Transmitting Antenna Number Optimization for Smart Base Station using Per Cell Spectral Efficiency Analysis

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

Abstract---In a base station the number of transmitting antenna number is in fixed numbers. In this paper a we propose a new antenna number optimization using the analysis of several parameters on Per Cell Spectral Efficiency. Additionally a new SE expression is derived from the new proposed precoding schemePZFn and is compared with different existing linear precoding schemes . The analysis of SE parameters with respect to thedifferent existingprecoding schemes conclude that the proposed linear scheme PZFn performs better than the existing schemes. Also it observed that when the antenna number is approaching towards 1000 the resultsshows a better performance. This supports 5G is standard which is expectedserve with 1000 transmitting antenna. In this paper 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. The simulated results shows a common pattern that theantenna number is proportional to the transmitted data. This results can be used by the base station which is equipped with antenna array having several antenna arrays. The number of antenna units used for transmission is decided from thesimulated parameters.

Keywords--- Massive MIMO, Spectral Efficiency(SE), Pilot Reuse Factor.

I. INTRODUCTION

5G is the cutting edge technology in thearea of wireless communication. It serves with 3 usecases[6-9].The three use cases are:

1. eMBB(Enhanced Mobile Broad band)
2. uRLLC (Ultra Reliable Low Latency Communication)
3. mMTC(Massive Machine Type Communication)

The above three use cases have their ownindividualpriority for the system parameter like large throughput, low delay and massive connectivity. Enhanced Mobile Broad band uses case concentrates more on huge quantity of data transmission. It focus on application like medical databases, smart home systems and augmented reality which usehuge database sharing, cloud sharing, high definition video streamingtechniques. Ultra Reliable Low Latency Communication is used in self driving cars where the amount of data transmitted is less where the reliability of communication is extremely high. Similarly Massive Machine Type Communication concentrate on the large number of device connectivity application like IoT.Different 5G applicationuses few network parameters of its priority depending upon the nature ofthe applicationby compromising few other network parameters.

The proposed work concentrate on obtaining higher throughput through higher Spectral Efficiency. Hence we start the work with the expression on network throughput .

The expression for throughput is given by a simple expression[2-5]

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

Higher Throughput can be achievedby increasing any one parameter fromright hand side of the equation (1).

5G standard is designed to increasing the data rate to 1000 times from the 4G standards. This can betheoreticallyachieved by increasing each parameter in the right hand side of equation (1) by a factor of 10, so that the Throughput in left hand side increases by 1000 times.But in real practice this is not viable. Bandwidth cannot be increased as the spectrum is currently fully occupied and costly. Cell density is the number of base station with in the specified area called the cell. It is practically difficult to increasing the number of base stations since it isexpensive to deploy and the intercell interference also increases.Hence the better and economic approach is to improve the spectral efficiency to improve Throughput. Hence we go for improving the SE.

In this paper a new Spectral Efficiency (SE) expression is derived. It is alsoanalyzed withthe different the linearprecoding schemes[1] with respect to few system parameters like intercell interference, range of antennas, SINR and , Coherence Block Length frequency reuse factor. The analyzedresultsareused to optimize the number of base station antennas by the Base Station Controller.

The paper is organized as follows.

In section A the System Model is describedand also the summary of the different linear precoding schemes.In section B we discuss Per Cell SE for fixed number of Users. The impact of pilot reuse factor β and achievable SE per UE for system with high Per Cell SE is discussed in Section C.In Section D Impactof SNIR is analyzed andImpactof Coherence Block Length on SE in Section E .In section F,SE with hardware impairments is simulated.

Section A

System Design

For designing a Smart Base Station Controllerfor the cellular network, we assume that the data istransmitted with universal time and frequency reuse in that network.

