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Retraction

Retracted: Performance Evaluation of Spectral Efficiency for Uplink and Downlink Multi-Cell Massive MIMO Systems

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] R. M. Asif, M. Shakir, A. U. Rehman, M. Shafiq, R. A. Khan, and W. U. Khan, "Performance Evaluation of Spectral Efficiency for Uplink and Downlink Multi-Cell Massive MIMO Systems," *Journal of Sensors*, vol. 2022, Article ID 7205687, 12 pages, 2022.

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Research Article

Performance Evaluation of Spectral Efficiency for Uplink and Downlink Multi-Cell Massive MIMO Systems

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Massive multiple-input and multiple-output (MIMO) systems have become the most persuasive technology for 5G as it increased the energy efficiency gigantically as compared to other wireless communication systems. Being the most vibrant research technology in the communication sector, this research work is based on the optimal model development of energy-efficient massive MIMO systems. The proposed model is a realistic model that augmented the spectral efficiency (SE) of massive MIMO systems where a multi-cell model scenario is considered. Channel estimation is carried out at the base stations (BSs) based on uplink (UL) transmission while the minimum mean-squared error (MMSE), Element-wise MMSE, and Least-square (LS) estimators are used for the estimation. We analyze the achievable SE of the UL based on the MMSE channel estimator with different receive combining schemes. Moreover, the downlink (DL) transmission model is also modelled with different precoding schemes by taking the same vectors used in combining schemes. The simulation results show a significant improvement in spectral efficiency by developing UL and DL transmission models and also realized that the average sum of SE per cell can be improved by optimized MMSE channel estimation, installing multiple BS antennas, and serving multiple UEs per cell. The findings of this work specify that the massive MIMO system can be developed by optimizing the channel estimation for the augmentation of SE in UL and DL transmissions. Conclusively, it can be summarized that some complex computations of MMSE channel estimators can enhance the average sum of SE per cell as per the results verified in this model.

1. Introduction

Advancement in Massive MIMO systems is a key factor in encouraging the 5G network as it has high spectral and energy efficiencies having multiple transmitters and receiver antennas [1–3]. Recently many researchers have been enthusiastic about the study of massive MIMO networks whereas channel estimation, uplink (UL) and downlink (DL) transmission, spectral efficiency, energy augmentation models are evaluated in the last decade. On the other hand, the uplink signal assumption becomes inefficient and complex due to the large number of antennas in the massive MIMO system. Meanwhile, the proposed algorithm in [4] is efficient and achieves optimal bit error rate (BER) which depends on the least-square (LS) channel estimator compared to the traditional uplink detection algorithm. Thus, 5G is designed to adjust the high reliability, data traffic, and to improve spectral and energy efficiency with low latency while the Richardson and Neumann series expansion (NSE) method has been used to avoid matrix inversion [5]. Meanwhile, a method in [6] provides a good arrangement between bit error rate and complexity with hundreds or thousands of antennas are used in a system for tens of users to provide services simultaneously and the channel is also estimated according to the pilot signals which are sent by the user to the base stations (BS) while the massive MIMO system provides the advantage of high reliability, high spectral and energy efficiency. Maximum likelihood, minimum mean square (MMS) method, M-MMSE, S-MMSE, Regular Zero-Forcing (RZF), Zero-Forcing (ZF), maximal ratio combining (MRC), and zero-forcing deduction for channel estimation are used in the [7–10] while MMSE is preferred as it has the ability of better spectral efficiency other than complexity [11]. Although circuit power preference algorithms have been proposed to maximize energy efficiency (EE) in a multi-cell environment but the precoding techniques are developing for increasing spectral efficiency in the MIMO system has a better impact. An antenna selection scheme is used to expand the energy efficiency of the UL transmissions while it has more power consumption of the mobile antennas [9, 12]. Therefore, pilot reuse techniques are proposed for reducing co-channel interference without increasing the bandwidth and cell density is also analyzed. Meanwhile, a low complexity in channel estimation is becoming a big concern, minimum mean-squared error (MMSE), Element-wise MMSE, and Least-square (LS) estimators are used for computing the complexity with the trade-off of SE. Moreover, power consumption and energy efficiency (EE) of the base stations can be improved by using an effective strategy and an efficient downlink MIMO system consisting of zero-forcing, beamforming, and perfect channel in the base station is discussed here. Although, unimodal and user data rate increase together for the point of maximum energy efficiency whereas, unimodal is an average energy efficiency per base station. The linear precoding of channels is an efficient way with downlink and uplink pre-coders to reduce the effect of inter-user and improper noise. Furthermore, large array and multiplexing gain are used for large spectral and energy efficiency where a base station is equipped with a large antenna array to develop the orthogonal channel pairwise among users and base station by the use of small-scale fading [13]. Besides that, a massive MIMO system reduces the transmitted power of the base station and terminal, the research carries some Full-duplex (FD) models that are more suitable for short-range of communication like that WiFi and small-cell network more than arrangements with realistic parameters proposed by zero-forcing (ZF) design [14]. Hence, 5G antennas' spectral efficiency (SE) and energy efficiency (EE) are major factors in the designing of 5G antennas. Furthermore, the latest idea of the massive MIMO networks and distributed antennas system is known to improve inter-cell interference and a balanced quality of experience. Therefore, massive MIMO technology gives an impressive spectral efficiency compared to the conventional co-located MIMO [15]. The achievable spectral efficiency of several precoding and combining structures are getting more attention in analogue-digital implementation and 5G should be supportive of low power consumption [16]. For sustainable development in 5G, it has to improve energy and cost efficiency comparatively by Integrating the massive MIMO with examining the impact of pilot contamination on this new communication scenario. However, existing literature claims that it is probable to attain SE by performance evaluation of UL ad DL transmission models with their channel estimation as some details are in Table 1. The purpose of this article is the mathematical modelling of the UL and DL signals transmission and different channel estimation schemes for the UL transmission are also computed for the SE. We have also compared the complexity and SE of the above-mentioned channel estimators. The second objective is to provide an accurate MR precoding model for DL transmission for enhancing the SE as presented in [17, 18]. A survey of related work has been undergone by considering the key features of the previous work as summarized in Table 1. Furthermore, the latest trends and approximation methods used for the augmentation of EE are particularized while combing and precoding schemes with power consumption models already used by researchers are also considered. The SE enhancement schemes are deeply analyzed, and key factors are elaborated as well.

Table 1: Comparison of Related Work of Se In Massive MIMO.

