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Effectiveness of Multiuser MIMO for the Research and Education Network: A Survey

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***Abstract*—Research and education network (REN) is a high performance communications network that provides connectivity among the educational and research institutions. However, there is no single accurate and effective structure of REN for the different countries, as its precise constitution structures and funding are heavily influenced by local conditions. This paper provides a survey for the effectiveness of multiple input multiple output techniques (MIMO) for REN. Multiuser MIMO (MU-MIMO) techniques are the key aspects of this survey with respect to REN. The survey include effectiveness of current IEEE standard implementation characteristics, design procedure, working capacities, scheduling techniques etc.**

Keywords—Research and Education Network, MU-MIMO, Mobile Broadband, Wireless Communication, Joint Detection.

I. INTRODUCTION

Research and **E**ducation **N**etwork (REN) consists of high speed backbone network to support dedicated channels for individual research projects. Thus, it needs proper coordination and collaboration which is generally confirm at the continental level. There are bit of dissimilarity on the structural model for the REN of different countries due to culture, research interest and funding. However, REN model for the developing countries need to be more robust, secure, faster and cheaper with respect to cost. The wireless communication system can be implemented in REN model by data rate manipulation through spatial multiplexing. Here, the system reliability also need to improve in terms of bit error rate (BER) which is applied using space time codes (STCs) for diversity maximization as shown in [1]. Thus, several systems introduce multiple antennas at the transmitting and receiving end. Generally this technique is known as MIMO. The MIMO exploits multipath propagation for improving reliability, higher spectral efficiency and spatial separation of users without the expense of additional bandwidth [2, 3]. Like the geometric mean decomposition (GMD) technique, MIMO combines the diversity and data rate maximization in optimal manner [4]. In these circumstances, multiuser MIMO is an attractive and promising option for REN [5, 6]. Thus, this paper provides a survey on the effectiveness of multiuser MIMO for research and education network. The paper extensively use of work [3] which provides a detail survey on MU-MIMO.

II. MIMO STRUCTURE AND IMPLIMENTATION

Figure 1 illustrates an approximate MIMO system where, the signals on the transmission antennas (*Tx*) appears at one end and the receive antennas (*Rx*) at the other end [1]. Here, The MIMO channel can be seen as parallel spatial sub channels which allow the transmission of parallel streams [7]. As shown in [8], user multiplexing is particularly beneficial in the downlink of multiuser cellular systems (as in research and education network) for serving multiple users on the same time frequency resources.

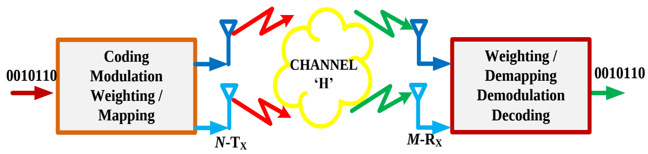

Fig 1: An approximate MIMO system [1].

In a single user MIMO, the transmission and reception strategy exploits the achieve capacity on approximately *minimum*(M, N) separate channels, where N is the number of transmit antenna and M is number of receive antennas as shown on [3, 7]. Thus, the bit error rate or data rate of the communication for each user will be improved [9]. On the other hand, MU-MIMO increases the spectral efficiency and potential capacity to support high transmission rate than the single-user MIMO [10]. The capacity**(**C**)** of an $M \times N$ single user MIMO system with M transmit and N receive antennas with respect to spectral efficiency is as follows [1, 11]:

$$C = log_2 [det\,(I_N + \rho\, HH^T/M)] \;\ldots\;\ldots\;\ldots\;(1)$$

Where H is the $N \times M$ MIMO channel matrix and ρ is the signal to noise ratio (SNR) at any receive antenna. According to [12], Eq.1 assumes that the M information sources are uncorrelated and have equal power. In terms of the Eigen values, the equation can be rewritten as [3, 12],

$$C = \sum_{i=1}^{m} log_2 [det(IN + \rho\lambda i/M\,)] \ldots\ldots\ldots (2)$$

Where λ_i represent the nonzero Eigen values of HH^T for $N \leq M$ and m=*minimum* (M, N). From Eq.2, we find that the performance of MIMO system is dependent on the channel Eigen values and the capacity has a finite high SNR limit for any channel distribution and thus is a major concern for any REN [13]. Although MIMO is a multi-antenna system, it is also an integral feature of emerging wireless systems such as 3GPP LTE [14, 15], 3GPP2 Ultra Mobile Broadband and IEEE 802.16 WiMAX [16]. The 802.11n standard supports a maximum of four MIMO streams that can serve a single user at a time with spatial multiplexing of up to four spatial streams [17]. The 802.11ac is the first 802.11 amendment to introduce MU-MIMO to serve multiple streams simultaneously [18].

