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FUTURE 6G SYSTEMS AND BEYOND
TRANSMISSION TECHNIQUES FOR FUTURE 6G SYSTEMS
Mário Marques da Silva
Universidade Autónoma de Lisboa & Instituto de Telecomunicações
6G: VISION, REQUIREMENTS, TECHNICAL CHALLENGES, STANDARDIZATION & IMPLEMENTATIONS
Shahid Muntaz
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AGE-AWARE GREEN UAV WIRELESS NETWORKS
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A LOOK BEYOND MASSIVE MIMO – WORKING WITH A HUGE NUMBER OF ANTENNAS
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Transmission Techniques for Future 6G Systems

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Fundação para a Ciência e a Tecnologia

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

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Article

On the 5G and Beyond

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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 MDPI

Article

Power-Ordered NOMA with Massive MIMO for 5G Systems

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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.

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

Citation: Marques da Silva, M.; Dinis, R. Power-Ordered NOMA with Massive MIMO for 5G Systems. *Appl. Sci.* 2021, *11*, 3541. https://doi.org/10.3390/app11083541

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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)

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Article

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

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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.

Reference

- Ali Gashtasbi, Mário Marques da Silva, and Rui Dinis. "IRS, LIS, and Radio Stripes-Aided Wireless Communications: A Tutorial" MDPI, Applied Sciences 12, no. 24: 12696; **11 December 2022**; https://doi.org/10.3390/app122412696

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Tutorial

IRS, LIS, and Radio Stripes-Aided Wireless Communications: A Tutorial

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Abstract: This is a tutorial on current techniques that use a huge number of antennas in intelligent reflecting surfaces (IRS), large intelligent surfaces (LIS), and radio stripes (RS), highlighting the similarities, differences, advantages, and drawbacks. A comparison between IRS, LIS, and RS is performed in terms of the implementation and capabilities, in the form of a tutorial. We begin by introducing the IRS, LIS, and RS as promising technologies for 6 G wireless technology. Then, we will look at how the three notions are applied in wireless networks. We discuss various performance indicators and methodologies for characterizing and improving the performance of IRS, LIS, and RS-assisted wireless networks. We cover rate maximization, power consumption reduction, and cost implementation concerns in order to take advantage of the performance increase. Furthermore, we extend the discussion to some cases of emerging use. In the description of the three concepts, IRS-assisted communication was introduced as a passive system, considering the capacity/data rate, with power optimization being an advantage, while channel estimation was a challenge. LIS is an active component that goes beyond massive MIMO; a recent study found that channel estimation issues in IRS had improved. In comparison to IRS, capacity enhancement is a highlight, and user interference showed a trend of decreasing. However, power consumption due to utilizing power amplifiers has restrictions. The third technique for increasing coverage is cell-free massive MIMO with RS, with easy deployment in communication network structures. It is demonstrated to have suitable energy efficiency and power consumption. Finally, for future work, we further propose expanding the conversation to include some cases of new uses, such as complexity reduction; design and simulation with LDPC code could be a solution to decreasing complexity.

Keywords: IRS; LIS; RS; 6 G

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Citation: Gashtasbi, A.; da Silva, M.M.; Dinis, R. IRS, LIS, and Radio Stripes-Aided Wireless Communications: A Tutorial. *Appl. Sci.* 2022, *12*, 12696. https://doi.org/10.3390/app122412696

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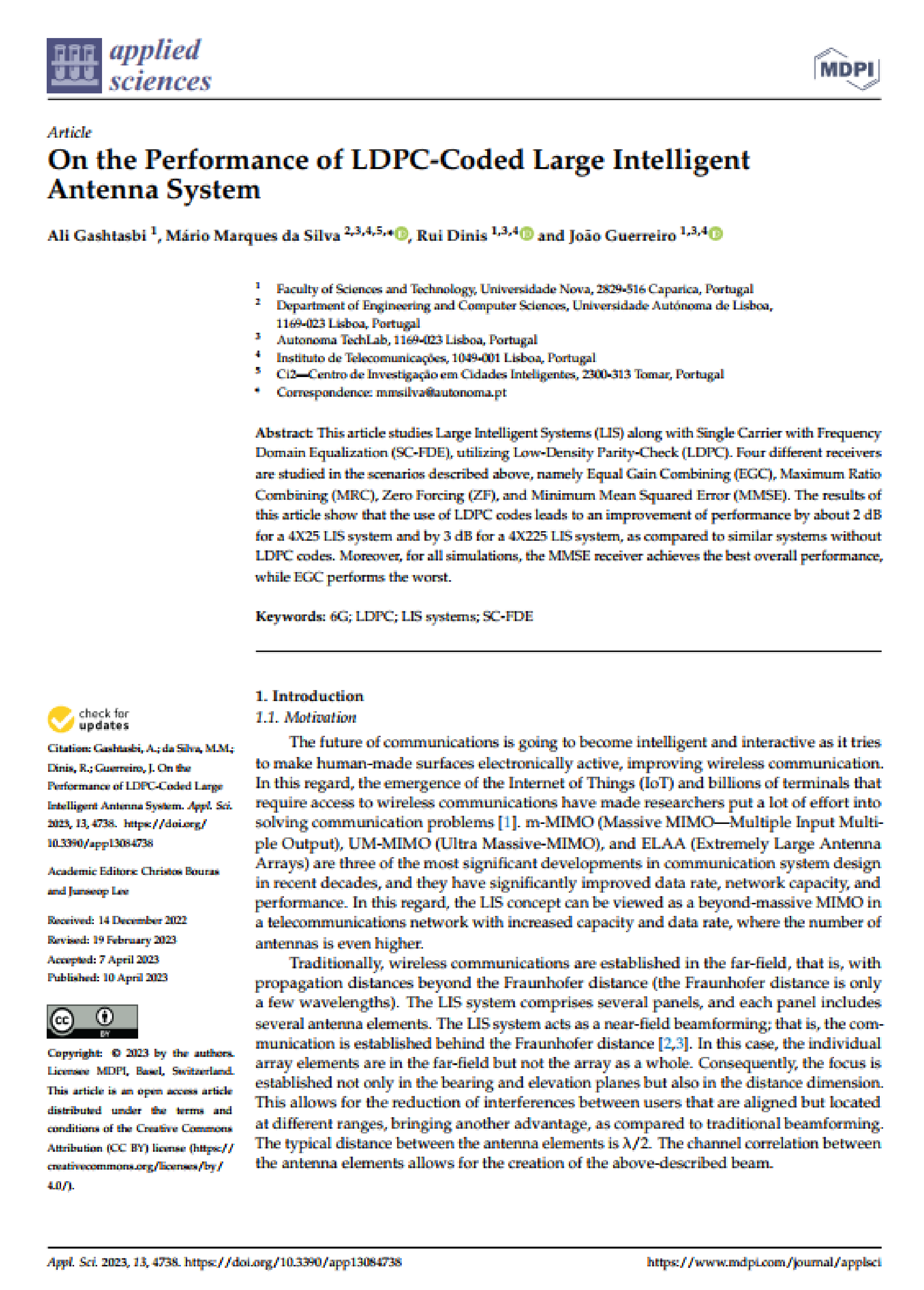
1. Introduction

1.1. Motivation

The fifth generation (5 G) telecommunications network structure has been developed and deployed. With the increasing popularity of Internet of Things (IoT) adoption among users, it is urgent to upgrade the existing working network to 6 G [1]. While improving the new design, attention to the needs of the users is expected. It includes increased capacity, higher data rates, increased bandwidth, less interference, the highest quality of service (QoS) for users, and low-cost implementation for operators [2]. This optimization is created on the side of the base station by increasing the number of antennas using MIMO, cell-free MIMO technology, and also using low-power small cells in a dense network. Therefore, designers are looking for three new techniques—IRS, LIS, and radio stripes—to deploy in the network. Intelligent reflecting surfaces (IRS) have piqued the interest of academics and businesses as a possible early-stage technology [3]. Usually, a wireless cellular communications network uses transceiver end-point transmission techniques to limit or use

Reference

- Ali Gashtasbi, Mário Marques da Silva, Rui Dinis, and João Guerreiro. "On the Performance of LDPC-Coded Large Intelligent Antenna System" MDPI, Applied Sciences Vol. 13, no. 8: 4738; **April 2023**; https://doi.org/10.3390/app13084738



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Article

On the Performance of LDPC-Coded Large Intelligent Antenna System

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Abstract: This article studies Large Intelligent Systems (LIS) along with Single Carrier with Frequency Domain Equalization (SC-FDE), utilizing Low-Density Parity-Check (LDPC). Four different receivers are studied in the scenarios described above, namely Equal Gain Combining (EGC), Maximum Ratio Combining (MRC), Zero Forcing (ZF), and Minimum Mean Squared Error (MMSE). The results of this article show that the use of LDPC codes leads to an improvement of performance by about 2 dB for a 4X25 LIS system and by 3 dB for a 4X225 LIS system, as compared to similar systems without LDPC codes. Moreover, for all simulations, the MMSE receiver achieves the best overall performance, while EGC performs the worst.

Keywords: 6G; LDPC; LIS systems; SC-FDE

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Citation: Gashtasbi, A.; da Silva, M.M.; Dinis, R.; Guerreiro, J. On the Performance of LDPC-Coded Large Intelligent Antenna System. *Appl. Sci.* 2023, 13, 4738. https://doi.org/10.3390/app13084738

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1. Introduction

1.1. Motivation

The future of communications is going to become intelligent and interactive as it tries to make human-made surfaces electronically active, improving wireless communication. In this regard, the emergence of the Internet of Things (IoT) and billions of terminals that require access to wireless communications have made researchers put a lot of effort into solving communication problems [1]. m-MIMO (Massive MIMO—Multiple Input Multiple Output), UM-MIMO (Ultra Massive-MIMO), and ELAA (Extremely Large Antenna Arrays) are three of the most significant developments in communication system design in recent decades, and they have significantly improved data rate, network capacity, and performance. In this regard, the LIS concept can be viewed as a beyond-massive MIMO in a telecommunications network with increased capacity and data rate, where the number of antennas is even higher.

Traditionally, wireless communications are established in the far-field, that is, with propagation distances beyond the Fraunhofer distance (the Fraunhofer distance is only a few wavelengths). The LIS system comprises several panels, and each panel includes several antenna elements. The LIS system acts as a near-field beamforming; that is, the communication is established behind the Fraunhofer distance [2,3]. In this case, the individual array elements are in the far-field but not the array as a whole. Consequently, the focus is established not only in the bearing and elevation planes but also in the distance dimension. This allows for the reduction of interferences between users that are aligned but located at different ranges, bringing another advantage, as compared to traditional beamforming. The typical distance between the antenna elements is $\lambda/2$. The channel correlation between the antenna elements allows for the creation of the above-described beam.

