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A Comparative Review on Handover and Co-Existence among Multiplexing Techniques for Future Generation Wireless Systems with Automatic Fall-back.

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Abstract: With increasing number of users and multimedia applications, bandwidth efficiency in cellular networks has become a critical aspect for system design. Bandwidth is a vital resource shared by wireless networks. Hence its in critical to enhance bandwidth efficiency. Orthogonal Frequency Division Multiplexing (OFDM) and Non-Orthogonal Multiple access (NOMA) have been the leading contenders for modern wireless networks. NOMA is a technique in which multiple users data is separated in the power domain. A typical cellular system generally has the capability of automatic fallback or handover. In such cases, there can be a switching from one of the technologies to another parallel or co-existing technology in case of changes in system parameters such as Bit Error Rate (BER) etc.Multi User Detection or MUD is a serious challenge faced in the field of wireless and cellular communications. Due to the high spectral efficiency, non-orthogonal multiple access (NOMA) based systems are becoming the latest choice for 5G networks and onwards. This paper presents a review on co-existence of NOMA and OFDM systems for future generation wireless networks.

Keywords:Wireless Networks, Co-Existence, Non-Orthogonal Multiple Access (NOMA), Multi User Detection (MUD), Inter Symbol Interference (ISI), Frequency Selective Channel, Bit Error Rate (BER).

1. Introduction:

The present scenario in wireless communication is seeing a rapid increase in the number of users and also the data size due to multimedia applications. This necessitates the use of high data rates for communication. Moreover, the spectral efficiency needs to be enhanced so as to incorporate more users in the available bandwidth. Non-orthogonal multiple access often termed as NOMA is an extremely effective alternate multiple access technique which scores over conventional multiple access schemes such as FDM and even OFDM. The effects of fading and frequency selective nature of wireless channels often results in high level crossing rate (LSR) for user equipments undergoing fading dips. While most of the MUD schemes may be derived from different principles, they usually rely on some prior estimate of the channel, obtained by either a blind or a training-sequence assisted channel estimation algorithm.

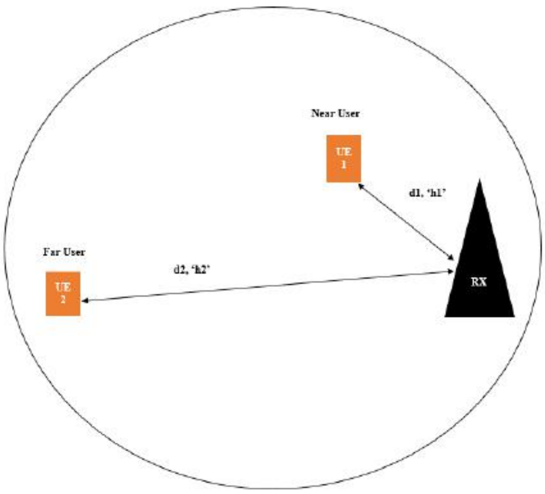

Fig.1 A Typical Multi-User Situation in wireless networks

OFDM	NOMA	Reference
Signals separated in Frequency Domain	Signals Separated in Power Domain	Cai et al., "Modulation and Multiple Access for 5G Networks, IEEE 2017.
Condition of Orthogonality Necessary	No need of orthogonality	Cai et al., "Modulation and Multiple Access for 5G Networks, IEEE 2017.
Lower Throughput (Mbps)	Higher Throughput (Mbps)	Nain et al., User Selection with optimal power allocation in Downlink NOMA, IEEE 2017
Lower Sum Rate (Bits/s/Hz) (Spectral efficiency 'ŋ')	Higher Sum Rate (Bits/s/Hz) (Spectral efficiency 'ŋ')	D Tse & P Viswanath, Fundamentals of Wireless Communication, 2004 (Book)
Receiver Design less complex	Receiver design based on interference cancellation much more complex	Guerreiro et al., "On the Receiver Design for Nonlinear NOMA-OFDM Systems, IEEE 2020
Relative more immunity to fading characteristics.	SNR-BER characteristics for fading channels in some cases can be similar to NOMA	Tusha et al., A Hybrid Downlink NOMA With OFDM and OFDM-IM for Beyond 5G Wireless Networks," IEEE 2020
OFDM is less susceptible to path loss and multipath fading compared to NOMA	NOMA is highly susceptible to path loss in case of fading channels and may result in poor quality of service.	A Al Khansa et al., Performance analysis of Power-Domain NOMA and NOMA-2000 on AWGN and Rayleigh fading channels, Journal of Physical Communication, Elsevier 2020.

