Channel aware sum rate maximization (CASRM) algorithm for MIMO cellular networks

Swetha Rani L[1], Dr. Suraiya Tarannumsurname[2]

[1]Assistant professor, Dept. of Telecommunication Engineering AMC Engineering College, VTU, Bangalore, India
[2]Professor, Dept. of Electronics & Communication Engineering, HKBK College of Engineering, VTU, Bangalore, India

ABSTRACT

During last decade MIMO (Multiple-Input and Multiple Output) has gained tremendous attraction from researchers to provide better performance for mobile communication systems. Improving efficiency of mobile communication systems to meet the ever increasing user needs is a major motivating factor. Various works have been carried out to improve performance of MIMO frameworks in terms of spectral efficiency, sum rate etc., using channel state information and time division multiple access (TDMA) transmission schemes. Rapid changes in channel states that exist in practical networks are not efficiently captured in the existing approaches effecting performance. In this work we propose Channel aware sum rate maximization (CASRM) algorithm for sum rate maximization for single cell MIMO system. Orthogonal frequency-division multiplexing (OFDM) techniques are used in constructing subcarriers. A complex Gaussian distribution model is created followed by linear precoding, using a transmit filter. A distortion model is derived in accordance to the dynamic channel conditions observed. Distortion model enables in correlating the received signal, corresponding transmitted signal and receive constellation error computation. Further to optimize sum rate, a covariance matrix is established between distortions and interferences observed. The mean square error is minimized to improved performance of sum rate. A comparative simulation study is carried out to show the performance of proposed work. Outcomes of proposed approach are compared with existing TDMA and With Statistical CSI based approach.

Keywords: Channel state information, distortion , precoding, MIMO cellular networks, sum rate, fading,

1. INTRODUCTION

In the field of wireless communication, utilization of multiple input multiple output (MIMO) antenna has grown rapidly during recent years because of its tendency to improve the capacity and performance of communication framework [1]. Demand of communication in cellular network is increasing day-by-day which requires prompt and efficient communication. By keeping this in mind, various approaches have been proposed to enhance the capacity of communication for wide range scenarios. For wide range scenarios and large antenna array, hybrid approach by consolidating both analog and digital precoding is proposed to optimize power utilization [2]. Initially, point-to-point communication system gained attraction for research where two or more devices are appointed with multiple antennas for communication. Nowadays, focus is expanding on multi-user MIMO communication system where multiple antennas are appointed in base station for establishing communication among autonomous users [3]. Various physical parameters such as antenna coupling [4], spatial correlation [5], channel interference, line of sight and frequency selectivity [6] are discussed which affect performance of MIMO.

In order to improve the performance of MIMO system in terms of spectral efficiency and multiplexing gain. Spatial precoding is one of the promising techniques, performed by transmitters [2]. Interference alignment (IA) precoding technique is proved technique to achieve optimal gain where interference is dominant [7]. According to interference alignment, interference is restricted to a lower-dimensional subspace for all receivers zero-forcing filtering is applied at receiver end. Various works have been carried out to improve the multiplexing gain and sum rate maximization for MIMO systems. Dirty paper coding [8] is capable to achieve improved performance by applying interference alignment precoding. In conventional MIMO frameworks, all transmitters follow same linear precoding technique by considering wide linear transmitters for wide range scenario but there exists some linear transmitters also, which affect sum rate performance of MIMO system. To overcome this issue, a linear transmitter filter scheme is designed which uses iterative approach to solve non-convex problem of sum rate maximization [9].

In cellular network MIMO system, multiple base stations are present which transmit signal to group of used in cells which causes interference. In this scenario, performance of framework degrades due to interference. To overcome this, linear transceiver based beamforming is proposed in [10]. Mitigation of intercell interference is crucial task for researchers [11]. In this perspective of cell interference, message splitting in common and private part is discussed. These messages are decoded by applying successive decoding and designed to optimize sum rate performance. Spectral selectivity is also key component which improves the performance of MIMO system. Consolidating spectral selectivity with TDMA (Time Division Multiple Access) provides efficient outcomes for large array and wide range MIMO communication framework [12].

Most of these works consider that channel state information is available at transmitter and receiver end. This assumption is effective for low mobility applications where configuration and realization varies very slow so it can be monitored and adopted at transmitter end but when mobility increases, fluctuation in channel increases which creates difficulty to track CSI. This becomes a critical issue for sum rate maximization in MIMO broadcast. Other key challenges for MIMO sum-rate optimization are dynamic range of channels, limited dynamic range of transmitter and receiver, imperfect channel state information. Dynamic range of channels is the ratio of inter and intra- modem separation. Limited dynamic range of transmitter and receiver is caused due to ADC (Analog to Digital converter), DAC (Digital to Analog Converter), amplifiers, oscillators etc. Imperfect CSI is resulted due to noise, channel time variation and dynamic range limitation. In [21] Y. Wu et al. introduced a new scheme for MIMO broadcast channel. Main aim of this work is to optimize the sum-rate which is carried out by applying gradient method but this work suffers from channel state information conditions. Moreover, internal noises and distortions are not focused in this work which leads to performance degradation in terms of sum rate of the system. To overcome these issues, we propose a new algorithm to optimize the sum rate of the system.