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Let us assume that the cellular network has a cell which is named with a index from the set of variables in the set L. Similarly the Base Station with in the cell is equipped with an antenna array havingM Antennas. Here the value of M is more than K which is the number of active userswith single antenna devices. Let maximum number of users be Kmax. For our system, Massive MIMOtopology is consideredfor the studyit is mandatory tochoose M>K. The active user numbers is not constant in a cellular network and thismay vary from time to time. For simulation each cell is assigned a number l Є L . Also the geographical positionZlk Є R2 is the location ofUser Equipment(UE) k in the cell l, whichis a random variable with cell specific distribution. This model is used to study the random behavior of UE k with the cell l.

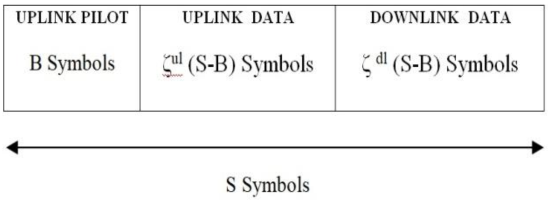

Fig. 1: The frame structure of the data transmission

Frames is the standard basic block for signal transmission through the Network.

The data transmission through the Network isdivided into frames of S symbols . Let the number of pilot symbols is taken asB.

Apart from the above the rest of the framebits is shared amonguplink and downlink depending on the uplink and downlink fraction ζul and ζdl respectively . These parametersseparate the rest of the bits into positive integerswith the constraintζul + ζdl =1.

Uplink

Uplink occurs at all cells of the Network. Let the cell l havethe UE k, whichis active in its range . The uplink signal is related to the transmit power given by the conditionP_{lk}>=0. Let hjlk is the channel response between theBS j andthe UE k in the cell l. xlk is the transmitted signal by the UE. Then the received signal is modeled as

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

Downlink

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

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

Where w_{lm} is the precoding vector.

The UL/DL model are assumed withperfect synchronization across all cells. Similarly for aMulticell Environment , the interference from the neighboring cells is synchronously received and can be suppressed[10-12][19]. But thesignal from far away cell is asynchronously received and cannot be suppressed.

Fortunately these signals havelow power which does not leads to serious interference.

Achievable UL & DL Spectral Efficiency

The achievable UL & DL Spectral Efficiencyis given as

$$\zeta^{(ul)}\left(1-\frac{B}{S}\right)E_{\{Z\}}\left\{\log_2(\mathrm{SINR}_{jk}^{(ul)})\right\}\text{--------------(4)}$$

Where SINR –Signal to interference ratio.

E{.} is calculatedwith respect to UE position.

With Pilot reuse factor, the expression of achievable SE is

$$\mathrm{SE}_j^{(ul)} = \mathrm{K}.\zeta^{(ul)}\left(1-\frac{B}{S}\right)\log_2\left(1+\frac{1}{I_j^{scheme}}\right)\text{------------------(5)}$$

$$\text{Where,} I_j^{scheme} = \sum_{l\in Lj(\beta)\{j\}}\left(\mu_{jl}^{(2)} + \frac{\mu_{jl}^{(2)}-(\mu_{jl}^{(2)})^2}{G^{scheme}}\right) + \frac{\left(\sum_{l\in l_j}\mu_{jl}^{(1)}z_{jl}^{scheme}+\frac{\sigma^2}{\rho}\right)\left(\sum_{l\in l_{j(\beta)}}\mu_{jl}^{(1)}+\frac{\sigma^2}{B\rho}\right)}{G^{scheme}}\text{-----------------(6)}$$

The literature[1] reveals the different Zand G terms of the above equation which is tabulated below.

Scheme	G^{scheme}	Z^{scheme}
MR	M	K
ZF	M-K	$K\left(1-\frac{\mu_{jl}^{(1)}}{\sum_{l\in L_{j(\beta)}}\mu_{jl}^{(1)}+\frac{\sigma^2}{B\rho}}\right)$ when $l \in Lj(\beta)$ K when $l \notin Lj(\beta)$
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 ZFWhere as the inter cell interference is reduced similar to PZF term.