Following section presents the effectiveness of current MU-MIMO techniques for REN model with respect to various wireless technology standards. Then an overview of antenna scheduling system with resource sharing and capacity explanation is given. Finally, based on this discussion a conclusion is draws in section VI.

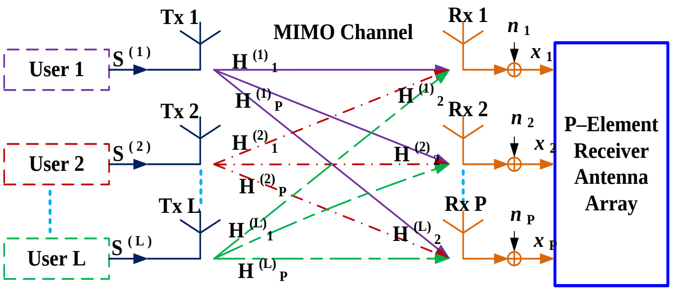

Fig. 2:MIMO–OFDM system model with single antenna at each user end [5].

TABLE I : CQI AND PMI FEEDBACK TYPES FOR TRANSMISSION MODE 5 IN LTE [25]

Mode	CQI type	PMI type
Aperiodic	Higher – layer configured, set of sub-bands: Sub-band and Wideband CQI per code word	Single PMI
Periodic	Wideband CQI for first code word Spatial differential CQI for RI > 1	Single PMI
Periodic	UE selected sub-bands: Full CQI for first code ward Spatial differential CQI for RI > 1	Single PMI

III. Implementations of Wireless Standars for REN

This section provides a brief description of the standards of current MIMO implementation such as IEEE 802.11, 802.16, 802.20, 3GPP LTE etc. Then the section describes how these techniques can be extended for REN model in different areas.

A. WI – FIFor REN

With the 802.11n, a device can only transmit multiple spatial streams at once, but can be directed to a single address [19]. But the IEEE 802.11ac defines MU-MIMO with MIMO–OFDM to enhance data rate. Thus, it is a suitable candidate for REN specifically if there exists institutions in rural or remote areas and these institutions want to connect with REN [3]. The IEEE 802.11ac encompasses a wider range such as four spatial streams, 160 MHz operation and MU-MIMO [19]. In MIMO-OFDM the initial data rate was in excess of 100 Mbps [20], but, current WLAN devices based on 802.11n Draft 2.0 are capable of achieving throughput up to 300 Mbps, depends on the number of wireless radios incorporated into it [20]. As mentioned in [3, 19], Recently the 802.11ac can speed up to 290 to 1300 Mbps within 80 MHz, whereas 802.11n can speed only 65 to 450 Mbps within 40 MHz. Fig. 2 shows an approximate MIMO–OFDM system model with single antenna at each user end. In [3], it is shown that, the MIMO technique implemented by including both spatial multiplexing and diversity techniques. At the transmitter end any channel state information (CSI) do not require for the open-loop MIMO techniques of [21], thus makes it more suitable for REN model for the institutions in everywhere.

B. WiMAXFor REN

A developed wireless MAN standard for MIMO is IEEE 802.16 Worldwide interoperability for Microwave Access (WiMAX) [3], which employs spatial multiplexing and diversity technique. For support mobility features Scalable – Orthogonal Frequency Division Multiple Access (S-OFDMA) is added in IEEE 802.16e standard [22]. The IEEE 802.16m is also an enhancement of 802.16 Wireless MAN OFDMA specification, which can support the 4th generation cellular system [23]. Both the IEEE 802.16e and IEEE 802.16m can support 6 GHz frequency band and include TDD and FDD duplexing scheme. These standards can incorporate in REN model for the institutions of the metropolitan areas, as for it can increase 20-30% cell coverage [24].

It extends and improves the MIMO modes with emphasis on multi-user MIMO, on both DL and UL. It enables up to 8 data streams in the DL and 4 data streams in the UL [24]. It also improves both the open-loop power and closed-loop control. Open-loop MIMO techniques include spatial multiplexing (SM) and space-time coding (STC) [22, 26].The IEEE 802.16m standard provides power saving by enhancing Sleep Mode and Idle Mode operation. It can dynamically adjust the mechanism of sleeping mode which can reduce the power consumption [24] and thus is suitable for REN Model.