In this work, a MIMO cellular broadcast system is designed. The Channel aware sum rate maximization (CASRM) algorithm proposed focuses on non-convex sum rate optimization problem present in multi user MIMO broadcast systems. Interference alignment using linear precoding scheme is considered. Distortions observed at transmitters and receivers are modelled using complex Gaussian distribution. Unlike in existing state of art mechanisms [21], internal noises and distortions are accounted for in CASRM algorithm. With the help of Gaussian distribution model, correlation matrix between antennas is computed. After applying correlation calibration, distortion is analyzed which provides the relation between computed distortion at receiver and transmitted signal (In all existing mechanisms receivers are assumed to perfectly estimate their respective channel matrix). Based on this statistics, transmitter antenna power is computed. Similarly, power consumption is computed for independent distortion from transmitted signal. Based on the power and signal distortions, receive constellation error is computed to measure the performance of this system. Once receive constellation error is estimated, sum rate optimization based on the covariance between distortion and interference is considered. Optimization of the convex problem is achieved considering fixed transmit filters and predefined mean squared errors. Computational and communication complexity is reduced by applying iterative convergence strategy for interference channels. Experimental study described proves effectiveness of proposed CASRM algorithm in improving sum rates in multi user MIMI systems.

Rest of the manuscript is organized as follows: related work is discussed in section II, section III describes proposed model for sum rate optimization, in section IV results and performance evaluation is studied and finally section V concludes the manuscript.

2. RELATED WORK

In this section we study, most recent sum rate optimization techniques for MIMO systems. By applying precoding scheme, sum rate can be maximized. In this context, various researchers proposed different precoding scheme. Recently W. Shin et al. [13] proposed a cooperative precoding scheme for full-duplex relay connected antenna and named as relay-aided successive aligned interference cancellation($RaSAIC$). Based on relay strategy, A. Y. Panah proposed a new technique as amplify-and-forward for two-way relay system. Channel estimation is carried out using training, performed on known pilot symbols, referred as pilot-aided modulation. Linear minimum mean square estimation (LMMSE) is evaluated to study the performance of this system. Orthogonality of pilot symbols shows that estimation error is reduced [14]. C. Shen et al. [15] utilized beamforming technique for performance improvement of MIMO broadcast. This scheme is implemented on multicell scenario where coordinated beamforming is used for intercell interference mitigation. H. Huh et al. [16] used another technique for intercell interference cancellation. In this work, dirty-paper coding and zero-forcing beamforming are considered for providing the solution. Multicell scenario is considered where partial cells are cooperative.

Kulkarni et al. [17] presented a comparative study for MIMO system by considering convergence and rate performance by applying hybrid beamforming technique. Increasing demand of mobile data traffic requires high speed setup to provide required data rate for the users. In this context, cloud radio access network is a developing promising technique. In this method, baseband signals are sifted to single base band unit which helps to provide efficient resource allocation and interference management. To improve this, green Cloud- radio access network is presented in [18] by Shi et al. Remote radio heads and beamforming are consolidated for performance optimization. In this work, a greedy selection algorithm is employed to provide near-optimal solution.

Similarly, based on cell coordination theory, Wilson et al. [19] presented a new method to achieve improve convergence rate for the iterative interference alignment algorithms. In this study interference channel is considered with channel coefficients for each transmitter and receiver in the network. Zhang et al. [20] considered a clustered multicell network where limited feedback is provided. In order to achieve optimal rate, downlink beamforming is applied by dividing sum rate problem into smaller sub-problems using uplink-downlink duality method. For channel state information extraction, compressive sensing is used with the help of novel feedback.

Y. Wu et.al. [21] Proposed a new approach for maximizing the sum rate for MIMO broadcast system where the channel state information at the transmitter end in known. This work considers general fading condition and then linear assignment operation is performed to support the sum rate optimization. In this work, authors applied iterative approach for sum rate optimization using gradient method. Upper bound of linear assignment is computed to support the optimization problem.

Another approach for interference cancellation which has grown lot of consideration is discussed in [22]. This work considers coordinated beamforming strategy where channel distribution information is known to transmitters. This work provides suboptimal solution but computation rich with the help of block successive upper bound minimization approach.