Achievable DL Spectral Efficiency

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

$$\zeta^{(dl)}\left(1-\frac{B}{S}\right)E_{\{Z\}}\left\{\log_2(\mathrm{SINR}_{jk}^{(dl)})\right\}\text{------------ (7)}$$

Section B

In this section the impact of average inter cell interference on SE is simulated.

Here the relationship between the SE term is compared with respect to the number of antennas with the assumption K=10.

This simulation is donewith the assumption that the communication is withinthe 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.

This large number of antenna reminds us the5G Massive MIMO scenario. The simulation is done for K=10 UEs.

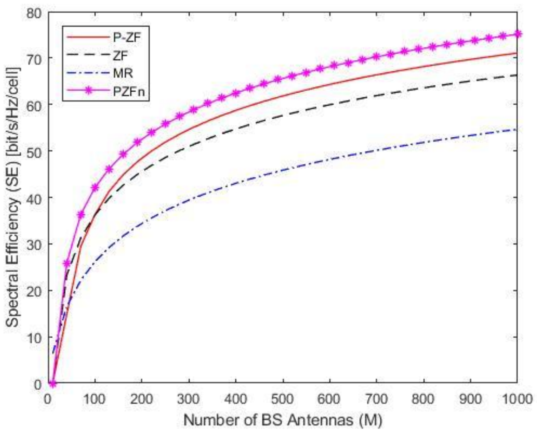

Fig.2: Per cell SE for K=10

The simulation results shows that all the precoding schemes follow the same pattern in its performance. The proposedP-ZFn performs better compared to other precoding schemes.It is observed that there is a linear growth in SEtill the antenna number approaches 500. Beyond 700 and towards 1000 the SE saturates . This shows that the SE becomes constant when antenna number increases to 1000.

Section C

The impact ofpilot reuse factor on SE is highly evident from the equation6. The system is simulated for a single cell having several base station . Fig.3 shows the simulated result withvariation in performance for the different pilot reuse factors, sayβ =3 and β =1.

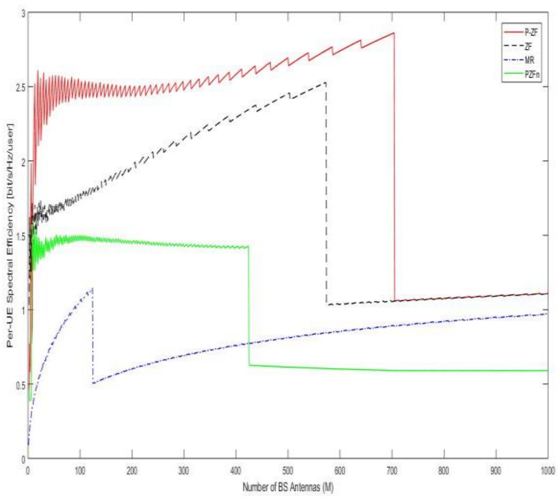

Fig. 3: Achievable SE per UE for the communication system with high per cell SE

The graph shows that there is considerable amount of change in system performance interms of achievable SE per UE for higher frequency reuse factors.The literature[1] shows that SE is proportional tothenumber of base station antenna .This property helps in scheduling of cell based on user data consumption and select the number of transmitting antenna.

Thethumb rule followed in Massive MIMO isthat the number of BS antennas are more than the UEs with in the cell. The simulated result shows the relationship of the number of BS antennas and the actual number of antennaservingeach UE.

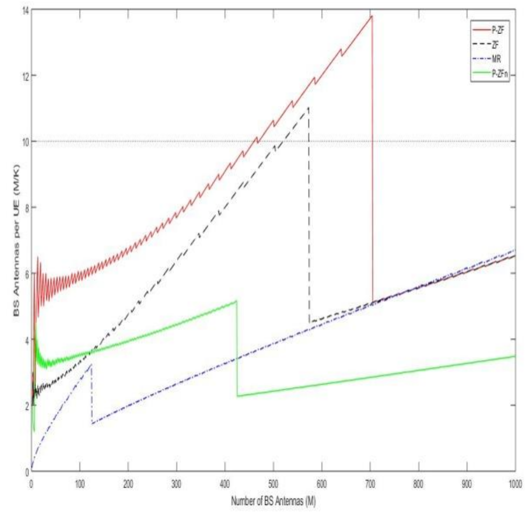

Fig. 4: The simulated result of Base station antenna serving per UEs

The ratio of base station antenna M to the number of active users K 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 active users with in the cell will be less than the number of total users[1][13].This means that all the users will not be communication at the same time.Certainusers who were communicating at any instant is called the scheduled users[13]. Some multiplexing techniques are used in serving these scheduled users simultaneously.

