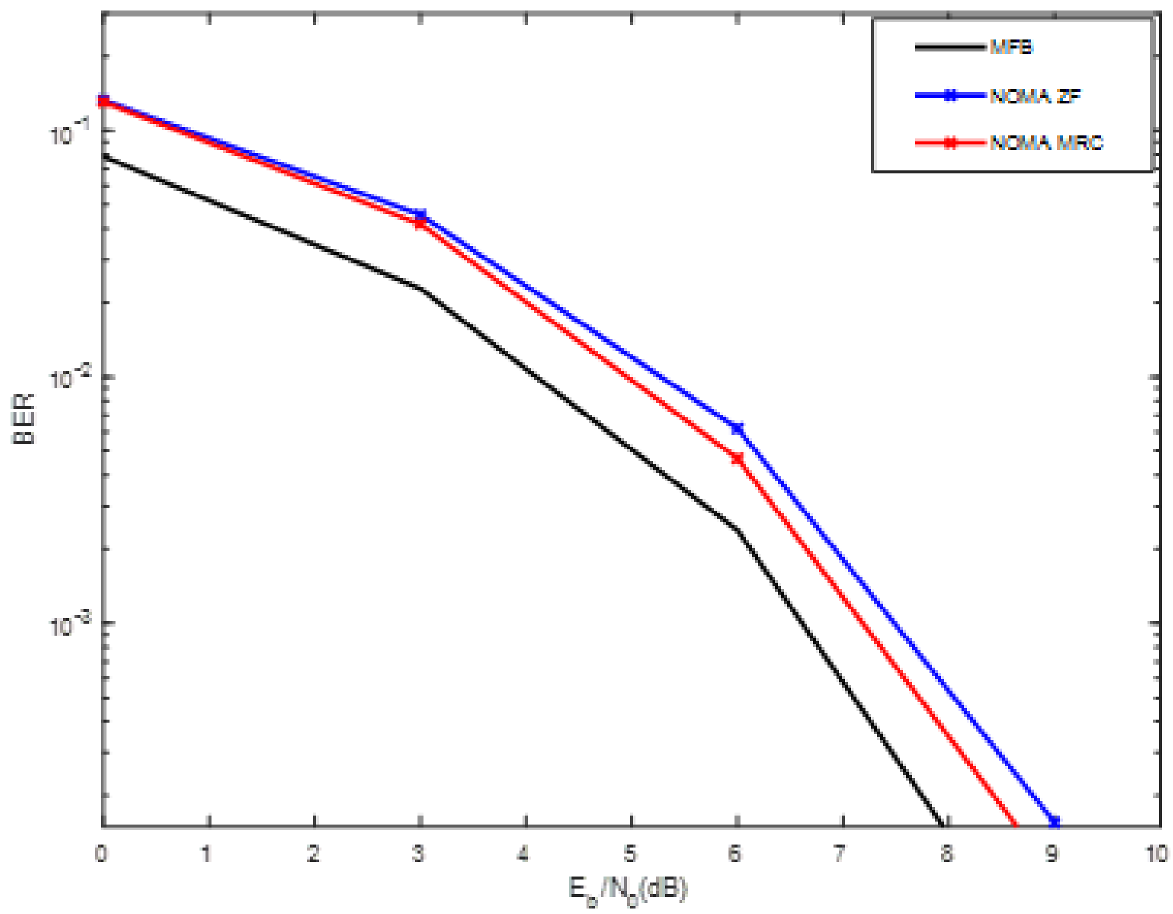


FIGURE 4 – RESULTS FOR 2 NOMA USERS WITH POWERS [0.5 1], 4X32 MIMO

3. Performance Results