Agenda

1. The Digital Transformation

2. 5G Communications

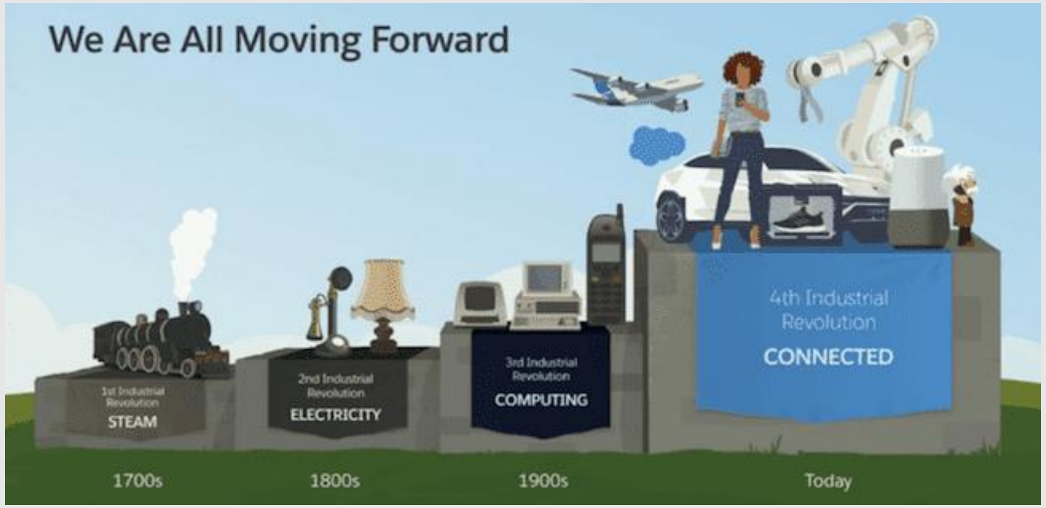
3. 6G Communications

Agenda

1. **The Digital Transformation**
2. 5G Communications
3. 6G Communications

1. The Digital Transformation

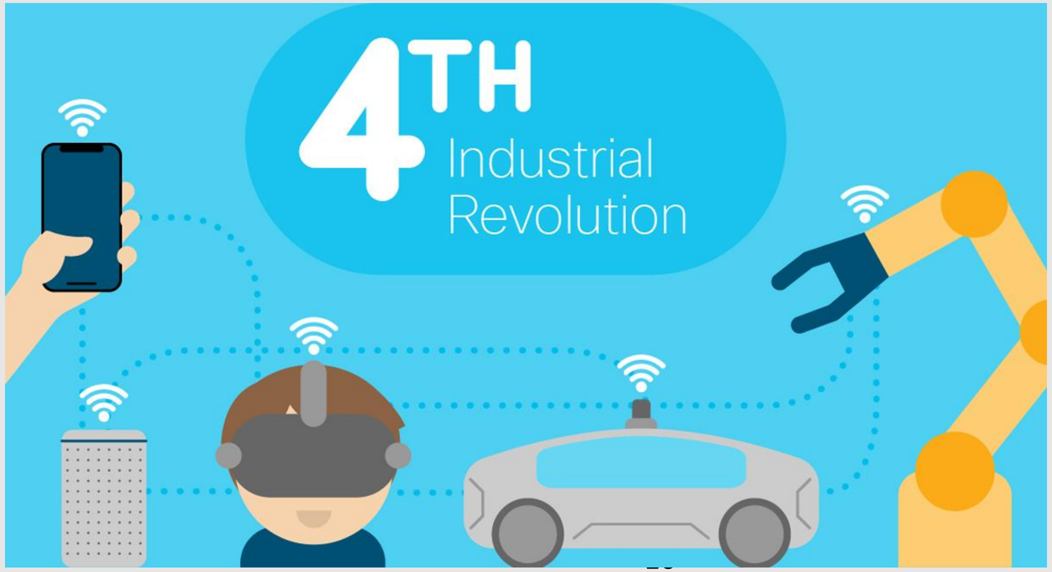
What is "Digital Transformation"?



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

} 3rd Industrial Revolution *Information Age*

- **Phase 3: Automation** || 4th Industrial Revolution - *Knowledge Age*
    - *ChatGPT versus static information*



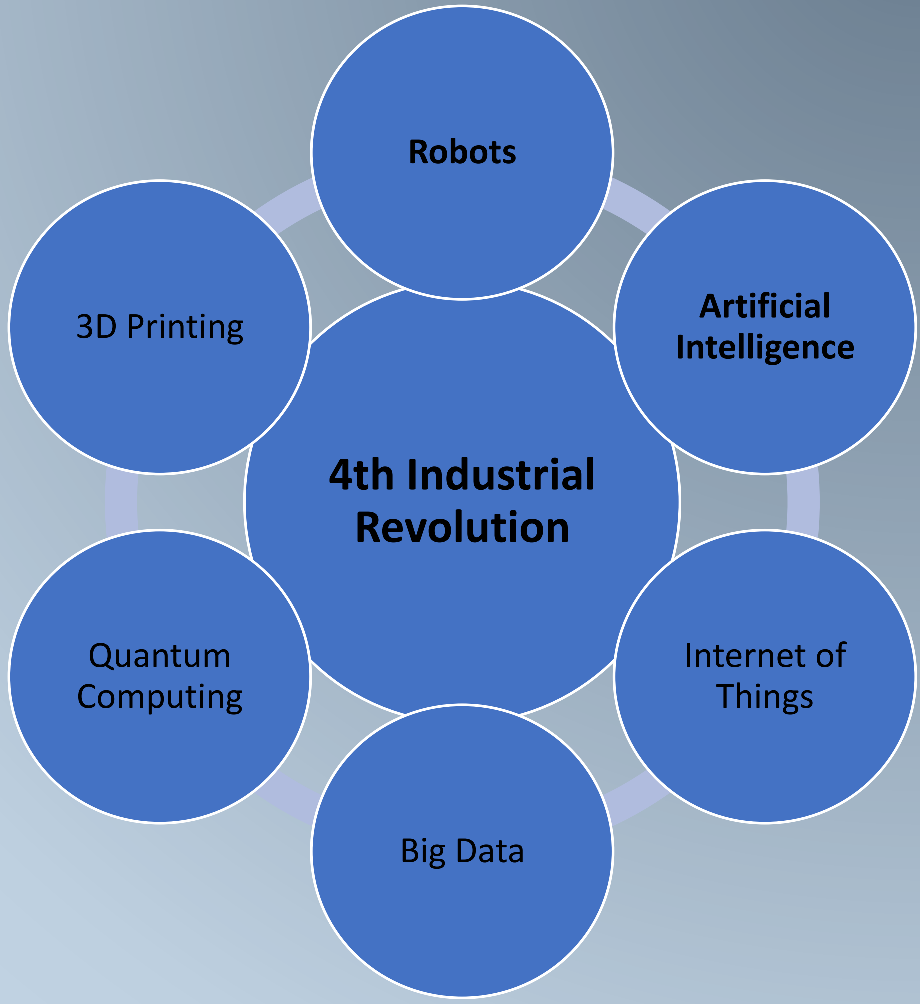
1. The Digital Transformation

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

More **efficient use of the Resources**.

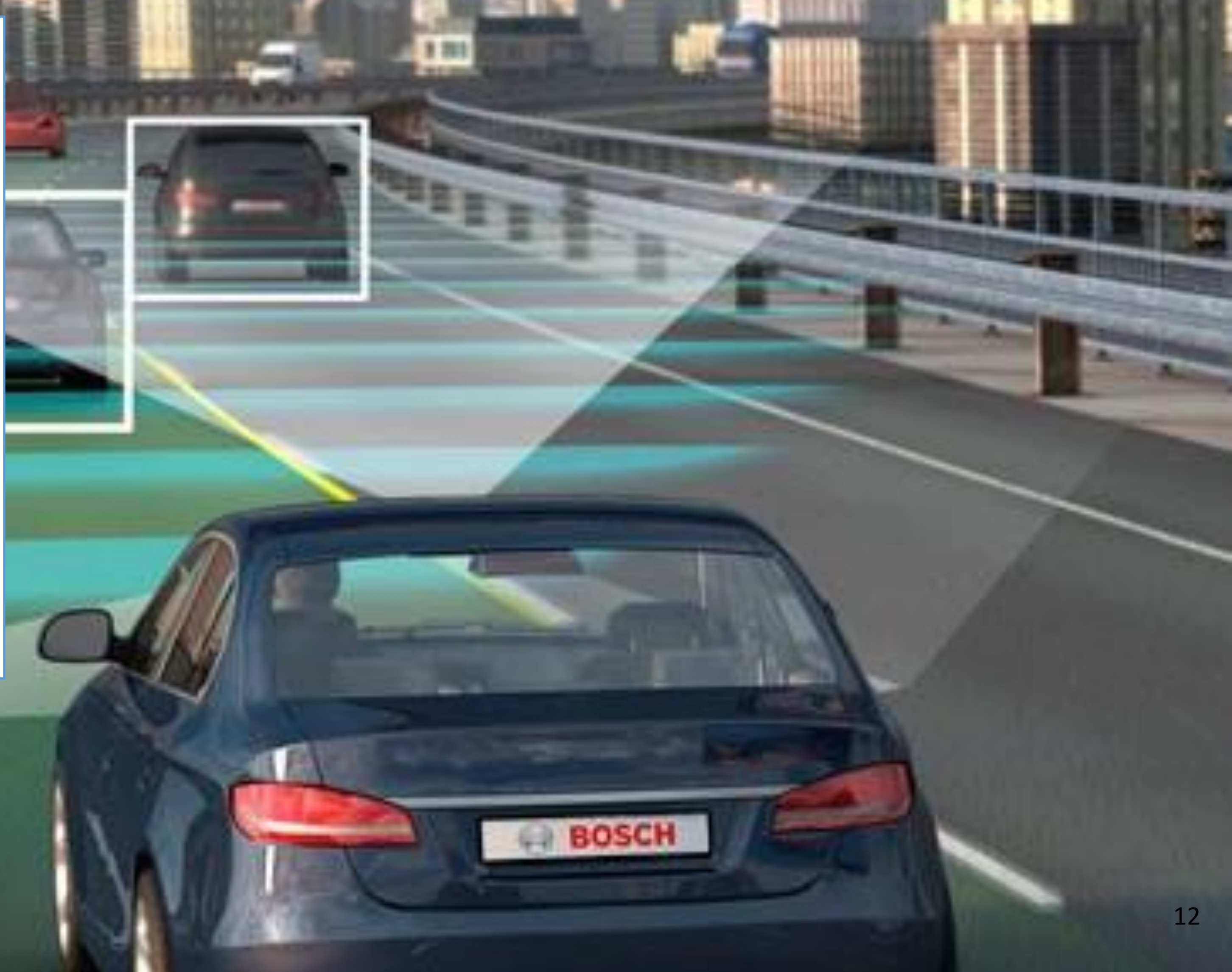
These technologies potentiate the **replacement of Humans by Robots** in diferent areas.