C. MBWA For REN

A complete cellular structure is proposed in the IEEE 802.20 [27]which is known as Mobile Broadband Wireless Access (MBWA). This technology is OFDMA based and is aimed to provide wide area coverage at high data rates with mobility[28].MIMO is performed by this standard in a true multi-stream fashion as well as beam-forming and SDMA [29].Voice transmission service is supported by MBWA as for its very low transmission latency [3] and 1 Mbps data rates. Both single code-word (SCW) and multiple code-word (MCW) MIMO are supported as scheme. In single code-ward MIMO, an encoded packet is distributed across many streams to form the MIMO transmission [28]. Feedback is required to control the rank of the MIMO transmission [29]. In multiple code-ward MIMO, several separately encoded packets are transmitted independently over the multiple antennas [3].As for wide area coverage at high data rate with mobility this standard is very much suitable for implement REN model in the remote areas institute.

D. REN Model In 3GPP LTE

In [3], it has been shown that, a new mobile communication standard for continuing migration from 3G to 4G is the 3rd generation partnership (3GPP) long term evolution (LTE). LTE supports MU-MIMO in the downlink as well as in the uplink. The downlink (DL) MU-MIMO is a point-to-multi-point transmission [30]. In MU-MIMO transmissions, for robust downlink detection, low complexity interference-aware receiver is proposed in [31].In terms of terminal feedback [25], rank indicator (RI), pre-coding matrix indicator (PMI), and channel quality indicator (CQI) are used.

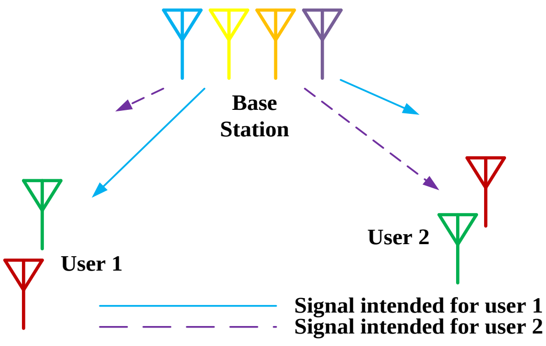

Fig. 3: MU-MIMO Downlink [38].

Both aperiodic and periodic feedback types as shown in Table I can use in the LTE MU–MIMO transmission mode 5. When a periodic reporting is configured, wideband CQI and higher layer selected sub-band CQI in combination with a single PMI is supported [25]. The full CQIs are reported for each code word. When periodic reporting is configured, either wideband CQI or UE selected sub-band CQI in combination with a single PMI is supported. This is a minimal MU–MIMO transmission scheme [3]. Higher transmission rate, lower cost, robustness, no single point of failure and mobility make this much more suitable for the REN. Most of current REN network follows the designed adapted in Europe which is based on hybridization of these techniques.

IV. MU- MIMO FOR REN

MU-MIMO is an improved form of MIMO technology that is gaining acceptance. It enables multiple independent radio terminals to access a system [32]. It provides significant performance gains. This increases the system capacity by enabling multiple users to simultaneously access the same channel without adding the additional bandwidth cost. The channels are provided by following spatial degrees of freedom, which makes this technology more effective for REN model. As shown in [33], spatial multiplexing is employed for enhancing the spectral efficiency in case of multiple antennas. Channel state information (CSI) of all users are required for MU-MIMO transmitting station [3]. MU-MIMO operations can done by using uplink and downlink scenarios. The uplink channels are known as multiple access channel (MAC) and downlink channels are known as broadcast channel (BC) [34].

A. MU-MIMO Uplink ChannelsFor REN model

MIMO-MAC is developed based on the known single user MIMO concept by broadened out for multiple users [32]. The users simultaneously transmit data over the same frequency channel [33]. For the MIMO-MAC the receiver performs much of the processing. Here, the receiver needs to know the channel state and uses channel state information at the receiver (CSIR). It perform point-to-point MIMO if the number of the receiver antennas is greater than the number of transmit antennas at each user [32].

- One of the MU-MIMO uplink model is MIMO SDMA-OFDM model. Space division multiple access (SDMA) technique solves the capacity problem of wireless communications systems, and achieve higher spectral efficiency.