Table 1. Comparative Analysis of NOMA and OFDM

However, channel estimation are usually affected by errors and most of existing MUD schemes are known to be sensitive to such errors. Moreover, for effective interference suppression, many MUD schemes also require an estimate of the covariance matrix of the received signal, which is typically the sample covariance matrix. The sample covariance matrix converges slowly, resulting in a poor estimate of the true covariance matrix when the number of samples of the received signal is relatively low.In wireless telecommunications, multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths.

Causes of multipath include atmospheric ducting, ionospheric reflection and refraction, and reflection from water bodies and terrestrial objects such as mountains and buildings. The effects of multipath include constructive and destructive interference, and phase shifting of the signal. In digital radio communications (such as GSM) multipath can cause errors and affect the quality of communications. Multipath signals are received in a terrestrial environment, i.e., where different forms of propagation are present and the signals arrive at the receiver from transmitter via a variety of paths. Therefore there would be multipath interference, causing multipath fading. Adding the effect of movement of the transmitter, receiver or the surrounding clutter to it, the overall received signal amplitude or phase changes over a small amount of time. Mainly this causes the fading.

The term fading, or, small-scale fading, means rapid fluctuations of the amplitudes, phases, or multipath delays of a radio signal over a short period or short travel distance. This might be so severe that large scale radio propagation loss effects might be ignored. The multiple paths carry multiple copies of the same signal. This causes information from the same source being received by the receiver at different times and thereby causing the phenomenon of **Inter Symbol Interference (ISI)**which is often responsible for high BER.

2. Multipath Fading Effects

Multipath Fading Effects:

In principle, the following are the main multipath effects: 1. Rapid changes in signal strength over a small travel distance or time interval. 2. Random frequency modulation due to varying Doppler shifts on different multipath signals. 3. Time dispersion or echoes caused by multipath propagation delays.

Factors Influencing Fading:

The following physical factors influence small-scale fading in the radio propagation channel:

a) Multipath propagation – Multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths. The effects of multipath include constructive and destructive interference, and phase shifting of the signal.

b) Speed of the mobile – The relative motion between the base station and the mobile results in random frequency modulation due to different Doppler shifts on each of the multipath components.

c) Speed of surrounding objects – If objects in the radio channel are in motion, they induce a time varying Doppler shift on multipath components. If the surrounding objects move at a greater rate than the mobile, then this effect dominates fading.

d) Transmission Bandwidth of the signal – If the transmitted radio signal bandwidth is greater than the “bandwidth” of the multipath channel, the received signal will be distorted.

In figure 2, a variation of signal strength as a function of distance from base station has been depicted. It can be seen that as the distance from the base station increases, the received signal strength decreases making the reception of signals more prone to errors and degraded quality of service.

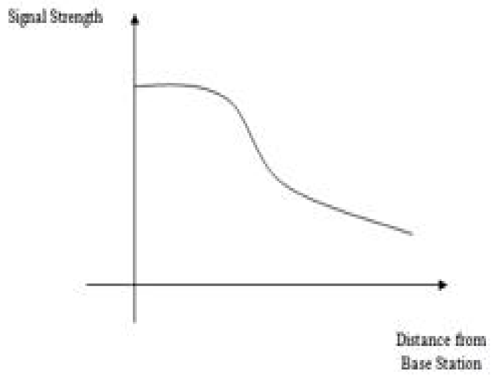

Fig.2 Signal Strength Variation in Multi-User Situations

After considering the multipath effects, it is convenient to understand the concept of successive signal detection and equalization.

3. Need for Equalization

The need for equalization lies in the fact that practical wireless channels do not fulfil the condition of distortion less transmission. A mechanism that reverses or nullifies the derogatory effects of distortion introducing channel is called an equalizer. The rate of data transmissions over a communication system is limited due to the effects of linear and nonlinear distortion. Linear distortions occur in from of inter-symbol interference (ISI), co-channel interference (CCI) and adjacent channel interference (ACI) in the presence of additive white Gaussian noise. Nonlinear distortions are caused due to the subsystems like amplifiers, modulator and demodulator along with nature of the medium. Sometimes burst noise occurs in communication system. Different equalization techniques are used to mitigate these effects. Different applications and channel models suit a different equalization technique.The main challenge of wireless communications is the random and frequency selective nature of wireless channels which does not follow the conditions for distortion less transmission.