Shi et al. [23] proposed a methodology to adapt beamformers and filters in TDMA-MIMO systems. According to this method, single beam is transmitted from each transmitter. The key point of this approach is that the priori channel state information is not known to transmitter. For this scenario, max-SINR scheme is proposed in which alternate pilot symbol transmission takes place.

The existing mechanism described, suffer due to lack of accurate channel information derived from the network. This issue is addressed in the proposed model described in subsequent section.

3. MULTI USER MIMO MODEL FOR CELLULAR NETWORKS

This section describes about proposed model for sum rate optimization for single cell MIMO system. System model is designed as that there are $\mathcal{B}_t$ base stations which are attending each user equipment or mobile station (represented as $\mathcal{MS}$) which are B_c . Communication between g^{th} mobile station and e^{th} base station is denoted as e_g. In order to achieve orthogonal narrowband channel from wideband channel, orthogonal frequency- division multiplexing is used. These narrowband channels are called subcarriers. In proposed study narrowband channels or subcarriers are studied autonomously without including subcarrier communication indexing.

For a given narrowband channel or subcarrier, signal reception at MS_{e_g} is given as

$$rx_{e_g} = \mathcal{F}_{e_g e} \uplus_{e_g} x_{e_g} + \sum_{(f,n)\neq(e,g)} \mathcal{F}_{e_g f} \uplus_{f_n} x_{f_n} + \sum_{f=1}^{\mathcal{B}_t} \mathcal{F}_{e_g f} d_f^{(t)} + d_{e_g}^{(r)} \quad (1)$$

Where $\mathcal{F}$ denotes flat fading, $\uplus$ is filter for transmitter, $d_f^{(t)}$ is distortion in transmitter and $d_{e_g}^{(r)}$ is distortion in receiver. Flat fading MIMO channel is denoted as $\mathcal{F}_{e_g f} \in \mathbb{C}^{M_r \times M_t}$, which is computed from f^{th} base station to mobile station MS_{e_g}. The ideal signal intended for mobile station is distributed with the help of complex Gaussian distribution $(\mathcal{C})$ denoted as $\mathcal{MS}_{e_g}, x_{e_g} \sim \mathcal{C}(0, \mathcal{S}_{\mathcal{N}_m})$, considering $\mathcal{S}_{\mathcal{N}_m}$ is the covariance matrix. This signal is precoded by applying linear precoding scheme by employing a transmit filter which is given as $\uplus_{e_g} \in \mathbb{C}^{M_t \times \mathcal{N}_m}$. Complete signal, represented in (1) carries desired signal, interference (inter and intra) and distortions of transmitters and receivers.
Distortion model is given as

$$d_f^{(t)} \sim \mathcal{C}(0, T_e^{(t)}) \quad (2)$$

Where $T_e^{(t)} = diag\left(t_{e,1}^{(t),2}, \dots, t_{e,M_t}^{(t),2}\right)$ is the transmitter diagonal covariance matrix.

Gaussian modeling is applied for transmitter distortion modeling because of distortion is combination of transmitter's residual distortion. If different radio frequency chains are used to serve antennas then due to precoding, antennas are correlated. After applying correlation, calibration and compensation, if distortion is still present then it is assumed that distortion is independent from the transmitted signal. Power of noise at m^{th} antenna $t_{e,m}^{(t),2}$, is denoted as

$$t_{e,m}^{(t)} = \zeta\left(\left(\sum_{g=1}^{B_c} \left\| \left[\uplus_{e_g}\right]_{m*} \right\|_F^2\right)^{\frac{1}{2}}\right) \quad (3)$$

It is a function of allocated power to the antenna, ζ is a non-negative function which describes the mapping of signal magnitude to transmitter distortion, $\|A\|_F = \left(\sum_{p,q} |a_{p,q}|^2\right)^{1/2}$ is the normalization computation and m^{th} row of A is $[A]_{m*}$
Similarly, receiver noise distortion is given as

$$d_{e_g}^{(r)} \sim \mathcal{C}\left(0, T_{e_g}^{(r)}\right) \qquad (4)$$

Where $T_{e_g}^{(r)} = diag\ \left(t_{e_g,1}^{(r),2}, \dots, t_{e_g,M_r}^{(r),2}\right)$ the receiver diagonal covariance matrix

As discussed before about signal independency from transmitted signal, distortion power is computed as

$$t_{e_g,m}^{(r),2} = \alpha_r^2 + \delta^2 \left(\sum_{(f,n)} \left\| \left[\mathcal{F}_{e_g f}\ \uplus_{f_n}\right]_{m*} \right\|_F^2\right)^{\frac{1}{2}} \qquad (5)$$

α_r^2 denotes thermal noise power, δ is a non-decreasing, convex and non-negative function which describes the mapping of received signal magnitude to received distortion