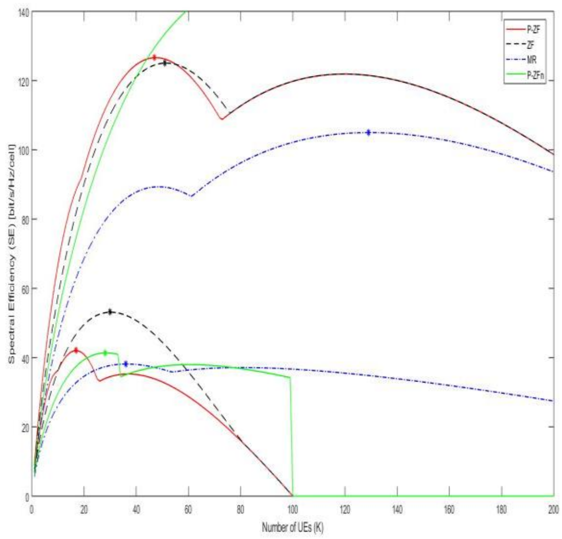

Fig.5: Simulated result of SE for scheduled users

Fig.5 shows the variations inSE for differentnumber of scheduled users for fixed number of antennas. Here the simulation is run for different number of base station antenna say M=100, 400, 500 and the variation in SE is analyzed. 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.

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This result is highly valid for real time massive MIMO scenario which has large number of transmittingantenna 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).It is well known fact that massive MIMO isoperated at low values of SNR with slight loss in its performance.The impact of SE on SNR is simulated and the result is shown in Fig.6.

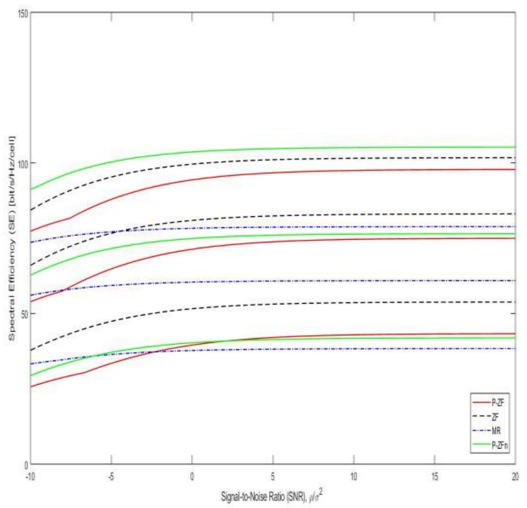

Fig. 6: Impact of SE with respect to SNR variation

Fig. 6 shows the impact of SE with respect to SNR variations for fixed number of antennas. The simulation is repeated for different number of base station antenna M. The graph shows that the SE is almost constant for SNR value, but SE shift forwards higher level when number of BS antennas M is increased. This shows that better SE is achieved for higher number of antenna irrespective of SNR.

Section E

Coherence blocks is one of the unit of data frame. The fig.1 shows the data frame with S Coherence blocks . This coherence block length also affects the per cell SE. The impactof coherence block length with respect to per cell –SE is simulated for different number of base station antennas, say M=100,500,800.