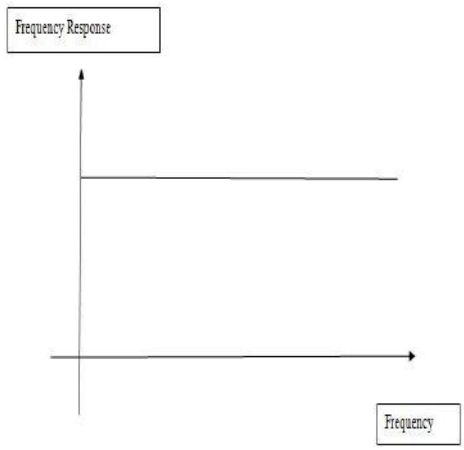

Fig.3 Frequency Response of a Flat (Ideal Channel)

For the transmission to be distortion less, the channel should have a flat frequency response as shown in the figure above. But practically, wireless channels are random and show non ideal characteristics.

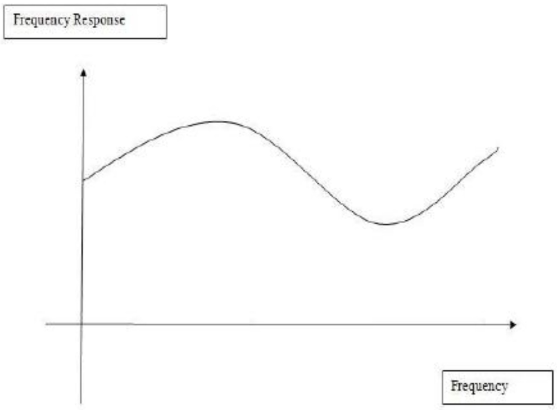

Fig.4 Frequency Response of a Frequency Selective (Non-Ideal Channel)

Such a channel introduces distortions in the received signal thereby degrading the BER performance of the system. If we know the frequency response of the channel **H(z),** then we can design the frequency response of the equalizer as **E(z)= 1/H(z).**

Since the wireless channels are realized as filters, hence equalizer structures also need to be realized as filters.One of the biggest challenges of realizing an equalizer is in designing an algorithm that would implement the equalizer transfer function. The design objective of the equalizer is to undo the effects of the channel and to remove the interference. Conceptually, the equalizer attempts to build a system that is a "delayed inverse" of the channel, removing the inter symbol interference while simultaneously rejecting additive interferers uncorrelated to the source. If the interference n (kT_s) is unstructured (for instance white noise) then there is little that a linear equalizer can do to improve it. But when the interference is highly structured (such as narrow band interference from another user) then the linear filter can often notch out the offending frequencies and thereby reduce the effects of inter symbol interference.

The effect can be graphically understood as:

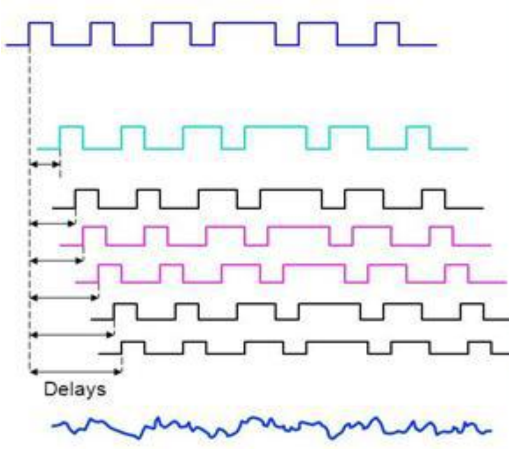

Fig 5 Multipath Interferences causing ISI in NOMA-MUD

Since errors arising out of ISI cannot be removed by simply increasing the transmitter power, hence they are called irreversible errors. The only way out is reversing the effect of the channel by design of equalizer.

4. The MUD Model.

The multi-detection mechanism can be understood using the conceptual block diagram of a MUD system which is shown in the following figure.

