PHYSICAL LAYER AND ACCESS TECHNOLOGIES FOR 5G AND FUTURE GENERATIONS WIRELESS NETWORKS

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In our research project, we as a group studied the major physical layer technologies which form the base for 5G networks. These physical layer technologies were subdivided into three major technologies (Non-Orthogonal Multiple Access Technology, Polar Code and Filtered-OFDM and massive-MIMO technology) among the three members of our group by our mentor.

Non-Orthogonal Multiple Access Technology is discussed among the New Radio (NR), which is a study item focussing on the design of next generation air interface. It is an upcoming multiple access technology specially designed for supporting 5G and future wireless communication scenarios which has improved features over traditionally used multiple access technologies in terms of better spectral efficiency, ability to accommodate larger number of users etc by virtue of its unique property of non-orthogonal resource allocation. NOMA can accommodate much more users via nonorthogonal resource allocation by allowing controllable interferences. Massive MIMO systems have shown potential to become a candidate for the next generation wireless technologies including 5G communication technology. Massive MIMO can be understood as an arrangement of MIMO systems having large quantity of antennas at base station and at terminals and these large number of antennas at base station work for fewer antennas at the terminals making use of same time and frequency resources. The growing number of served users and the increasing demand for large amounts of data opened the doors for this technology. The scaling of MIMO technology to large scale is to increase the capacity by 10 times so as to have the capability of supporting the future generations wireless networks. Polar codes, presented by Arıkan, are a class of error-correcting codes that are proven to achieve channel capacity for long block codes. They have been designated for the next generation of wireless communication standards. The 5G standardization process is putting its main focus on improved error-correction performance, lower power consumption, lower latency and higher throughput. For example, machine-to-machine communications in 5G require massive connectivity among a huge number of devices, on a scale much higher than the most bandwidth-demanding applications in 3G and 4G, with a limited power budget. Therefore, consistent and efficient encoding and decoding methods need to be constructed.

We studied various research papers and also performed simulations on MATLAB and Simulink platform for understanding the key features, advantages and various research trends related with this technology. The important facts were then presented in form of poster and a detailed report for final submission in the Armour R&D Expo. Apart from this, our research group also got an opportunity to work on a research problem related to future generations wireless communication assigned by our mentor regarding an efficient constellation scheme for transmission of symbols from large number of users with optimized average energy and maximised distance between adjacent symbols. We presented a mathematical formulation for this problem and a developed a MATLAB code for testing the constellation characteristics based on the various input symbols from different users and then observed and compared the different constellation shapes and presented the findings to our mentor.

NON ORTHOGONAL MULTIPLE ACCESS

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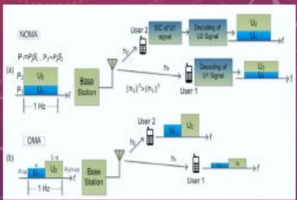
INTRODUCTION

The continuously increasing demand of internet and huge number of users is posing a challenge for 5G wireless communications. The conventional orthogonal multiple access technologies i.e. Frequency Division Multiple Access (FDMA) for 1G, time Division Multiple Access (TDMA) for 2G, Code Division Multiple Access (CDMA) for 3G and Orthogonal Frequency Division Multiplexing (OFDM) for 4G can't accommodate such large number of users here, different users are allocated orthogonal resources in either the time, frequency, or code domain in order to avoid interference.



The Non-Orthogonal Multiple Access (NOMA) schemes have attracted lots of attention recently as they can accommodate much more users via non-orthogonal resource allocation. Rather than utilising orthogonal signals to differentiate between signals at the receiving end, the NOMA technique utilizes the superposition coding principle to multiplex multiple users onto the same time and frequency resources while ensuring controlled symbol collisions. In this manner, NOMA increases the number of connections at an additional cost of increased complexity of receiver for separating the signals. Thus they are promising techniques to improve spectral efficiency and support massive connectivity.