Performance measurement is carried out by computing receive constellation error at transmitter antenna which can be computed as

$$RCE_m^{(t)} \equiv \sqrt{\frac{t_{e,m}^{(t),2}}{\left(\left(\sum_{g=1}^{B_c} \left\| \left[\uplus_{e_g}\right]_{m*} \right\|_F^2\right)^{\frac{1}{2}}\right)}} \qquad (6)$$

Or it can be written as

$$RCE_m^{(t)} \equiv \frac{\zeta\left(\left(\sum_{g=1}^{B_c} \left\| \left[\uplus_{e_g}\right]_{m*} \right\|_F^2\right)^{\frac{1}{2}}\right)}{\left(\sum_{g=1}^{B_c} \left\| \left[\uplus_{e_g}\right]_{m*} \right\|_F^2\right)^{\frac{1}{2}}} \qquad (7)$$

From (7) it is evident that the receive constellation error $RCE \propto \uplus_{e_g}$, i.e. the error depends on the transmit filter considered. In this section to accurately obtain channel information i.e. rx_{e_g}computation is discussed . Computation of $d_f^{(t)}$ (distortion in transmitter) and $d_{e_g}^{(r)}$ (distortion in receiver) is included in the system model to accurately attain dynamic channel information in cellular MIMO networks. This channel information is adopted to improve performance using CASRM algorithm discussed below.

A. Channel aware sum rate maximization (CASRM) algorithm

This section describes proposed CASRM algorithm to improve network performance. The major goal of the CASRM algorithm is to maximize sum rate considering channel state information obtained considering (1). A iterative weight based optimization technique is adopted in the CASRM algorithm. By considering parameters from [1], achievable data rate is given by

$$\mathcal{R}_{e_g} = \log_2 det\left(\mathcal{S} + \uplus_{e_g}^{\mathcal{H}}\ \mathcal{F}_{e_g e}^{\mathcal{H}} \left(\mathcal{Q}_{e_g}\right)^{-1} \mathcal{F}_{e_g e}\ \uplus_{e_g}\right) \qquad (8)$$

$\mathcal{Q}_{e_g}$ is the covariance matrix considering distortion and interference, $(.)^{\mathcal{H}}$ is the Hermitian transpose of a matrix.
The weighted sum rate which is computed as

$$\mathcal{R}_{WSR} = \sum_{(e,g)} \gamma_{e_g} \mathcal{R}_{e_g} \qquad (9)$$

γ_{e_g} is weight of non- negative data rates.
For each base station, the weighted sum rate problem can be solved as

$$\underset{\{\uplus_{e_g}\}}{maximize} \sum_{(e,g)} \gamma_{e_g} \mathcal{R}_{e_g} \qquad (10)$$

This problem is solved by considering distortion model and transmit filter such as

Subject to $Tr\left(T_e^{(t)}\right) + \sum_{g=1}^{B_c} \left\| \left[\uplus_{e_g}\right] \right\|_F^2 \leq \mathcal{P}_e, e = 1, \dots, B_t$ (11)

Where $\mathcal{P}$ is the per base station power constraint

Here we compute local optimal point as eq. (8) (10) and (11) are nonconvex problems. In order to perform the computation of local optimal point, mean squared error is introduced for user e_g which is given as

$$\mathcal{E}_{e_g} = \mathbb{E}\left(\left(x_{e_g} - u_{e_g}^{\mathcal{H}} r x_{e_g}\right)\left(x_{e_g} - u_{e_g}^{\mathcal{H}} r x_{e_g}\right)^{\mathcal{H}}\right) \quad (12)$$

Where $u_{e_g} \in \mathbb{C}^{M_r \times \mathcal{N}_m}$ denotes a linear receive filter and MSE weight matrix is denoted as $W_{e_g} \in \mathbb{C}^{\mathcal{N}_m \times \mathcal{N}_m}$, $\mathbb{E}$ is the expectation.

Finally, an optimal point is estimated by computing mean squared error which is given as

$$\underset{\substack{\{u_{e_g}\} \\ \{W_{e_g}\} \\ \{\uplus_{e_g}\}}}{minimize} \sum_{(e,g)} \gamma_{e_g}\left(Tr\left(W_{e_g}\mathcal{E}_{e_g}\right) - \log_2 \det(W_{e_g})\right) \quad (13)$$

Subject to $Tr\left(T_e^{(t)}\right) + \sum_{g=1}^{B_c} \left\|\uplus_{e_g}\right\|_F^2 \leq \mathcal{P}_e, e = 1, \ldots, B_t$

W_{e_g} is a weight matrix and $Tr(A)$ represents the trace of A .

