Information-theoretic capacity bounds for dynamic wireless networks via IA (Interference Alignment)

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1 Abstract

In this thesis, we try to obtain efficient IA-based transmission schemes. Multiple source-destination pairs utilize the same communication channel in wireless interference networks. The interference from unintended sources affects the signal receipt at each destination. It could lead to a strategic scenario in which every source attempts to recompense for the nonpositive impact from interfering at their wanted destination while expanding interference in the other destinations by raising its driving force. Failure to do so will follow in a substantial waste of the radio resource available. That can also decode signals of interest as well as remove interfering signals of unwanted transmitters. The transmissions of the channels appear to be orthogonal with common IA strategies. However, users can then send by using a system for alignment of interference to address inter-user interference. Preferably, the IA principle regulates its transmitting purposes, including its transmitter, in a rather manner whereby interference signals from multiple unwanted transmitters are mitigated at each receiver within the same subspace, that differs compared to the signals of interest from the subspace.

2 Acknowledgments

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3 List of Abbreviations

5G	Fifth generation
AWGN	Additive White Gaussian Noise
BEP	Bit error probability
BER	Bit error rate
BIA	Blind IA
BS	Base Station
CoMP	Coordinated multipoint
CSIT	Channel state information at the transmitter
dB	Decibel
DoF	Degree of freedom
FDMA	Frequency-division-multiple-access
i.i.d.	Independently and identically distributed
IA	Interference Alignment
IC	Interference channel
ICI	Inter-channel interference
MIMO	Multiple-Input Multiple-Output
NOMA	Non-orthogonal multiple-access
PDF	Probability Density Function
SIC	Successive interference cancellation
SNR	Signal-to-noise ratio
TDMA	Time-division- multiple access
TP	Transmission points
UE	User equipment
uRLLC	Ultra-reliable low latency communication
V-BLAST	The Vertical Bell Laboratories Space-Time
XCI	X-channel’s interference

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5 List of Notations

$[j,k]$	User channel matrix
γ	The instant SNR per bit
$\mathcal{CN}(m,1)$	Complex Gaussian distribution with mean m and variance 1
$\mathbf{H}_{j,j}^{[k]}$	The channel among BS
$\mathbf{J}_1^{[i]}$, $\mathbf{J}_2^{[i]}$	Efficient channel matrices after the implementation of the ICI channel cancelation scheme
$\mathbf{K}_2$	The subspace spanned from cell 2 to cell users by the aligned, efficient interference channel 1
$\mathbf{s}_i$	Signal of BS i
$\mathbf{U}_j^{[k]H}$	Receive beamforming matrix
$\mathbf{V}_j$	Transmit beamforming matrix in cell j
$\tilde{\mathbf{n}}_j^{[k]}$	The effective zero-mean white additive Gaussian noise (AWGN) vector at beamformer output
$\tilde{\mathbf{y}}_j^{[k]}$	The signal received by the user interested
d_s	Specific amount concerning transmitted information streams of every BS
$I_j^{[k]}(SNR)$	User-interest sum-rate attainable for that SNR
i	BS i, cell i, i = 1,2,3
j	BS j, cell j, j = 1,2,3
K'	Number of users in a fully-overlapped region
K	Number of users
k	User k
L'	The amount of sources of information
l	BS l, l = 1,2,3
L	Number of cells
N_r	Number of receive antennas

N_t	Number of transmit antennas
$null$	Null space
$p_\gamma(\gamma)$	PDF of instantaneous SNR
$P_b(E\|\gamma)$	Conditional BEP of instantaneous SNR
$span$	The matrix's subspace

6 Introduction

In recent past years, wireless networking has been a significant interest owing to the exponential development of multimedia networks and the need for all-round access [1]. The networks of the fifth generation are of crucial importance. The communication network in the 5G describes the next-generation mobile infrastructure and is a wireless infrastructure that includes modified packages and a wide transmission range [2]. In comparison to 4G technologies, the main features of the 5G network are global standards for networking, cognitive radio access, radio interfaces, all-round computing, electronic devices, and broadband coverage [2]. The cellular 5G network includes wireless technology. Wireless connectivity is effective in interacting with users instantly over long and short distances [3]. The advantages of 5G technology are improved power, speed, energy consumption, and bandwidth [4]. The 5G network can support society significantly, as it offers self-driving cars, emergency care, smart homes, intelligent traffic control, and the environment. The use of 5G cell networks is also critical as this improves capacity, data speed, and data flow. The 5G mobile network is a next-generation cellular network compared to previous generations [5]. A possible mix of various networking systems would tend to be 5G networks, including massive MIMO, full-duplex communications, and beamforming [6].

In the last decade, the market for wireless communications applications has grown enormously, and wireless traffic will continue to rise in the future. In various technologies, including speech and video communications, enormous burden and high quality of service should be supported in the emerging wireless networks. The fact that radio services are not enough and that wireless contact medium characteristics mean that fulfilling this expectation is still tricky. The fading effect is generally associated with wireless channels. For several years, substantial research has been undertaken into reducing the harmful effects of fading and the development of valuable techniques. For example, multiple antennas to achieve spatial flexibility offer considerable improvements in efficiency over traditional single-antenna technologies. Furthermore, each user's contact will be interacted with by other users because of the media's wireless communication aspect. Inter-user interference in cellular networks is usually much more complex than fading. For instance, each source's power of propagation affects the signal identification at their intended destination and the other destination within two-user wireless interference network, where both users wish toward concurrently communication between corresponding locations of interest within similar frequency range. Thus, such an optimization for an output is interrelated with the output of each source-destination pair. The problem gets much tricky if sources amount reaches two. For the efficient operation of the networks, therefore, proper interference alignment is necessary. The possible problem is the reuse of frequency as high frequencies are reached. Among the second-level components of the heterogeneous network, the same licensed frequency band can be reused efficiently many times, increasing the spectrum efficient requirement by network region including capacity [7]. Alongside exponential increase from devices worldwide comes signal interference. Various sources-destining partners' signals tend to become more orthogonal with conventional interference control techniques, for example, frequency-division multiple access (FDMA) and time-division multiple access (TDMA). That condition induces the subspaces from separate interfering signals toward orthogonal and orthogonal signals toward the wanted signal at every receiver [8]. Interference at the low spectral quality expense is avoided. The efficiency of wireless networks was thus thought to be limited by general interference. [9] separate interference signals will be synchronized to provide the intended broadcast with other radio tools, although with the elegant interference alignment architecture [10]. Suppose the multi-user networks of bigger compared to two source-destination pairs, for example. Such interference signals should be balanced at any destination to leave to its signal at most half signal space [10]. Each consumer will then reach half the frequency of interruption, regardless of how many interferers are present. In comparison with orthogonal transmission methods, though, the realization of interference alignment can be very complicated [8].

Nowadays, we face the Interference bottleneck when several interfering signals should be aligned properly. This problem can be solved using IA. In such signal subspace including a size less compared to interferences, IA mitigates interference through aligning more interfering signals [11]. IA is a beneficial approach to align the interference [12]. The objective of IA remains to optimize the interference-free dimensions by optimizing the interference overlap between the subspaces of each signal at each receiver as an innovative interference management approach to achieve a full degree of freedom (DoF) [13].

With support from DoF, IA could be more prominent throughout wireless interference networks. If K cells each have a singular BS, although TDMA and FDMA obtain one DoF, its achievable DoF could be found to increase K with IA. Quite specifically, IA will accomplish $d = K/2$ DoF throughout that situation [10]. Specifically, within that K-cell case, it could only transmit a single data stream to something like a single user via TDMA and FDMA. However, IA allows that sending of separate data streams across that network. IA allows one to use the available spectrum further effectively with more significant sum rates and use equal frequency and time tools as traditional interference control strategies such as TDMA or FDMA. IA has become a wide field of study that covers two different areas in particular. First comprises information-theoretical experiments, including the achievable DoF [10]. The second covers the signal processing elements, such as assessing feasible situations and the construction with various algorithms with specific cases depending on various optimization parameters. IA technique can be classified into separate paths. Although some IA systems are built on some symbolic time extension and frequency, specific IA strategies were suggested using several antennas towards cancelation of its interference with the signal space alignment. These systems for IA were often iterative because they often remove the need to extend its symbol over the time-frequency domain, making them rather convenient or tempting in advance.