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

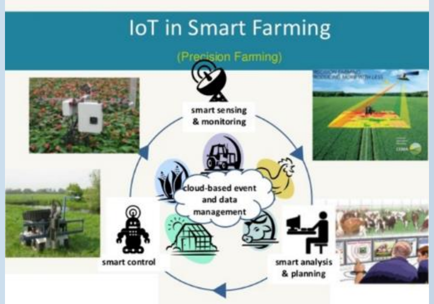


4th Industrial Revolution

- **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**

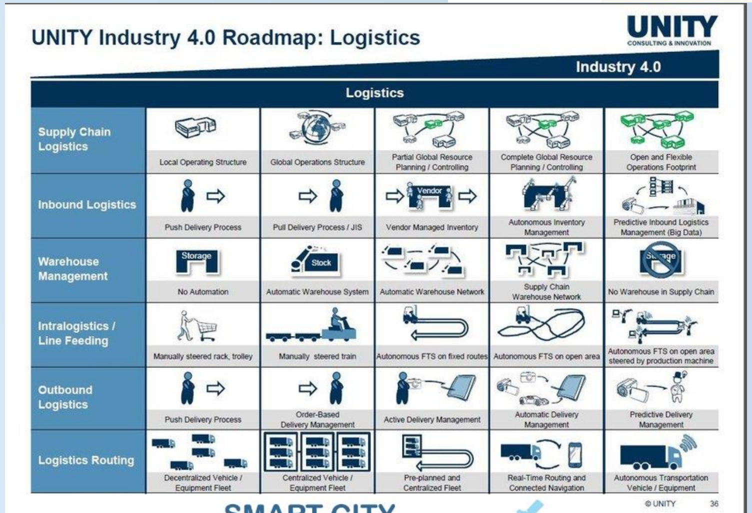


1. The Digital Transformation



Higher dependency from Cybersecurity, but with new Cybersecurity Solution

Under the Skin Surveillance



UNITY Industry 4.0 Roadmap: Logistics

UNITY CONSULTING & INNOVATION

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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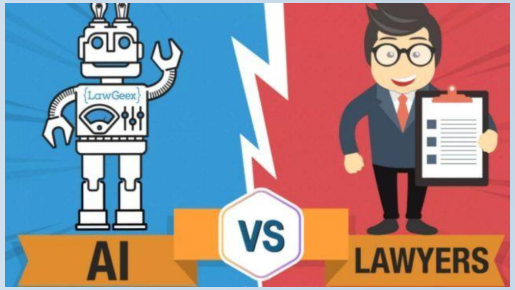


Agenda

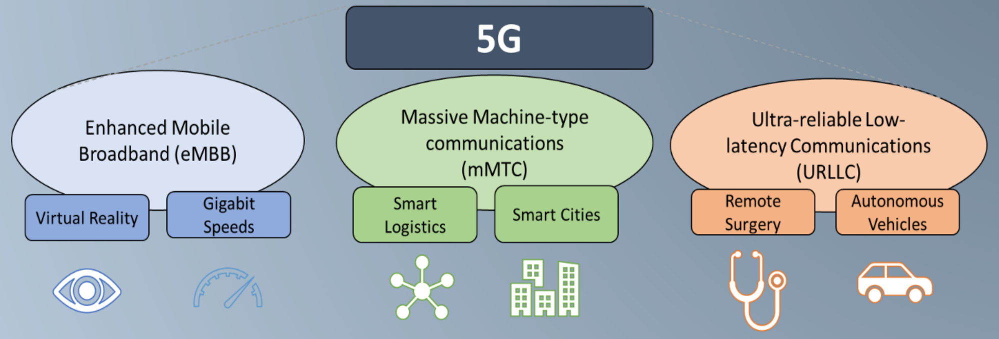
1. The Digital Transformation

2. 5G Communications

3. 6G Communications

2. 5G Communications

- **Disruptive:** Not only **higher throughputs**, but **IoT-oriented, w/out base station, increased Capacity**, and **lower lattencies 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]

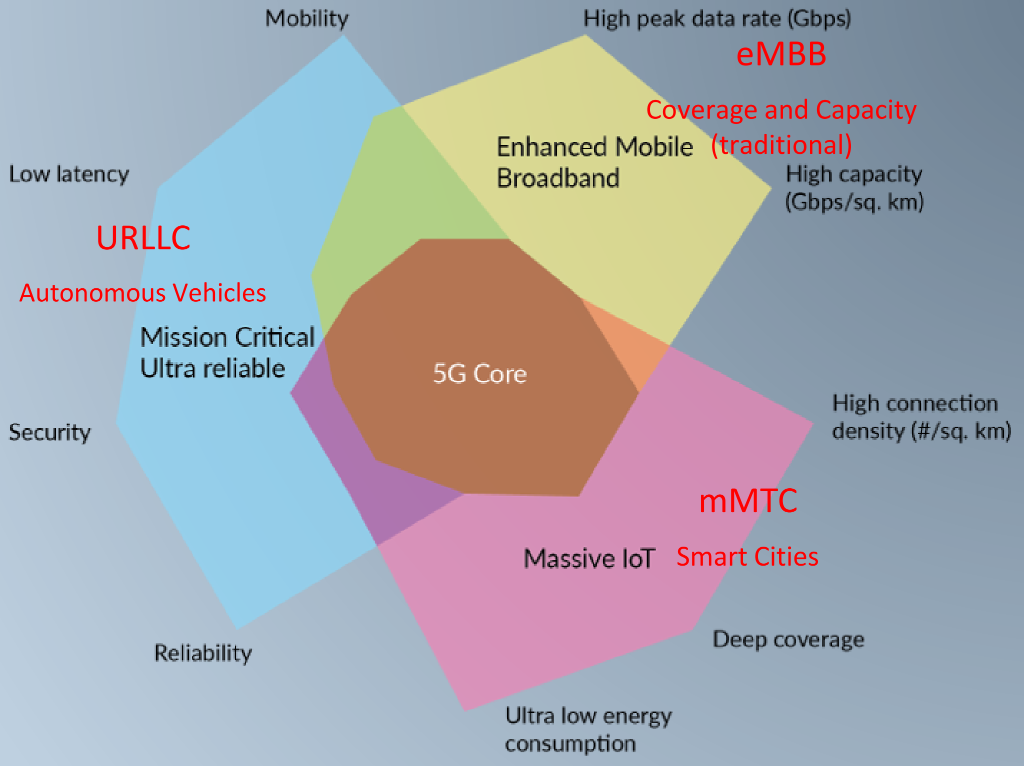
Capabilities	5G		4G
Peak Data Rates	eMBB	20 Gb/s (downlink)	1 Gb/s (downlink)
Experienced Data Rates		100 Mb/s (downlink)	10 Mb/s(downlink)
Mobility Speed		500 km/h	350 Km/h
Connection Density	mMTC	1 million devices per Km^2	100,000 devices per Km^2
Latency	URLLC	1 ms	10 ms

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 use cases: **mMTC & URLLC, Network Slicing** (splitting services in different uses cases/QoS, reserving resources), 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.



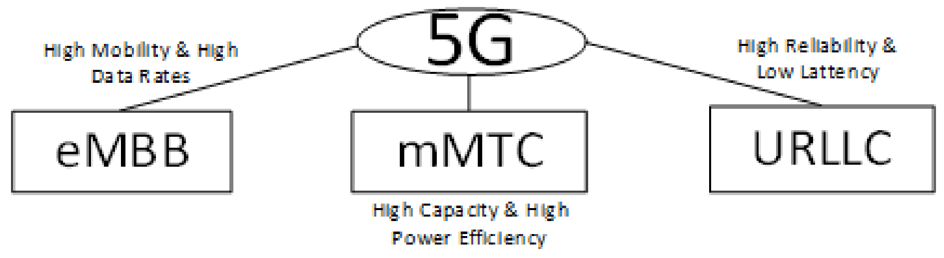
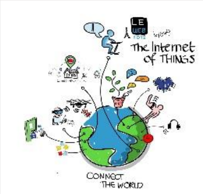


FIGURE 1 THE THREE GROUPS OF USE CASES OF 5G

2. 5G Communications

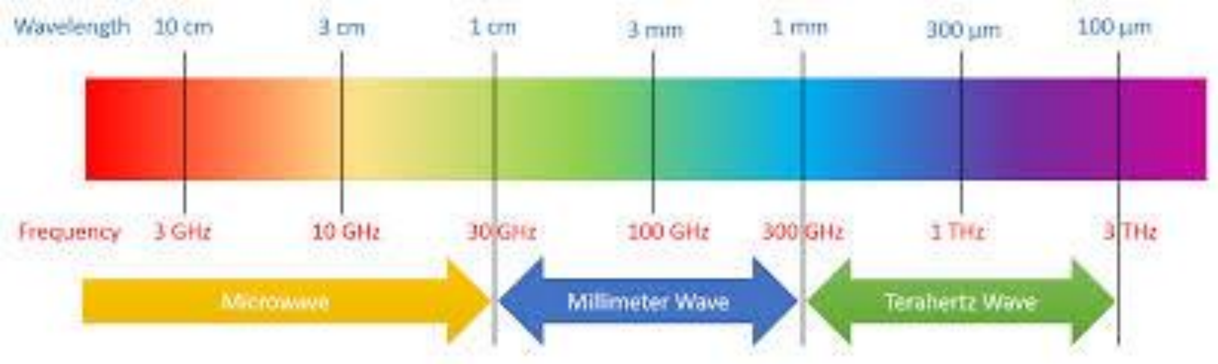
5G systems (2019/20) are aimed to achieve [as compared to 4G]:

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

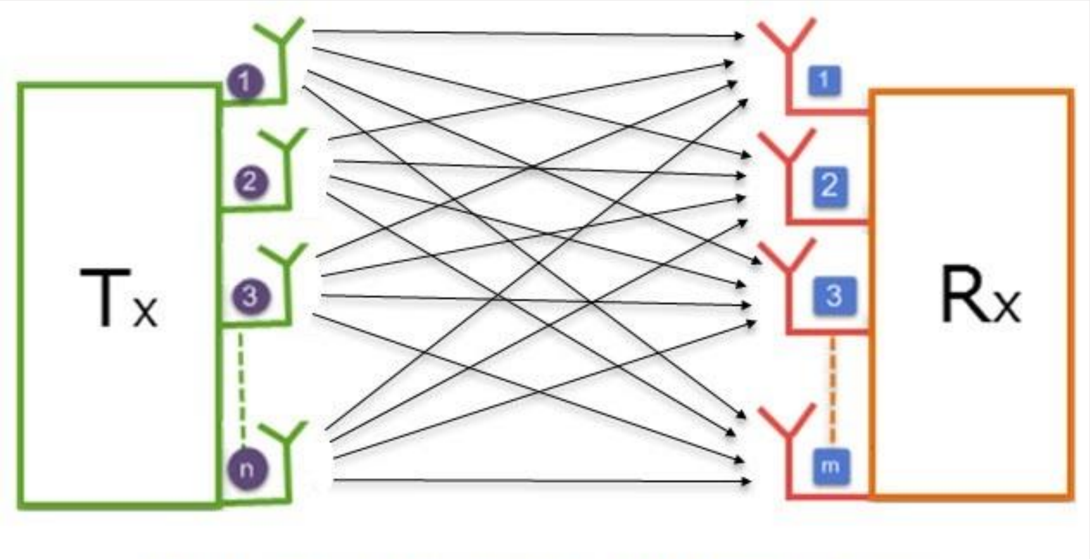


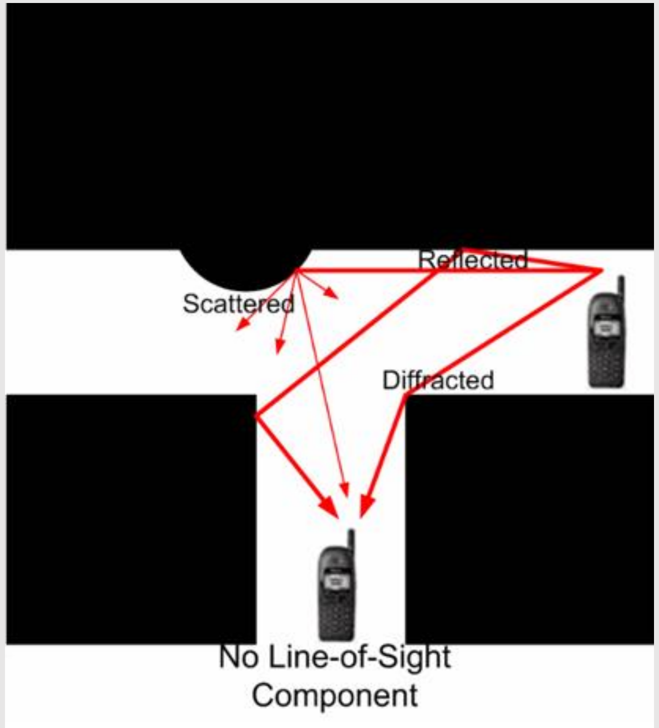
Support of new and Emergent Services:

- **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

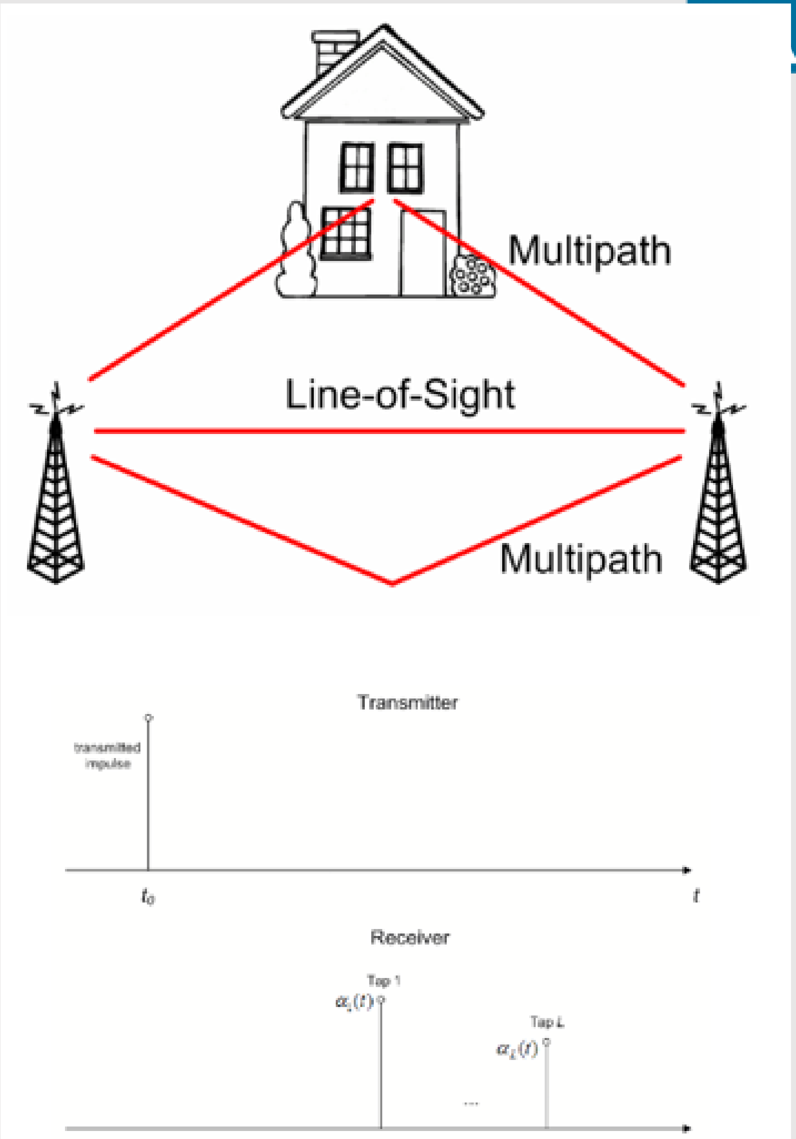


Millimeter Waves & Massive MIMO schemes involving several hundreds of antenna elements are the central technologies for 5G systems



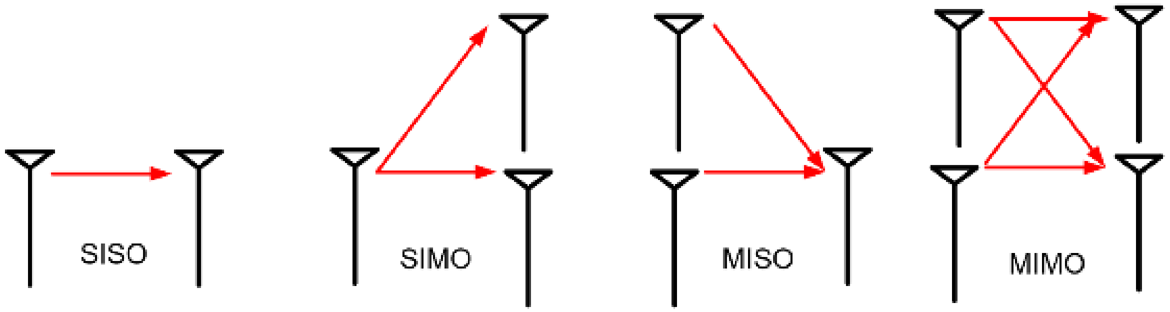


- **Higher Signal Bandwidth corresponds to higher Intersymbol Interference**
- **This is not only a matter of Spectrum**



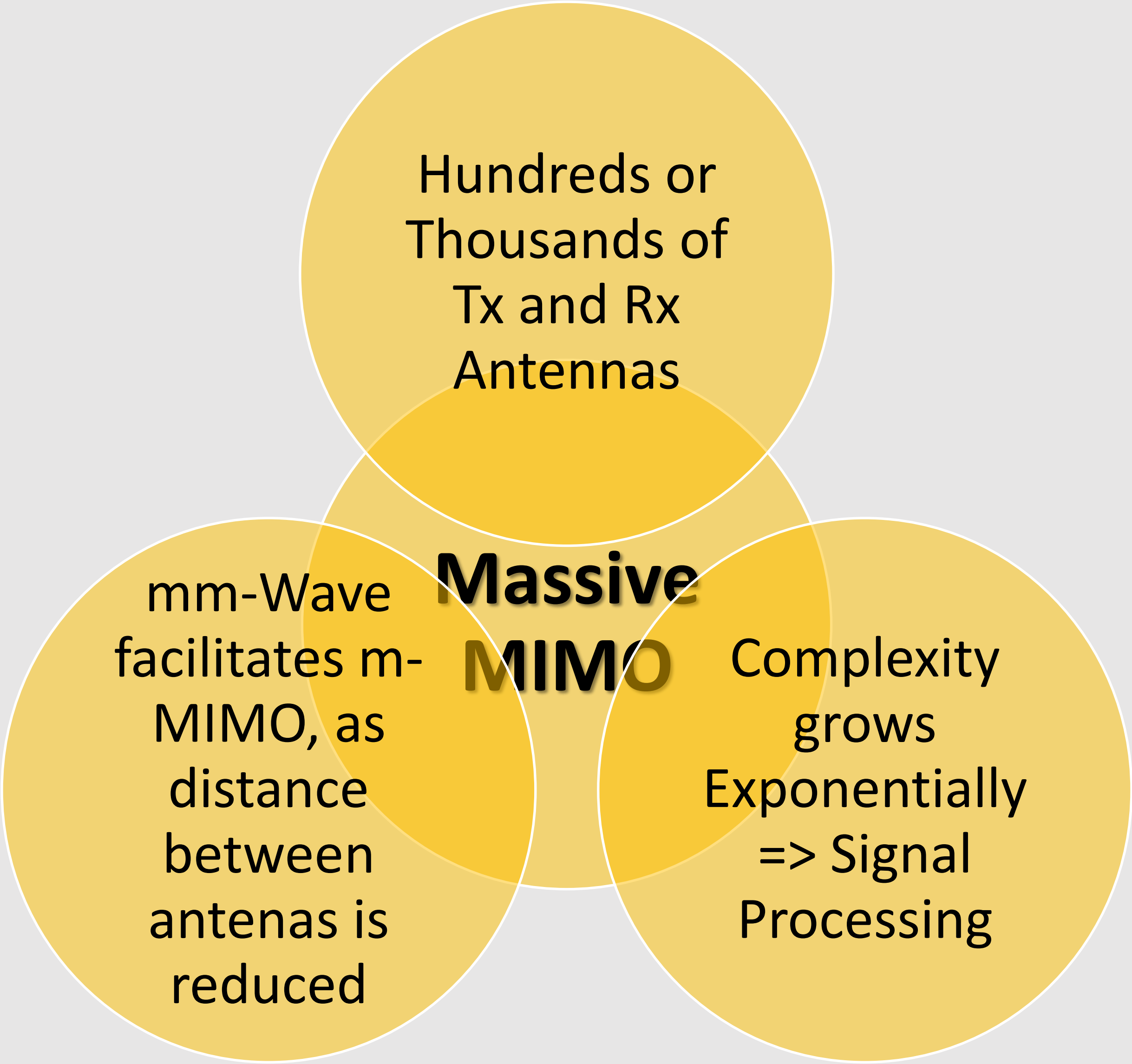
MIMO Systems

- 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

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.

