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Analysis of per Cell Spectral Efficiency parameters for Smart Base Station Controller

K. P. Rajesh and M. Mary Synthuja Jain Preetha

Abstract*: *In this paper a new Base Station Controller is designed with the analysis of several parameters on Per Cell Spectral Efficiency. The new SE expression is derived based on the new precoding scheme and is analyzed with different existing linear precoding schemes. The analyzed results with the different precoding schemes conclude that the proposed linear scheme PZFn performs better than the existing schemes, especially when the antenna number is approaching towards 1000. This is a good sign, as 5G is standardized to serve with 1000 transmitting antenna within a single base station of the cell. Here Per Cell Spectral Efficiency is analyzed with parameters like Per Cell SE for fixed number of Users, pilot reuse factor β ,achievable SE per UE, SNIR , Coherence Block Length and finally with hardware impairments. All the simulated results conclude that antenna number is proportional to the transmitted data. Hence the base station can decide the number of antenna to be used to transmit data depending upon the amount of data to be transmitted.

***Index Terms*: Massive MIMO, Spectral Efficiency, Pilot reuse factor**

I. INTRODUCTION

5G is the latest Research area in wireless communication with 3 use cases [1-5]. The three use cases are

i) eMBB (Enhanced Mobile Broad band)

ii) uRLLC (Ultra Reliable Low Latency Communication)

iii) mMTC (Massive Machine Type Communication)

Each use case focuses on certain system parameter like large throughput, low delay and massive connectivity. Different 5G application uses few network parameters of its priority depending upon the nature of the application by compromising few other network parameters.

The expression for throughput is given by a simple expression [6-8]

Network Throughput= Bandwidth *Cell Density*Spectral efficiency [bits/s/Hz/Cell] (1)

Throughput can be increased by increasing any one parameter from the equation (1). In this paper we propose a new Spectral Efficiency (SE) expression and also analyze the SE expression from the linear precoding schemes [1] with respect to few system parameters like intercell interference, range of antennas, SINR and, Coherence Block Length frequency reuse factor. Finally the analysis results are used by the Base Station (BS) controller for activating the number of antennas depending upon the active number of users, SE and power constraints for data transmission [9]. The paper is organized as follows. In section A we describe the System Model and the summary of the linear precoding schemes. In section B we discuss Per Cell SE for fixed number of Users. In section C we discuss the impact of pilot reuse factor β and achievable SE per UE for system with high Per Cell SE. In Section D Impact of SNIR is analyzed. In Section E Impact of Coherence Block Length on SE is analyzed. In section F, SE with hardware impairments is simulated.

II. SYSTEM DESIGN

For designing a Smart Base Station Controller for the cellular network, we assume that the data is transmitted with universal time and frequency reuse in that network. Let us assume that the cellular network has a cell which is named with an index from the set of variables in the set L. Similarly the Base Station with in the cell is equipped with an antenna array having M Antennas. Here the value of M is more than K which is the number of active users with single antenna devices. Let maximum number of users be Kmax. For our system, Massive MIMO topology is considered for the study it is mandatory to choose M>K. The active user numbers is not constant in a cellular network and this may vary from time to time. For simulation each cell is assigned a number l Є L. Also the geographical position Zlk Є R2 is the location of User Equipment (UE) k in the cell l, which is a random variable with cell specific distribution. This model is used to study the random behavior of UE k with the cell l.

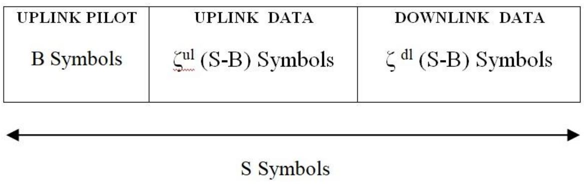

Fig 1. Frame structure of the data transmission

Section A

Frames are the standard basic block for signal transmission through the Network. The data transmission through the Network is divided into frames of S symbols. Let the number of pilot symbols is taken as B. Apart from the above the rest of the frame bits is shared among uplink and downlink depending on the uplink and downlink fraction ζul and ζdl respectively. These parameters separate the rest of the bits into positive integers with the constraint ζul + ζdl =1.

Uplink:

Uplink occurs at all cells of the Network. Let the cell l have the UE k, which is active in its range. The uplink signal is related to the transmit power given by the condition P_{lk}>=0. Let hjlk is the channel response between the BS j and the UE k in the cell l.

