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A Study on Non-Orthogonal Multiple Access (NOMA) for 5G systems and beyond

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***Abstract*-This paper presents a comprehensive survey on Non-Orthogonal Multiple access for 5G systems and onwards. With the advent of 5G Communications, increasing number of users, increased bandwidth and data requirement yet limited bandwidth availability have become serious challenges. Hence 5G networks would need improved multiple access techniques than their present day counterparts. Non-Orthogonal Multiple access is a technique in which multiple users data is separated in the power domain. The problems addressed by NOMA are low overall bandwidth for multiple users.**

***Index Terms*:- 5G, NOMA, BER**

I. INTRODUCTION

With increased number of users, higher data traffic due to big data technologies and limited bandwidth; it has become mandatory to offer networking services with high Quality of Service, (QoS). Multi-user scenario has become a commonplace. The challenge which networks face is however the detection of all users with equal accuracy. As we can see the high paced networking of communications globally, this can be seen as one of major progress in technical aspect in our civilization to date. It became possible only with the onset and use of the digital communication framework in the world today. The recent era demands a very high speed networking environment to keep pace with the ongoing technical advancements. With increase in noise and many other reasons and causes for distortion of the signal, it remains a challenge to be able to send the signal correctly. The sole aim of the communication system that is digital is to send transmit signal properly and without any distortion with least errors.

II. Comparison of FDM, OFDM and NOMA:

A comparative spectral analysis of FDM, OFDM and NOMA is shown in the figure below-

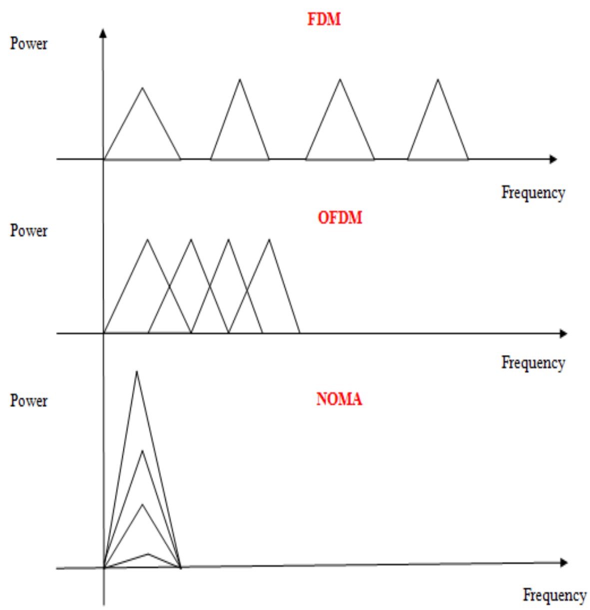

Fig.1 Comparative Spectra of FDM, OFDM and

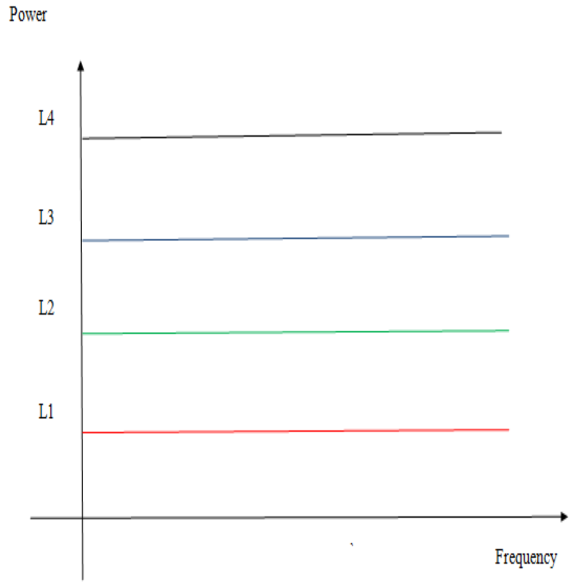

Fig.2 CONCEPT OF NOMA

II.REVIEW

The following section presents the previous work in the related field.