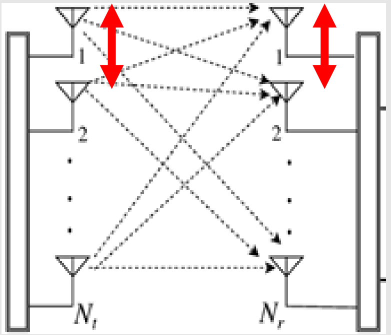
The **distance between antennas is reduced**, facilitating a higher number of antenna elements (Massive MIMO).

Moreover, antennas size are also reduced.

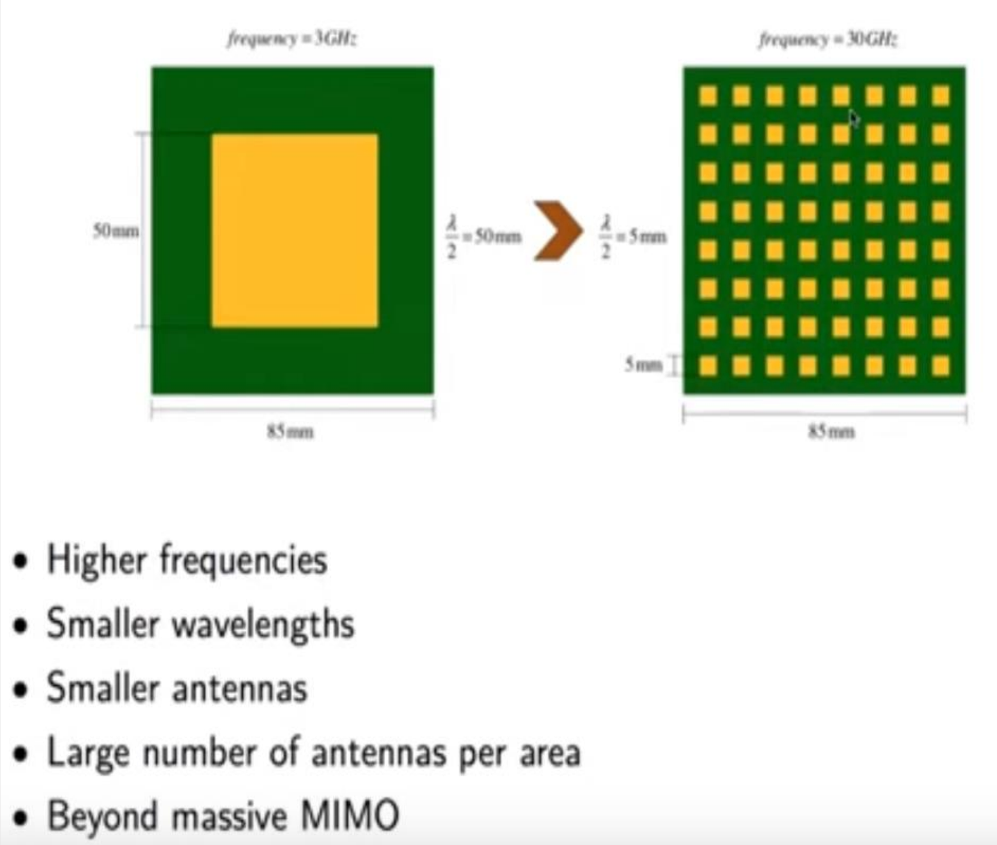
However, mm-Wave suffers from high path loss and rain and oxygen absorption.

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

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



$$c = \lambda \cdot f$$
$$\lambda = c / f$$
$$with\ f = 60\,GHz$$
$$\lambda = \frac{3\times10^8}{60\times10^9} = \frac{1}{200} = 0{,}005\,m = 5\,mm$$



Agenda

1. The Digital Transformation

2. 5G Communications

3. 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 an extremely high number of low-power devices
  - Support of flying vehicles and increased mobility speed

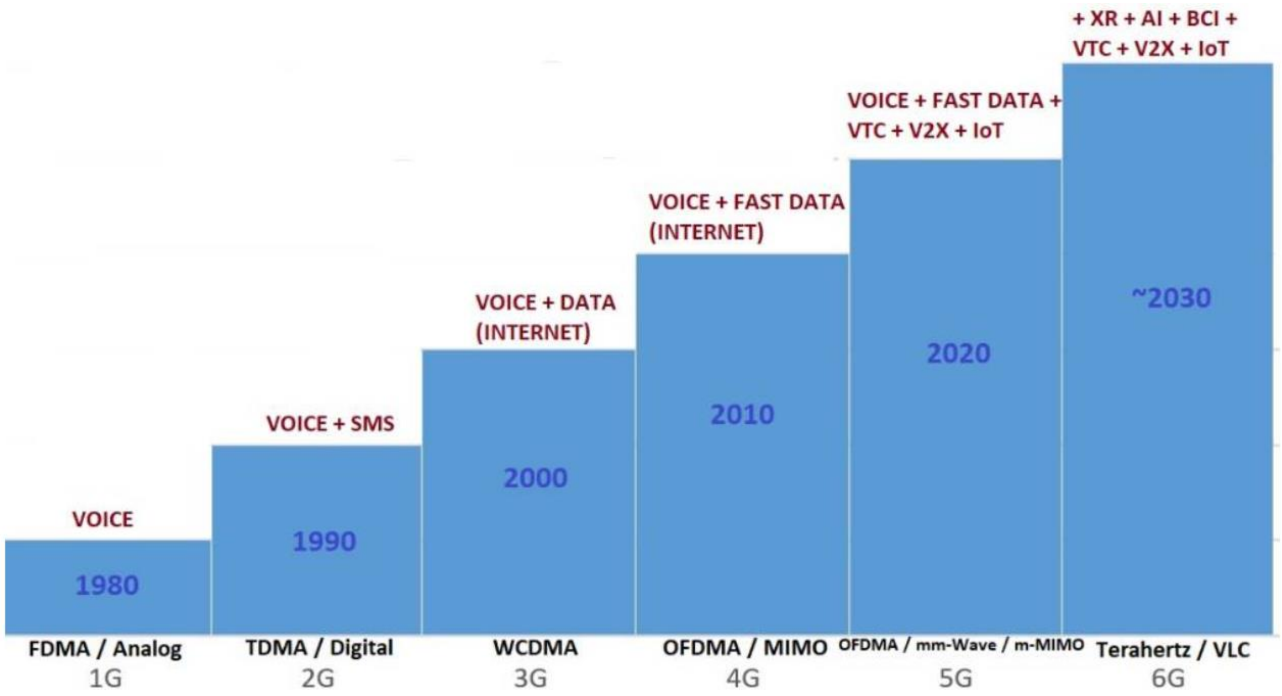


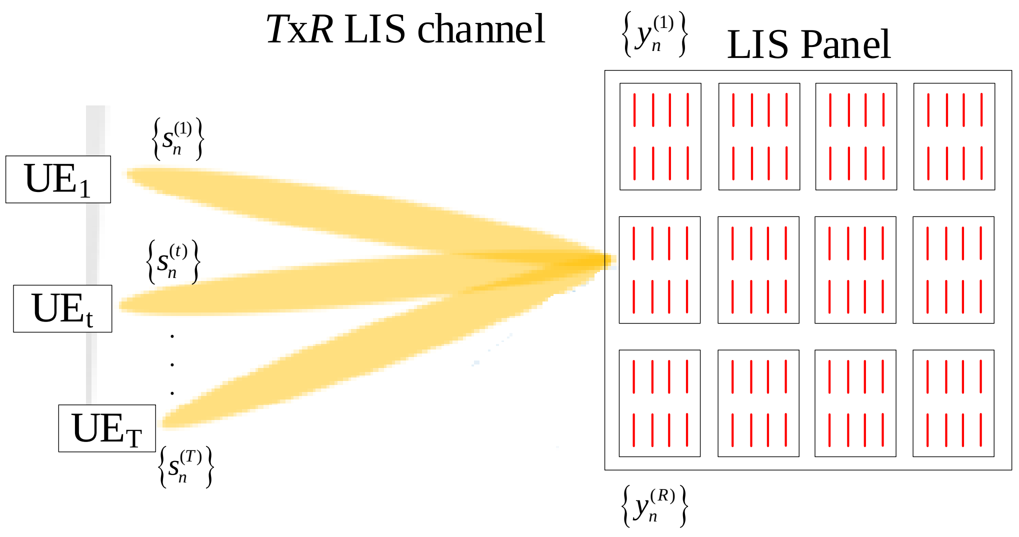
Figure 8. Evolution of cellular generations.

