Non-Orthogonal Multiple Access with applications :A Survey

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Abstract

This review presents the different access technologies in 5G in various environments. The paper gives deep insight to the researcher about the comparison made for orthogonal and non orthogonal behavior of the system. It also categorizes the differential coders for MAC based systems, it also provides the interference cancellation scheme. The paper provides an explanation for the STBC for differential and non differential nature for MIMO and wireless communication, and categorizes the Alamouti codes' performance in terms of efficiency, equalization for STBC, Orthogonal-STBC. Mainly it focuses on Non-Orthogonal Multiple Access with adaptive detector for SU-MIMO and limited feedback for Massive MIMO along with a generalized concept of Cooperative relaying using NOMA and Cooperative NOMA selection with dual relay is explained. This paper presents the different approaches in channels like Rayleigh, Ricean and Nakagami-m fading channel. Results indicate that there are some proposed schemes on the already present dedicated schemes which shows improvement in the performance while considering different parameters.

1. Introduction

Communication is the way of conveying any information from a single person, place or group to another. The three main components of communication are: sender, channel and receiver. It looks very easy to do so, but in actual it's a very tough task. 5G is planning to have Millimeter waves as in this the range is restricted in comparison to microwave and the size of cell are small along with the antenna size in terms of few inches only and another technique is Massive MIMO in which multiple antennas are present in each cell and multiple antennas can transmit from transmitter side and on the receiver side multiple antennas can receive the data in parallel known as beam forming. Today's radio resources are allocated to different users using Orthogonal Multiple Access, but as the number of users increases this will not be helpful for requirement of high spectral efficiency, and low latency, etc. so, NOMA proves to be an improvement in the performance in [1]. NOMA outperforms OMA in terms of sum rate in both perfect and imperfect SIC as the achievable sum rate is degraded by 0.52 bits/s/Hz in case of imperfect SIC as compared to perfect SIC when 100 simultaneous users are considered.

This paper provides the proposed scheme to maximize the ergodic capacity of NOMA [34] in comparison to OMA scheme. NOMA works on the principle to serve large number of users using power domain at the transmitting side and cancellation of interference, i.e., SIC at the receiver side. The performance of NOMA is analyzed in different environments, one is Nakagami-m fading channels [2] considering relay networks and it outperforms in terms of spectral efficiency and fairness than conventional OMA using amplify and forward relay when the distance between base station and relay is less than or equal to 0.5. NOMA can be used for future radio access [3] and in this combination of NOMA with SIC is done to achieve 30–40 % improvement in the throughput of the users present at the edge of the cells and capacity.

The Multiple Access techniques can be divided into two categories, i.e., OMA and NOMA. OMA uses different MA, i.e., frequency, time and code division multiple access in which multiple users are allowed to share the spectrum on simultaneous basis and NOMA in three categories is compared [4] and after comparing it shows 40% reduction in SIC for STBC –NOMA in comparison to C-NOMA when users are taken 4 and 70% when users are 8 in number and the two prominent types of NOMA i.e. Code domain and Power domain are discussed [5] along with their resource management and comparison is done with OFDM that clearly shows that if the overloading factor grows from 1 to 1.67 then the number of scheduled users increases in code domain.

The impact on NOMA performance by different user pairing is analyzed in [6], by using two strategies of power allocation first one is fixed power allocation (FNOMA) and second one is Cognitive radio NOMA (CR NOMA). In the second one, the user with best channel condition is paired with the user with second best channel condition, whereas in the first one it is paired with the user having worst channel condition. Not only in stable condition, in moving condition too for providing better services there is NOMA Vehicular small cell network (VSCN) [7] to cater the mobile data demands. In this network architecture that is embedded with NOMA is designed so as to get improved spectrum and energy efficiency with approximately 16% improvement in proportional fairness and 17% increase in average service time whereas the power consumption gets reduced by 10W in the proposed scheme.