In the year 2018, Xiaojuan Zhao,Shouyi Yang Aihua Zhang , Xiaoyu Li , et al. proposed that Multi-User Detection (MUD) for uplink grant-free Non-orthogonal Multiple Access (NOMA) has received much attention recently. In this paper, the authors consider the scenario in which a Base Station (BS) is equipped with multiple antennas, and propose a Compressive Sensing-based Hard Fusion Algorithm (CSHFA) to realize multi-user detection. [1]

In 2017, Shao-Yu Lien, et al. proposed a foundations of radio access including deployment scenarios sustaining LTE/NR interworking, frame structure multiplexing multiple numerologies, DFT-S-OFDM- and CP OFDM based new waveforms, NOM-based multiple access, RA with beam steering, and enhanced CA for RA latency improvement are revealed. The insights provided thus boost knowledge not only for engineering practice but also for further technological designs.[2]

In the year 2016, B. Wang at al. proposed a technique based on compressive sensing of the wireless channel or radio between the transmitting and receiving ends. The approach was rather customized for up-link data transmission form several nodes to a common receiving point or node. The approach was based on the dynamic compressive sensing of the radio wherein the channel state information was sensed using compressive sensing.[3]

In 2016 Xi Zhang et al. presented an overview and an in-depth analysis of the most discussed 5G waveform candidates are presented. In addition to general requirements, the nature of each waveform is revealed including the motivation, the underlying methodology, and the associated advantages and disadvantages.[4]

In 2016, Ali A. Zaidi et al. proposed a flexible physical layer for the NR to meet the 5G requirements. A symmetric physical layer design with OFDM is proposed for all link types, including uplink, downlink, device-to-device, and backhaul. A scalable OFDM waveform is proposed to handle the wide range of carrier frequencies and deployments.[5]

In the year 2016, J.Choi et al. put forth a mechanism for maximum likelihood detector for channel estimator. In this case, a one bit analog to digital converter was used for detecting the values of the received signal stream and to be adjudged as bit-0 or bit-1.[6]

In the year 2016, Maha Alodeh et al. proposed a technique for multi user detection which used an energy efficient mechanism based on symbol level pre-coding of data stream prior to transmission. The approach followed interleaved pre-coding so as to avoid burst errors in packet data transmission.[7]

In the year 2015, Fabian Monsees et al. proposed a technique based on compressive sensing for sporadic machine type communication. In this approach, the authors used a compressive sensing technique for sensing the channel to find out the channel's frequency response. The approach is rather sporadic wherein the shadowing or noise effects are pre-dominant only in certain frequency ranges.[8]

In 2015, Xi Zhang et al. showed that the underlying waveform has always been a shaping factor for each generation of the cellular networks, such as orthogonal frequency division multiplexing (OFDM) for the 4th generation cellular networks (4G).[11]

In 2015, Amir Aminjavaheri et al. presented a study of the candidate waveforms for 5G when they are subject to timing and carrier frequency offset. These waveforms are: orthogonal frequency division multiplexing (OFDM), generalized frequency division multiplexing (GFDM).[12]

In the year 2015, Bichai Wang et al. proposed a new system for multi user detection which used Compressive sensing using the energy detector approach. The approach was suited for non-orthogonal access. The technique was intended for spectral widths of users which were separated by large guard bands and hence was used for uplink access.[9]

In 2013, Vida Vakilian et al. proposed a propose a multi-carrier transmission scheme to overcome the problem of intercarrier interference (ICI) in orthogonal frequency division multiplexing (OFDM) systems.[10]

III. MATHEMATICAL MODELLING FOR NOMA BASED SIGNAL DETECTION

Considering signals of different users travelling through different paths {R}, then the received signal would be:
R(n), R(n-1), R(n-2)… are the delayed version of the received bits (1)
e(n) is the actuating error signal
F(n) is the weight adapting function corresponding to different paths (2)
S(n) is the final signal at the receiving end (at demodulator) (3)

The approach focuses on detecting the strongest among a set of composites and then iterating the process i.e.