Wireless network interference is a basis for models of multi-source and destination networking networks. Each outlet tends to interact with its target, and both sources use the same media. Given the wireless medium's transmitted aspect, the signals from unintentional sources are often overheard by each destination. Therefore, the transmitted signal combined from desirable and unwanted sources, which weigh the resulting channel benefits, is noisily observed at each destination. There are also realistic scenarios for wireless networking. Examples cover mobile networks, ad hoc networks, local wireless, and cognitive radio networks. In the future, growing demand has been expected for wireless data traffic. It would lead to an expansion of the existing wireless networks, wireless technology, and wireless applications on those networks. It also would add to a growing need of radio services, for example, electricity or bandwidth. That radio spectrum occurs to be, however, limited including its fact of being among the most costly natural commodities. The trend of massive energy consumption and energy prices is also growing steadily. Also, due to its low battery storage space, the energy budget of mobile terminals is limited. For emerging wireless technology, spectral and energy-efficient architecture is essential. Though, this remains generally hard to obtain the most effective transfer schemes and characterize the highest wireless network results. Proper IA strategies are required to make effective use of radio resources. The general interference network consists of two source-destination pairs. For several years, this network study has been concerned with its power area's characterization (closure of rate vectors for which interactions with independent sources can be jointly reliable). Specific internal and external boundaries for the capacity region were defined, and researchers studied the two-user interference network. In later literature, some feasible rates and upper limitations were also suggested. However, the capacity area is generally still undisclosed except in certain particular situations, such as a great deal of interference between users.

Three main methods in multi-user interference network management are non-orthogonal transmission, orthogonal transmission, and interference alignment. Consider non-orthogonal transmission and decoding as interference is treated as noise when all sources transmit in the same frequency range simultaneously. Any source uses the techniques of single-user coding. The target signal cannot be differentiated from the interference signals at each destination. Thus, by directly treating interference signals as noise, this endpoint is decoded. In the low-SNR area, proper power management techniques will restrict the degree of interference. However, inter-user interference is dominant while SNR is high. The conventional solution is to orthogonalize the transmissions of various users to prevent interference at destinations. Any source-destination pair can access just part of the access channel. However, signal receiving does not explicitly include inter-user interference at each destination. The reason for that is since the interference signals span the received signal area at each destination because they are orthogonal to each other excessively. Suppose only the interference signals can be minimized at each destination. In that case, a more significant interference-free subspace for the intended transmission will be left at each destination. In particular, a new technique known as IA can be used [9]. Besides, IA for interference networks means that signals' architecture casts overlapping shadows on receivers, whereas interference is provided, whereas destination receivers where desired are distinctive [10]. There can generally be two conditions. First, interference signals are aligned in the one subspace, known as subspace of interference. Secondly, that subspace which remains to the signal of interest must be free of the subspace interference. The second is the required subspace. The IA strategies require both conditions. Interference can be accommodated in various fields, including space (across many antennas [9],[10]), time (use transmission delays or time-varying channel coding [10]), frequency (coding on frequency-selective networks between separate carrier modules), and code (aligning interference in signal levels). Interference is an inherent occurrence in wireless networking networks consisting of different communication systems [14]. In multi-user networking communications, IA is an important scientific challenge. In the recent past, IA was suggested to manage interference optimally to provide K users with half of the capacity for one user's interference-free channel capability. Via IA with multiple dimensions, maximum interference channel (IC) DoF can be reached in space, time, and frequency [15]. IA ensures that the interference from different transmitters in the same subspace aligned as various devices occupy the same radio spectrum, the remaining non-interference space used to absorb the users' desired signal. IA improves the DoF-channel reuse gain and improves the system's spectral efficiency, and becomes an efficient way to solve communication network interference [16]. Applications of interference mitigation include cellular networks, X-networks, Y-networks, mesh networks, mobile phone systems, compound networks, multicast, two-way networks, multi-hop, multi-flow networks, distributed data storage networks, cognitive radio networks, and cooperative communication networks [17]. One example is a wireless IC in which the K-sender-receiver pairs will concurrently transmit at data rates same as half from its interference-free channel potential toward the intended destionation due to interference mitigation, considering the arbitrary size of the number of K users, which indicates that the IC is not inherently limited [17]. In [18], precoding technology was used to develop IA. Precoding design research is a study that is emphasized by the IA. In [19], the authors suggested that IA technique mixing with the SIC to handle wireless multi-hop sensor networks and characterize this interference management strategy's application process by building the structure of system model with maximizing the data rate issue. These results of [19] demonstrate that using IA technology within multi-hop, wireless sensors would reach a more extensive system by applying a fair combination of IA and SIC technologies, thereby increasing the network efficiency of the wireless sensors. The research is planned to consider several network scenarios, including Y-network, X-network, mesh network, and blind IA (BIA). Simulation in MATLAB is one of the approaches applied to carry out a qualitative assessment of these scenarios.

BIA is an approach which utilizes the information from coherence patterns of channel on transmitters rather than instantaneous channel coefficients [20]. The method proposed in [20] is analogous to BIA [21] as the interference signals are both aligned without channel state information at the transmitter (CSIT). However, an approach presented differs such that it does not require a consistent pattern of the channel or the ability to switch reconfigurable antenna on each recipient to perform IA. A constant channel setting is viable for the proposed scheme, whereas a traditional BIA requires time-varied channel coefficients to achieve alignment. In [21], which determined the number of information symbols assigned to each user by another system parameter [21]. Unlike previous work in [21], it is worth mentioning that the proposed approach [22] was dealing with asymmetrical or arbitrary allocations, the construction of transmission-forming vectors and selection modes was much more complex. The contribution [22] was that the authors developed a systematic construction procedure for the transmission of beamforming vectors and selection mode patterns that blindly align interference, even for the use of very asymmetrical data symbols.

Mesh network is a crucial technology in the next-generation communication network. The authors in [23] implemented a general IA and interference cancelation algorithm within a multi-hop mesh network.

In the Y network case, the aim is to understand the given model, consisting of three nodes including two antennas at every node and three antennas on relay, which is also called a bidirectional relay interference network. We also have six messages W_{ij} (j-node originated, i - desired node) [16]. In the Y network model, we have no direct links between nodes, which denotes that each node is linked with a relay. Uplink phase when each node transmits signal toward this relay. A downlink phase when that relay sends signal toward every node [17]. In [16], the authors examined the network flow of data of the Gaussian MIMO network using 3 users with one relay between them. Every antenna-fitted user provides two separate unicasting signals toward two various users in this network, and two messages were received from other users through antennas from the intermediate relay. Such a network was called the MIMO Y channel and was introduced in [16].

The highest standard DoF value for a one user including an N antenna means two within a MIMO channel with no some symbolic extend in terms of frequency and time and including a minimal antennas. That is small compared to $K/2$. The feasibility dilemma, i.e., whether IA should eliminate interference of each the source of interference or not in this channel form, is another difficulty in implementing IA after channel parameters have been set. The feasibility problem is considered the solvability of bilinear structures when their i.i.d. continuous distribution coefficients are drawn.

In [24], the MIMO X-channel case for such a combined L-cell MIMO system is proposed as well as the cell-side customer's achievable sum-rate may be improved. While in [25], the feasibility was examined in compounded MIMO networks. One of the results in [25] shows that the mean transmission pace like 8.8, 11.4, also 12.75 bits/s/Hz was achieved of ninety percent chance in cases of 10, 30, and 50 antennas on the transmitter's edge. Keep in mind that using additional antennas allows one to solve the high similarity, and the device should then be viewed as medium correlated. Section 6 of this thesis is the introduction. In Section 6, background, proposed work, and literature review were presented. Section 7 provides an overview of the research methodology. Section 8 gives an overview of successive IA-based spectrum efficiency enhancement techniques with system model. In Section 9, the results are provided. Next, Section 10 sums up the thesis and summarizes work done and future directions.