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xlk is the transmitted signal by the UE. Then the received signal is modeled as

$$yj = \sum_{l\in L} \sum_{k=1}^{K} \sqrt{P_{lk}}\, hjlk\, xlk + nj \quad (2)$$

Downlink:

MIMO TDD uses channel reciprocity. Hence the uplink (UL) parameters are similar for downlink (DL) expression. The DL signal Zjk at UE k in the cell is modeled as

$$z_{jk} = \sum_{l\in L} \sum_{m=1}^{K} h_{jlk}^{T} w_{lm} s_{lm} + n_{jk} \quad (3)$$

Where w_{lm} is the precoding vector.

The UL/DL model is assumed with perfect synchronization across all cells. Similarly for a Multicell Environment, the interference from the neighboring cells is synchronously received and can be suppressed [11-14]. But the signal from far away cell is asynchronously received and cannot be suppressed. Fortunately these signals have low power which does not lead to serious interference.

Achievable UL & DL Spectral Efficiency

The achievable UL & DL Spectral Efficiency is given as

$$\zeta^{(ul)} \left(1 - \frac{B}{S}\right) E_{\{Z\}} \left\{\log_2(SINR_{jk}^{(ul)})\right\} \quad (4)$$

Where SINR –Signal to interference ratio. E{.} is calculated with respect to UE position.

Scheme	G^{scheme}	Z^{scheme}
MR	M	K
ZF	M-K	$K\left(1 - \frac{\mu_{jl}^{(1)}}{\sum_{l\in L_{j(\beta)}} \mu_{jl}^{(1)} + \frac{\sigma^2}{B\rho}}\right)$
P-ZF	M-B	$K\left(1 - \frac{\mu_{jl}^{(1)}}{\sum_{l\in L_{j(\beta)}} \mu_{jl}^{(1)} + \frac{\sigma^2}{B\rho}}\right)$
Proposed P-ZFn	M-Average (K,B)	$K\left(1 - \frac{\mu_{jl}^{(1)}}{\sum_{l\in L_{j(\beta)}} \mu_{jl}^{(1)} + \frac{\sigma^2}{B\rho}}\right)$

The proposed scheme P-ZFn which is modified version of PZF, the first term of SE maintains array gain in the way between MR and ZF Where as the inter cell interference is reduced similar to PZF term. Achievable DL Spectral Efficiency

By Channel reciprocity we get a similar expression for DL. DL Spectral Efficiency for a cell j is given as

$$\zeta^{(dl)} \left(1 - \frac{B}{S}\right) E_{\{Z\}} \left\{\log_2(SINR_{jk}^{(dl)})\right\} \quad (5)$$

III. SIMULATION RESULTS

Section B

In this section we focus on the average inter cell interference case of the communication scenario. Here SE terms are compared with respect to the number of antennas. This simulation is done for the single cell. Initially the simulation is done with antenna numbers chosen from 10 to 1000 range. As a special case for optimizing the number of antennas the simulation is then focused to the antenna range from 500 to 1000. 5G Massive MIMO take priority for such large number of Base Station Antennas. The simulation is done for K=10 UEs.

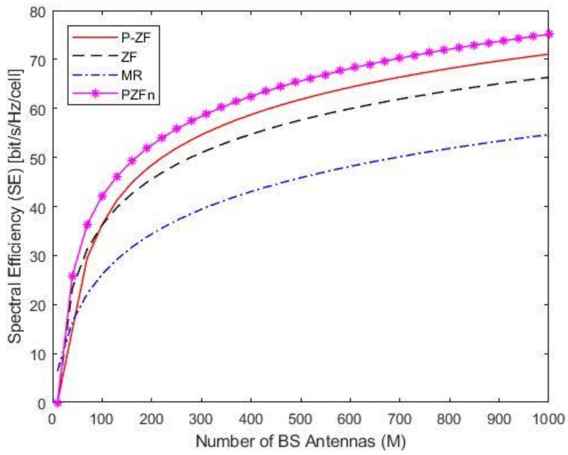

Fig.2 Per cell SE for K=10.

The simulation results shows that the P-ZFn performs better compared to other precoding schemes when the number of antenna is higher, which is similar to the practical scenario of Massive MIMO 5G base station with large number of antennas. Thus the new scheme can be used for 5G to improve SE. The improved SE in turn will improve the performance, throughput and data rate of the 5G system.

Section C

The pilot reuse factors have a greater impact on per cell SE. This is highly evident from the equation 5. The system is simulated for a single cell having several base stations. Fig.3 shows the simulated result. Also the variation in performance for the different pilot reuse factor β =3 and β =1.