A scenario is shown in Fig. 1 assuming that User 1 (U1) is strong and User 2 (U2) is weak. More specifically, it means that U1 is having better channel condition than U2 and perfect Successive interference cancellation is assumed at the receiver side. The Base station can cater two users providing same frequency, time and code, but not power levels. NOMA provides more power to U2 which is weak as compared to U1 which is assumed to be strong. So, this becomes a great improvement in performance for NOMA as compared to OMA providing user fairness [8] and somehow same but with a different proposed strategy is presented in [9] that NOMA achieves fairness performance with power allocation. Now, U2 as provided high power of transmission can easily decode the message directly considering the message from U1 as noise but U1 being strong user cannot decode the message directly so, it implements Successive interference cancellation first for decoding U2 message and then it will subtract it from the overlying signal to get its own message.

The paper presents NOMA in terms of sum rate and outage performance in different scenarios but it definitely depends upon the data rates of targeted users and the power allocated to them as an application of MIMO applies to NOMA [10]. Therefore, a new matrix is also developed for precoding and detection to improve the performance in terms of outage probability.

Figure 2 illustrates a flowchart for NOMA functioning, clearly showing the main concern is random users further in the next step a protocol or scheme is deployed for functioning, whether it can be a proposed one or already present one as the case in cooperative NOMA there is always a cooperation from a user with strong channel condition to the weaker one. A strategy named dual relay selection strategy (DRS) is proposed [11] and without even surrendering the spectral efficiency besides achieving full diversity gain and

its comparison is done with Single relay selection (SRS) with dynamic power allocation(DPA) and fixed power allocation(FPA), results shows that DRS-FPA performed preferable however the outperforming results can be achieved from simulation from DRS-DPA.

The paper presents the review of all the techniques and proposed schemes that have been used for improving the performance of NOMA and other coding methods. This review will try to serve as a research for the researchers in selecting proper technique to solve their problem in a simplest way as the paper will provide the different coding techniques in terms of fairness, spectral efficiency, power allocation, bit error rate, diversity gain, peak to average power ratio etc. Section 2 summarizes the Differential decoder proposed for non-unitary constellation for MAC and Sect. 3 explains some MIMO applications in NOMA while Sect. 4 describes the Space time block codes and their performance in different scenarios along with Alamouti codes in NOMA and at last Sect. 5 provides the conclusion and future directions.

Table 1
Some Protocols made along with assumptions-1

Paper	Evaluation Tool	Duplex Mode/ Relay	Considered Users	Key Assumptions	Result Parameters
Jinjin[2], 2015	Simulation	Half Duplex (Amplify and Forward Relay)	Variable	Nakagami-m	SNR Vs Outage probability
Nasar[4],2018	Simulation	-	Variable	Rayleigh	Transmit power Vs Sumrate
Stelios[9],2015	Simulation	-	Variable	Rayleigh	Total power Vs Outage Probability
Jing [11], 2018	Simulation	Half Duplex (Relay)	2 users	Rayleigh	SNR Vs Outage Probability

2. Differential Decoder For Mac

A decoder for differential data is proposed for MAC accompanied by two users [12] providing each user and destination a single antenna in contrast to multiple antenna at transmitter and receiver are used in [13] therefore two different decoders are proposed here, one is partially differential decoder which does not use the channel knowledge of one user at the base station and the other one is heuristic differential decoder which does not use any information of both users. In both the papers, transmission is assumed to be in proper synchronization in terms of frequency and phase. In [14], pair-wise error probability is

derived and Rayleigh fading channel is used in both the cases. Among the two schemes mentioned above, the proposed decoder outperforms the traditional decoders.

2.1 Maximum Likelihood Decoder

There are some cases of Non unitary constellation like PAM and QAM in which multiple number of blocks of data are received [15] however this is also applicable to unitary constellation like M-PSK. Maximum Likelihood decoder is derived for Orthogonal-STBC over two transmit antennas and single receive antenna using Rayleigh channel and in converse of this proposed code [16] applicable for both Orthogonal and Non- orthogonal STBC.

Another ML decoder is derived which is for Non Orthogonal STBC with Non unitary constellation only [17]. The results are compared for conventional already available differential codes. One more decoder is derived, for Orthogonal STBC however the channel used here is Ricean MIMO channels [18] for MPSK, M-PAM, M-QAM and the previous decoder uses for MPSK only. This code outperforms previous code as it only requires two samples of data received in consecutive manner.