7 Methodology

A systematic literature survey on IA scenarios, such as X, Y, mesh networking, and BIA, is the first step in the study. For the planning of a literature survey, Google Scholar, Elsevier Science Direct, Web of Science, Scopus, and IEEE XPlore may use the aforementioned online databases. Previous research in this direction offer researchers and scientists valuable findings. The concept of IA was suggested. Such a system is intended to be energy efficient and to minimize network interference. Firstly, an overview of the viability of the mesh network. It helps to explain the idea of a study of feasibility. Then it is vital to extend feasibility research on the Y-network, X-network, and BIA principles after feasibility analysis of the mesh network. In the Y-network case, the goal is to understand the given model, which comprises three nodes and a relay of three antennas, also known as the two-way relay interference network [17]. BIA is a scenario or approach which uses channel coherence pattern information on transmitters instead of instantaneous coefficients of channels [20]. The third stage is the results in capacities, BER, and probability of outage. These observations are also used to compose a paper for the conference. As a next step, we would examine the context factors, i.e., technical know-how and other features. Consequently, acceptable specifications, X, Y, blind IA, and network scenarios are specified. At this point, the student participates considerably through research and the distribution of the findings through the conference publications. The submission of the conference paper would develop language comprehension, writing skills, and presentation skills. At the last point, the master thesis is scheduled to submit. The results of this progress report described in the next section.

8 Successive IA-based spectrum efficiency enhancement

8.1 Introduction

IA is a growing idea or technique arising from the interference network capacity examination [1]. This idea questioned much of the traditional understanding of wired networks and wireless network performance limitations in a bit of time [1]. IA's incredible advantages have been demonstrated to date mainly through theoretical hypotheses, for example, infinite resolution, worldwide channel awareness, delays, extension, including power of high signal and bandwidth. Nevertheless, this concept has immediately become interesting within networking, information theory , communications, network, signal processing, also created a wide range of opportunities [1]. In [1]-[4], the authors state that the objective of IA is to optimize the interference-free dimensions by optimizing the interference overlap between the subspaces of each signal at each receiver as an innovative interference management approach to achieve a full DoF. In [3], the authors suggest that interference is an inherent occurrence within wireless networking systems consisting from different communications technologies. We can overcome the issue by using several techniques by orthogonalizing every signals toward another signals by frequency, time, and subspace. Those strategies may prevent interference via splitting these supplies within every region though may not allow efficient using through channel's capability. Within that sense, IA recently became well known for technology able about preventing interference among several connections including optimizing the capacity of broadcast. As each user pair is unable to recognize data regarding another network users within a current communication system, the best approach is to manage its transmission rate. However, with IA, its sum rate rises consistently with both the number of large SNR users. That IA aligns any interference into some shared subspace with the receiver equipped with a multi-antenna system for complete signal space. It divides the space for interference from the desired signal area so that some transceivers can work simultaneously or at the same frequency [14].

Due to its ability to achieve high spectral efficiency and relatively small complexity and with no instantaneous channel state detail, the Vertical Bell Laboratories Space-Time (V-BLAST) means common approach for MIMO technologies [5]. And successive interference cancellation (SIC) was described in [5] as an inherent part of V-BLAST and denotes as that base from non-orthogonal multiple-access (NOMA) power domain. In recent applications, the SIC was used to exclude inter-layer interference (intra-user) within a user. In contrast, the inter-users interference for this former example was used to cancel it. Therefore, there is an important motivation to use these two popular techniques correctly. In [6], the authors state that SIC is the most popular detection technology of NOMA systems, but it experiences a loss of efficiency due to error propagation in practical communication systems. Notably, the SIC receiver's output can weaken further when there are correlations between user access channels. Alternatively to a linear equalization of the channel, particular authors of [7] suggest that this multi-user interference can be handled using the concept of successive interference cancelation. Following worst relation efficiency, the V-BLAST algorithm in [7] optimizes the SIC detection order - of high significance in multi-user cases. With SIC, users and BS can successfully decode various signals at the receiver side [26]. The concept of V-BLAST was described in [11], which is to divide bits into several substreams and send them with the same frequency using a set of transmission antennas. Transmitting antennas' number remains same as substreams' total amount.

Besides, using higher frequencies has made it imperative to use beam-based transmission in future networks. While these straps have less contact with cell edges than omnidirectional transmission, they are far more susceptible to blockages. That makes it much harder to fulfill the stability restrictions for uRLLC (ultra-reliable low latency communication) applications. In this scenario, a potential solution is synchronized transmission from multiple TPs (transmission points). While CoMP (coordinated multipoint) was motivated by coordination between adjacent TP's to boost the efficiency of UE (user equipment) cell edges, CoMP Spatial Diversity may be used to solve many 5Gs and beyond needs [27].

8.2 System model

The MIMO model within the thesis shows mobile L-cell network including every cell serving many users. Suppose that the BSs possess the equal coverage region, system settings and serve an equal amount of users by cell, K spread arbitrarily. (Fig. 8.1). The interested user is described by $[j, k]$, [28], [29], wherein j or k are respectively cells including user indices. Therefore, the obtained signal is decoded by each user doubling that by some beamforming matrix. It can later be written in one following form

$$\tilde{\mathbf{y}}_j^{[k]} = \underbrace{\mathbf{U}_j^{[k]H}\mathbf{H}_{j,j}^{[k]}\mathbf{V}_j\mathbf{s}_j}_{desired\ signal} + \underbrace{\mathbf{U}_j^{[k]H}\sum_{i=1,i\neq j}^{L}\mathbf{H}_{j,i}^{[k]}\mathbf{V}_i\mathbf{s}_i}_{interference} + \tilde{\mathbf{n}}_j^{[k]}, \ \ \forall j \in L, \ \forall k \in K, \tag{1}$$

whereas $\mathbf{U}_j^{[k]} \in \mathbb{C}^{N_r * d_s}$ denotes an interest user's beamforming matrix, and $\tilde{\mathbf{n}}_j^{[k]} = \mathbf{U}_j^{[k]H}\mathbf{n}_j^{[k]} \in \mathbb{C}^{d_s*1}$ denotes the white additive Gaussian noise (AWGN) and effective zero-mean vector at beamformer output, including $\mathbb{E}\{\tilde{\mathbf{n}}_j^{[k]}\tilde{\mathbf{n}}_j^{[k]H}\} = \sigma_{\tilde{n}}^2\mathbf{I}$. $\mathbf{H}_{j,i}^{[k]} \in \mathbb{C}^{N_r * N_t}$ refers to the channel among BS i including clientele $[j, k]$ wherever all $\mathbf{H}_{j,i}^{[k]}$ entries are generated using random $\mathcal{CN}(0, 1)$ variables independently and identically distributed (i.i.d.). Every channel stays often believed as quasi-stationary with flat fading frequency. It must be remembered that while, i.e., entries are generally believed, e.g., [30], [31], the association that may occur between antennas is not considered in practice, usually leading to a deterioration inefficiency. Please refer [32], [33] for more detailed discussions on this effect. We do not take the possible connection between the antenna elements into consideration. $\mathbf{V}_i \in \mathbb{C}^{N_t * d_s}$ equals one broadcast beamforming matrix, including $tr\{\mathbf{V}_i\mathbf{V}_i^H\} = 1$, where d_s represents specific amount concerning transmitted information streams of every BS. Because we believe such $\mathbf{s}_i$ means some vector with the, i.i.d., Gaussian data symbols also is taken of the wanted constellation, which produces $\mathbb{E}\{\mathbf{s}_i\mathbf{s}_i^H\} = \mathbf{I}$. The medium energy restriction on that BS met under all these (sufficient) conditions.