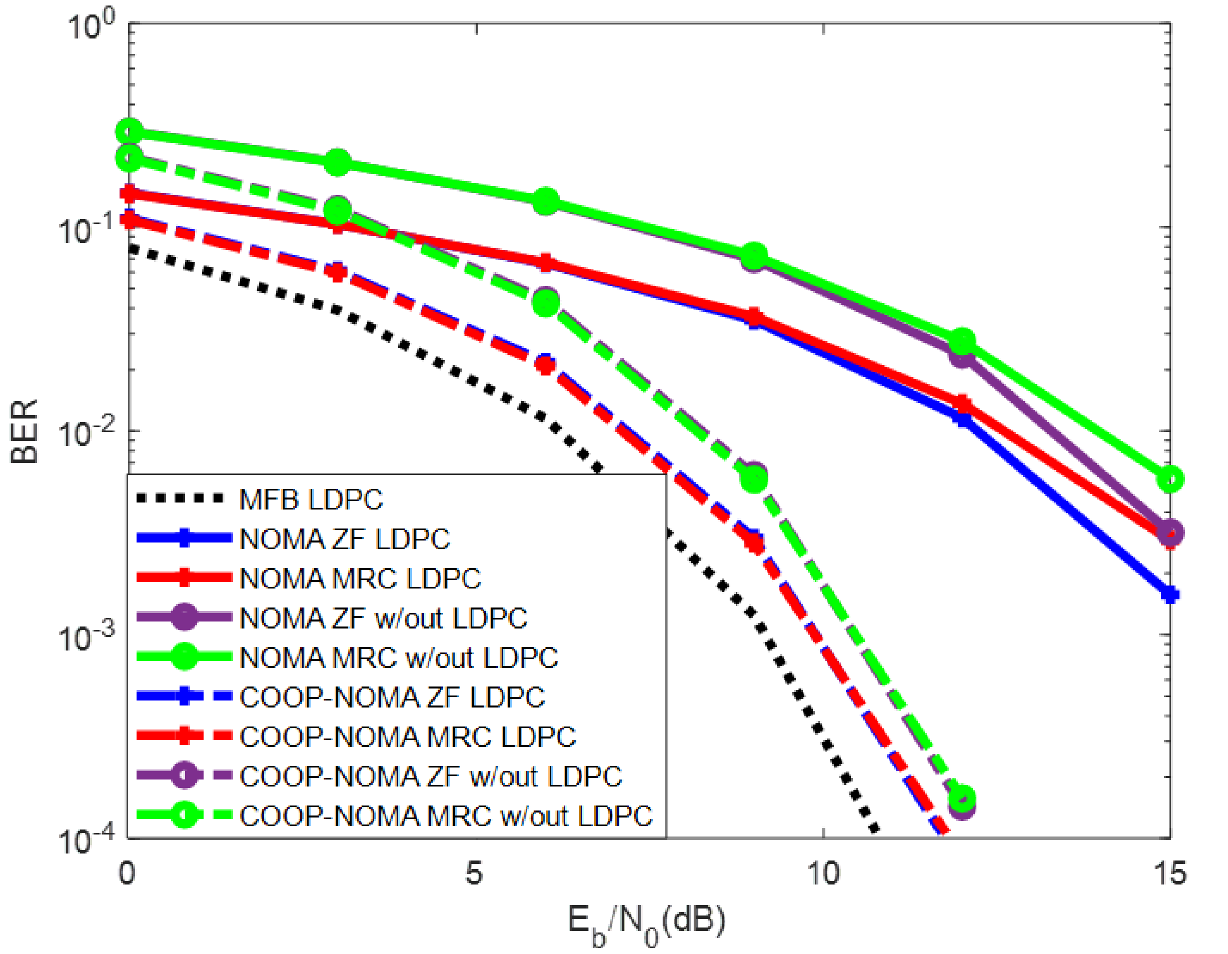


Figure 5. Results for 3 NOMA users with powers [1 0.5 2], with 8X64 MIMO (with and without LDPC codes).