Figure 2 shows the MIMO SDMA–OFDM system model, where each user L, uses a single transmit antenna while the receiver is equipped with multiple P, antennas. The complex–valued P×1 received signal vector at the receive antenna array for the k^{th} sub-carrier of the n^{th} OFDM symbol is given by [3]-

$$x = HS + n \ldots\ldots\ldots (3)$$

where, S is the transmitted signal vector, n is the P×1 Additive white Gaussian noise (AWGN) vector and H is the P×L channel transfer function matrix. The *minimum mean square error* (MMSE) MUD improves the performance, when the number of antennas in the receive antenna array increased, but when the number of user increased, it degrades the performance [3].The effect of multi user interference (MUI) as well as channel fading can mitigate by combining MMSE and SIC. For the effectiveness of inaccurate power control SIC-MUD becomes suitable for REN model.

- In [35], it has been shown that, for the CDMA uplink V-BLAST based MUD scheme referred to as layers space – time MUD (LAST - MUD). Here, the channels between the users and receivers are considered as a frequency–flat fading MIMO channel. The frequency-flat fading MIMO channel is assumed as well as perfect channel estimation and symbol synchronization [35]. For avoiding the correlation of user's antennas, the users are separated by a considerable distance. This scheme is applicable to rural and remote areas REN models for its substantial increase in network capacity by accommodating a large number of simultaneous users with good SER [3].

- The hybridization of MMSEMUD and SIC MUD suffers from performance loss, when multiple closely spaced antennas are located at the same UE [36]. By transforming the uplink of MU–MIMO channel into a set of parallel SU–MIMO channels [3] this performance loss can be overcome. The matrix can be represent as [3] –

$$H = [H_1\ H_2 \ldots\ H_k] \ldots \ldots \ldots (4)$$

where, $H_i \in \mathbb{C}^{M_R \times M_{T_i}}$ is the MIMO channel matrix between user and receiver. Following the receive filtering by the receive filter, SIC is performed to eliminate the multi user interference (MUI) [35].

- In [27], the SMMSE SIC detection is considered as STBC based MIMO transmission. Besides the full diversity gain equal to that of STBC, dominant Eigen mode transmission (DET) provides the maximum array gain by transmitting over the strongest Eigen mode of the MIMO channel[36, 37].Increasing the performance by array gain in transmission, it is more suitable for REN.

- Finally, another uplink channel for MU-MIMO is Turbo MMSE MUD. This scheme can detect multiple users transmit antennas. From the undetected users MUI can canceled along with co-channel interference (CCI) and ISI through soft cancellation [35, 36]. As for lower performance this type of uplink strategy is far acceptable for REN.

B. MU-MIMO Downlink Channels For REN models

MU–MIMO downlink channel is known as the MIMO broadcast channel (MIMO–BC) [34] where, the user terminal is equipped with multiple antennas. In Fig. 3, it simultaneously transmits data to multiple users as consisting of one or more antennas each. This strategy optimize the interference by using transmit beam-forming or dirty paper coding [32]. This technique also supports user scheduling and power loading algorithm. CSI feedback from each user is also required for pre-coding at the users terminal [3]. MU-MIMO downlink process can be classified depend on the inter-user interference, QoS constraints, whether single or multiple antennas present, whether or not multiple data streams are transmitted to each user [38].

❖ Channel Inversion technique simply undoing the effects of the channel via pre-coding [3]. It is a linear pre-coding technique which support each user equipped with a single receive antenna in MU–MIMO downlink [38]. It uses the inverse of the channel matrix for pre-coding to remove the MUI. If the number of receiving antennas is less then number of transmit antennas, then [39] –

$$s = \frac{1}{\sqrt{\gamma}} H^{*}(HH^{*})^{-1} d \ldots\ldots\ldots(5)$$

where, γ is the limit of total transmitted power to some predetermined value, d is the vector of data symbols to be pre-coded.

This technique cancelled all user interface [38] and suitable for high transmit power. As this pre-coding technique is only suitable for low-noise or high transmit power, so it is not better applicable for REN in heavy industrial regions or remote areas institutions.

❖ Block Diagonalization (BD) is known as block channel inversion. It is a generalization of channel inversion to multi – antenna UEs [38]. It requires the number of transmit antenna is greater than the number of receive antenna over all the users. Here each receive antenna is considered as a separate user when each transmitted data stream is decoded independently on each receive antenna. This techniques removes inter user interference [40].