The interference must be mitigated with space of interference on a receiving side to decode the signal needed successfully. Such that, the signal you want must be linearly independent of the

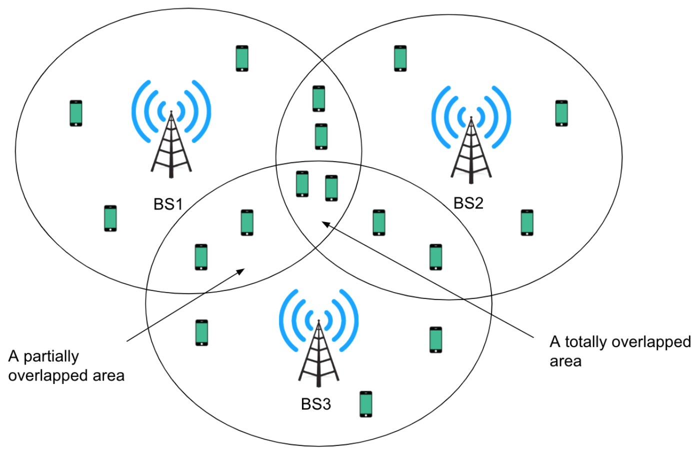

Figure 8.1: The network comprising of three cells, including an overlaid region.

interference such these interfering signals will achieve by aligning them into the orthogonal subspace $\mathbf{U}_j^{[k]}$. The subsequent requirements need also do met by the user $[j, k]$ concerning the network mentioned

$$\mathbf{U}_j^{[k]H}\mathbf{H}_{j,i}^k\mathbf{V}_i = \mathbf{0}, i \neq j, \ \ \forall i, j \in L, \ \forall k \in K, \tag{2}$$

$$rank(\mathbf{U}_j^{[k]H}\mathbf{H}_{j,j}^k\mathbf{V}_j) = d_j^{[k]}, \ \ \forall j \in L, \ \forall k \in K, \tag{3}$$

whereas $d_j^{[k]}$ denotes most solvable data stream without interference.

The entire joined region could be calculated using overlapped regions including non-overlapped regions with the network coverage [34], [35]. The overlaid region represents a particular area wherever many BSs occupy equal space. Therefore, in the overlapped region, the number of BSs varied between 2 and L. We may describe absolutely and partly overlapping areas depending on the amount of overlapping BSs.

Fig. 8.1 demonstrates a multi-cell MIMO network of many users supported by the BSs. When heavy interference deteriorates network capacity, any user in the overlapped region faces the worst case. Therefore, we concentrate our work on users in the overlapping space. We also assume that any BS will support $K^{'}$ as users in a fully-overlapped region also, $K^{'}$ means this one toward each L cells under one dense system scenario.

Since this definition about MIMO point-to-point model can construct a cellular MIMO network, each separate collection of messages differentiates the IC plus X channels. In addition, IC means some case if every BS i represent each respective user i. Simultaneously, that X-channel situation remains characterized via a set of messages where every BS i possesses diverse user information. Since we have customers with several antennas, it can reasonably be assumed to have the data from several BSs obtained by the user interested in the entirely overlapped region. Consequently, a compounded MIMO network scenario (IC-X channel) can be determined where each cell comprises users with a multi-source $L^{'}$ BS transmission of $1 < L' < L$. Therefore, the observed network can be classed being some series from $(L - L')$ IC, including L' X channels, some relevant interventions might describe XCI and ICI. As a convenience, suppose that customers within a cell want the equivalent information. This means further possible toward the situation in which customers inside a cell get separate messages from the respective BS. That signal of BS i might therefore represented by

$$\mathbf{s}_i = [c^{[i,1]} c^{[i+1,2]} c^{[i+L'-1,L']}]^T, \ \ \forall i \in L, \ 1 < L' < L, \tag{4}$$

whereas $c^{[j,l]}$ denotes as BS i l^{th} representation on this cell j operator, later this amount regarding BS data streams is the same as $L', (d_s = L')$. This signal sent (4) assumes that this initial information source of the BS i for cell i customers, where this secondary stream belongs for cell users $(i+1)$, etc. The numeration of the index $(i+L'-1)$, for example, $L' = 2(L = 3)$ including $i = 3, (i+L'-1) = 4 \rightarrow 1$, varies circularly, toward that number.

This information signal obtained from (1) may written in the following form according to (4)

$$\tilde{\mathbf{y}}_j^{[k]} = \underbrace{\mathbf{U}_j^{[k]H} \sum_{i=j-L'+1}^{j} \mathbf{H}_{j,i}^{[k]} \mathbf{V}_i \mathbf{s}_i}_{desired+XCI\ signals} + \underbrace{\mathbf{U}_j^{[k]H} \sum_{l=j+1, l\neq i}^{L} \mathbf{H}_{j,l}^{[k]} \mathbf{V}_l \mathbf{s}_l}_{ICI} + \tilde{\mathbf{n}}_j^{[k]}, \ \ \forall j \in L, \ \forall k \in K'. \tag{5}$$

The transmitting beamforming matrix can then be decoupled to few portions. It may look like by

$$\mathbf{V}_i = \mathbf{V}_i^{[ICI]} * \mathbf{V}_i^{[XCI]}, \ \ \forall i \in L, \tag{6}$$

whereas $\mathbf{V}_i \in \mathbb{C}^{N_t * d_s}, \mathbf{V}_i^{[ICI]} \in \mathbb{C}^{N_t * Z}$ $, and$ $\mathbf{V}_i^{[XCI]} \in \mathbb{C}^Z * d_s$ are the complete transmission beamforming matrix and the ICI- and XCI-compliant partial transmitting beamformers, respectively. Sections 8.3.1 and 8.3.2 describe the cancelation schemes for the ICI and XCI names. The meaning Z is the amount regarding columns in the $\mathbf{V}_i^{[ICI]}$ matrix, similarly as that amount like rows within the $\mathbf{V}_i^{[XCI]}$ matrix depends on each user's number of data flows. As the average likelihood of BEP fades, it possibly determined by [36],

$$P_b(E) = \int_0^\infty P_b(E|\gamma) p_\gamma(\gamma) d\gamma, \tag{7}$$

whereas $P_b(E|\gamma)$ and $p_\gamma(\gamma)$ denotes as instantaneous SNR conditional BEP including PDF, respectively. Thus, the instant SNR over each bit can be expressed by $\gamma = \alpha^2 E_b/N_0$, where α depends on the efficient fading channel's nature.

To evaluate the efficiency of that multi-antenna device in this SNR area, we describe the degree of independence to all user regarding concern since factor of pre-log in that sum-rate [37],[38]

$$\theta = \lim_{SNR \to \infty} \frac{I_j^{[k]}(SNR)}{\log_2(SNR)} = L', \ \forall j \in L, \forall k \in K', 1 < L' < L, \tag{8}$$

whereas $I_j^{[k]}(SNR)$ means user-interest sum-rate attainable for that SNR, including L' which denotes the amount of sources of information equivalent to the user-solvable interference-free streams $[j,k]$. This sum-rate may therefore be denoted by $I_{\sum}(SNR) = \sum_{j=1}^{L} \sum_{k}^{K'} I_j^{[k]}$. The feasible DoF may therefore be determined from a network point of view as

$$\Theta = \lim_{SNR \to \infty} \frac{I_{\sum}(SNR)}{\log_2(SNR)} = LK'L', \ 1 < L' < L. \tag{9}$$

Still, in terms of this customers's view, the cumulative volume DoF of s_j transmitted from BS j $(d_j = d_s, \forall j \in L)$ while normalizing the amount regarding customers on that overlapping region toward an area $(K' = 1)$. We can then generalize it for $L \geq 3$ and $K' \geq 1$, respectively.

8.3 Multi-cell multi-user MIMO network using transmit beamforming

Within Fig. 8.1, assume that the system includes various $(L = 3)$ cells. Moreover, all cells retain an equivalent $(K' = 2)$ amount from customers within this overlaid region. Hence, any user endures interference of both $(L' = 2)$ non-comparable BSs. Suppose that any BS, including every user, uses N_t and N_r antennas.