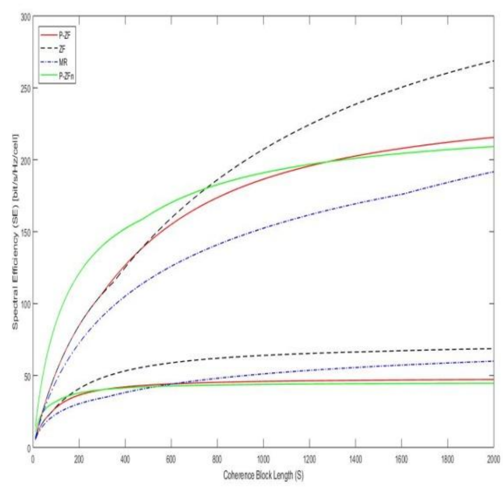

Fig.7: Simulated result of Per cell SE as function of Coherence block length

When M=100, the gain is relatively small. Because of lessgain the system cannotschedule 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. This shows that increase in M eventually increase M/K ration which in turn increases SE. Simulated results showthat overall performance increases with increase in M.

Section F

Hardware Impairments

In the previous sections all the analysis and simulations are done with the assumptions that the communicationsystem has an ideal transmitter and ideal receiver. The ideal transmitter is expectedto radiate signals without any distortion and loss.Similarlythe receiver is expected to receives with infinite resolution. But in real practice, several inevitable non linearity occurs [15-18]. In this section we discuss the effect of hardware impairments onsystem performance, interms of their achievable spectral efficiency. Hardware impairment models are developed and their performance with respect to several parameters are evaluated in [15-17]. It is found that BS array has negligible effects [14] with hardware impairments hence we consider hardware impairment for UE only the hardware impairments models proposed in [15-17]. Thisshows that there is $\sqrt{1-\varepsilon 2}$ time reduction in original signal.

The parameter ε definesthe level of impairment. This parameter is interpreted on EVM (Error Vector Magnitude) [16].The expression is simplified such that for ideal hardware, $\varepsilon=0$ and for hardware with higher EVM value takes$\varepsilon=0.1$.

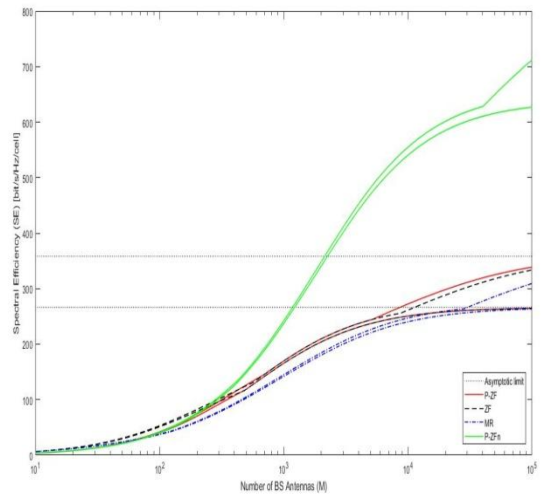

Fig.8: Simulated result of SE with and without hardware impairments

Base Station Controller

In all the preceding section it is found that when antenna number reaches 1000, SE is saturated and becomes constant. Another few results reveal that SE shows a shift in its values when the simulation is run for higher number of antennas.

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The impact of Coherence block and SNR also shows a better performance for higher number of Antennas.All the above simulated results conclude that the proposed PZFnLinear precoding scheme performs better than its rivals and the performance is reaching the peak values when the base station antenna number reachesa high value say above M=1000 . The knowledge of all these simulated results can be used by a base station controller to determine the number of antennas can be chosento transmit data depending up on the size of the bulk data.

II. CONCLUSION

In this paper, Per Cell Spectral Efficiency of the 5g network systemis 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 is performed and the results are analyzed with the existing linear precoders.The synthesizedresultconclude 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.

REFERENCES

[1] E. Bjornson, E. G. Larsson and M. Debbah, “Massive MIMO for Maximal Spectral Efficiency: How Many Users and Pilots Should Be Allocated”,IEEE Trans. Wireless Communication, vol. 15, no. 2, pp1293-1308,2016.

[2] Moby P, Athira Krishna K, AxamolCharly et.al , “Enhancement of Channel Potential and Spectral Efficiency using Hyper-MIMOIn 5G”, Asian Journal of Applied Science and Technology, Vol. 2, Issue 1, Pages 71-76, 2018.