$$Find: \max(Sn)\ to\ evaluate\ x1 = max1 \quad (4)$$

Here,
x1 is the strongest in search of iteration 1.
The iteration is carried out till the last of the composite NOMA signal is not decoded.
The composite signal at a distance d can be statistically expressed as:

$$\bar{L}(d) = \bar{L}(d_0) + 10n\,log_{10}\left(\frac{d}{d_0}\right) \quad (5)$$

d_o=reference distance
n= constant value which is 2for LOS link but mostly uses higher than 2 for Multi path channel in NOMA based system

$$L(d) = \bar{L}(d_0) + 10n\,log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \quad (6)$$

IV. THE SUCCESSIVE SIGNAL DETECTION ALGORITHM

Since the NOMA signal is separated in power domain, hence frequency or time based separation at the receiver is not possible. Hence the successive detection of signals based on the descending magnitudes of power is the optimal choice. The mathematical modeling for the same is given below:

Step1. Generate random data stream S in binary form.

Step2. Design a multi path model with variable channel gain (g)

Here,

G1 is the path gain for strongest user

G2 is the path gain or the weakest user

G3 is the path gain for the average user

Step3. Generate the complex modulated signal given by:

$$x(t) = K_1 \sin(\omega t) + jK_2 \sin(\omega t) \quad - \quad (7)$$

The signal can also be expressed as a complex exponential,

$$x(t) = K_1 s e^{j(\omega t - \varphi)} + K_2 s e^{j(\omega t - \varphi)} \quad - \quad (8)$$

Step4. Design a channel with impulse response h(t) in the time domain.

Step5. Obtain the channel frequency response in the frequency domain by computing the integral:

$$H(f) = \int_{-\infty}^{+\infty} h(t) e^{-j2\pi f t}\, dt \quad - \quad (9)$$

Step.6 Generate an Additive White Gaussian Noise environment with noise psd of $N_0/2$

Step7. From the Db scale, convert the noise into linear scale using the equation:

$$n(t) = 10^{\left[\frac{SNR\ \ in\ dB}{10}\right]} \quad - \quad (10)$$

Step8. Add noise to the signal in time domain to obtain the noise added signal in channel:

$$S_{channel} = s(t) + n(t) \quad - \quad (11)$$

Step9. Find the strongest signal among the multitude of signals in the composite signal S given by:

$$S_{composite}(t) = x_1(t) + x_2(t) + \cdots x_n(t) \ - (12)$$

The strongest among all can be found by evaluation:

$$S_{strongest} = \max\{S_{composite}(t)\} \quad - \quad (13)$$

Step10. Compute the system load given by:

$$\beta = \frac{N_b K}{N_b N_s - (N_b - 1)N_0} \quad - \quad (14)$$

Here,

N_b is the number of users

N_s is the sub-carrier spacing

K is the number of data nodes

Step11. Computation of BER:

BER is defined as:

$$BER = \frac{No\ of\ Error\ Bits}{Total\ Number\ of\ Bits} \quad - \quad (15)$$

Step.12 The system BER can be evaluated as:

$$BER_i = 1 - \sum (s_i - s_i^{'})/nN_0 \quad - \quad (16)$$

$$BER_q = 1 - \sum (s_q - s_q^{'})/nN_0 \quad - \quad (17)$$

Here,

I represents the in phase component and Q represents the quadrature component.

N is the number of bits

N_0 is the oversampling ratio

Thus the overall average BER can be computed as:

$$BER = \frac{K[BER_i + BER_q]}{2} \quad - \quad (18)$$

The overall BER of the system for different conditions depict the Quality of Service (QoS) of the system.

Conclusion: It can be concluded from previous discussions that NOMA is an effective prospect for 5G systems and onwards due to its extremely high spectral efficiency. However, challenges remain in attaining low Bit Error Rate (BER) and system complexity. Since future generation networks would be hard pressed for bandwidth and high data rates, NOMA can serve as the multiplexing technique. The paper presents contemporary work on NOMA which may pave the path for future researchers.

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