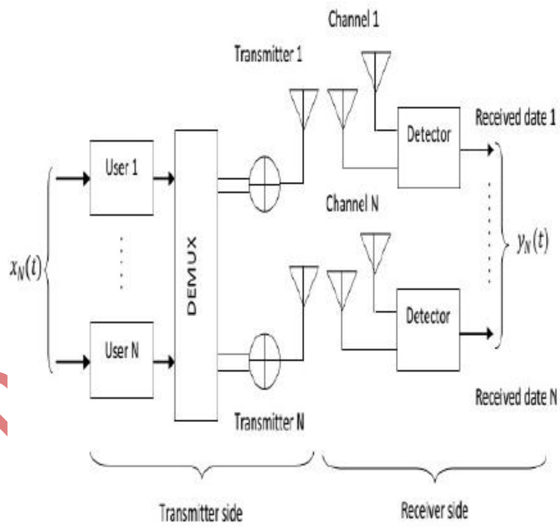

Fig.6 The MUD Transceiver

5. Signal Detection

The successive DFE equalization approach is an efficient technique of equalizing the received signal power and is capable of detecting different multi-path components (MPCs) under varying signal strengths or BER conditions. The approach requires the following information:

a) Individual signal strength of each MPC be given by:

$$S_i = g_i\sqrt{P_i} \quad (1)$$

Where S represents i[th] MPC power,

'g' represents gain of the i^{th} path

P represents the power of the i^{th} MPC

b) The cross correlation of the spreading function applied on the data stream:

$$\text{Spreading Function} = R_i, j(k)$$

(c) The noise statistics for the k^{th} sample

i.e. $n_i(k)$

Thus the different MPCs corresponding to paths can be mathematically written as:

$$r_k = R_k . D . S_k + n_k \qquad (2)$$

Where D represents the signal strength matrix corresponding to different MPCs given by:

$$S_i = g_i \sqrt{P_i} \qquad (3)$$

The proposed algorithm can be explained as: Let the various MPC strengths be:

$S_1.G_1,\ S_2.G_2,\ S_3.G_3$................. $S_n.G_n$

It can be observed that the signal power of transmitter is multiplied with the corresponding channel gain where the channel gain for different MPCs varies due to frequency selectivity of the channel.

Considering that we have the information about the signal strengths given by equation (4)

$$P_1 {g_1}^2 > P_2 {g_2}^2 > \dots \dots \dots P_M {g_M}^2 \qquad (4)$$

We decide the strongest among all the received user MPCs.

2. Detect the k^{th} strongest MPC among all the signals using the following equation:

$$S_k = dec(P_i G_i)^M \qquad (5)$$

3. Cancel the first strongest MPC interference at the receiver end according to the equation:

$$y_{e+1}^{(i)} = y_e^{(i)} \_ g_e \sqrt{P_e} R_i, e(k) \hat{S}_k^{(e)} \qquad (6)$$

Here we subtract the interference from the strongest interfering signal from each signal received at the receiver using the Decision Feedback actuating Signal $e(k)S_k^{(e)}$

The channel state information (CSI) can be obtained by channel sounding, which will typically render a temporal varying pattern, as depicted in figure 4. The typical CSI obtained is a sampled version of the channel frequency response given by:

$$CSI_t = \sum_{i=1}^{n} H(f, t - Ti) (7)$$

Here,
T is the time period for channel sounding.
$$i \in 1,2 \dots ..$$
CSI_t is the time varying CSI.
H is the channel frequency response.
It can be observed here that the channel response is a function of both frequency and time. A temporally varying pattern is typically obtained on channel sounding

Conclusion

From the previous discussions, it can be said that there are two important challenges in the detection of multiple signals corresponding to multi-user detection in Wireless Networks. One important problem is the difficulty in reception of weak signals in the presence of string signals. The other is nullifying the effect of degradations done by the wireless channel. In this work, a review on practical multi-user scenario in a wireless channel has been cited using a near and far user approach. The differentiation among the near and far users has been done based on the path loss factor. A higher path loss factor corresponds to a far user in this case. Equalization has been proposed in both the cases of NOMA and OFDM to reduce the BER of the system by inverting the negative effects of the transmission channels. It has been shown using a comparative analysis that a co-existence among the techniques such as

NOMA and OFDM may exist for future generation wireless networks.

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