Table 2
Some Protocols made along with assumptions-2

Paper	Evaluation Tool	Constellation used	Considered Users/Antennas	Key Assumptions	Result Parameters
Manav[13], 2009	Simulation	BPSK,QPSK	2 Users	Rayleigh	SNR Vs SER
Manav[15],2010	Simulation	8-QAM, BPSK	2Tx and [1Rx, 2 Rx]	Rayleigh	SNR Vs SER
Manav[18],2008	Simulation	QPSK,4PAM, 16QAM	2Tx and 1Rx	Rayleigh and Ricean	SNR Vs SER

2.2 Maximal Ratio Receiver Combining (MRRC)

A decoder is derived using two transmit antennas and single receiver antenna which gives the diversity gain of the same order of Maximum ratio receiver combining but MRRC uses single transmit and receive antenna [19] and this is also generalized for same two transmit antennas but M receive antennas so that diversity gain of 2M is achieved and no feedback is required. In case of equal radiated power, the proposed decoder need two half power amplifiers, which needed a full in case of MRRC.

3. Multiple Input Multiple Output (Mimo) In Noma

Basic approach generally used in MIMO-NOMA is assigning different beams to different users first.

Described in Fig. 3, this approach shows the beams are forced to satisfy the Quality of Service (QoS) in order to satisfy an order which is already defined as first the message for the user present at the edge of the cell is decoded for all the users and then subsequently now the message for second user is decoded but after the subtraction of the message received by first user. In the same way, all the users get their decoded messages.

3.1 MAC Protocol for MIMO

Cooperative MIMO is a scheme in which the user which is in strong channel condition always cooperates with the user in which the condition of the channel is weak. The user with strong channel condition can act as a relay for the weaker channel users to provide message copy even if it takes extra time slots in getting them so that the diversity gain and outage performance of the system increases and reduction in latency and the power used for transmission [20] in which a MAC protocol is developed in wireless sensor networks for cooperative MIMO schemes in two forms i.e. optimal beam forming and spatial multiplexing but the results showed that optimal beam forming performed better in terms of latency and outage performance than other schemes.

Similarly, a different MAC protocol i.e. load adaptive is developed [21] for MIMO Software designed radio (SDR) Mobile Ad hoc networks (MANETs) and comparison is done with traditional access techniques. It performed better in terms of latency and throughput.

3.1.1 MAC Protocol in SU/MU-MIMO

Sometimes, different MAC protocols are developed for Single user and Multi user MIMO [22] besides MAC layer, Physical layer is also considered with a new approach here to compare the performance for one antenna but crosstalk interference is considered as the results varies for SU- MIMO and MU-MIMO. Bandwidth is taken as 20MHz and Time Vs Signal power per frame, and throughput results are simulated in terms of SU-MIMO and MU-MIMO with and without CTI. In terms of throughput, gain and stability SU-MIMO performs better but in contrast to this SU-MIMO performed worst in jitter and packet loss when compared to MU-MIMO but a new MAC protocol is designed for MU-MIMO [23] based on Wireless local area networks (WLANs) for the improvement in throughput as compared to [22] in which there is throughput problem. A scheme is proposed for SU/MU MIMO [24] based on power allocation, but here channel state information is used partially.

Some more WLANs MAC protocols are discussed [25] to give a thorough deep insight into the protocols to ensure that performing the system is improved for both uplink and downlink in which Multi user Detection (MUD) and Multi user Interference Cancellation (MUIC) techniques are designed for de/pre coding of samples. Constellation constrained (CC) capacity regions are computed for Gaussian MAC with two users [26, 27] in MIMO, both having proposed a scheme i.e. Trellis coded modulation (TCM) with M-PSK and M-PAM to improve the sum rate.

3.2 NOMA with MIMO

Non- Orthogonal Multiple Access (NOMA) is considered as a technique for improving the spectral efficiency and throughput of the system. NOMA is combined with MIMO [28] in for improvement in spectral efficiency in this SU-MIMO is considered by designing Limited Search and adaptive decoder as these are low complexity receiver methods as comparison is done between SNR Vs BLER and Bandwidth is taken as 1.4 MHz. A new technique i.e. with limited feedback [29] but this is designed for Massive MIMO. In this scheme, the massive MIMO is decomposed into separate SISO and the performance analyzed in terms of throughput is better in massive NOMA as compared to OMA.