Work	Cell	UL/DL	Combining/precoding scheme
[7]	Multicell	UL&dl	MMSE precoding and combining
[8]	Multicell	UL&dl	MMSE, RZF, ZF, MR precoding
[9]	Multicell	UL	MMSE precoding
[10]	Single	UL&dl	ZF precoding
[16]	Single	UL&dl	—

Given objectives are well accomplished and summarized as:

(1) A multi-cell scenario is considered where the UL and DL transmission models are taken into account with inter-cell interference and noises

(2) MMSE, EW-MMSE, and LS channel estimator schemes are modelled to carry the max. SE in UL transmission. However, MMSE is better as compared with EW-MMSE, and LS because of high SE and better interference mitigation practice

(3) MR precoding model for DL transmission for enhancing the SE is evaluated in the last section

The computed results of our proposed models are appropriate to indorse the massive MIMO systems that can able to enhance SE in a 5G cellular network. This paper is structured as follows. Section 1 is an illustration of a massive MIMO system model for both uplink and downlink communication. In section 2 the UL Spectral Efficiency with the MMSE estimator is compared with EW-MMSE and LS. Section 4 the MR precoding scheme is modelled for augmentation of DL Spectral Efficiency. Finally, key insinuation conclusions are drawn in Section 5. The Table 2 and Table 3 show the symbolic and acronyms representations used in our paper.

2. System Model for Uplink & Downlink Massive MIMO

This section includes the specifications of a multicell massive MIMO system covering the UL and DL transmission

Table 2: Symbolic Representations.

Symbols	Description
$\mathbb{E}(.)$	*Expectation*
$\vert . \vert$ and $\Vert . \Vert$	*Absolute values and Euclidean norm*
I_K	*$K \times K$ identity matrix*
Ψ	*Pilot signal sequence*
n_j^{dl}	*Additive receiver noise*
B	*Bandwidth*
T_{coh} & B_{coh}	*Coherence Time & Coherence Bandwidth*
$w_{lr} \in C^{M_l}$	Assigned as transmit precoding vector
$y_j^{UL} \epsilon \mathbb{C}$ and $y_j^{DL} \epsilon \mathbb{C}$	*Transmission symbols (uplink & downlink)*
τ_{UL}/τ_{coh}& τ_{DL}/τ_{coh}	*Uplink transmission & downlink transmission pre log factor*

Table 3: Acronyms Representations.

Symbols	Description
MMSE	Minimum mean-squared error
ZF	Zero-forcing
RZF	Regular zero-forcing
MRC	Maximal ratio combining
LS	Least-Square
SE	Spectral efficiency
MIMO	Massive multiple-input and multiple-output
BSs	Base stations
UL	Uplink
DL	Uplink
BER	Optimal bit error rate
NSE	Neumann series expansion
ML	Maximum likelihood
EE	Energy efficiency
FD	Full-duplex
EW	Element wise

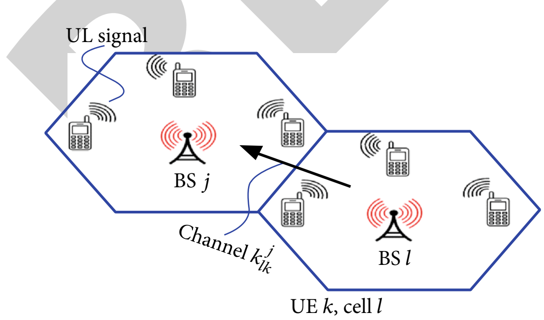

Figure 1: Illustration of the UL Massive MIMO transmission in cell j and cell l.

models, linear processing schemes, and channel models. The systems describe the UL and DL MIMO transmission in cell j and cell l as illustrated in Figure 1. Channel vectors h_{lk}^j and h_{jk}^l are considered in UL and DL, respectively, between the BS j and UE k. The *UL* data transmission signal has considered the desired signal, inter-cell interference, and noise. On the other hand, *DL* data transmission signal has added part of the intra-cell signal.

On the above-mentioned consideration, the following segments are modelled.

2.1. Uplink. In this stage, user K transmits the data to one of the correspondence BSs. Let the users K have the transmitted symbol vector in the l cell is $s_l = [s_{l,1} s_{l,2} \cdots s_{l,k}]$ and the received *UL* signal $y_j^{UL} \epsilon \mathbb{C}^M$ from the users K at BSj can be written as:

$$y_j^{UL} = \sqrt{\rho ul}\sum_{l=1}^{L}\sum_{K=1}^{K_i} h_{lk}^j S_{lk}^{UL} + n_j^{UL} \quad (1)$$

Where $n_j^{UL}$is an additive receiver noise denotes $n_j^{UL} \sim C \mathcal{N}(O_{M_j}, \sigma_{UL}^2 I_{M_j})$ while O_{M_j} is zero mean and σ_{UL}^2 is variance. Then the UL signal in cell l denote $s_{lk}^{UL} \epsilon \mathbb{C}$ has power $p_{UL,lk} = \mathbb{E}\{|s_{lk}^{UL}|^2\}$ and ρ_{UL} >0 means the uplink SNR and UL signal $y_j^{UL} \epsilon \mathbb{C}^M$ is given as:

$$y_j^{UL} = \sqrt{\rho_{UL}}\sum_{K=1}^{K_j} h_{jk}^j S_{jk}^{UL} + \sqrt{\rho_{UL}}\sum_{\substack{l=1\\ i\neq j}}^{L}\sum_{K=1}^{K_i} h_{li}^j S_{li}^{UL} + n_j^{UL} \quad (2)$$

Whereas, $\sqrt{\rho_{UL}}\sum_{K=1}^{K_j} h_{jk}^j S_{jk}^{UL}$ is desired signal and $\sqrt{\rho_{UL}}\sum_{\substack{l=1\\ i\neq j}}^{L}\sum_{K=1}^{K_i} h_{li}^j S_{li}^{UL}$ is inter-cell interference. The BS as dedicated in cell j selects the receive combining vector $y_j^{UL} \epsilon \mathbb{C}^M$ at the time of data transmitting for separating the desired

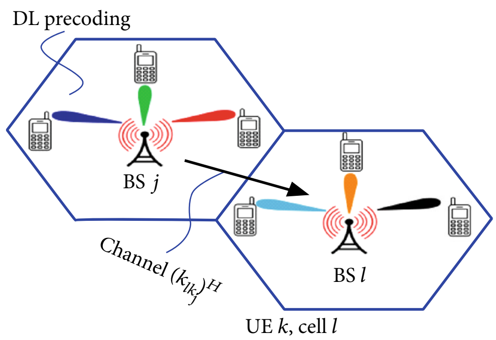

Figure 2: Illustration of the DL Massive MIMO transmission in cell j and cell l.