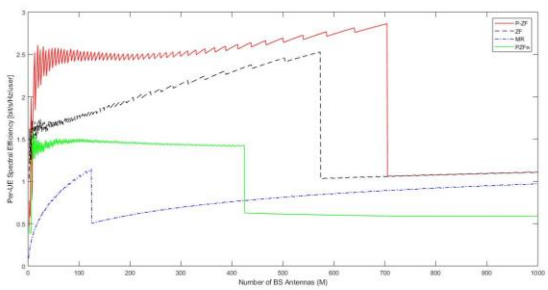

Fig 3. Achievable SE per UE for the communication system with high per cell SE

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The graph shows that there is considerable amount of change in system performance in terms of achievable SE per UE for higher frequency reuse factors. The simulation study [1] shows that SE is increases with number of base station antenna and this robust properly helps in scheduling and planning of cell based on user data consumption. In massive MIMO we have a common practice of following the thumb rule that the number of BS antennas is more than the UEs. The simulated result showing the relationship among the number of BS antennas and how many can effectively serve each UE.

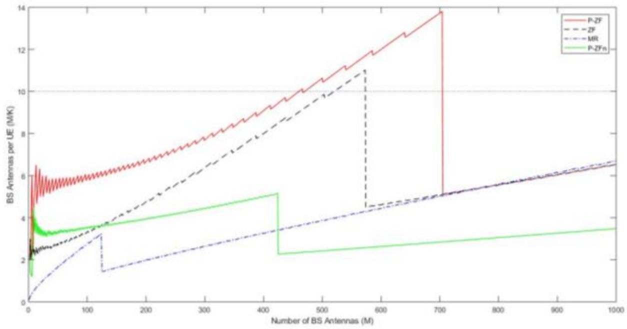

Fig 4. The simulated result of Base station antenna serving per UEs

The Fig.4 shows the ratio of number of base station antenna M to the number of active users K. This ratio is interpreted in literature [12]. Fig.4 shows that the proposed method exhibits better performance than its rival and operator in the same way on linear precoder.

In real world scenario the total number of users within the cell will not be communicating at the same time [1], [13]. Hence the number of active users will be less than the number of total users. This user who was communicating at any instant is called the scheduled users [13].

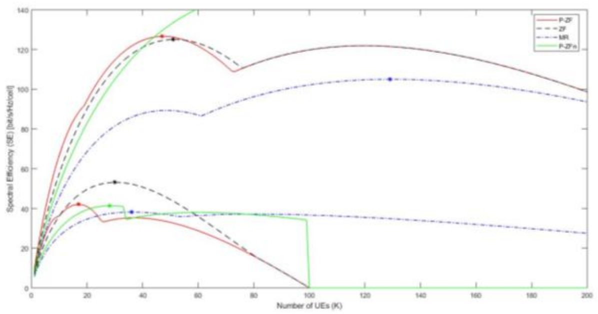

Fig.5 Simulated result of SE for scheduled users

Fig.5 shows the impact of SE on the number of scheduled users. Also the simulation is run for different number of base station antenna say M=100, 400, 500. The simulated result shows that SE is increased for the proposed PZFn method and also SE increases with increasing number of base station antenna M. This result is highly valid for real time massive MIMO scenario which has large number of transmitting antenna at base station which naturally increases the SE.

Section D

The investigation of SE on SNR variation is studied [1] with respect to the formula (SINR).we know that massive MIMO can be operated at low values of SNR with slight loss in its performance. The simulation is run for SE and SNR and the following graph is obtained.

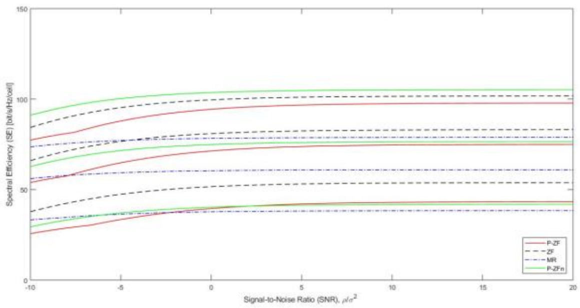

Fig 6. Impact of SE with respect to SNR variation

Fig. 6 shows the impact of SE with respect to SNR variations. The simulation is done for different number of base station antenna M. The simulated results shows that the SE is almost constant for SNR value, but SE shift forwards higher level when number of BS antennas M is increased.