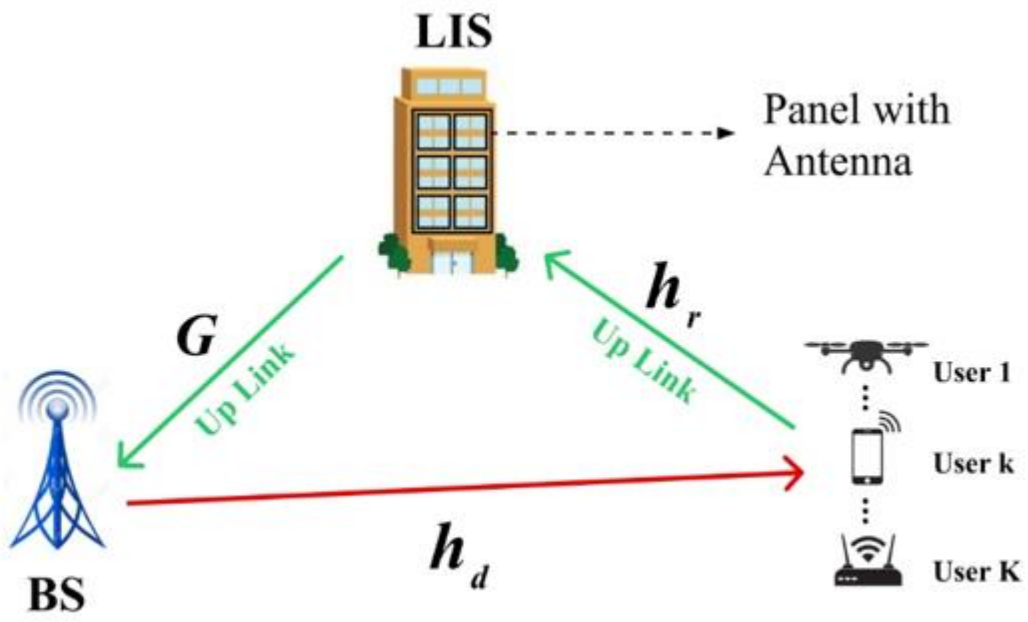
Perspectives for 6G

- 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).
    - LIS Systems

Transmission Techniques for 6G
4. 6G Communications

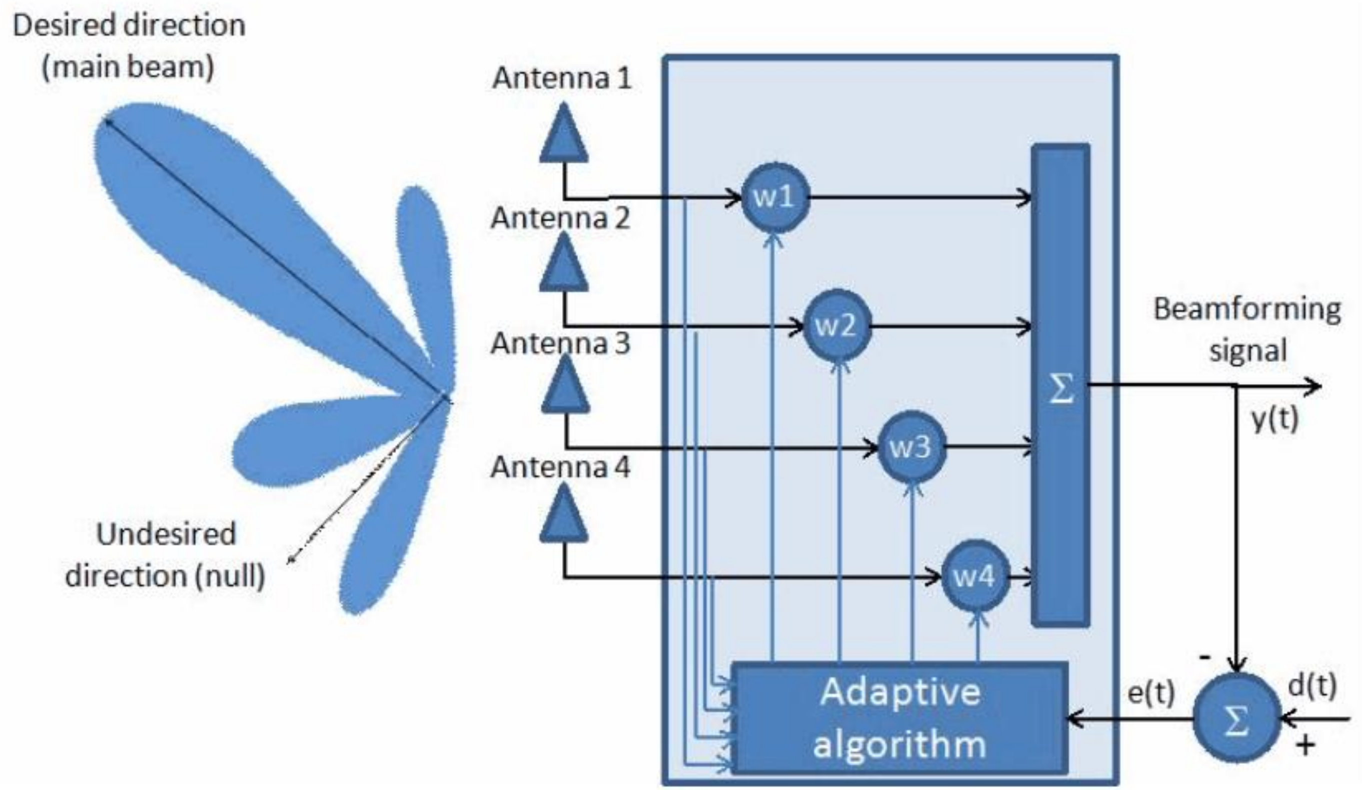
- How to achieve 1 Tbps and low latencies, in 6G, focusing on IoT?
  - Large Intelligent Antenna Systems (Antenas LIS)
  - Terahertz Bands Communications & Visible Light Communications
    - Higher Carrier Frequencies correspond to higher channel Coherence Bandwidth
  - Digital Signal Processing

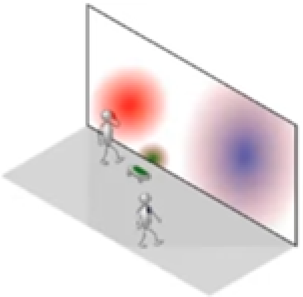




Beamforming

- 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.





Transmission Techniques for 6G
4. 6G Communications

- LIS System has differences over traditional Communications:
  - Short Range
  - Near-Field Communications (near-field Beamforming)
  - LoS Communications

  - Corresponds to Beyond **Massive MIMO** (5G) – Higher Number of Antennas
  - Traditional far-field wireless communications are typically established at propagation distances greater than the Fraunhofer distance (the Fraunhofer distance is only a few wavelengths).
  - While MIMO systems have an antenna element separation of 3λ to 4λ, the LIS has an antenna element spacing typical of λ/2.
  - Individual elements of the LIS array can be seen in the far field, but not the whole array, which acts in the near-field.
  - So, the focus is set on the distance, the bearing, and the elevation planes. This acts like a lens to focus the sun's energy on a piece of paper. Note that traditional beamforming does not focus on distance, but only on bearing and elevation.
  - LIS is different from traditional beamforming in that it can **get rid of interference between users who are aligned**, in terms of bearing and elevation, but at **different ranges**. This makes the process of concentrating energy even better.
  - Some receiver types might allow us to forego the necessity for **channel estimation** (equalization).

RESULTS FOR Large Intelligent Antenna Systems

- **BER** as a function of Eb/N0 obtained with Monte Carlo Simulations.
- SC-FDE Transmission (similar to OFDM but with better PAPR).
- LDPC Codes, with ½ Code Rate.
- **Five** statistically independent equal average power paths => Extreme Rayleigh Fading Channel.
- Receiver Types: ZF, MMSE, MRC and EGC (low complexity receivers).
- 2, 5 and 10 users.
- LIS composed of **4 panels** of 25 versus 225 antennas.

4. 6G Communications

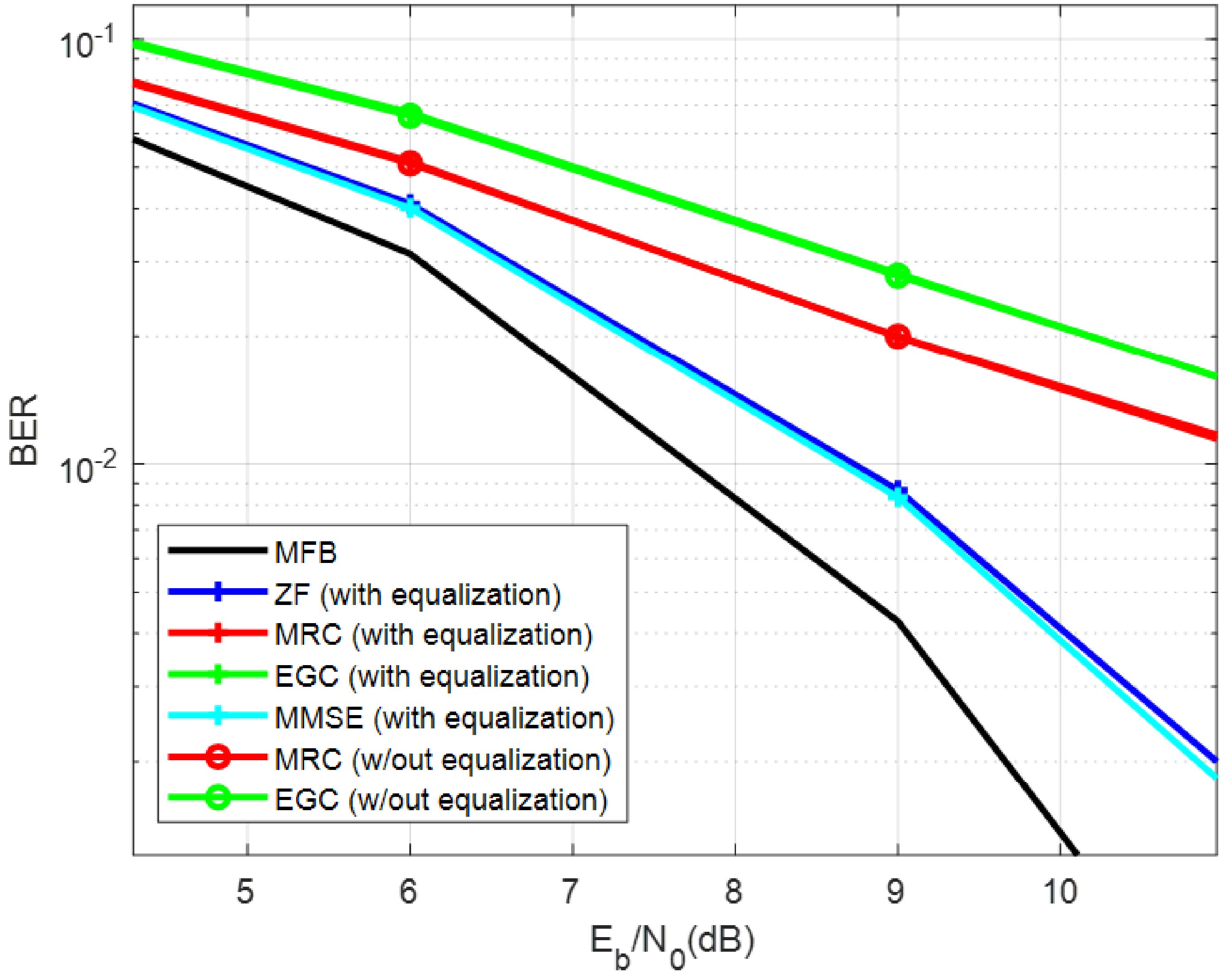


Figure 4. Results for 4X25 LIS System, with 5 users, without LDPC codes, with and without equalization.