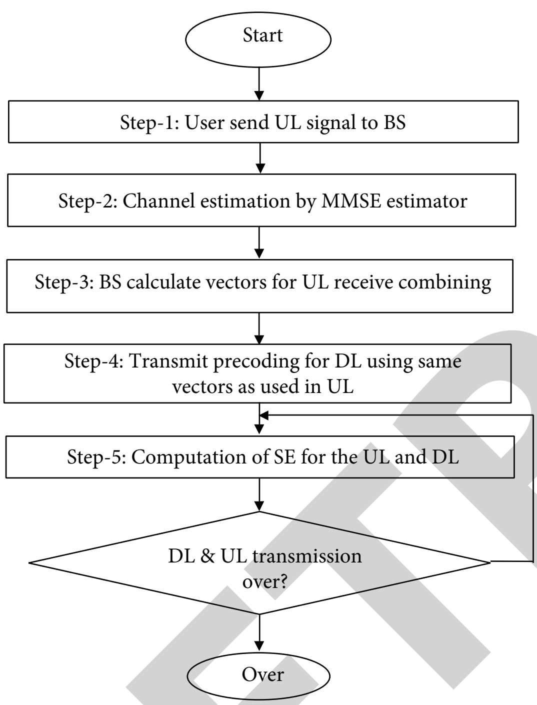

Figure 3: Computational Flow.

UE signal from the interferences and can be written as:

$$V_{jk}^{UL} y_j^{UL} = \sqrt{\rho_{UL}}\, V_{jk}^{UL} h_{jk}^{j} s_{ji}^{UL} + \sqrt{\rho_{UL}} \sum_{\substack{i=1 \\ i \neq k}}^{K_j} V_{jk}^{UL} h_{jk}^{j} s_{ji}^{UL} + \sqrt{\rho_{UL}} \sum_{\substack{i=1 \\ i \neq j}}^{L} \sum_{i=1}^{K_i} V_{jk}^{UL} h_{jk}^{j} s_{ji}^{UL} + n_j^{UL} \quad (3)$$

Then the desired signal becomes $\sqrt{\rho_{UL}}\, V_{jk}^{UL} h_{jk}^{j} s_{ji}^{UL}$ with intra-cell signals and inter-cell interference. The selection of combing vector modelling in terms of spectral efficiency is analyzed with the different combining schemes in the next section.

2.2. Downlink. As per the Massive MIMO illustration in Figure 2 for *dl* transmission, BS *j* transmits the signal in cell *l* that is written as:

$$x_l = \sum_{i=l}^{k_l} W_{lir_{li}} \quad (4)$$

Where $w_{lr} \in C^{M_l}$ is assigned as transmit precoding vector. Then the received signal $y_j^{DL} \epsilon\, \mathbb{C}$ is modelled as:

$$y_j^{DL} = \sqrt{\rho_{DL}} \sum_{l=1}^{L} \left(h_j^{DL}\right)^H xl + n_j^{DL} \quad (5)$$

The symbol vector is denoted as $x_l = [x_{l,1} x_{l,2} \cdots x_{l,k}]$ and n_j^{DL} is an additive receiver noise. The term $\sqrt{\rho_{DL}} > 0$ means the SNR of *DL*. Then y_j^{DL} can be written as:

$$y_j^{DL} = \sqrt{\rho_{DL}} \sum_{l=1}^{L} \sum_{i=1}^{K_l} \left(h_{jk}^{DL}\right)^H W_{lirli} + n_j^{DL} \quad (6)$$

$$y_j^{dl} = \sqrt{\rho_{DL}} \left(h_{jk}^{j}\right)^H w_{jkr_{jk}} + \sqrt{\rho_{DL}} \sum_{\substack{i=1 \\ i \neq k}}^{K_j} \left(h_{jk}^{j}\right)^H W_{jir_{ji}} + \sqrt{\rho_{DL}} \sum_{\substack{l=1 \\ l \neq j}}^{L} \sum_{i=1}^{K_l} \left(h_{jk}^{DL}\right)^H W_{lir_{li}} + n_j^{DL} \quad (7)$$

Then the desired signal becomes $\sqrt{\rho_{DL}} (h_{jk}^{j})^H w_{jkr_{jk}}$ for the *dl* with intra-cell signals and inter-cell interference. The selection of transmit precoding vectors in terms of spectral efficiency is analyzed with the different precoding schemes in the next section.

3. Methodology and Calculations

M-MMSE, S-MMSE, RZF, ZF, and MR combiner and precoder are used in our model for SE of UL and DL, respectively. The enhancement in ES for the given system and optimized modeling are the main aims of this article. We explored the methodology for the SE in MIMO systems in which, the SE is optimized by proposed estimators. The first comparison of different estimators is done by estimating the channel of MMSE, EW-MMSE, and LS. Although the LS and EW-MMSE are less complex in computing but the loss in SE incurred by these estimators is not ignorable as discussed in the section 4 whereas MMSE is preferred as it has the ability of better spectral efficiency other than complexity [11]. Different combing and precoding schemes are tested by proposed numerical equations for SE of UL and DL transmissions after the selection of MMSE channel estimation. The computational flow of our model is shown in Figure 3. The UL data and channel estimation are calculated in the first two steps. Step 3 and step 4 are the computation stage of

Table 4: Computational complexity per coherence block of different combining schemes.

Scheme	Reception multiplication	Computing combining vectors multiplication
Multicell MMSE	$\tau_{UL} M_j K_j$	$\sum_{l=1}^{L} \frac{\left(3M_j^2 + M_j\right)K_l}{2} + \frac{M_j^3 - M_j}{3} + M_j \tau_p \left(\tau_p - K_j\right)$
Single-cell MMSE	$\tau_{UL} M_j K_j$	$\frac{3M_j^2 K_j}{2} + \frac{M_j K_j}{2} + \frac{M_j^3 - M_j}{3}$
RZF	$\tau_{UL} M_j K_j$	$\frac{3K_j^2 M_j}{2} + \frac{3K_j M_j}{2} + \frac{K_j^3 - K_j}{3}$
ZF	$\tau_{UL} M_j K_j$	$\frac{3K_j^2 M_j}{2} + \frac{K_j M_j}{2} + \frac{K_j^3 - K_j}{3}$
MR	$\tau_{UL} M_j K_j$	—

Table 5: Simulation parameters.