Appropriate power scaling for users are consist by BD techniques. Optimal power allocation is achieve able by water-filling [36, 39]. As power is very important factor for continuous transmission, so, this technique is implemented in REN globally to maximize the overall transmission rate.

❖ Successive Optimization (SO) is also known as successive pre-coding algorithm which addresses the power control problem in BD. In [36] it has been shown that, the capacity loss occurs, due to the nulling of overlapping subspaces of different users. In this method, at first, the optimum orders of the users are determined. Then for each user the pre-coding matrix designed separately in a successive manner [38]. As a result, it lies in the null space of the channel matrices of the previous users. As for transmission power optimization this technique can be implemented in REN.

❖ Dirty Paper Coding (DPC) is a technique which is used in interferer channel for transmission. This strategy uses the AWGN channel which is modified by adding interference [32]. Concept “writing on dirty paper,” can be explained by using an analogy where a dirty paper is used. Normally black ink is used for writing, but if the paper is dirty that is full of black the writings cannot be seen. Then white ink can be used for writing on that dirty paper, not in white paper. Same concept is used on the data transmission [33]. So, this technique can applyin REN model.DPC is applied at each user’s signal in the receiver terminal. As a result, the known interference from other users can be avoided which is very useful for REN model.

A well-known dirty paper coding is known as *QR decomposition* of channel matrix [33], given by $H= LQ$, where L is a lower triangular matrix and Q is a unitary matrix. In this method each users sees interference from the preceding users. Another dirty paper coding technique is known as *Vector pre-coding*[3]. It jointly pre-codes the user’s signal.The operation is followed by channel inversion, resulting the transmitted signal x, [33] given by –

$$x=H^{-1} (d+\tau l)\ldots\ldots\ldots(6)$$

where, vector l is chosen to minimize the power of x.

Dirty paper coding techniques sum the capacity of the MU-MIMO downlink channel. This is defined as the maximum system throughput achieved by maximizing the sum of the information rates of all the users[38].

❖ Another non-linear pre-coding technique is low complexity quantized CSI-based Tomlinson-Harashima Pre-coding (THP) technique [3]. In the spatial domain THP can mitigate the MUI for MU-MIMO downlink system. It can achieve the capacity sum rate when the perfect knowledge of CSI is present from the users [39]. By combining successive optimization (SO) with THP, performance are improved by eliminating outstanding MUI. SO THP involves successive BD, reordering the users and finally THP [3]. Since transmit power increases for using THP REN can use these techniques. In case of THP-MMSE the interference cannot be fully eliminated, because the MMSE achieves a compromise between noise amplification and interference cancellation [39].

❖ Generally, in the multi-antenna user system performance degradation occurs. The successive MMSE [41] technique define this problems of performance degradation. For finding these problems, SMMSE successively calculate the columns of the combined pre-coding matrix. Here, each column represents a beam-forming vector corresponding to a particular receive antenna [3]. Due to higher complexity this technique can less far consider for REN model.

❖ In MU-MIMO transmission, CSI feedback needed from the users [36].Here, the downlink scheme utilizes partial CSI. The partial CSI consist long term channel statistics, along with rapid channel information, such as - SNR, SINR etc [40].The SNR, SINR helps to measure the transmission QoS. It also reduces the feedback overhead in the transmission. High multi-user diversity gain is also provided by partial CSI Feedback scheme. This diversity gain can achieve by optimizing the resource allocation at the receiver station. It also simplified the utilization of instantaneous channel norm feedback from the UEs [3]. So it can apply in REN model for those areas where high rate of noise and interference occur.