- Results for 4x25
- Best results for ZF and MMSE
- MRC and EGC may operate without equalization (same performance):
  - Less Complex Receivers
  - **May avoid Equalization**
    - **And Channel Estimation**

4. 6G Communications

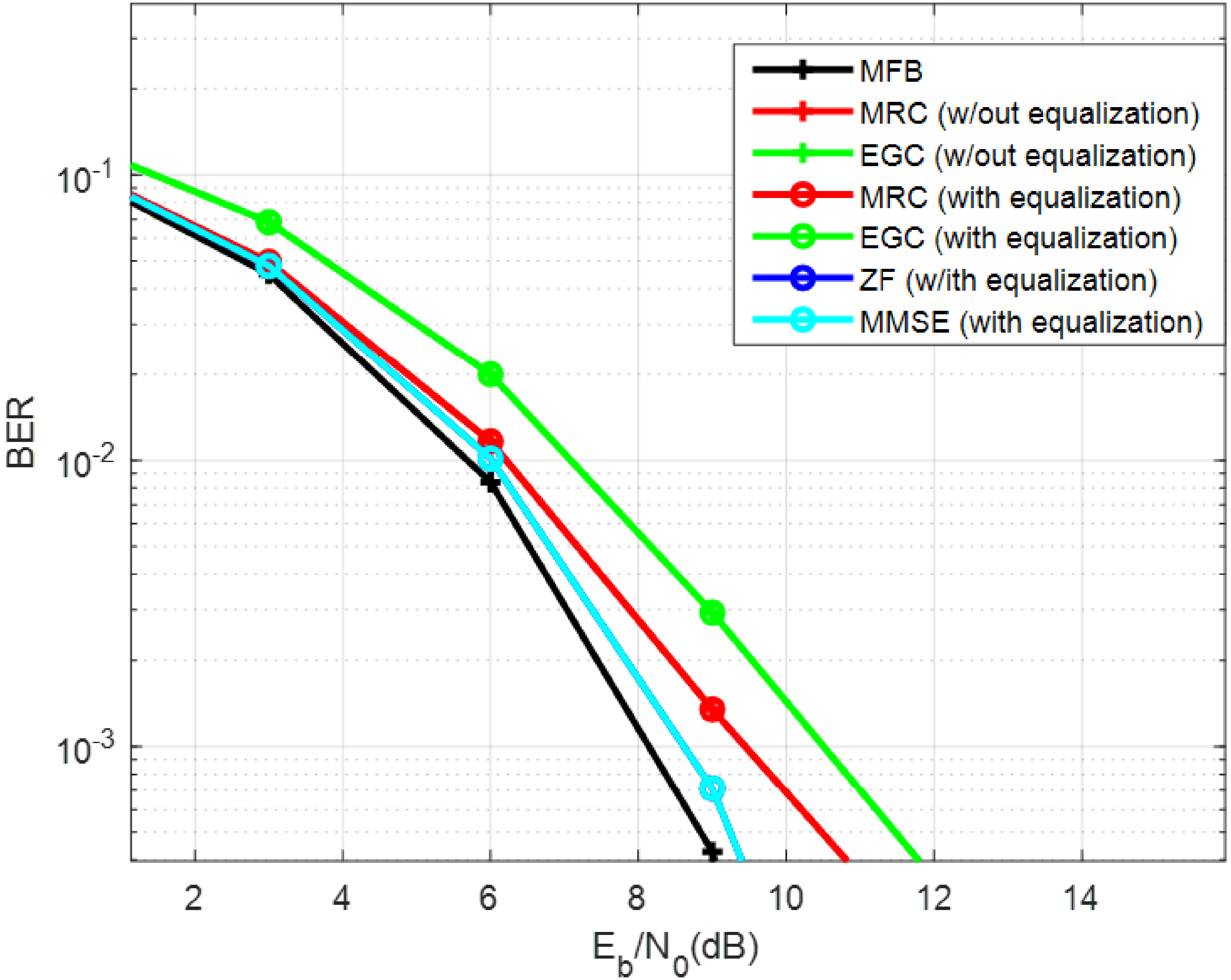
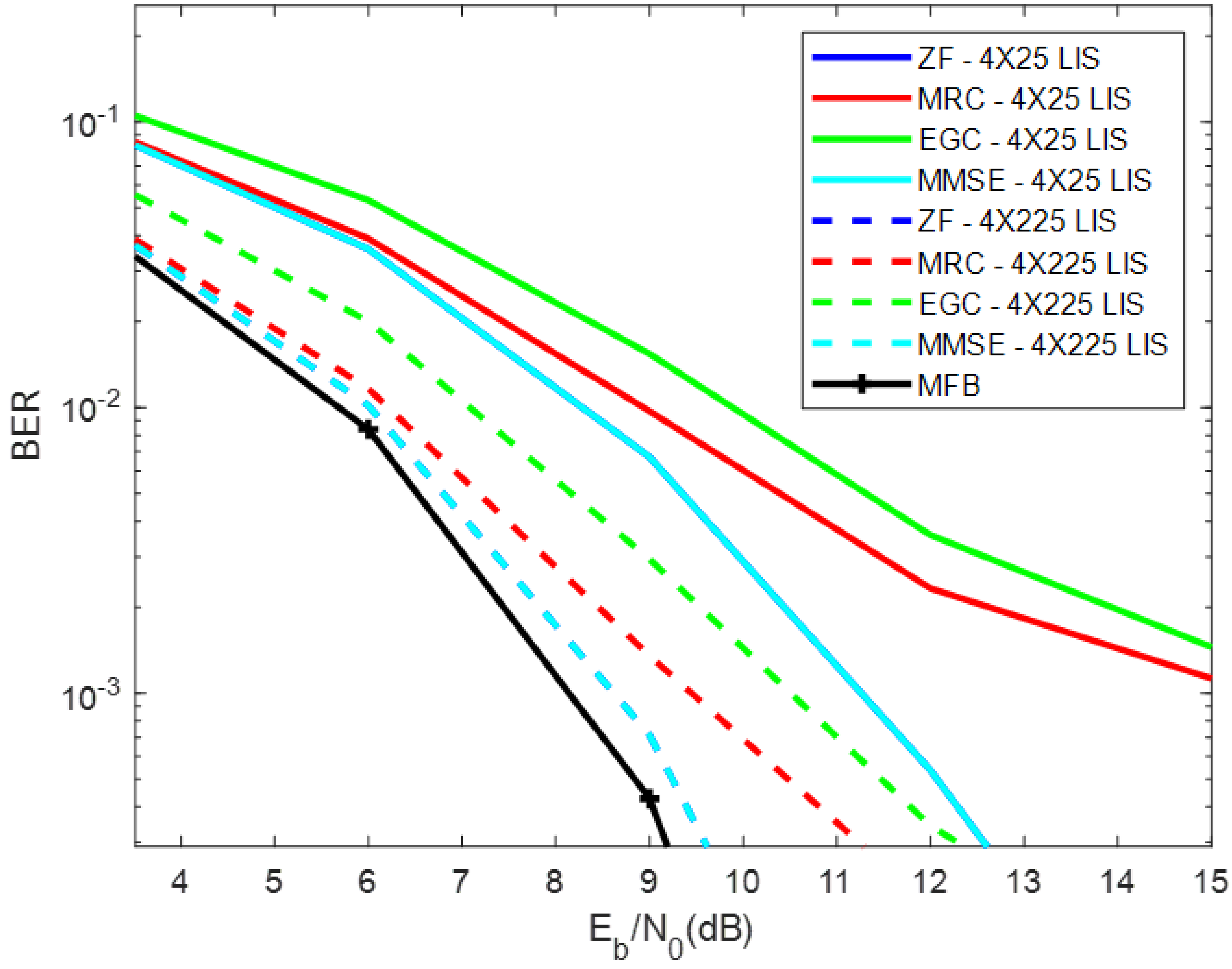


Figure 5. Results for 4X225 LIS System, with 5 users, without LDPC codes, with and without equalization.

- Results for 4x225 (instead of 4x25)
- Best results for ZF and MMSE → **But MRC and EGC perform closer to ZF/MMSE**
- MRC and EGC may operate without equalization (same performance):
  - Less Complex Receivers
  - May avoid Equalization
    - And Channel Estimation

4. 6G Communications



Results for 4X25 versus 4X225 LIS System, with 2 users, missing LDPC codes.