Parameters	**M = 500**
$\mathbf{CP_1}[\boldsymbol{Watt}]$	15
$\boldsymbol{ETP}\,[\boldsymbol{Watt}]$	2
$\boldsymbol{\sigma^2}$ / $\boldsymbol{\beta_0^0}$	-3 dBm
$\boldsymbol{\mu}$	0.5

Table 6: Simulation Parameters.

Simulation parameter	Values.
Required bandwidth (B)	20 MHz
Coherence time (T_{Coh})	10 msec
Maximum distance/cell radius(r)	(200) Meters
Maximum antennas (M)	500
Channel attenuation (ω)	$10^{-3.5}$
UEs (K)	18
The effective SNR	−10 dB to 20 dB
Network layout	Square pattern
Receiver noise power	−94 dBm
Samples per coherence block	$\tau_{coh} = 200$

different combing and precoding schemes with the same vectors. In further, the average sum of SE per cell is optimized for UL and DL in step 5 while the data is still not over, then the computation is again computed. In this way the average sum of SE per cell is expended as per the following stages:

3.1. Channel Estimation. In dedicated UL, each cell transmits a pilot sequence for allowing the BSs to compute H_{jj} of their local channel H_{jj} while the sequence is mutually orthogonal. The channel estimation is based on random variables and the statistical distribution of variable are taken into account. The received signal correlates with the pilot sequence and MMSE estimate the channel vector $\hat{h}^j_{li}$, given as:

$$y^{tr}_{jk} = \hat{h}^j_{UL} + \sum_{l\neq j} \hat{h}^j_{ULi} + \frac{1}{\sqrt{\rho tr}} n_{jk} \tag{8}$$

$$\hat{h}^j_{ULi} = \sqrt{p_{ULi}} R^j_{ULi} \Psi^j_{ULi} Y^p_{jULi} \tag{9}$$

Where $Y^p_{jUL}$is the uplink pilot transmission and pilot sequence become:

$$\Psi^j_{ULi} = \left(\sum_{(v,i')\in p_{UL}} pvi' \tau_r R^j_{ULl'i'} + \sigma^2_{ULi} I_{M_j} \right)^{-1} \tag{10}$$

Where the Estimation error is $\hat{h}^j_{ULi} = h^j_{ULi} - \hat{h}^j_{ULi}$ has correlation matrix $C^j_{ULi} = \mathbb{E}\{\hat{h}^j_{ULi} (\hat{h}^j_{ULi})^H\}$ given as:

$$C^j_{ULi} = R^j_{ULi} - p_{ULi} R^j_{ULi} \Psi^j_{ULi} R^j_{ULi} \tag{11}$$

The MMSE is estimated by invoking the orthogonal property and the estimated error is statistical independent of $\hat{h}^j_{UL}$. As per the pilot communication phenomenon, UEs that have the same pilot sequence for the transmission can mutually pollute the channel estimation. Although channels are statistically independent but the interference reduces the estimation quality by increasing MSE and make the channel estimation statistically dependent. Above channel estimation can mitigate the interference of UEs that practice the same pilot. The massive MIMO systems have a huge influence rather than conventional networks due to large numbers of UEs having pilot sequences that can easily suppress the interference. Besides, the MMSE estimator minimizes the MSE of the channel estimate, given as:

$$\mathbb{E}\left\{\left\|h^j_{ULi} - \hat{h}^j_{ULi}\right\|^2\right\} = \mathbb{E}\left\{\left\|\hat{h}^j_{ULi}\right\|^2\right\} = \mathbb{E}\left\{\operatorname{tr}\left(\hat{h}^j_{ULi}\left(\hat{h}^j_{ULi}\right)^u\right)\right\} = \operatorname{tr}\left(C^j_{ULi}\right) \tag{12}$$

We are considered the cell j and cell l for the $UE\,k$ and ULi the interference, respectively, and the correlation matrix at BS j is:

$$\mathbb{E}\left\{\hat{h}_{jk}^{j}\left(\hat{h}_{ULi}^{j}\right)^{u}\right\} = \begin{cases} \sqrt{p_{ULi}p_{jk}}R_{jk}^{j}\Psi_{ULi}^{j}R_{ULi}^{j} & (UL,i) \in \mathcal{P}_{jk} \\ O_{M_j \times M_j} & (UL,i) \notin \mathcal{P}_{jk} \end{cases} \tag{13}$$

And the antenna correlation coefficient is written as:

$$\frac{\mathbb{E}\left\{\left(h_{ULi}^{j}\right)^{u}h_{ULi}^{j}\right\}}{\sqrt{\mathbb{E}\left\{\left\|h_{jk}^{j}\right\|^{2}\right\}\mathbb{E}\left\{\left\|h_{ULi}^{j}\right\|^{2}\right\}}} = \begin{cases} \dfrac{\operatorname{tr}\left(R_{ULi}^{j}R_{jk}^{j}\Psi_{ULi}^{j}\right)}{\sqrt{\operatorname{tr}\left(R_{jk}^{j}R_{jk}^{j}\Psi_{ULi}^{j}\right)\operatorname{tr}\left(R_{ULi}^{j}R_{ULi}^{j}\Psi_{ULi}^{j}\right)}} & (UL,i) \in \mathcal{P}_{jk} \\ 0 & (UL,i) \notin \mathcal{P}_{jk} \end{cases} \tag{14}$$

Whereas, $\mathbb{E}\{(h_{li}^{j})^{u}h_{li}^{j}\} = 0$ for all UEs with $(UL,i) \neq (j,k)$. The expression of non-zero expectation is carried out from the UL transmission section and taking into account all the considerations with $(UL,i) \in \mathcal{P}_{jk}$ while channel vector is $y_{jk}^{p} = y_{jULi}^{p}$, written as $\mathbb{E}\{y_{jULi}^{p}(y_{jULi}^{p})^{u}\} = \tau_{p}(\psi_{ULi}^{j})^{-1}$and the normalized MSE (NMSE) is written as:

$$\text{NMSE}_{UL}^{j} = \frac{\operatorname{tr}\left(C_{UL}^{j}\right)}{\operatorname{tr}\left(R_{UL}^{j}\right)} \tag{15}$$

This expression is used for the comparison of the estimation quality using different estimation schemes in different scenarios. The MMSE estimation provides enough statistical information for the UL data transmission that can help in decoding. This computation has required an inverse matrix of Ψ_{ULi}^{j} and makes the method very complex as attached large antennas with huge numbers of users [19]. This provokes us to solve for the simpler calculations and the estimation that is EW-MMSE. Lemma 1 is an EW-MMSE estimation with the statistics of the estimates. The assumption is made on the correlation matrix R_{ULIi}^{j} that depends on $A_{ULi}^{j}|_{mm}$ diagonal.