C. Scheduling in Multiuser MIMO for REN model

For multi-user MIMO scheduling no fixed rules are available if the perfect instantaneous channel information is not available. But when a large number of users are sharing a network with rapidly time varying channels, a base stations need to use intelligent scheduling algorithm [40].Because in MU-MIMO the receiver can support only a limited number of simultaneous users for MU–MIMO downlink transmission with acceptable performance [3]. As a result the number of users that are simultaneously supported becomes lesser. When the BS generally serve a larger number of users, an efficient scheduling is required to select the group of users.MU–MIMO scheduling is dependent on the channel feedback to the receiver terminal from the user [40]. The scheduling will occur spatially multiplexed by the receive antennas at a certain time and frequency. Here, the receiver terminal will maintain a time frame for transmitting data to the users by maintain a time slot, depend on total requested time. It also keeps track of users by given unique identity for prioritizing them. Then the receiver calculates the data frame from users and give chance to all users by maintaining a log list. Let, consider user A and B which are transmitting a large amount of data when user C also try to transmit small amount of data. Here, user A and B makes request first then the user C make request to transmit data by using the same BS. In this scenario BS will avoid deadlock situation by giving a priority tag to the users with their identity depend on requesting time. First it continues to transmit data of user A and B simultaneously as their request comes at a time by multiplexing antennas. But when user C's request come and the BS calculation shows that its requested data size is lesser than the users A and B. In this situation the BS continuous to transmit until that time frame complete. After completing the continuous time frame then the BS will take decision whose requested data will be transmitted depend on the priority, requested time. It also take care the amount of data size. If the BS takes decision to transmit user C's data simultaneously with user A and user B, then it will free few channel for it and transmit data. At that time user A and B's transmission can suspend for few moment because of freeing channel for user C. When all channels are free then it can allocate all channels to the users A and B.

It will also avoid grouping spatially correlated users [3]. Fairness ensures that all users are served including those channels which are weak to transmit which makes this attractive to REN network. Otherwise, the BS will transmit to the strong users only and the weaker ones will be ignored. Using this technique, BS can maximize system performance while maintaining fairness to all users.

V. CAPACITY ANALYSIS OF MU–MIMO FOR REN

For characterizing any communication channel, capacity is a fundamental tool. As the capacity region of a MIMO MAC is known, so the expressions are quite straightforward. The capacity of the MIMO-MAC can be written as the convex closure satisfying the user-by-user power constraints [9].The maximum capacity of a MU – MIMO system is expressed in terms of the sum capacity [40] of the broadcast channel which is necessary for all type of REN models. Here, the sum capacity represents the maximum achievable system throughput.

The sum capacity of a Gaussian MIMO broadcast channel with an arbitrary number of BS transmit antennas and multi – antenna users, is the load point of a mini-max problem [34, 41]. The capacity region of the Gaussian MIMO-BC with single-antenna users is equivalent to the dirty paper coding (DPC) rate region under a certain total transmit power constraint [42]. In the low SNR regime, un-coded transmission produces very poor error probability performance. In [43] Costa presents a pre-coding technique which is known as Costa pre-coding and the idea is,

$$y=s+i+w\ldots\ldots\ldots(7)$$

where, s is the signal used to transmit a code ward, i is interference with power known deterministically at the transmitter, but unknown to the receiver, w is Gaussian noise and the received data is y. If the signal has power constraint $|s|^2\leq\rho$, then the capacity of this system is [43] -

$$C=\log(1+\rho/N)\ldots\ldots\ldots(8)$$

To extend the dirty – paper analogy, the "capacity" of dirty paper is the same as for a sheet without this known "dirt". Two simple summaries *e.g.*, the mean capacity and capacity outage are used to describe the capacity [2, 12] of MU-MIMO.

VI. CONCLUSION

This paper provides a survey on efficiency of multiuser MIMO for the research and education network (REN). The detailed of multiuser MIMO MAC and MIMO broadcast channel are also explained. The survey [3], has extensively been referred throughout the paper. In the MU-MIMO MAC, the LAST-MUD scheme technique provides good performance and is applicable in REN models. The higher complexity Turbo–MUD scheme achieves better performance by jointly detect the transmit antenna and can also be used in REN. The MU–MIMO broad cast channel for REN models, SMMSE pre-coding has manageable complexity. On the other hand, the nonlinear dirty paper coding techniques are capable of achieving the sum capacity of Gaussian multiuser channels with single-antenna users. The iterative linear MMSE techniques provide excellent un-coded and coded BER performance for single stream transmission. The survey also discussed on the MU-MIMO capacity detection for REN. It depends on the statistical properties of the channel which helps on decision making to gain higher speed and performance for the REN models. Accurate channel estimation is the prime importance in the MU-MIMO communication performance for REN models. Channel estimation errors may results in severe performance degradation. Antenna scheduling is necessary for gaining the performance in multiuser MIMO system. Performance also increases when merging massive MIMO techniques in multiuser MIMO. Here many antennas are used for transmission in the REN networks. Although multiuser MIMO is bit costly but it is acceptable for REN, since in REN better performance is always the key.

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