BS sends the signal of interest to cell users 1 and 2 and leads cell 3 to interfere. In users of cell two cell three shown to be interference of cell one, the signal $\mathbf{s}_2 = [c^{[2,1]}c^{[3,2]}]^T$ of BS two become essential. Alike, BS 3 interferes with cell 2 users with $\mathbf{s}_3 = [c^{[3,1]}c^{[1,2]}]^T$ signal and then tends to transmit the message in cells 1 and 3 to users. Both channel connections that cause interference can also be considered IC channels. Formerly, the valuable data is conveyed to the user groups through other canals. Cell one users want $[c^{[1,1]}c^{[1,2]}]^T$ only, whereas cell two and cell three users are interested in decoding just $[c^{[2,1]}c^{[2,2]}]^T$ with $[c^{[3,1]}c^{[3,2]}]^T$. However, each user often detects non-conforming symbols emitted from the requested BSs toward (4) aside of interference from IC. In short, a clientele category only needs one particular part of data from the desired direction arriving on the receiving side, and the other data is known to be X-channels. In this sense, that received signal at specific user interested may be expressed by

$$\tilde{\mathbf{y}}_j^{[k]} = \underbrace{\mathbf{U}_j^{[k]H} \sum_{i=1, i\neq j+1}^{L=3} \mathbf{H}_{j,i}^{[k]} \mathbf{V}_i \mathbf{s}_i}_{desired+XCI\ signals} + \underbrace{\mathbf{U}_j^{[k]H} \mathbf{H}_{j,j+1}^{[k]} \mathbf{V}_{j+1} \mathbf{s}_{j+1}}_{ICI} + \tilde{\mathbf{n}}_j^{[k]}, \ \ \forall j \in L, \ \forall k \in K'. \qquad (10)$$

8.3.1 ICI Mitigation

The network under consideration (Fig. 8.1) comprises from three BS including two customers by cell staying within that completely overlaid region, also any customer requires two DoF. Based on (4), the BS 1 scenario triggers disturbance to cell three users through the signal $\mathbf{s}_1 = [c^{[1,1]}c^{[2,2]}]^T$ sent. BS 2 interferes with cell one users who want to collect a series of signals $[c^{[1,1]}c^{[1,2]}]^T$, also BS three that carries signal $\mathbf{s}_3 = [c^{[3,1]}c^{[1,2]}]$, do no provide valuable information toward cell two customers. The ICI channel connections are presented in these networks.

Let us analyze the cell one users to clarify the suggested ICI mitigation system. Since we thought that all cell users want the same signals to be found, we may group cell 1 users to evaluate the ICI's shared space from BS 2.

$$\mathbf{K}_2 = span(\mathbf{H}_{1,2}^{[1]H}\mathbf{U}_1^{[1]}) = span(\mathbf{H}_{1,2}^{[2]H}\mathbf{U}_1^{[2]}), \tag{11}$$

where span $(\cdot)$ denotes the matrix's subspace. The area covering the ICI interference portion of cell 1 is labeled $\mathbf{K}_2$ for BS 2, causing such interference. In (11), superscripts belong to any cell user. Every spanned expression from (11) may be expressed by $\mathbf{K}_2 - \mathbf{H}_{1,2}^{[k]H}\mathbf{U}_1^{[k]} = \mathbf{0}$ *or* $[\mathbf{I} - \mathbf{H}_{1,2}^{[k]H}][\mathbf{K}_2; \mathbf{U}_1^{[k]}] = \mathbf{0}$. The following matrix equation can therefore be defined as fulfilling the intersection subspaces condition (11) and represented as

$$\begin{bmatrix} \mathbf{I}_{N_t} & -\mathbf{H}_{1,2}^{[1]H} & \mathbf{0} \\ \mathbf{I}_{N_t} & \mathbf{0} & -\mathbf{H}_{1,2}^{[2]H} \end{bmatrix} \begin{bmatrix} \mathbf{K}_2 \\ \mathbf{U}_1^{[1]} \\ \mathbf{U}_1^{[2]} \end{bmatrix} = \mathbf{C}_1\mathbf{D}_1 = \mathbf{0}, \tag{12}$$

where $\mathbf{K}_2$ represents the subspace spanned from cell 2 to cell users by the aligned, efficient interference channel 1. Since the size of the $\mathbf{C}_1$ matrix is $(2N_t * (N_t + 2N_r))$, null spaces are only available when $2N_r > N_t$ is unavailable for a sufficient number of antennas to be fitted with receivers. Hence it remains probable to extract the receiver's vectors with beamforming toward the alignment of ICI if this condition is met. With large numbers of N_t and N_r antennas, BSs and users can find the solutions challenging to find. We deconstruct the equation matrix in (12) into two matrix equations as shown below to decrease the number of receiving antennas' complexity and demand.

$$\begin{bmatrix} \mathbf{I}_{N_t} & -\mathbf{H}_{1,2}^{[1]H} \end{bmatrix} \begin{bmatrix} \tilde{\mathbf{K}}_2^{[1]} \\ \tilde{\mathbf{U}}_1^{[1]} \end{bmatrix} = \tilde{\mathbf{C}}_1^{[1]}\tilde{\mathbf{D}}_1^{[1]} = \mathbf{0}, \tag{13}$$

$$\begin{bmatrix} \mathbf{I}_{N_t} & -\mathbf{H}_{1,2}^{[2]H} \end{bmatrix} \begin{bmatrix} \tilde{\mathbf{K}}_2^{[2]} \\ \tilde{\mathbf{U}}_1^{[2]} \end{bmatrix} = \tilde{\mathbf{C}}_1^{[2]} \tilde{\mathbf{D}}_1^{[2]} = \mathbf{0}, \tag{14}$$

where the interference directions from BS 2 to cell users 1 and 2 are responsible for matrices $\tilde{\mathbf{K}}_2^{[1]}$ and $\tilde{\mathbf{K}}_2^{[2]}$. Nullspaces $\tilde{\mathbf{D}}_1^{[1]}$ and $\tilde{\mathbf{D}}_1^{[2]}$ are present in matrices $\tilde{\mathbf{C}}_1^{[1]}$ and $\tilde{\mathbf{C}}_1^{[2]}$ respectively. It is still necessary to achieve $\tilde{\mathbf{D}}_1^{[1]}$ and $\tilde{\mathbf{D}}_1^{[2]}$ since the two matrices are of similar size $\tilde{\mathbf{C}}_1^{[1]}$ and $\tilde{\mathbf{C}}_1^{[2]}$ $(N_t{*}(N_t{+}N_r))$, respectively). The beamforming matrices are, therefore, still available. For designing matrix $\mathbf{V}_2^{[ICI]}$, $\tilde{\mathbf{K}}_2^{[1]}$ and $\tilde{\mathbf{K}}_2^{[2]}$ shall be included. The cell 1 users are clustered together after adding the two receiver beamforming matrices so that BS2's ICI interference can be lined up under these subspaces $\tilde{\mathbf{K}}_2^{[1]}$ including $\tilde{\mathbf{K}}_2^{[2]}$. We are defining the crossing from span space by $\tilde{\mathbf{K}}_2^{[k]}$ which is equivalent toward this $\mathbf{K}_2$ space to evaluate $\mathbf{U}_1^{[k]}$ from $\tilde{\mathbf{D}}_1^{[k]}$ [28]. Like users in cell 1, for users of cells 2 and 3 we describe the span subspaces as below

$$\mathbf{K}_3 = span(\mathbf{H}_{2,3}^{[1]H} \mathbf{U}_2^{[1]}) = span(\mathbf{H}_{2,3}^{[2]H} \mathbf{U}_2^{[2]}), \tag{15}$$

$$\mathbf{K}_1 = span(\mathbf{H}_{3,1}^{[1]H} \mathbf{U}_3^{[1]}) = span(\mathbf{H}_{3,1}^{[2]H} \mathbf{U}_3^{[2]}). \tag{16}$$

By adding (13) and (14), we also decompose $\mathbf{K}_1$ and $\mathbf{K}_3$. Consequently, the respective subspace sets denoted $\tilde{\mathbf{K}}_1^{[k]}$ and $\tilde{\mathbf{K}}_3^{[k]}$ $(\forall k \in K')$ is obtained. So the matrices $\mathbf{U}_2^{[k]}$ and $\mathbf{U}_3^{[k]}$ are derived. Since each user observe a single $\mathbf{K}_i$ related ICI channel connection under the scenario under consideration, we decide the first ICI accounting factor as follows:

$$\mathbf{V}_i^{[ICI]} = null([\mathbf{K}_i(\mathbf{U}_{i-1}^{[k]H} \mathbf{H}_{i-1,i}^{[k]})^H]^H), \;\; \forall i \in L, \forall k \in K', \tag{17}$$

whereas this $(i-1)$ index varies, for example, with $i = 1 \rightarrow (i-1) = 3$.