From (13) three parameters namely $\uplus_{e_g}$, W_{e_g} and $\mathcal{E}_{e_g}$ are to be computed. From (12) , $\mathcal{E}_{e_g} \propto u_{e_g}$, i.e. the mean square error is dependent on the linear receive filter parameters considered. Hence, by obtaining optimal values of $\uplus_{e_g}$, W_{e_g} and u_{e_g} maximum sum rate can be achieved. In proposed CASRM algorithm two parameters out of the three ($\uplus_{e_g}$, W_{e_g}, u_{e_g}) are kept constant and the optimized value of the remaining one is obtained. This operation is carried out iteratively until optimized values of $\uplus_{e_g}$, W_{e_g}, u_{e_g} are obtained. Using the optimized parameters obtained an experimental study is conducted to evaluate performance. The experimental study is discussed in the next section of the paper.

4. RESULTS AND DISCUSSION

In this section we discuss outcome of the proposed approach for sum rate maximization using single cell MIMO systems. This simulation study is carried out using MATLAB tool and simulation parameters are discussed in the following section.

In order to carry out the simulation study and performance analysis considered a single cell environment for cellular networks. In this study we have employed 3 base station based $B_t = 3$, one number of transmitter, four number of receivers. Among the base stations, 500m distance is considered for placement. Path loss is described based on the distance between base station and mobile station which is r in meters. Path loss is computed as $L_{db} = 15.3 + 37.6\, log_{10}(r)$. For all users, the penetration loss is assumed as 20 db. In this study gain of the base station is computed as $12\left(\frac{\theta}{35^\circ}\right)^2$.

For evaluation we compute sum rate w.r.t SNR and sum rate w.r.t. Iteration. Proposed simulation results in terms of SNR, are compared with other state of art algorithm [21]. In [21], sum rate maximization is evaluated and compared by applying TDMA scheme and Algorithm 1(Optimal matrix based performance).

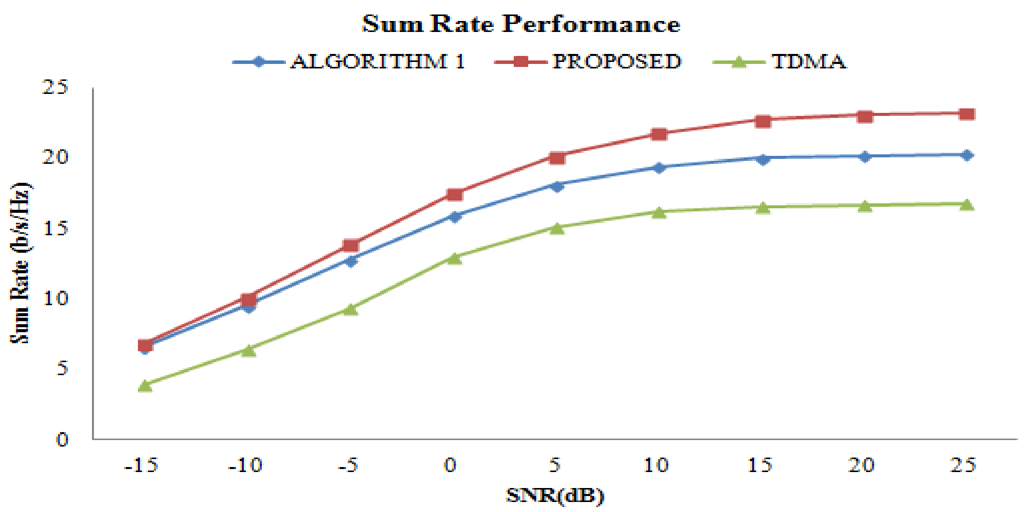

Figure 1 Sum Rate performance

Above given figure shows comparative analysis for sum rate maximization by applying TDMA, Algorithm 1 [21] and proposed algorithm. For this study, SNR variation is considered and based on this variation outcome of proposed approach in terms of sum rate is computed. From figure 1, it can be concluded that proposed algorithm outperforms when compared to existing algorithm. Based on this study, proposed approach achieves 10.25% improvement in sumrate when compared to Algorithm 1 and 28.36% improvement is noted when compared to existing TDMA approach. Average sum rate performance is depicted in figure 2. According to this figure, Algorithm 1 achieves 15.87(b/s/Hz) sumrate, TDMA achieves 12.67 (b/s/Hz) and proposed achieves 17.69 (b/s/Hz).