3.3 Application of MIMO to NOMA

Besides previous content, some schemes are proposed regarding an application to NOMA, a new precoding and detection matrices is designed to as to improve the performance of MIMO-NOMA considering a fixed number of coefficient relative to allocation of power in comparison to traditional Orthogonal Multiple Access. Ergodic capacity improvement is considered [30] of MIMO NOMA so two schemes are proposed i.e. optimal power allocation (OPA) and another is low complexity (SOPA) Suboptimal power allocation scheme for the maximization of ergodic capacity compared to OMA.

Another application is in Visible light communication system [31], in this a proposed NOMA technique applies to achieve an improvement in sum rate. A Normalized gain difference power allocation (NGDPA) technique is used for efficiency and low complexity, as with NGDPA the sum rate improved by 29% as compared to GRPA (Gain ratio power allocation).

4. Space Time Block Code (Stbc)

Space time block coding is a method which is used in wireless communication in which multiple copies of data stream are transmitted through multiple antennas and to improve the reliability of the data transfer, the various received versions of the data are accomplished. The transmitted signal withstand refraction, scattering and reflection which traversing through difficult environment and then again corrupted by noise such as thermal noise so at the end some received copies of the data will be better than the others. This proximity results in a higher chance of being able to use one or more of the received copies helpful in decoding the received signal. The Space time coding combines all the copies of the received signal in a most helpful way to extract as much information from each of them as possible.

For an OSTBC with N_T transmit antennas, transmitting M complex symbols in L channel uses or time instants, the ST codewords are

$$X = \sum_{k=1}^{2M} C_k r_k$$

Where C_k are complex symbols and r_k are real symbols.

Table 3 describes [32, 33, 34, 35, 36, 37] the space time block codes study for different environments. In the study of Spectral efficiency Continuous Phase Modulation (CPM) [38] is introduced as STBC-CPM gives advantage of spectral and power efficiency, both at the same time. In, this Quasi Orthogonal STBC is introduced, which provides spectral efficiency increment of 0.5 bits/s/Hz compared to the traditional Orthogonal STBC.

Another scheme i.e. Quasi Orthogonal STBC included with Minimum decoding complexity [MDC-QO-STBC] [38] provides the distribution of power between the antennas in an even manner and change scalability for different transmit antennas is good and outperforms in terms of performance of decoding compared to traditional schemes. The enlargement of QO-STBC is used for improving the power scaling with 4 transmit antennas and single receive antenna and SNR Vs throughput is done using ML decoding and parameters are Alamouti code, QO-STBC and proposed code [39] while initially done for 2 transmit antennas to reduce the peak to minimum power ratio (PMPR) and guarantees full diversity. Simulation is done to analyze the performance of STBC for wireless communication [40] and with no extra processing, it outperforms for multiple transmit antennas considering Rayleigh fading channel along with Maximum Likelihood decoding.

Cooperative Diversity is a very important technique nowadays to improve the system capacity and to handle fading efficiently so that the area to provide the services will increase [41, 42, 43] Cooperative Relaying System (CRS) is proposed with STBC-NOMA. With using STBC i.e. CRS-NOMA the results in terms of performance gain degrades and placing relay between the transmitter and receiver improves the performance and power allocation scheme is proposed which is suboptimal. Similarly, Cooperative Spectrum sharing is required [44] so a cooperative spectrum sharing algorithm is designed in two phase and the results show improvement both in ergodic capacity and outage performance than the traditional scheme. Somehow, capacity of mobile link can be analyzed in a channel, say Rayleigh fading channel [45] coherence interval is computed according to the number of transmit antenna if the receiver know the propagation coefficients. SNR values range from 0,6,12 dB and a single transmitter and receiver antenna is used.

A new scheme proposed for Square STBC [46] in this there is no knowledge of CSI on the transmitter and receiver. This provides less error probability and complexity compared to already existing differential unitary STBC. Other than Conventional Differential STBC, Non constant modulus constellation i.e. QAM is proposed which provides improvement in SNR gain and SER in comparison to conventional Differential STBC using transmitter antenna 2 or 4 and receive antenna is 1 in number and two constellations are considered i.e. 16PSK and 16QAM. Differential STBC can also be proposed with non constant modulus constellation [47] with a lot of advantages over conventional differential STBC in terms of gain, SNR, SER performance.