NOMA Simulation Results with/without LDPC

3. Performance Results

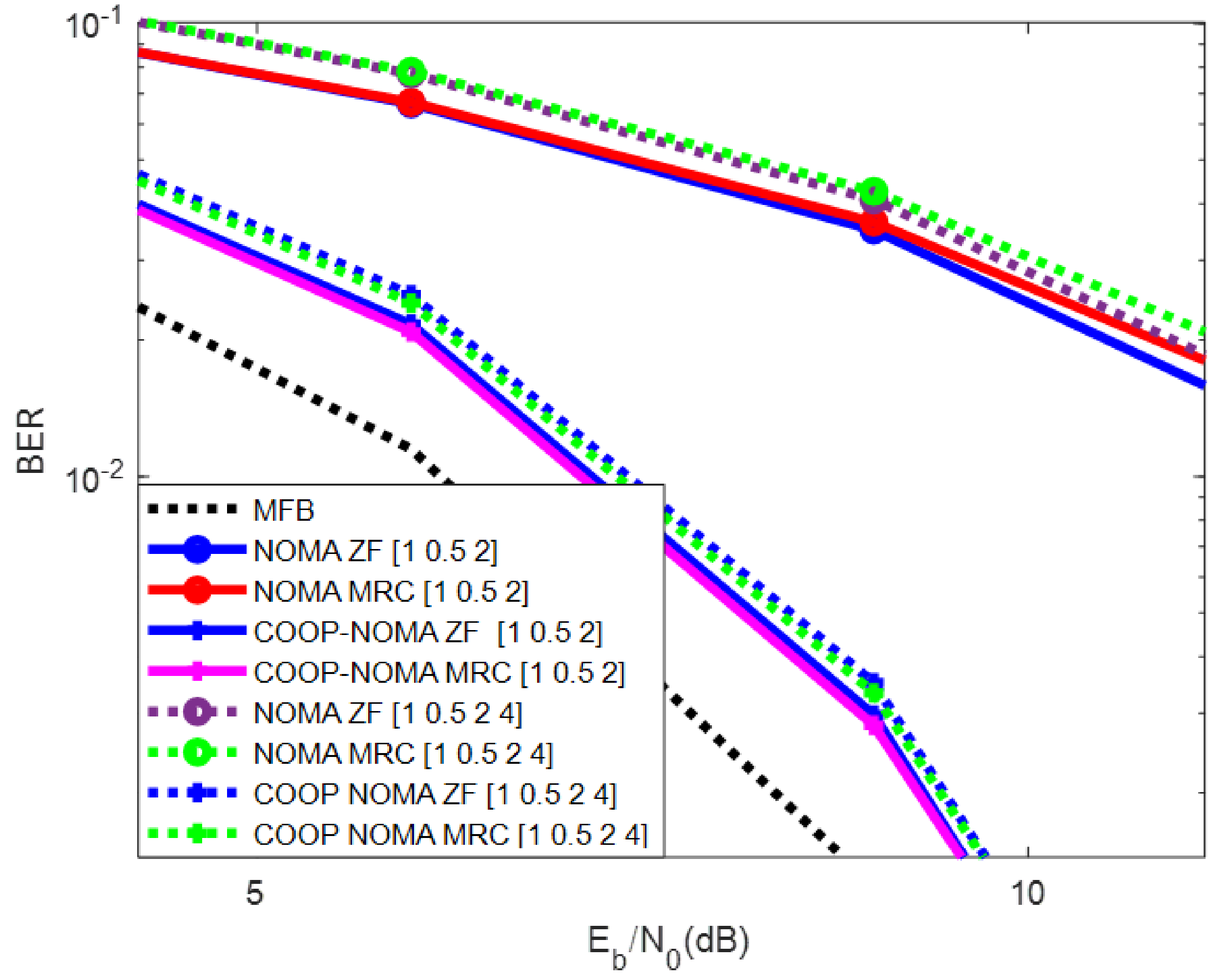


Figure 7. Results for 3 and 4 NOMA users, with 8X64 MIMO, with LDPC codes.

NOMA Simulation Results

Agenda

1. The Digital Transformation
2. 5G Communications
3. Future Evolutions & NOMA
4. **6G Communications**

4. 6G Communications

- 5G focus on the initial requirements of the 4th Industrial Revolution.
- 6G (2030) aims to improve such implementation.
- The digital society of 2030 and beyond, comprises more and more connected devices (IoT), including sensors, vehicles, aerial drones, and data.
- 6G aims to consider:
  - **Augmented Reality (AR) and Extended Reality (XR)**
  - **Artificial Intelligence (AI) infused applications**
  - Wireless Brain-Computer Interactions (BCI)
  - **Holographic services**
  - The integration of communications with localization, mapping and remote control
  - Emerging eHealth applications
  - **Improved autonomous vehicles**
  - More efficient support of IoT, namely smart cities and smart houses, supporting extremely high number of low-power devices
  - Support of flying vehicles and increased mobility speed