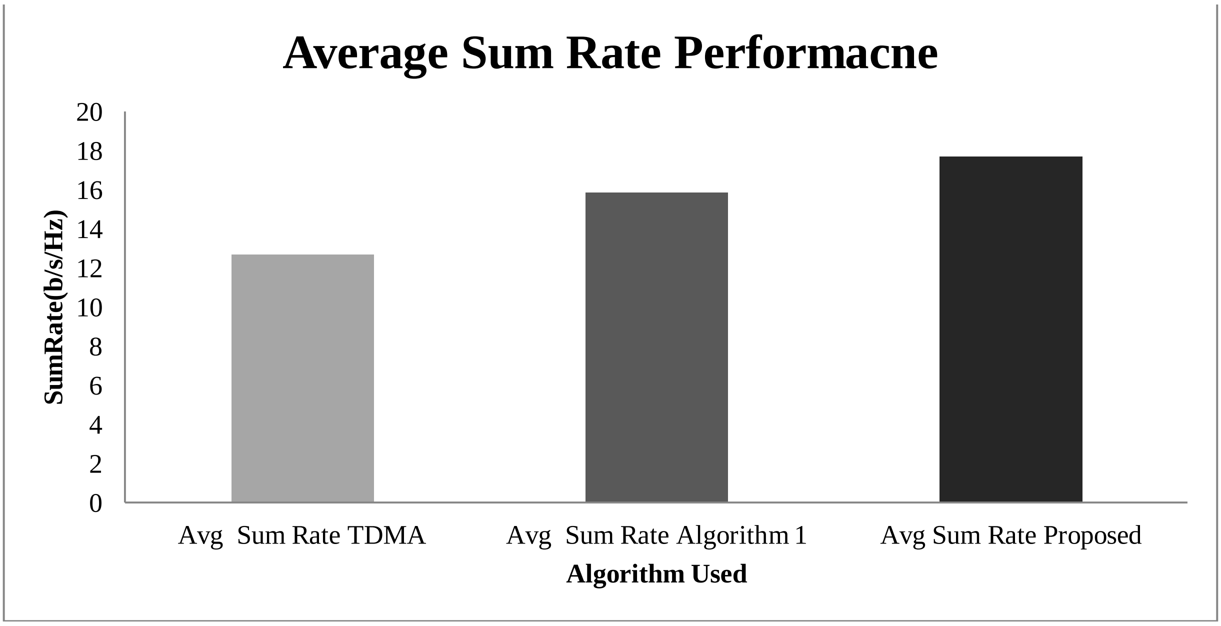

Figure 2 Average Sum Rate performance

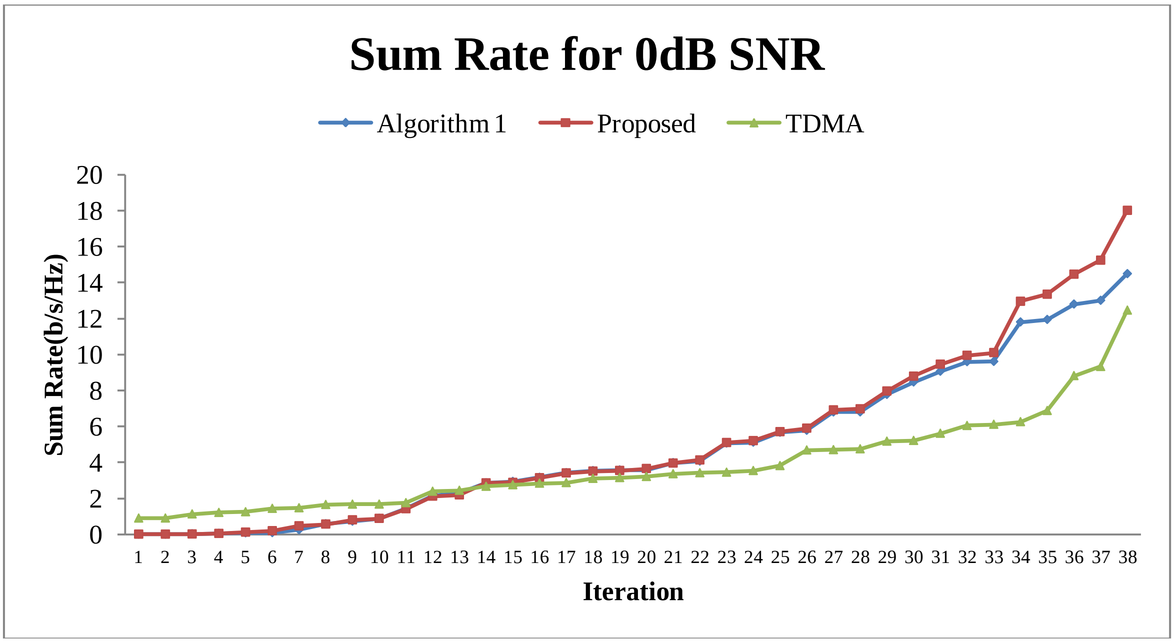

Figure 3 Sum rate for varied iteration

In order to show the robustness of proposed approach, we consider other scenario for performance evaluation where SNR is kept constant and iterations are varied to achieve the best performance of sum rate. In figure 3, performance for 0 SNR is displayed and compared with TDMA and Algorithm 1 results which show 6.4 % improvement when compared to TDMA and 34% when compared to Algorithm 1.