This system model (Fig. 8.1) can then be considered an ICI-free network after adding the first component of the transmission beamforming matrices.

8.3.2 XCI Mitigation

Every customer owns a couple of channel notes, including a preferred symbol by channel, after implementing the ICI mitigation scheme. The obtained signal can then be represented as an on every user k within cell one.

$$\begin{aligned}\tilde{\mathbf{y}}_1^{[k]} &= \mathbf{U}_1^{[k]H}\mathbf{H}_{1,1}^{[k]}\mathbf{V}_1^{[ICI]}\mathbf{V}_1^{[XCI]}\mathbf{s}_1 + \underbrace{\cancel{\mathbf{U}_1^{[k]H}\mathbf{H}_{1,2}^{[k]}\mathbf{V}_2^{[ICI]}\mathbf{V}_2^{[XCI]}}\mathbf{s}_2}_{ICI=0} + \mathbf{U}_1^{[k]H}\mathbf{H}_{1,3}^{[k]}\mathbf{V}_3^{[ICI]}\mathbf{V}_3^{[XCI]}\mathbf{s}_3 + \tilde{\mathbf{n}}_1^{[k]} \\ &= \sum_{i=1, i\neq 2}^{L=3} \mathbf{U}_1^{[k]}\mathbf{H}_{1,i}^{[k]}\mathbf{V}_i^{[ICI]}\mathbf{V}_i^{[XCI]}\mathbf{s}_i + \tilde{\mathbf{n}}_1^{[k]}, \ \ \forall k \in K'. \end{aligned} \tag{18}$$

That term may also generalized in every j cell for any user k, as given below

$$\tilde{\mathbf{y}}_1^{[k]} = \sum_{i=1, i\neq j+1}^{L=3} \mathbf{U}_j^{[k]H}\mathbf{H}_{j,i}^{[k]}\mathbf{V}_i^{[ICI]}\mathbf{V}_i^{[XCI]}\mathbf{s}_i + \tilde{\mathbf{n}}_j^{[k]}, \ \ \forall j \in L, \forall k \in K', \tag{19}$$

whereas the channel matrix $\mathbf{H}_{j,j}^{[k]}$ is a channel which transmits a primary stream of BS j toward user $[j, k]$, and $\mathbf{H}_{j,i}^{[k]}$ $(j \neq i)$ denotes such a collateral channel that transmits a secondary datastream from BS i interested of user $[j, k]$ among all the remaining channel notes of this point of view of that user-intention info. We have two users in each cell $(K = 2)$. That failure from this $\mathbf{H}_{j,i}^{[k]}$ channel matrix $(i = j + 1)$ indicates the cancelation of the following ICIs.

We have two dimensions for extracting the two desired symbols because this amount including antennas obtained equivalent as BS' amount from information streams $(d_s = N_r = 2)$. It means that the different couple of symbols which is seen as unwanted information should be considered in the second section of our decomposed beamforming matrix.

As supposed that these customers in the each cell need similar data in every $\mathbf{H}_{j,i}^{[k]}$ channel matrix from BS i including that customer of interest that is an element from that generic channel matrix $\mathbf{H}_{j,i}$ is determined by

$$\mathbf{H}_{j,i} = \begin{bmatrix} \mathbf{H}_{j,i}^{[1]} \\ \mathbf{H}_{j,i}^{[2]} \end{bmatrix}, \ \ \forall i, j \in L, \tag{20}$$

whereas $\mathbf{H}_{j,i} \in \mathbb{C}^{K' N_r * N_t}$, the superscripts apply to the $j^t h$ cell user index and $K' = 2$ cell users.

Since the vector signal transmitted has a $d_s * 1$ size, the matrix $\mathbf{V}_i^{[XCI]}$ must have columns d_s. Configuration for a next component for this beamforming matrix, then

$$\mathbf{V}_i^{[XCI]} = \begin{bmatrix} \mathbf{p}_1^{[i]} & \mathbf{p}_2^{[i]} \end{bmatrix}, \quad \forall i \in L, \tag{21}$$

whereas $\mathbf{p}_1^{[i]}$ and $\mathbf{p}_2^{[i]}$ vectors nullify the X-channel scenario interference. The following are the columns of the matrix $\mathbf{V}_i^{[XCI]}$ using (20)

$$\mathbf{p}_1^{[i]} = null(\mathbf{H}_{j,i}\mathbf{V}_i^{[ICI]}) = null(\mathbf{J}_1^{[i]}), \ \ \forall i \in L, \tag{22}$$

$$\mathbf{p}_2^{[i]} = null(\mathbf{H}_{i,i}\mathbf{V}_i^{[ICI]}) = null(\mathbf{J}_2^{[i]}), \ \ \forall i \in L, \tag{23}$$

whereas $\mathbf{J}_1^{[i]} = \mathbf{H}_{j,i}\mathbf{V}_i^{[ICI]}$, and $\mathbf{J}_2^{[i]} = \mathbf{H}_{i,i}\mathbf{V}_i^{[ICI]}$ denoted as efficient channel matrices after the implementation of the ICI channel cancelation scheme. A collateral channel among BS i channel including cell j customers $(j \neq i)$ is shown by that former channel matrix, while the former channel matrix is the effective direct connection between BS i and cell i. That effective structure for that $\mathbf{V}_i^{[XCI]}$ matrix involves finding at least one satisfying vector (22), (23). The size of every $\mathbf{J}_l^{[i]}$ matrix. We must satisfy $(N_t - 2N_r) > 2N_r$ to define (22), (23) solutions. In $N_r = 2$, after implementing the ICI mitigation algorithm, the minimum number of efficient channel columns is five. For all cells, $i \in L(L = 3)$, the procedure specified by (21)–(23) has been reused.

In this regard, for cell j user k, the signal (19) obtained by

$$\begin{aligned} \tilde{\mathbf{y}}_j^{[k]} &= \mathbf{U}_j^{[k]H} \sum_{i=1, i\neq j+1}^{L=3} \mathbf{H}_{j,i}^{[k]} \mathbf{V}_i^{[ICI]} \mathbf{V}_i^{[XCI]} \mathbf{s}_i + \tilde{\mathbf{n}}_j^{[k]} \\ &= \begin{bmatrix} \tilde{h}_{jj}^1 & 0 \\ \tilde{h}_{jj}^2 & 0 \end{bmatrix} \begin{bmatrix} c^{[j,1]} \\ c^{[j+1,2]} \end{bmatrix} + \begin{bmatrix} 0 & \tilde{h}_{ji}^1 \\ 0 & \tilde{h}_{ji}^2 \end{bmatrix} \begin{bmatrix} c^{[i,1]} \\ c^{[j,2]} \end{bmatrix} + \tilde{\mathbf{n}}_j^{[k]} \end{aligned}$$