[3] Patteti Krishna, M.SampathReddy and B.Balaji, “ Study and Improvements of Spectral Efficiency Analysis in MIMO Communications”, International Journal of Pure and Applied Mathematics, Vol.114, Pages 109-118, 2017.

[4] M.M. Matalgah, J. Qaddour,A. Sharma et.al, “Throughput and spectral efficiency analysis in 3G FDD WCDMA cellular systems”, GLOBECOM '03, IEEE Global Telecommunications Conference ,2017.

[5] ShrutiTiwari, R. K. Chida, “Massive MIMO: Maximal User Allocation with Uniform Power for Enhancement of SpectralEfficiency”, International Journal of Engineering Research & Technology,Vol.6, Issue 09, September2017.

[6] MehrdadShariat, Omer Bulakci, Antonio De Domenico et.al ,“A Flexible Network Architecture for 5G Systems, Wireless Communications and Mobile Computing ,Vol.10, 2019.

[7] Maria A. Lema, Andres Laya, ToktamMahmoodi et.al, “Business Case and Technology Analysis for 5G Low Latency Applications”,IEEE Access, Volume 5 , 2017.

[8] RupendraNath,MitraDharmaP.Agrawal, “5G mobile technology: A survey, ICT Express”,Volume 1, Issue 3, December 2015, Pages 132-137.

[9] MansoorShafi, Andreas F. Molisch, Peter J. Smith et.al, “5G: A Tutorial Overview of Standards, Trials, Challenges, Deployment, and Practice”, IEEE Journal on Selected Areas in Communications ,Vol.35 , Issue 6 , June 2017.

[10] T. L. Marzetta, “Noncooperative cellular wireless with unlimited numbers of base station antennas,” IEEE Trans. WirelessCommun., vol. 9, no. 11, pp. 3590–3600, Nov. 2010.

[11] J. Jose, A. Ashikhmin, T. L. Marzetta, and S. Vishwanath, “Pilot contamination and precoding in multi-cell TDD systems,” IEEE Trans. Commun., vol. 10, no. 8, pp. 2640–2651, Aug. 2011.

[12] J. Hoydis, S. ten Brink, and M. Debbah, “Massive MIMO in the UL/DL of cellular networks: How many antennas do we need?” IEEE J. Sel. Areas Commun., vol. 31, no. 2, pp. 160–171, Feb. 2013.

[13] E. Bj¨ornson, L. Sanguinetti, J. Hoydis, and M. Debbah, “Optimal design of energy-efficient multi-user MIMO systems: Is massive MIMO the answer?” IEEE Trans. Wireless Commun., vol. 14, no. 6, pp. 3059–3075, Jun. 2015.

[14] E. Bj¨ornson, J. Hoydis, M. Kountouris, and M. Debbah, “Massive MIMO systems with non-ideal hardware: Energy efficiency, estimation, and capacity limits,” IEEE Trans. Inf. Theory, vol. 60, no. 11, pp. 7112– 7139, Nov. 2014.

[15] T. Schenk, RF Imperfections in High-Rate Wireless Systems: Impact and Digital Compensation. Springer, 2008.

[16] M. Wenk, MIMO-OFDM Testbed: Challenges, Implementations, and Measurement Results, ser. Series in microelectronics. Hartung-Gorre, 2010.

[17] W. Zhang, “A general framework for transmission with transceiver distortion and some applications,” IEEE Trans. Commun., vol. 60, no. 2, pp. 384–399, Feb. 2012.

[18] U. Gustavsson et al., “On the impact of hardware impairments on massive MIMO,” in Proc. IEEE GLOBECOM, 2014.

[19] H. Yin, D. Gesbert, M. Filippou, and Y. Liu, “A coordinated approach to channel estimation in large-scale multiple-antenna systems,” IEEE J. Sel. Areas Commun., vol. 31, no. 2, pp. 264–273, Feb. 2013.

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