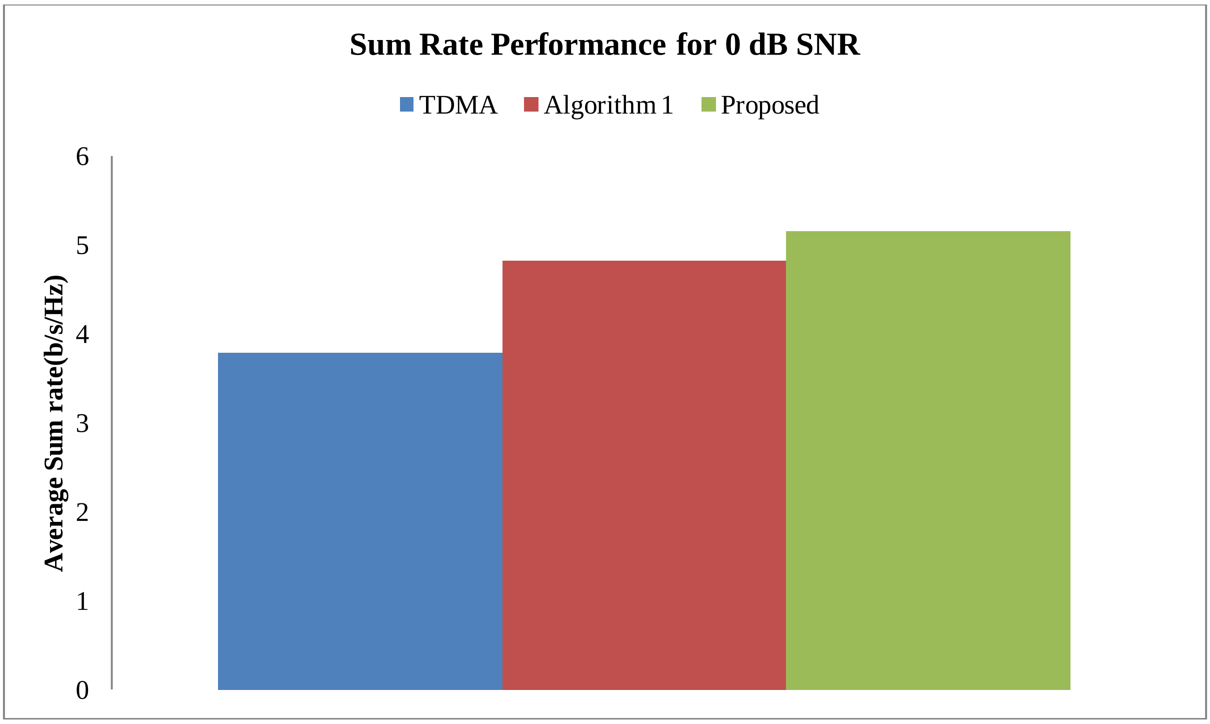

Figure 4 Average Sum Rate for 0 dB SNR

For same similar scenario as considered in figure 3, we show average Sum Rate performance and similar comparisons are carried out which shows improved Sum Rate performance by applying proposed approach for sum rate maximization, given in figure 4.