$$= \begin{bmatrix} \tilde{h}_{jj}^{1} \\ \tilde{h}_{jj}^{2} \end{bmatrix} c^{[j,1]} + \begin{bmatrix} \tilde{h}_{ji}^{1} \\ \tilde{h}_{ji}^{2} \end{bmatrix} c^{[j,2]} + \tilde{\mathbf{n}}_j^{[k]}$$
$$= \begin{bmatrix} \tilde{h}_{jj}^{1} & \tilde{h}_{ji}^{1} \\ \tilde{h}_{jj}^{2} & \tilde{h}_{ji}^{2} \end{bmatrix} \begin{bmatrix} c^{[j,1]} \\ c^{[j,2]} \end{bmatrix} + \tilde{\mathbf{n}}_j^{[k]}$$
$$= \overline{\mathbf{H}_j^{[k]}} \mathbf{C}_j + \tilde{\mathbf{n}}_j^{[k]}, \ \ \forall j \in L, \forall k \in K', \tag{24}$$

whereas $\overline{\mathbf{H}_j^{[k]}}$, $\mathbf{C}_j$ indicate, after applying a proposed algorithm, the efficient user channel matrix $[j, k]$ including that vector from those wanted symbols, and every entry within $\overline{H}$ which denotes arbitrary $\mathbb{E}(\mathbf{U}_j^{[k]H}\mathbf{H}_{j,l}\mathbf{V}_l\mathbf{V}_l^H\mathbf{H}_{j,l}^H\mathbf{U}_j^{[k]}) = \xi^2\mathbf{I}$ variable based on $\mathcal{CN}(0, \xi^2)$ (BS l send information toward the wanted user, $l \in L$). The effective noise vector of $\tilde{\mathbf{n}}_j^{[k]}$ stands for $\tilde{\mathbf{n}}_j^{[k]} = \mathbf{U}_j^{[k]H}\mathbf{n}_j^{[k]}$.

8.4 Conclusion

In this study, the IA-specific, transmission strategies were examined and tested for spectral and power-efficient interference networks. In comparison to standard orthogonal transmission, the efficiency of the systems considered was noted to increase significantly. The results obtained in terms of SNR with 20 dB, 25 dB, including 30 dB. The proposed scheme can improve the spectrum efficiency with the use of IA method. Therefore, the interference can be mitigated using this technique.

9 Results

In Figures 9.1-9.4, the results obtained of BER for two users from Monte Carlo simulation and IA. The number of iterations is 10^5. Here we also try to compare obtained BER and SNR, which means typically the ratio between desired signal's power over noise plus the power of undesired signals. In this case, we also try to obtain BER, a metric that can characterize a communication system's performance. In other words, BER is the average rate of Bit Error that occurs during the communication process. 20 dB, 25 dB, and 30 dB were selected as subjects of observation in the proposed scenario.

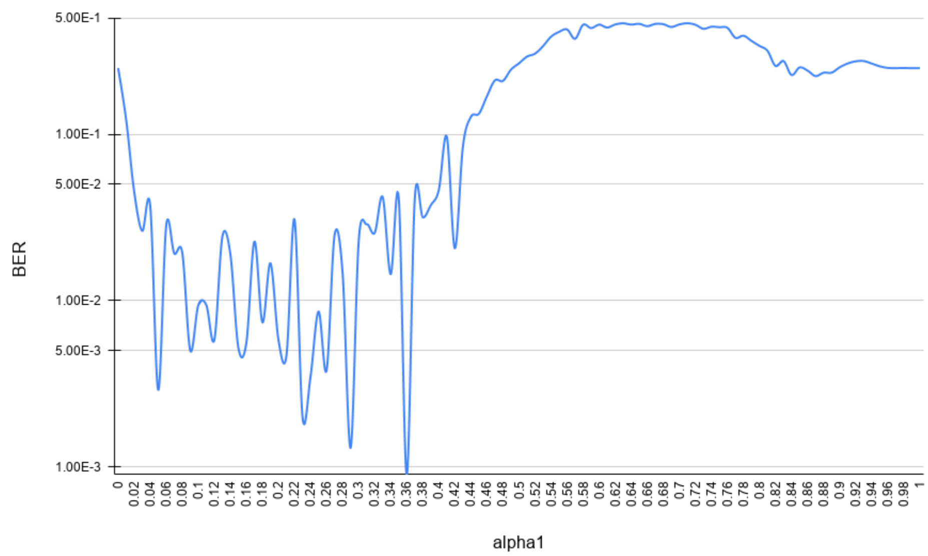

Figure 9.1: Average BER for SNR=20 dB, and 100000 iterations.

In Figure 9.1, the average BER for SNR equal to 20 dB was obtained. Generally, we can observe an almost similar pattern of performed Figures 9.1-9.3 with some minor differences in BER performances. This graph also shows some fluctuations from α = 0 till α = 0.42 and starting from 0.42 the BER performance starts reaching till almost 0.5 and then remains steady.

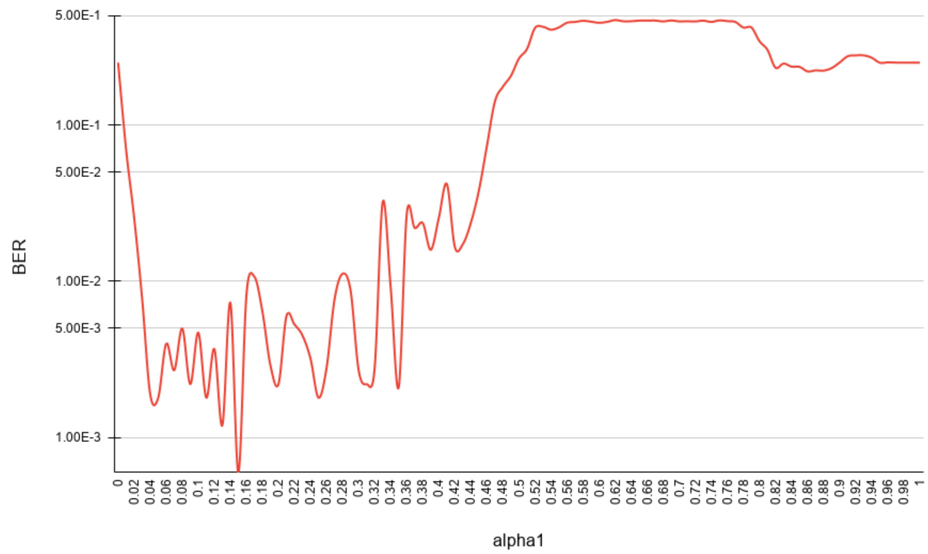

Figure 9.2: Average BER for SNR=25 dB, and 100000 iterations.

In Figure 9.2, the average BER for SNR with amount of 25 dB was performed. This graph was also obtained from MATLAB simulations with the number of iterations equal to 10^5. Similar to Figure 9.1, Figure 9.2 represents some vacillations between α = 0 and α nearly 0.43, then starts approaching BER of 0.5 and stays steady till α = 1.

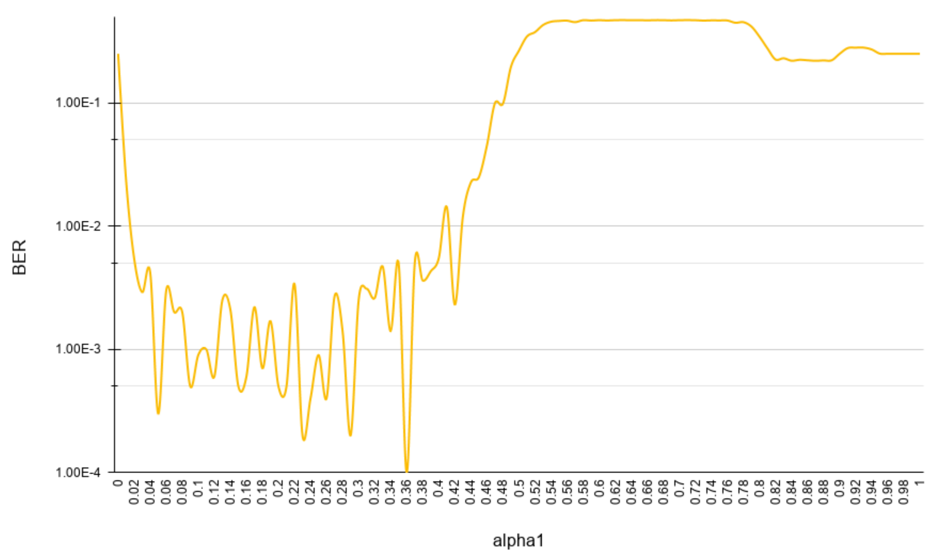

Figure 9.3: Average BER for SNR=30 dB, and 100000 iterations.