Lemma 1. *If base l uses an EW-MMSE estimation where the channel is estimated between users k in cell l. Although each element can be estimated by MMSE but the EW-MMSE estimates the vectors with error and vectors without error.*

$$A_{ULi}^{j}\Big|_{mm} = \frac{\sqrt{p_{ULi}}\left|R_{ULIi}^{j}\right|_{mm}}{\sum_{(l',i')\epsilon p_{li}} p_{UL'i'}\tau_{p}\left|R_{l'i'}^{j}\right|_{mm} + \sigma_{UL}^{2}} \quad m = 1, \cdots ..M \tag{16}$$

This is quite simpler in computational as compared to MMSE, except in the case of diagonal spatial correlation matrices where each channel element estimates it separately. It is notable that A_{ULi}^{j} reduces the complexity. The EW-MMSE is obtained as:

$$\text{MSE} = \operatorname{tr}\left(R_{ULi}^{j}\right) - \frac{\rho_{ULi\tau_{p}}\left(\left|R_{ULi}^{j}\right|_{mm}\right)^{2}}{\sum_{(UL',i')\epsilon p_{ULi}} p_{UL'i'}\tau_{p}\left|R_{UL'i'}^{j}\right|_{mm} + \sigma_{UL}^{2}} \tag{17}$$

In the case of noise-free calculation then the LS channel estimator is considered [20] as it is very simple and low complexity. The LS channel estimator is estimated in Lemma 2.

Lemma 2. *In our model y_{jULi}^{pi} having the desired channel $\sqrt{p_{ULi}}\tau_{pi}\hat{h}_{ULi}^{j}$ in cell l and $\hat{h}_{ULi}^{j}$is an LS estimator of h_{ULi}^{j}. MSE deviation is obtained as $\|y_{jULi}^{pi} - \sqrt{p_{ULi}}\tau_{pi}\hat{h}_{ULi}^{j}\|^{2}$, $\hat{h}_{ULi}^{j}$ is written as:*

$$\hat{h}_{li}^{j} = \frac{1}{\sqrt{p_{ULi}}\tau_{pi}} y_{jULi}^{pi} \tag{18}$$

The LS estimators become simple as discussed $\mathbf{A}_{ULi}^{j} = 1/\sqrt{p_{ULi}}\tau_{pi}\mathbf{I}_{M_j}$ and the complexity of the LS estimator is proportional to the Mj. As per equations called in Lemma 1 the MSE is written as:

$$\text{MSE} = \operatorname{tr}\left(\sum_{(UL\text{⚙},i\text{⚙})\epsilon\mathcal{P}i_{ULi}/UL,i} \frac{p_{UL\text{⚙}i\text{⚙}}}{p_{ULi}}\boldsymbol{R}_{UL\text{⚙}i\text{⚙}}^{j} + \frac{\sigma_{UL}^{2}}{p_{ULi}\tau_{pi}}\mathbf{I}_{M_j}\right) \tag{19}$$

3.2. Uplink Spectral Efficiency with the Combing Schemes of MMSE Estimator. In this part, we analyze the achievable SE of the UL based on the MMSE estimator with different receive combining schemes. As earlier discussed, a signal $y_{j}^{ul}\epsilon\mathbb{C}^{M}$ is received at $BSj$and the UL signal in cell l from UE k is S_{jk}^{ul}s having the power of $p_{ul,lk}$= $\mathbb{E}\{|s_{lk}^{ul}|^{2}\}$ and ρul >0, then the total UL capacity of UE k in cell j is written as:

$$\begin{aligned} \mathrm{V}_{jk}^{\mathrm{UL}}\mathrm{y}_{j} &= \mathrm{V}_{jk}^{\mathrm{UL}}\hat{h}_{jk}^{j}\mathrm{s}_{k} + \mathrm{V}_{jk}^{\mathrm{H}}\tilde{\mathrm{h}}_{jk}^{j}\mathrm{s}_{jk} \\ &+ \sum_{\substack{i=1 \\ i\neq k}}^{K_j} \mathrm{V}_{jk}^{\mathrm{H}}\mathrm{h}_{ji}^{j}\mathrm{s}_{jk} \sum_{\substack{l=1 \\ i\neq j}}^{L}\sum_{i=1}^{K_1}\mathrm{V}_{jk}^{\mathrm{UL}}\mathrm{h}_{Uli}^{j}\mathrm{s}_{li} + \mathrm{V}_{jk}^{\mathrm{UL}}\mathrm{n}_{j} \end{aligned} \tag{20}$$

$$\text{SE}_{jk}^{UL} = \frac{\tau_{ul}}{\tau_{coh}}\mathbb{E}\left\{\log_{2}\left(1 + \text{SINR}_{jk}^{\mathrm{L}}\right)\right\} \tag{21}$$

Where τ_{ul}/τ_{coh} is a pre-log factor is the ratio of UL data samples per coherence block.

Proposed algorithm
Step 1: According to Table 5, adjust the simulation parameters.
Step 2: Randomly drop UEs in each cell and compute UL sequence
Step 3: Generate random estimated channel vectors $\widehat{h}_{\mathrm{jk}}^{\mathrm{j}}(\widehat{h}_{\mathrm{ULi}}^{\mathrm{j}})^{\mathrm{u}}$
Step 4: Compute receive combining vectors $\mathbf{V}_{\mathrm{jk}}^{\mathrm{ULM}-MMSE} = [\mathrm{v}_{\mathrm{j1}} \cdots \mathrm{v}_{\mathrm{j}}\mathrm{k}_{\mathrm{j}}]$
Step 5: Compute DL sequence for precoding
Step 6: Compute precoding vectors $\mathbf{V}_{\mathrm{jk}}^{\mathrm{DLM}-MMSE} = [\mathrm{v}_{\mathrm{j1}} \cdots \mathrm{v}_{\mathrm{j}}\mathrm{k}_{\mathrm{j}}]$
Step 7: If MMSE algorithm = true
And resulting SINRUL as eq.(22) and eq. (27)
End
Step 8: Compute SE for
$\mathrm{SE}_{jk}^{UL} = (\tau_{ul}/\tau_{coh})\mathbb{E}\{\log_2(1+\mathrm{SINR}_{jk}^{\mathrm{L}})\}$ &
$\underline{\mathrm{SE}}_{\mathrm{jk}}^{\mathrm{DL}} = (\tau_{\mathrm{DL}}/\tau_{\mathrm{coh}})\log_2(1+\underline{\mathrm{SINR}}_{\mathrm{jk}}^{\mathrm{DL}})$ bit/Hz
Step 9: Plot of figures
SE for multi-cell combining & precoding schemes; M-MMSE, S-MMSE, RZF, ZF, MR

Algorithm 1: Sequence of Simulation.