ADVANTAGES AND CHALLENGES

Benefits of NOMA over OMA

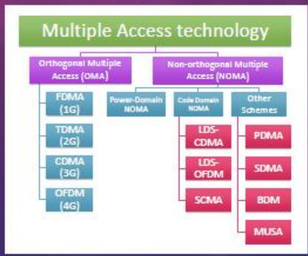
- Better Spectral Efficiency
- Better Cell Edge Throughput
- Massive Connectivity
- Low transmission latency
- Relaxed Channel Feedback

Challenges in NOMA

- Dynamic User Pairing
- Resource Allocation Complexity
- Receiver Complexity
- Error Propagation
- Signalling Overhead
- Effect of Interference and Distortion

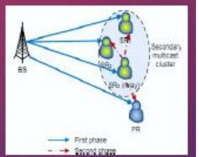
CLASSIFICATION

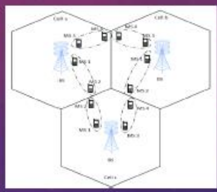
Multiple access schemes allow users to share the given spectrum in most effective manner. The classification of these schemes are based on the fact whether the resources are being allotted orthogonally or non-orthogonally to these users and the further subdivision of these schemes are done based on the fact that the resource being allotted is code domain, frequency domain or time domain in case of orthogonal access and power and code domain in case of non-orthogonal access.



FUTURE TRENDS IN NOMA

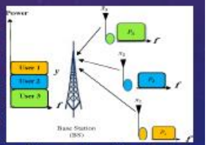
Cooperative NOMA (C-NOMA): It, relies on several relay nodes to help source in forwarding information to the respective destinations. In Cooperative NOMA, users having better channel conditions act as a relay in assisting the users with poor channel conditions. Some techniques such as Bluetooth and UWB schemes is used for delivering signals from users with better signal condition to users with poor channel condition at the cost of additional time slots.





NOMA with MIMO: The MIMO technology is being used in 5G for increased capacity. MIMO-NOMA can be extended to MIMO and performs better than MIMO-OMA in terms of the sum channel capacity. The MIMO-NOMA system improves the sum capacity by allowing two users to share a single beamforming vector. To ensure the mitigation of problem of the inter-beam interference and the intra-beam interference, the power allocation is done on the basis of correlation among the users and channel gain difference.

Network NOMA: Generally, the cell-edge users face great interference from the neighbouring cell users. In the given figure, strong interference is expected between users 1 and 3, which degrades the overall performance of NOMA. Therefore, to resolve this problem of inter-cell interference, Network NOMA utilizes joint precoding of the users' signals across the neighbouring cells. The optimal pre-coders are difficult to design since each base station should know all users' data and channel information.



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ACKNOWLEDGEMENT

We would like to acknowledge Birla Institute of Technology, Mesra, BIT Mesra Alumni Association North America and Illinois Institute of Technology , Chicago for sponsoring this Research Immersion Program. We would also like to thank our professor Dr. Atkin for providing his valuable guidance.

MASSIVE MIMO TECHNOLOGY

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INTRODUCTION

The coming age of wireless technology has brought with itself a burden of excess demand from the ever-increasing users for cellular mobile, Internet and multimedia services. The growing number of served users and the increasing demand for large amounts of data opened the doors for Multiple Input Multiple Output (MIMO) technology.

Massive MIMO can be understood as an arrangement of MIMO systems having large quantity of antennas at base station and at terminals and these large number of antennas at base station work for fewer antennas at the terminals making use of same time and frequency resources. The performance of these m-MIMO systems has shown significant improvement in bandwidth efficiency along with reduction in transmitted power, thus leading to spectral efficiency .

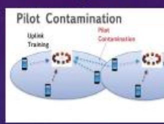
ADVANTAGES AND CHALLENGES

Benefits of m-MIMO systems

- Enhanced Transmission Reliability
- Enhanced spectral efficiency
- Enhanced energy efficiency
- Enhanced system security
- Applicability for mm-wave bands

Implementation Challenges in m-MIMO technology

- Pilot Overhead In Channel Estimation
- Channel Feedback Problem
- Hardware Impairments



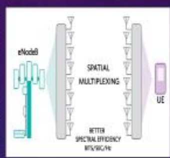
BEAMFORMING TECHNIQUES

Beamforming can be analysed by arranging the signal elements in an organised array to produce the desired radiated beam patterns by processing the signals in the direction of the desired terminals and cancelling beams of interfering signals. This can be accomplished by using Finite Impulse Response (FIR) Filter.

CLASSIFICATION OF BEAMFORMING

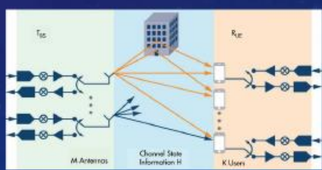
MAJOR TECHNOLOGIES

Spatial Multiplexing: Massive MIMO systems use the spatial modulation technology which involves incorporating the spatial dimensions as an additional dimension for transmitting information in these communication systems so as to reduce the required amount of transmitted power, and most importantly increase the number of channels that a base station can serve without allocation of more frequency channels.