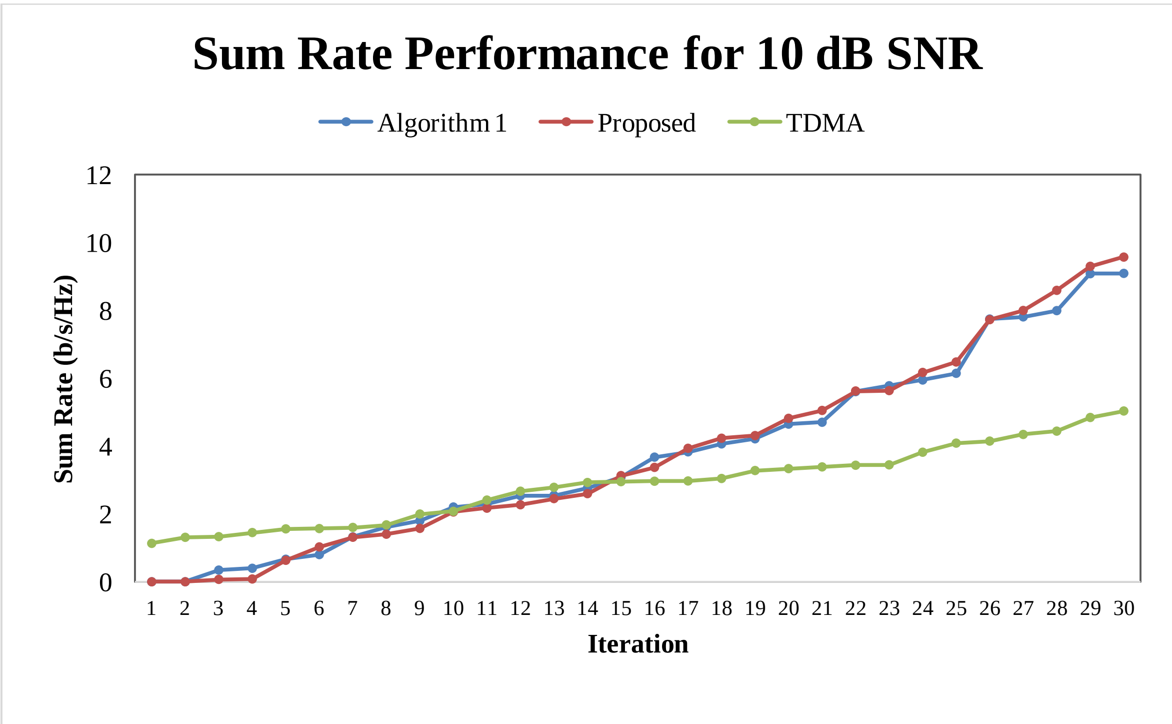

Figure 5 Average Sum Rate for 0 dB SNR.

Later, SNR is kept at 10 db and simulation iterations are varied. This performance is presented in figure 5 which shows improved results for sum rate. Similarly, for 10 dB scenario, average performance is computed as given in figure 6.

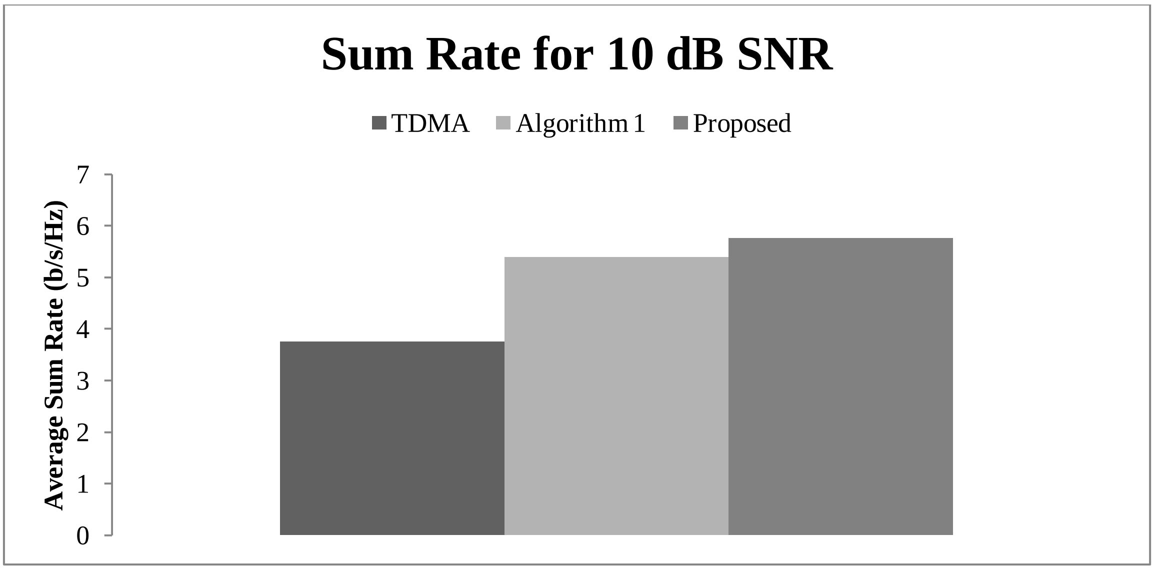

Figure 6 Average sum rate for 10 dB SNR

In figure 6, average sum rate performance is depicted for varied iteration. A comparative study is given b considering TDMA and algorithm 1 approaches, proposed approach shows improved results for varied iteration for 10 dB SNR. From this discussion, it can be concluded that proposed approach for sum rate maximization provides better results for a single cell simulation environment.

CONCLUSION

Considering MIMO cellular networks, knowledge of channel information is critical to improve performance. Channel state information is modelled using a comprehensive set of practical parameters that exist. Higher sum rates exhibit better network performance and network utilization. To maximize sum rate In this work, sum rate capacity performance is analyzed for multiple users broadcast system by taking MIMO system in consideration. In this study it is assumed that correlation matrices are different for each user. Here we propose sum rate maximization approach for single cell environment. A simulation study is carried out to analyze and compare the performance of proposed approach with other existing approaches which shows that proposed algorithm is robust and provides better performance compare to other works. In future, we try to optimize and maximize sum rate for multiple cell communication environment.

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