Where the effective SNR becomes:

$$\mathrm{SINR}_{jk}^{\mathrm{UL}} = \frac{p_{jk}\left|\mathrm{v}_{jk}^{\mathrm{H}}\widehat{h}_{jk}^{j}\right|^2}{\sum_{l=1}^{L}\sum_{\substack{i=1 \\ (Ul,i)\neq(j,k)}}^{K_1} p_{Uli}\left|\mathrm{v}_{jk}^{\mathrm{H}}\widehat{h}_{jk}^{j}\right|^2 + \mathrm{v}_{jk}^{\mathrm{H}}\left(\sum_{l=1}^{L}\sum_{ULi=1}^{K_1} p_{ULi}\mathbf{C}_{ULi}^{j} + \sigma_{UL}^2\mathbf{I}_{M_j}\right)\mathrm{v}_{jk}} \tag{22}$$

As per $\mathrm{SINR}_{jk}^{\mathrm{UL}}$ used in (21) for UE k in cell j is optimized through multicell MMSE (M-MMSE) and M-MMSE combining vector for $k = 1, \cdots, K_j$ and $\mathbf{V}_{jk}^{\mathrm{ULM-MMSE}} = [\mathrm{v}_{j1} \cdots \mathrm{v}_j\mathrm{k}_j$] is given as:

$$\mathbf{V}_{jk}^{\mathrm{ULM}-MMSE} = \mathrm{tr} * p_{jk}\left[\sum_{l=1}^{L}\sum_{i=1}^{K_1} p_{Uli}\left(\widehat{h}_{Uli}^{j}\left(\widehat{h}_{Uli}^{j}\right)^{u} + \mathbf{C}_{Uli}^{j}\right) + \sigma_{UL}^2\mathbf{I}_{M_j}\right]^{-1}\widehat{h}_{jk}^{j} \tag{23}$$

Which further leads to

$$\mathrm{SINR}_{jk}^{\mathrm{ULM}-MMSE} = \mathrm{tr} * p_{jk}\left(\widehat{h}_{Uli}^{j}\right)^{u}\left[\sum_{l=1}^{L}\sum_{\substack{i=1 \\ (l,i)\neq(j,k)}}^{K_1} p_{Uli}\widehat{h}_{Uli}^{j}\left(\widehat{h}_{Uli}^{j}\right)^{u} + \sum_{l=1}^{L}\sum_{i=1}^{K_1} p_{Uli}\mathbf{C}_{Uli}^{j} + \sigma_{UL}^2\mathbf{I}_{M_j}\right]^{-1}\widehat{h}_{jk}^{j} \tag{24}$$

This is the case when estimated channels are known then it not only optimizes the SINR and also minimizes the MSE. The expression in (24) provides exact and optimize SINR for the massive MIMO systems. As discussed in the previous section, the reduction in complexity has to pay a reduction in SE and MMSE has superior SE. In this regard, the different combining schemes of the MMSE channel estimator proposed in the previous section are shown in Table 4 with Computing combining vectors Multiplication. SE analysis is discussed in section 4.

3.3. Downlink Spectral Efficiency. As related in (7), the DL signal received y_{jk}^{DL} in cell l is:

$$\begin{aligned} y_{jk}^{DL} = {} & \underbrace{E\left\{\sqrt{\rho_{DL}}\left(h_{jk}^{DL}\right)^{H}W_{jk}^{DL}\right\}r_{jk}^{DL}} \\ & + \underbrace{\sqrt{\rho_{DL}}\left(\left(h_{jk}^{DL}\right)^{H}W_{jk}^{DL} - E\left\{\left(h_{jk}^{DL}\right)^{H}W_{jk}^{DL}\right\}r_{jk}^{DL}\right)} \\ & + \underbrace{\sqrt{\rho_{DL}}\sum_{\substack{i=1 \\ i\neq k}}^{K_j}\left(h_{jk}^{DL}\right)^{H}W_{ji}^{DL}r_{ji}^{DL}} \\ & + \underbrace{\sqrt{\rho_{DL}}\sum_{\substack{l=1 \\ l\neq j}}^{L}\sum_{i=1}^{K_l}\left(h_{jk}^{l}\right)^{H}W_{DLi}r_{DLi}} + \underbrace{n_{jk}} \end{aligned} \tag{25}$$

Then the desired signal becomes $E\{\sqrt{\rho_{DL}}(h_{jk}^{DL})^{H}W_{jk}^{DL}\}$ r_{jk}^{DL} with average pre-coded channel $E\{(h_{jk}^{DL})^{H}W_{jk}^{DL}\}$ having the third and fourth term as intra-cell interference and inter-cell interference, respectively. The second term is also desired for the unknown channel. The Selection of transmit precoding vectors in terms of spectral efficiency is based on hardening bounding which can take any type of pro coding vector and channel estimation as well. The DL channel capacity in terms of the spectral efficiency of UE k in cell j as a lower bound is:

$$\underline{SE}_{jk}^{DL} = \frac{(\tau_{DL}/\tau_{coh})\log_2\left(1+\underline{SINR}_{jk}^{DL}\right)\mathrm{bit}}{\mathrm{Hz}} \tag{26}$$

Where τ_{DL}/τ_{coh} is a pre log factor ratio of samples of DL

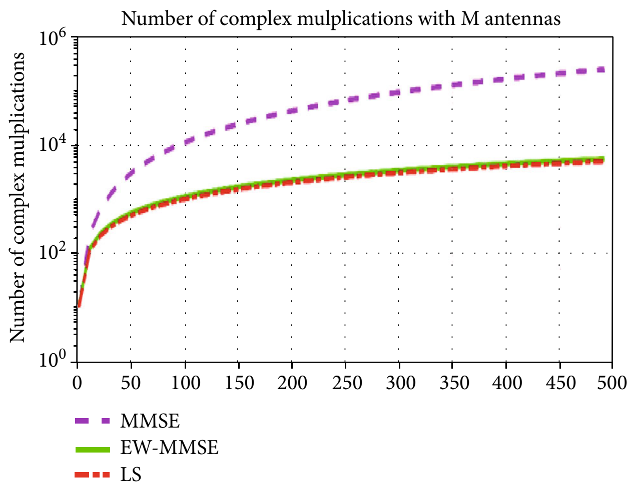

FIGURE 4: Results of number of complex multiplication vs number of antennas.