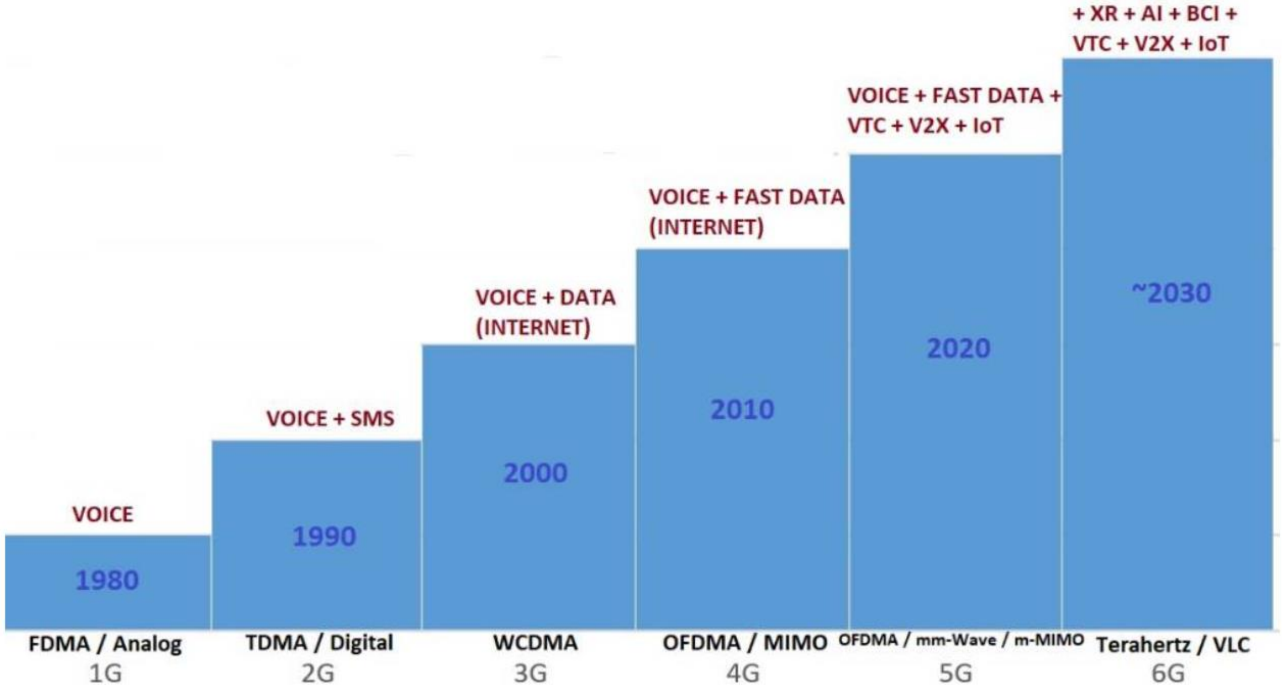


Figure 8. Evolution of cellular generations.

Perspectives for 6G

- Some of the **foreseen requirements** for 6G include:
  - Nomadic peak data rate of at least 1 Tbps (100 times higher than 5G)
  - Mobile data rate of 1 Gbps (10 times higher than 5G)
  - Energy efficiency 10 to 100 times better than 5G
  - Spectral efficiency 5 to 10 times better than 5G
- While 5G requirements are achieved based on mm-Wave and m-MIMO, 6G must incorporate new concepts and frequency bands not yet considered for cellular communications.
  - This includes **Visible Light Communications** (VLC) and **Terahertz bands** (100 GHz – 10 THz).

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Special Issue "Massive MIMO Systems for 5G and beyond Networks: Latest Advances and Prospects"

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A special issue of *Applied Sciences* (ISSN 2076-3417). This special issue belongs to the section "Electrical, Electronics and Communications Engineering".

Deadline for manuscript submissions: **31 January 2022**.

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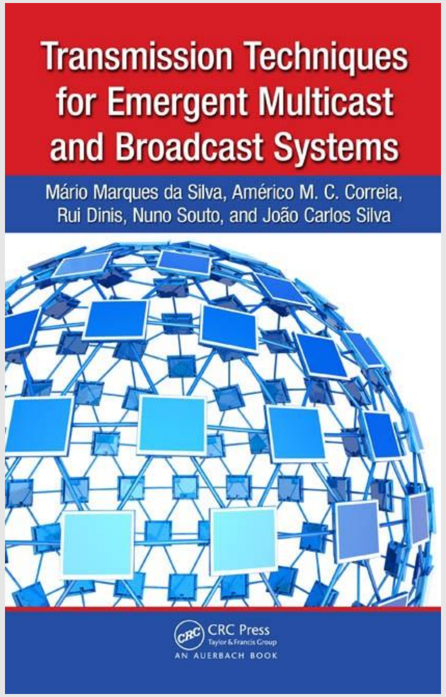
Special Issue Editor

Prof. Dr. Mario Marques Da Silva E-Mail Website SciProfiles
Guest Editor
1. Institute of Telecommunications, 1049-001 Lisboa, Portugal;
2. Department of Sciences and Technologies, Autonoma University of Lisbon, 1150-293 Lisboa, Portugal
Interests: cellular communications; 5G and beyond; massive-MIMO; millimeter-wave communications; block transmission techniques; NOMA