4.1 STBC with MIMO

STBC MIMO system with Orthogonal Frequency Division Multiplexing (OFDM) is investigated to get reduced Peak to average power ratio (PAPR) [48] using Selective Mapping (SLM) Technique which

provides improved PAPR as compared to other scheme like partial transmit sequence (PTS) and the overall BER performance is improved. STBC can also be used with massive MIMO [49] and large MIMO systems [50] also and analysis is done in broadcasting with coherence interval which is limited in nature and different Orthogonal STBC are compared in terms of outage capacity. In [50], a technique is proposed in which by properly using Orthogonal STBC that are small in dimension and null space is used to derive a decoder so that at last analysis are done to receive SNR and Symbol error rate(SER) is also extracted.

Till now, each analysis gives ergodic capacity and outage performance dependency but still there is still a scope of independency [51], a closed form approximation is simply done for many fading channels i.e. Rayleigh, Ricean, Nakagami, Weibull etc and it is also useful for MIMO and shows that the ergodic and outage capacities does not depend upon a number of transmit antennas and channel parameters if high number of antennas are considered. Non Orthogonal Amplify and forward (NAF) MIMO technique is proposed [52] but for half duplex and all the relays here are employed with a multiple number of antennas and provides full diversity.

Table 3
Some Protocols made along with assumptions – 3

Paper	Evaluation Tool	Number of antennas	MUD	Key Assumptions	Result Parameters
Vahid[32], 1999	Simulation	N	Maximum Likelihood	Rayleigh/Ricean	Transmission Rate
Sumeet[33], 2000	Analysis	M Rx > 1 Tx	Maximum Likelihood	Rayleigh	Spectral Efficiency
Mathias[34], 2001	Analysis + Simulation	2Tx		Rayleigh/Multipath	Closed loop power control
Hao[35],2005	Analysis	N Tx M Rx	Maximum Likelihood	Rayleigh/Ricean/ Nakagami	Capacity and Error probability
Mandana[36], 2015	Simulation + Analysis	2 Tx	Maximum Likelihood	Rayleigh	Bit error rate
Kazuyuki[37], 2017	Simulation	2 and 4 Tx	CPM	Rayleigh	Spectral Efficiency

In the presence of relay assisted MIMO, the performance of STBC along with Vertical bell labs layered space time (VBLAST) in which all the sequences are transmitted from different antennas, Multi layered

STBC (MLSTBC) and Hybrid STBC VBLAST that combines the features of STBC along with VBLAST [53] and their capacities are compared. The results show MLSTBC display higher at low SNR(-10 to 15 dB) and Hybrid STBC VBLAST indicates significant improvement in capacity and gain as compared to rest at high SNR (above 15dB).

By using the proposed algorithm [54], 2M diversity order can be achieved with two transmit and over two receive antennas, and Rayleigh fading is used SNR Vs BER. Another algorithm for interference cancellation based on Bayesian analysis [55] having two antennas each at transmitter and receiver, the results does not vary as [56, 57] using 4 transmit and receive antennas and in another one using two transmit antennas and constellation used are QPSK, 16QAM and 256 QAM but in this prediction of the performance is possible of decoding algorithms according to SNR w.r.t BER.

4.2 Alamouti Code

The Generalization of Alamouti [58] scheme assumes Rayleigh fading for two transmit antennas and ML decoding providing full rate and full transmit diversity and maximum rate is achieved for real constellation (PAM) and inferior rate for complex constellation (QAM, PSK) for many transmit antennas.

An approach is proposed for improving the code efficiency [59] for high data rates and increasing the spectral efficiency, also assuming ML decoding. Conventionally, two transmit antennas are used in Alamouti but a case is specified in which 4 transmit antennas and single receive antenna is considered [60] and performance is compared with conventional Alamouti code so, there is performance gain in proposed code as compared to the previous one using Rayleigh fading.