- Results for 4x25 versus 4x225
- 4x225 performs better than 4x25

4. 6G Communications

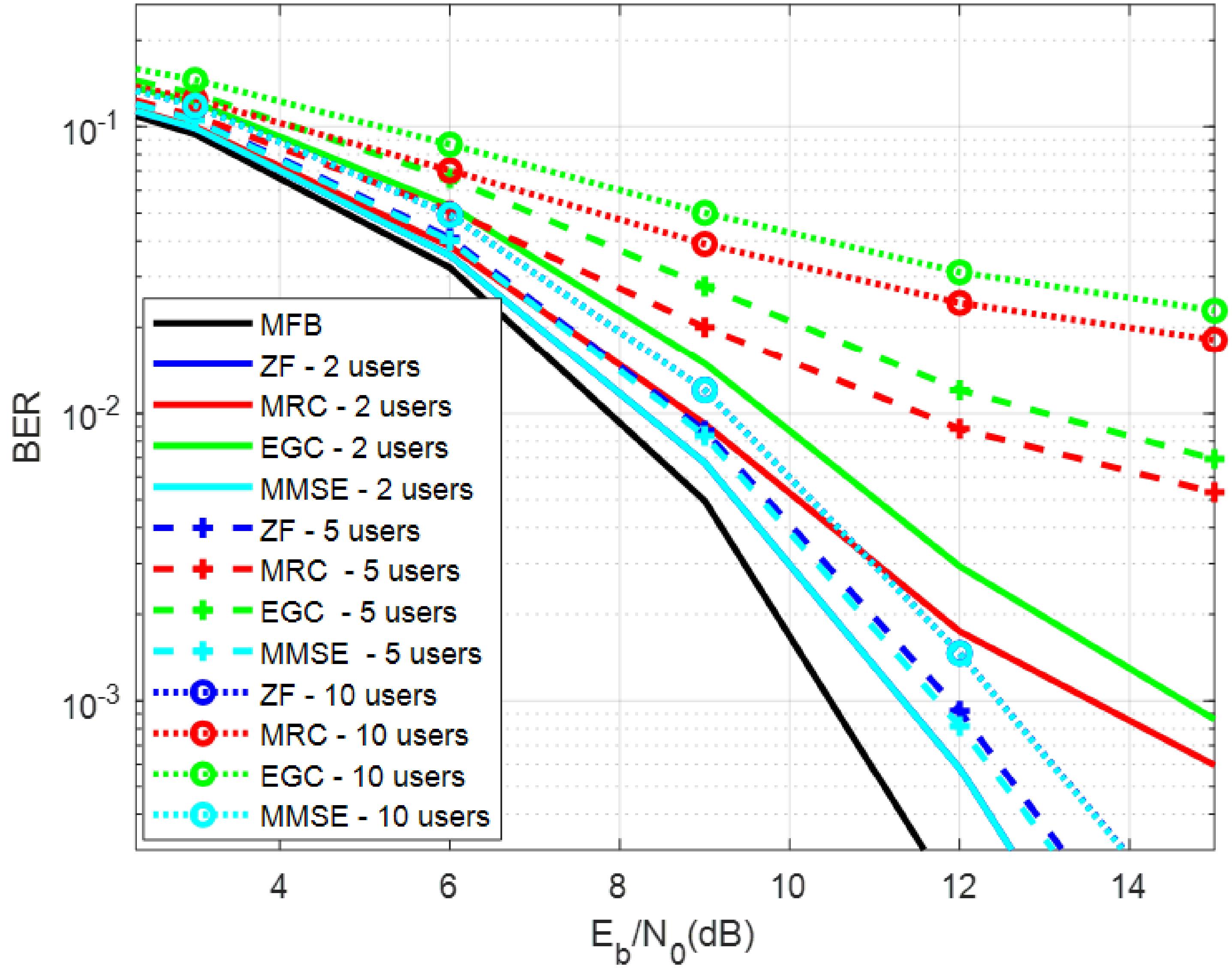
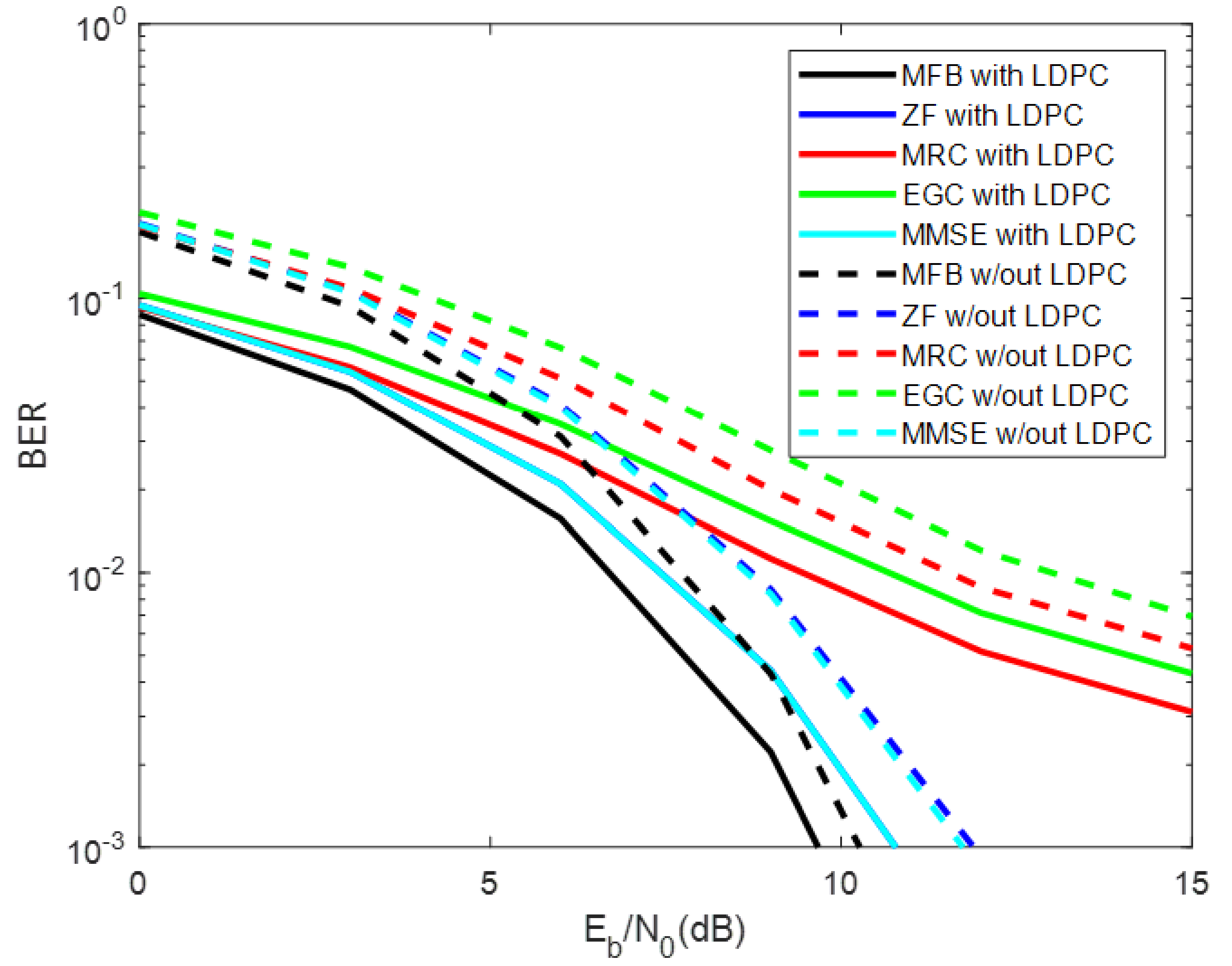


Figure 7. Results for 4X25 LIS System, with 2, 5 and 10 users, without LDPC codes.

- Results with 2, 5 and 10 users, without LDPC Codes
- Performance decreases with increase of the number of users

4. 6G Communications



Results for 4X25 LIS System, with 5 users, with and without LDPC codes.

- Results **with and without LDPC Codes**
- **Increase of performance with LDPC Codes**

4. Conclusions

- An advantage of the LIS System relies on its good performance and simplicity (equalization can also be avoided for some receivers).
- Performance improvement with:
  - Increase of the number of antennas that form the LIS.
  - With LDPC Codes.
- Although performing better, ZF and MMSE receivers are more complex.
  - Difference of performance (MRC/EGC vs ZF/MMSE) reduces for higher number of antennas.
- MRC and EGC receivers may be used **without equalization**, without degrading the performance (ZF and MMSE cannot).
  - MRC and EGC can avoid channel estimation.
- A system comprising LIS, associated with LDPC codes, and coupled with the SC-FDE transmission technique, exhibits performance optimization that improves with an increased number of antennas.

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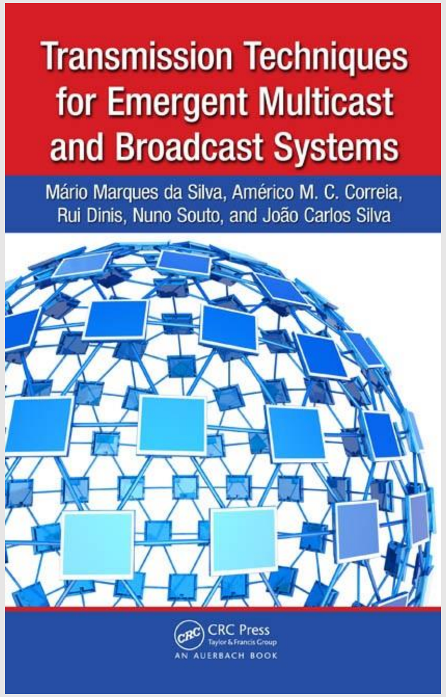
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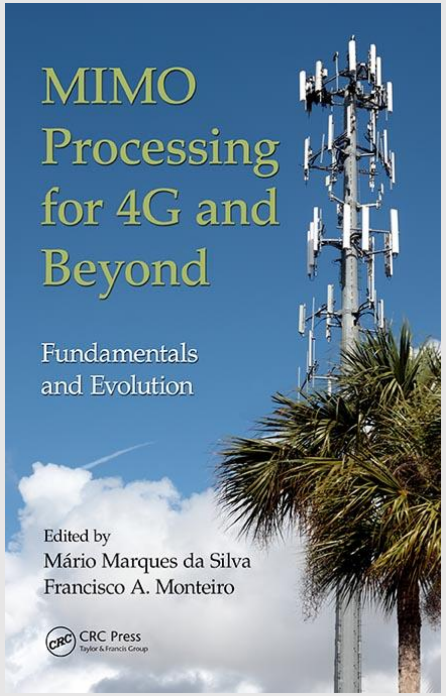
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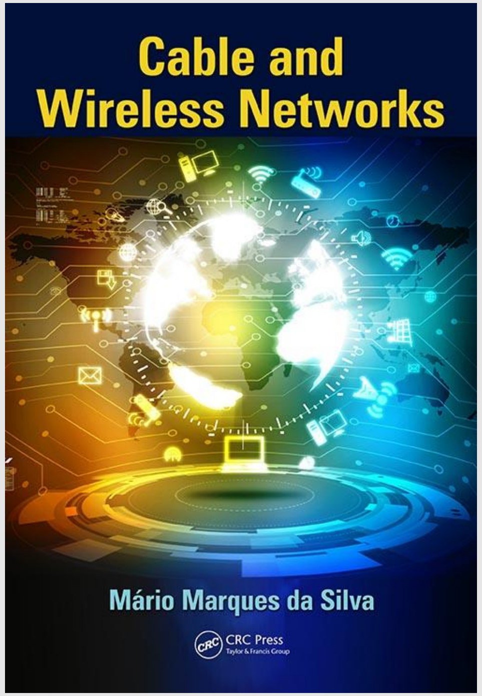
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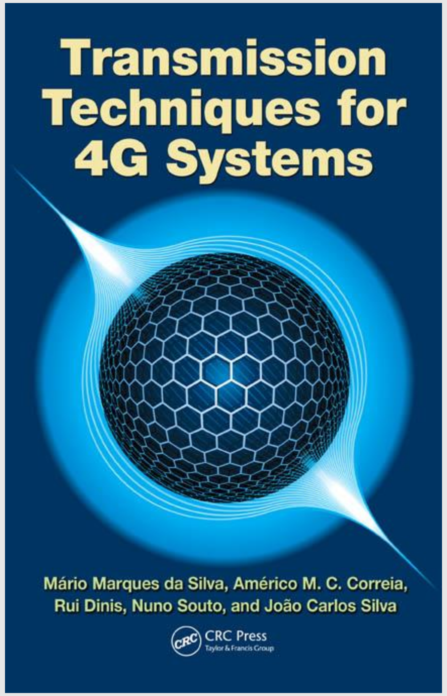
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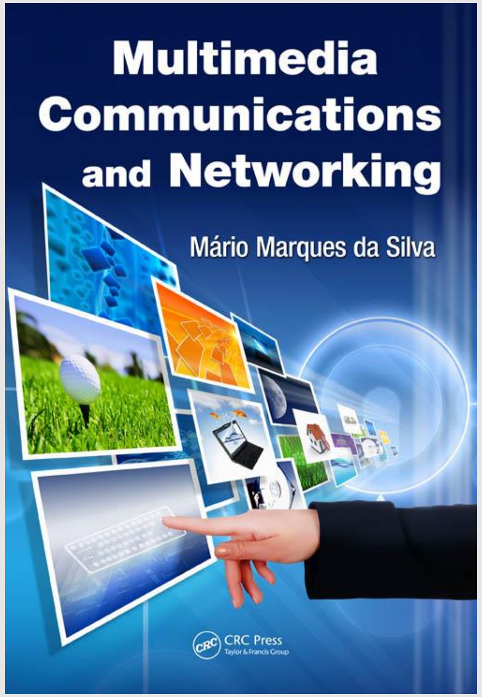
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