Special Issue Information

Dear Colleagues,

Transmission techniques, such as massive multiple-input multiple-output (MIMO), non-orthogonal multiple access (NOMA), block transmission techniques, or millimeter-wave communications (mm-Wave) are expected to be a crucial part of 5G (Fifth Generation) systems and beyond. Similar techniques are being adopted by IEEE 802.11 standards,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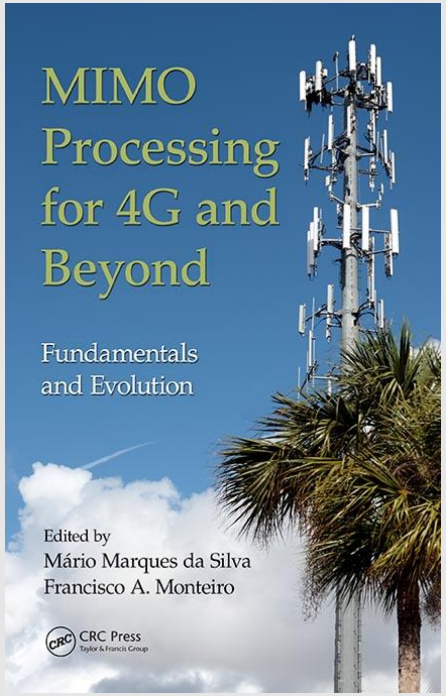
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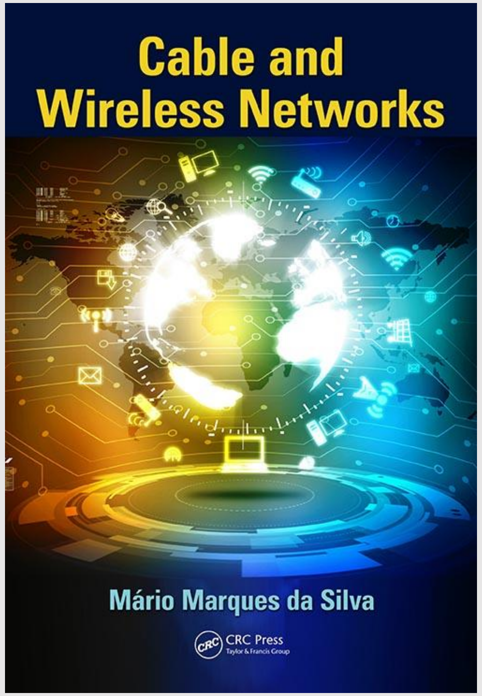
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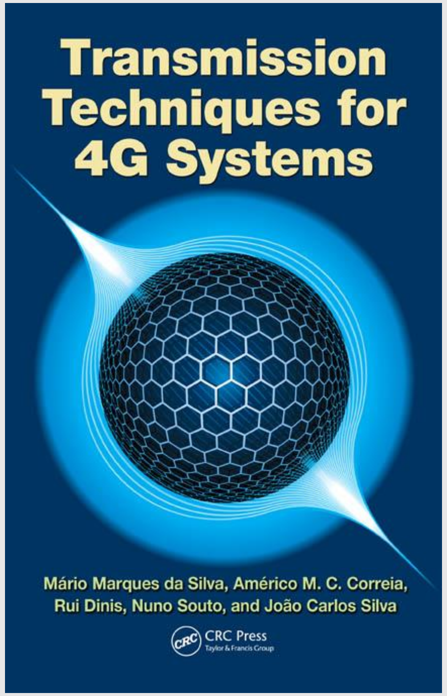
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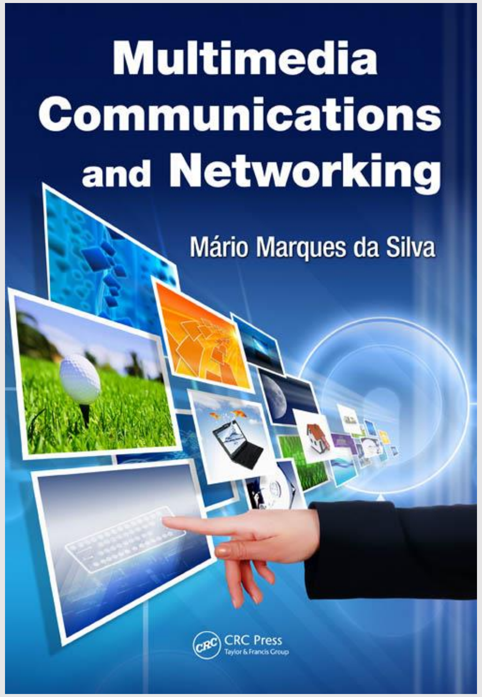
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