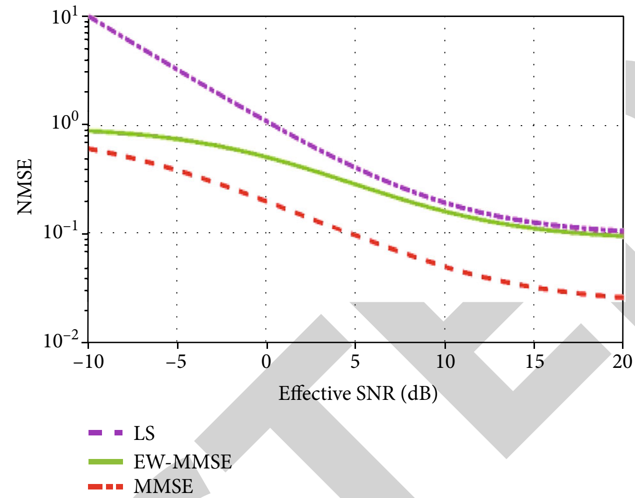

FIGURE 5: Results of MMSE vs number of antennas.

data and samples per coherent block and then $\underline{SINR}_{jk}^{DL}$ is:

$$\underline{SINR}_{jk}^{DL} = \frac{\rho_{jk}\left|E\left\{W_{jk}^{H}h_{jk}^{DL}\right\}\right|^{2}}{\sum_{l=1}^{L}\sum_{i=1}^{K_l}\rho_{DLi}E\left\{\left|W_{DLi}^{H}h_{jk}^{l}\right|^{2}\right\} - \rho_{jk}\left|E\left\{W_{jk}^{H}h_{jk}^{DL}\right\}\right|^{2} + \sigma_{DL}^{2}} \quad (27)$$

In (26), $\underline{SE}_{jk}^{DL}$ refers $\underline{SINR}_{jk}^{DL}$ as effective SINR of fading channel related to UE k in cell j. $\rho_{jk}|E\{W_{jk}^{H}h_{jk}^{DL}\}|^{2}$is the gain of the desired signal by the average precoded channel. ρ_{DLi} $E\{|W_{DLi}^{H}h_{jk}^{l}|^{2}\}$ is donated as the total power of all signals and $\rho_{jk}|E\{W_{jk}^{H}h_{jk}^{DL}\}|^{2}$is the power of the desired signal.

In previous work as done in [20, 21] the energy consumption models include only the radiated power whereas the power consumption of the radio frequency circuit was not included. These models revealed some improved results on Massive MIMO but all are based on theoretical analysis. For example, power allocation and time framing have been analyzed to optimize the EE in [21], and the tradeoff of SE-EE is studied in [20]. There is a need for system design in cellular systems of massive MIMO where EE performance should be reviewed using practical measurements. For an instant, in [22], the authors presented the practical power consumption model by considering the number of antennas, UE_s and power consumption models for optimizing the EE where uplink and downlink of multiuser massive MIMO networks are considered. In our work, we considered some systems parameters including the numbers of antenna estimation, assessment of maximum users, and modelled the practical effective transmit power and circuit power as shown in Table 5.

The SE expression in (26) is computed for precoding based on the MMSE channel estimation computed in the previous section. If $W_{jk} = \widehat{h}_{jk}^{DL}/\sqrt{E\{t||\widehat{h}_{jk}^{DL}||^{2}\}}$ then $\underline{SINR}_{jk}^{DL}$ for MR precoding based on MMSE channel estimation is:

$$\underline{SINR}_{jk}^{DL} = \frac{\rho_{jk}^{DL}tr\left(R_{jk}^{DL}\Psi_{jk}^{DL}R_{jk}^{jDL}\right)p_{jk}^{DL}}{\underbrace{\sum_{l=1}^{L}\sum_{i=1}^{K_l}\left(\rho_{DLi}tr\left(R_{lk}^{l}\Psi_{lk}^{l}R_{lk}^{l}\right)/tr\left(R_{lk}^{l}\Psi_{lk}^{l}R_{lk}^{l}\right)\right)} + \underbrace{\sum_{(l,i)\epsilon p_{jk}\setminus(j,k)}\left(\rho_{DLi}p_{jk}\tau_{p}\left(R_{jk}^{l}\Psi_{lk}^{l}R_{lk}^{l}\right)/tr\left(R_{lk}^{l}\Psi_{lk}^{l}R_{lk}^{l}\right)\right)} + \sigma_{DL}^{2}} \quad (28)$$

Where $\Psi_{jk}^{DL}\Psi_{li}^{DL}$ define in (9) and (10) for UL as similar is here. In the denominator, the first term is non-coherent interference and the second term is coherent interference having spatially uncorrelated factor $R_{li}^{j} = \beta_{li}^{j}I_{M_j}$. The SE of DL is analyzed in the next section by taking the same combing vectors $\mathbf{V}_{jk}^{\mathrm{ULM-MMSE}} = [\mathrm{v}_{j1} \cdots \mathrm{v}_{j}\mathrm{k}_{j}]$ in precoding schemes based on MMSE channel are:

4. Results and Discussion

In this section, SE expression for UL and DL evaluated in previous sections are simulated and validated in a proposed scenario for the massive MIMO cellular network. The calculation of SE with M-MMSE, S-MMSE, RZF, ZF, MR combining and precoding schemes by taking M number of antennas having simulation parameters of Table 6.