There are so many newly developed algorithms, one of them is Alamouti BLAST for multiuser detection [61] for decoding of single user and multi user Quasi orthogonal STBC and with ML decoding full diversity at transmitter and receiver is achieved [62] i.e. NM where N is number of transmit antennas and M is number of receive antennas and as the number of receive antennas increases, it certainly degrade the bit error rate and subsequently the diversity gain improves in Alamouti space time codes [63]. Orthogonal STBC that allows linearization of transceiver signal is a very well known case of alamouti code [64]. The sum rates for NOMA can be improved for two point system [65] by using superposition coding mainly coordinated superposition coding (CSC) and for providing better rate of transmission to the users present at the edges of the cell, alamouti code are included with CSC.

4.2.1 Alamouti code with STBC and MIMO

The best known Space time block code is Golden STBC [66], frequency selective channels are used and performing Golden STBC with OFDM and without OFDM is compared and it is analyzed that the Golden STBC with OFDM provides low Peak to average power ratio (PAPR) as compared to Alamouti code with OFDM.

Table 4
Result of Shobhit[66], SNR Vs BER

Parameters	Antennas	Constellation used	Result
Alamouti STBC & Golden STBC	2 Tx and 1 Rx	16 PSK	2.5 dB
Golden STBC with and without OFDM	2 Tx and 2 Rx	QPSK	3 dB
Alamouti STBC-OFDM and Golden STBC - OFDM	2 Tx and 2 Rx	16 PSK	5 dB

There are Double STBC OFDM system proposed in [67] and for this system MIMO ML decoding is combined with Decision feedback equalization (DFE) and this proposed scheme shows improvement in performance compared to conventional MIMO detector. However, Rather than Rayleigh or frequency selective channel it uses Nakagami-m fading channel [68] and it shows that the diversity order of the system just doubles if downlink NOMA with Alamouti code is used in Nakagami-m environment and error performance analysis in Nakagami-m is done [69] of Alamouti and Coordinated interleaved orthogonal design (CIOD) STBC, a closed form approximate formula is derived to evaluate the coding gain and diversity order.

However, if there is need to use omnidirectional codes in Massive MIMO, then two types of omnidirectional codes are proposed [70] i.e. precoded alamouti code and other one is Quasi Orthogonal STBC. The complexity of decoding i.e. ML decoding is more in precoded QOSTBC with a diversity order of 4 whereas precoded Alamouti code provides diversity order of 2 with no complexity issue and even fast decoding.

The Alamouti scheme initially with 4 transmit antennas is used but if there are more than 4 antennas [71] then without sacrificing much gain, it can be achieved but here Zero forcing, MMSE and ML decoding techniques are compared for 2 and 4 transmit antenna alamouti code. MMSE shows little improvement as compared to ZF whereas ML outperforms both the schemes.

Equalization in Alamouti STBC is done [72] but in conventional case it can be done if the number of receive antennas is equal to the number of transmit antennas but in practical case Widely Linear (WL) equalizer is designed which shows an improvement in gain compared to the conventional one.

5. Conclusion

This paper presents the overall progress made in recent years in 5G systems. We have found that NOMA is the most commonly found technique used. Not only NOMA alone, but along with other coding schemes used. NOMA extensively used along with MIMO. As Single user MIMO, Multiuser MIMO, Massive MIMO. Another coding presented in most of the researches are Space time block codes. Along with the generalization, many things like interference cancellation in STBC and Orthogonal STBC, Quasi Orthogonal STBC are studied. Omnidirectional STBC is discussed. Special OSTBC code i.e. Alamouti

codes are discussed known for two antennas, but somehow for 4 and more antennas are also presented in this review. Most of the researches assumed Maximum Likelihood Decoding and Rayleigh fading channel but we have tried to elaborate in some more decoding techniques like MMSE, ZF etc. and channels like Frequency selective channels, Ricean and Nakagami-m channels. The analyzed and simulated results are studied in terms of ergodic capacity and outage performance by comparing different parameters. Although the review is only on the techniques but it will provide deep information about each coding along with the environment used. Future studies should investigate by considering new parameters and environment by proposing new algorithms and seek their contribution towards the universal framework.

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*No data and material have been used.

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No data is used for this work

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Figures

Figure 1

Two user NOMA in downlink with cooperative using dotted lines.

Figure 2

NOMA functioning

Figure 3

MIMO – NOMA basic approach