In Figure 9.3, the average BER for SNR equivalent to 30 dB was obtained. The results obtained in this chapter show that using IA techniques, the spectrum efficiency can be reached and improved. The reason is that we aligned interference signals at the receiving sides in the subspace, and each receiver obtained the desired signals from the transmitters. Consequently, the suggested technique and system model will eliminate any user interference. The overall BER performance is quite similar in three graphs with minor differences when SNR equivalent as 20 dB, 25 dB, including 30 dB. However, overall performance concerning a scheme when SNR = 30 dB is better than the other two.

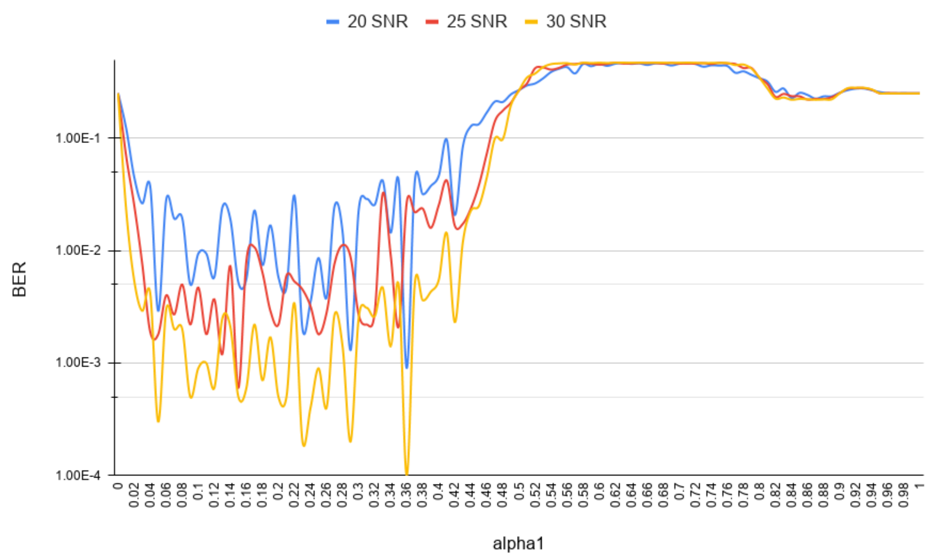

Figure 9.4: Merged picture of three average BER figures.

In Figure 9.4, we can observe that when SNR = 30 dB, it outperforms the scenarios when SNR is 20 dB and 25 dB, respectively. The bigger the SNR than the smoother and the better the BER results. It also works for power coefficients (α) or power allocation of transmitters. The BER performance is smoother when the α becomes larger.

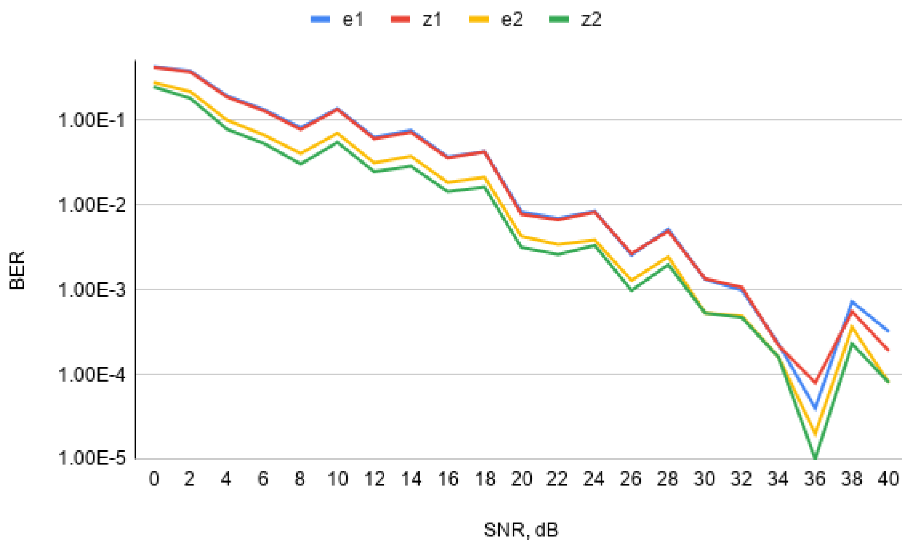

Figure 9.5: BER vs. transmit SNR.

In Figure 9.5, the BER vs. transmit SNR is represented. In this graph, the BER is lesser when the SNR is approaching 40 dB. Therefore, from this graph, we can observe that the chance of bit error is much lesser when SNR is high.

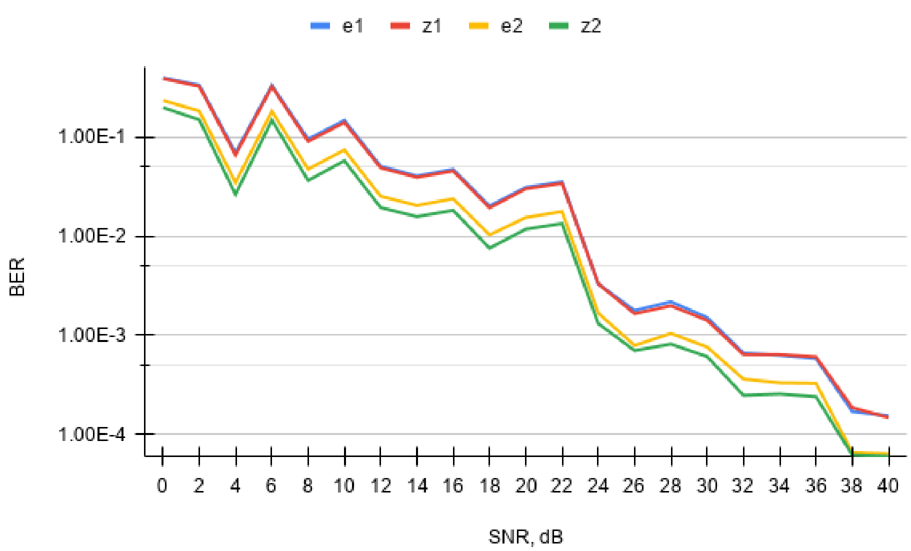

Figure 9.6: BER vs. transmit SNR (second case) .

Similar to Figure 9.5, Figure 9.6 shows the BER vs. transmit SNR. The difference between this Fig. 9.6 and Fig. 9.5 is the iterations' number used during simulation. In Fig. 9.5, the iterations' number was equal to $5 * 10^5$, while in Fig. 9.6, the number of iterations performed was 10^5.

10 Conclusion and future research

Through the use of mobile devices that need high-speed wireless networking of emerging wireless networks would prevail. Both bandwidths and energy-efficient architecture of these networks get significant because of the lack of radio resources. In this thesis, we obtained results in terms of BER using Matlab software, IA technique and Monte Carlo simulation method. In comparison with standard orthogonal transmissions, the overall efficiency of studied network scenario could be noticeably increased. There are some potential additions to the findings of methods mentioned in this research to extend the knowledge of enhancing the power and spectrum performance related to wireless interference networks. Firstly, a feasibility analysis discussed in this thesis does not include the different number of antennas within the network to understand the benefit of correctly constructed network scenarios. Such limitation will therefore influence the analysis of feasibility and possibly would therefore be examined in the future. Wireless channels may be concerned about the possible influences like noise, including latency in wireless networks. Investigating the effects of these flaws throughout communication efficiency will allow for a deeper understanding of effective transmission. A fascinating area of future research will be the construction of transmission systems that are resilient to these flaws.

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