Time Division Duplexing: The time division duplexing technology is popularly adopted in communication systems because of its several attractive features including accommodating various patterns of uplink and downlink traffic in cellular networks. The TDD schemes are commonly categorized as static and dynamic TDD.

Space Time Coded Systems: Space Time Codes are used in wireless communication to transmit multiple copies of a data stream across a number of antennas and to exploit the various received versions of the data to improve the reliability of data transfer.



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POLAR CODES AND FILTERED OFDM

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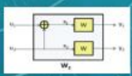
INTRODUCTION

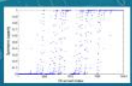
The growing demand for better data transmission and the planning towards the evolution of 5G has increased the interest in finding ways to improve the throughput and reliability of data transmission. Channel coding plays an important role in improving these.
Polar codes, introduced by Arikan, represent an emerging class of channel coding technique with the power to approach the capacity of a discrete memoryless channel. They have been designated for the next generation of wireless communication standards.

Encoding: The basic idea of polar coding is to create a coding system where one can access each channel individually and send data only through the reliable ones. It is based on **Channel polarization**, which is splitted into two phases:

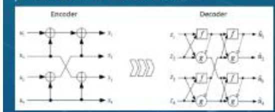
1. **Channel Combining:** It combines two copies of channel recursively until N channels are combined.



2. **Channel Splitting:** It splits the combined channel back into N channels, but with changed reliability.



Decoding: In this process, one bit is decided before the probabilities for the next bit is calculated.



ADVANTAGES

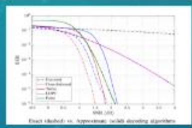
- Simple encoding and decoding
- Lower computational complexity
- Similar error correcting capability compared to that of LPDC and turbo Codes
- Performs well for long data blocks
- Universal and versatile

CHALLENGES

- Data Dependencies
- Complex hardware design
- Poor performance for short blocks
- Inflexible and limitations due to serial structure
- Backwards compatibility

PERFORMANCE

When we transmit BPSK over the AWGN channel, the convolutional codes, turbo codes and the polar codes with half code rate, the following BER vs SNR graph is obtained. The error correction capability is similar for LDPC and polar codes, but both perform poor in comparison to turbo codes.



APPLICATIONS

- 60Ghz Millimetre Wave
- Optical Access Networks
- Physical layer security
- Enhanced Mobile broadband
- Ultra-reliable Low Latency Communication (URLLC)
- Massive Machine type communication (mMTC)

FUTURE SCOPE

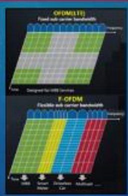
- Reducing the calculation operations or increasing the parallelism of the decoder so as to decrease the decoding latency, or to increase the throughput.
- Polar coded modulation i.e. jointly describe polar code and modulation.
- Hybrid automatic repeat request (HARQ) for link adaptation.

COMPARISON WITH OTHER CODES

		POLAR CODE	TURBO CODE	LDPC CODE
ENCODING	Structure	Recursive Encoder	Convolutional Encoder	Matrix Multiplication
	Complexity	Medium	Low	High
DECODING	Structure	SC, SCL, SSCL, F-SSCL	Iterative BCJR	BP
	Complexity	Low	High	High
PERFORMANCE	Throughput	> 100 Gbps	< 20 Gbps	> 20 Gbps
	Latency	0.05 µs	0.25 µs	0.05 µs
FLEXIBILITY		Inflexible	Flexible	flexible

FILTERED OFDM

F-OFDM is a spectrally localized waveform in which different sub-band filters are used to create OFDM subcarrier groupings with different inter sub-carrier spacing, OFDM symbol durations and guard times. This significantly lower the out-of-band emission (OOBE) that can mitigate interference in asynchronous access. Filtered-OFDM is currently in its nascent stage. It requires prototyping and field testing.



Need for F-OFDM:

- Personalized services to different needs and channel characteristics
- Reduced out-of-band emission (OOBE)
- Flexibility, spectrum efficient and MIMO-friendly
- Low power consumption
- Supports asynchronous transmission
- Supports multiple waveforms

F-OFDM Transceiver Structure

Transmitter creates its OFDM signal based on the given block of consecutive sub-carriers. The F-OFDM signal is then obtained by sending the OFDM signal through an appropriately designed spectrum shaping filter, which is centred in frequency at the assigned sub-carriers.

At receiver side, the signal is first sent through the filter, which is matched to the transmitter filter. The signal is then passed through the OFDM receiver, to extract the symbols from respective sub-carriers after channel equalization.

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