Section E

In Fig.1, The data frame consists of S coherence blocks. This coherence block length also affects the per cell SE. The effect of coherence block length with respect to per cell–SE is simulated for different number of base station antennas, say M=100,500,800.

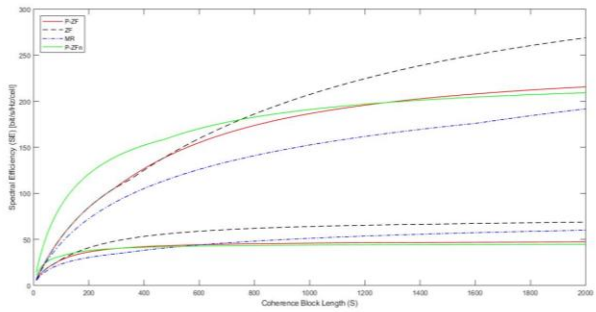

Fig.7 Simulated result of per cell SE as function of Coherence block length

In case of M=100, the gain is relatively small. Since gain is reduced the system is incapable of scheduling more UEs. This is because M/K ratio is less but when M=500, the gain is comparatively higher and M=800 it keep on increasing. Even from this figure, it is found that overall performance increases with increase in M.

Section F

Hardware Impairments

The analysis and simulations in the previous section are done with the assumptions that the common system has an ideal transmitter and ideal receiver. The ideal transmitter is assumed to radiate signals without any distortion and the receiver receives with infinite resolution. But in real practice, several inevitable non linearity may occur [12-15]. In this section we discuss how hardware impairments affect the system performance in terms of achievable spectral efficiency.

Hardware impairment models are developed and their performance with respect to several parameters is evaluated in [15-16]. It is found that BS array has

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negligible effects [14] with hardware impairments hence we consider hardware impairment for UE only the hardware impairments models proposed in [14-15] shows that there is $\sqrt{1-\varepsilon 2}$ time reduction in original signal. The parameter ε is responsible for the level of impairment. This parameter is interpreted on EVM (Error Vector Magnitude) [16].The expression is simplified such that for ideal hardware, ε=0 and ε=0.1 corresponds to higher EVM value.

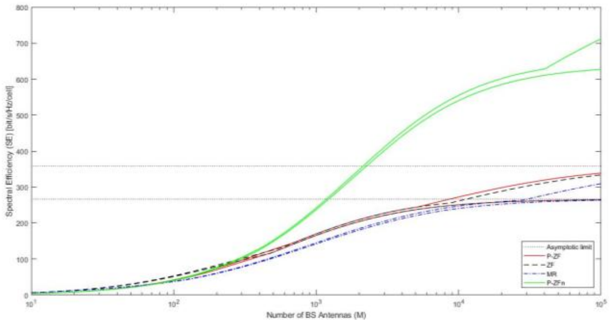

Fig.8. Simulated result of SE with and without hardware impairments

Base Station Controller

All the above simulated results conclude that the proposed PZFn Linear precoding scheme performs better than its rivals and the performance is reaching the peak values when the base station antenna number reaches a high value say above M=1000. All these data can be analyzed and the base station controller can allocate the data to be transmitted to the optimized number of Base Station Antenna by just simple threshold values rather than complex algorithms. Hence it can serve all the UE effectively and provide higher SE to all Scheduled users. Also since complex algorithms are avoided the computation time is also reduced. Hence in each and every aspect the analysis results improve the performance of the base station controller.

IV. CONCLUSION

In this paper, Per Cell Spectral Efficiency of the 5g network system is analyzed with different parameters like Per Cell SE for fixed number of Users, pilot reuse factor β, achievable SE per UE, SNIR, Coherence Block Length and finally with hardware impairments. The simulation results are analyzed with the existing precoders and all analysis conclude that antenna number is proportional to the transmitted data. Also the analyzed data can interpret the number of antennas needed to transmit data effectively. This data can be used by base station controller which can decide the number of antenna to be used to transmit data depending upon the amount of data to be transmitted.

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AUTHORS PROFILE

K. P. Rajesh is presently Research Scholar in Electronics and Communication Engineering department, Noorul Islam Centre for Higher Education, Kumaracoil, India. His research interests include digital circuits, wireless communication and robotics.

Dr. M. Mary Synthuja Jain Preetha is working as Associate Professor in Electronics and Communication Engineering, Noorul Islam Centre for Higher Education, Kumaracoil, India. She has been published several research papers in international journals. Her area of research includes robotics, Digital circuits, Image processing.

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