The spectral efficiency of UL and DL for BS and UEs according to listed parameters in Table 6 is simulated as

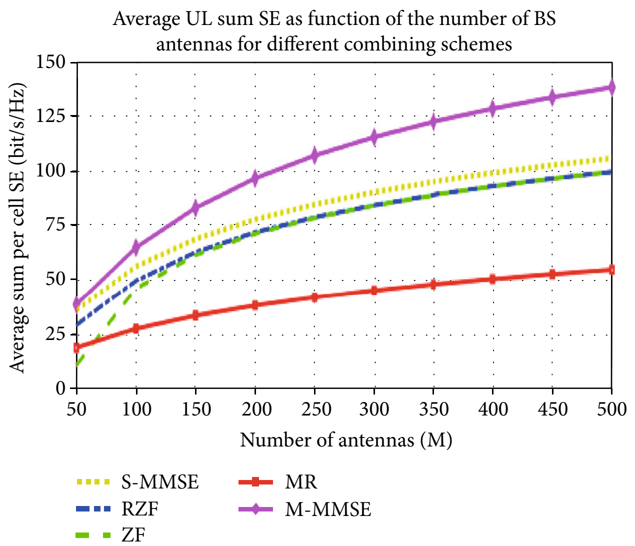

Figure 6: Desired Spectral Efficiency: Interference from other cell and noise added to the signal during UL Transmission.

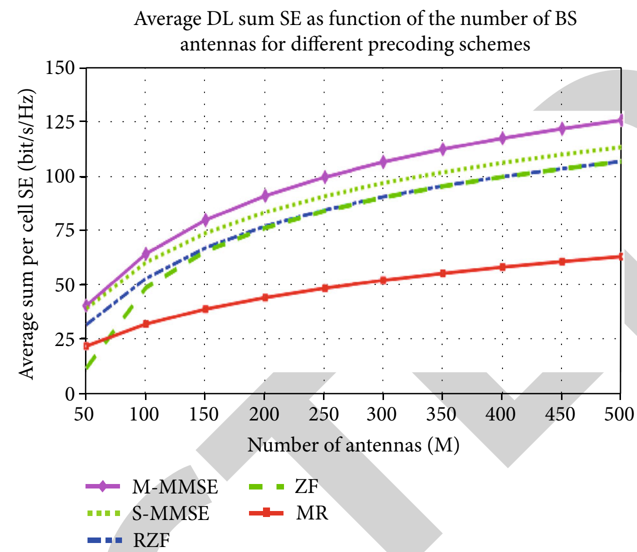

Figure 7: Desired Spectral Efficiency: Interference from other cell and noise added to the signal during DL transmission.

$$\mathbf{V}_{jk}^{\mathrm{DLM}-MMSE} = \left[\mathrm{v}_{j1} \cdots \mathrm{v}_j \mathrm{k}_j\right] = \begin{cases} V_{JK}^{M-MMSE} \; of\, M - MMSE\, precoding \\ V_{JK}^{S-MMSE} & of\, S - MMSE\, precoding \\ V_{jk}^{RZF} & of\, RZF precoding \\ V_{JK}^{ZF} & of\, ZF precoding \\ V_{JK}^{MR} & of\, MR\, precoding \end{cases} \quad (29)$$

per table sequence. Simulations are based on Figure 1, Tables 6 and Algorithm 1 and the optimized result is discussed in section 4.

4.1. Channel Estimators Comparison. The full potential of massive MIMO systems cannot be achieved without the selection of the best suitable channel estimation at the time of UL pilot transmission. As per the proposed scenario BS j estimates the channel of UE k and another cell transmits the same pilot signal. The effective SNR as per Table 5 is taken as it varied from −10 dB to 20 dB. In Figures 4–5, the results of the number of complex multiplication and MMSE vs number of antennas in the multi-cell scenario with MMSE, EW-MMSE, and LS channel estimators are shown. These estimators are numerically computed in section A of the methodology segment while Lemma 1 and Lemma 2 are considered for the EW-MMSE and LS, respectively. As mentioned in [11] that the MMSE channel estimator has superior SE as compared to other estimators having greater complexity in the computation. The statistical characteristics obtained from the MMSE estimator are fine as the Minimum means square error decreases gradually with the increment in effective SNR as result shown in Figure 5. This is tested in our models of channel estimation and found the same patron as termed in [11]. Meanwhile, our model is based on SE and required minimum MMMSE other than the complexity. In this regard, the result publicized in Figure 5 also depicts that we can able to compute better SE for our model while ignoring the result of Figure 4 as the MMSE estimator is complex.

4.2. Results for SE of UL Combining Schemes. The results of SE with different combining schemes are shown in Figure 6. The proposed model has better improvement in SE as compared to previous work done in [19]. The SE of a system is gradually increased with the number of antennas and cells as Figure 6 demonstrates that multicell MMSE (M-MMSE) has greater SE than single-cell MMSE(S-MMSE) having increment in SE by increasing of antennas. As literature highlights that the SE of UL massive MIMO systems has great intention in channel estimation instead of combing schemes. Meanwhile, the results of our proposed model are simply compared with the MMSE combining scheme of [23] after comprehensive numerical computation of channel estimation. The summary of improvement in SE with previous work is given in Table where our proposed MMSE estimator for multicell M-MMSE has great augmentation in SE compared to given combing schemes and M-MMSE given in [23] as well.

Table 7: Comparison: Results in Figure 4 & past works.

Precoding Schemes	Results [24]		Results [25]		Results [26]		Results (proposed model)	
	EE Bit/Hz Per cell	M	EE Bit/Hz Per cell	M	EE Bit/Hz Per cell	M	EE Bit/Hz Per cell	M
M-MMSE	105	500	110	500	—	128	125	500
S-MMSE	—	500	—	500	—	128	110	500
RZF	—	500	108	500	110	128	105	500
RF	103	500	—	500	110	128	105	500
MR	58	500	45	500	85	128	65	500

Table 8: Comparison: Results in Figure 3 & past works.

Combining schemes	Results (proposed model)		Results [23]	
	EE Bit/Hz per cell	M	EE Bit/Hz per cell	M
M-MMSE	140	500	33	100
S-MMSE	105	500	—	—
RZF	90	500	—	—
RF	90	500	—	—
MR	52	500	—	—

4.3. Results for SE of DL Precoding Schemes. Figure 7 illustrates the achievable average sum of SE per cell against the proposed massive MIMO system for five precoding schemes. As per K user and effective SNR is given in Table 5, the average SE per cell increases as the number of antennas grows. It indorses the dramatic benefits of implantation in large-scale antennas in BS. We also observed that at the same configuration, the desired average SE rate with MMSE precoding is approximately doubled with the MR scheme. The comparison of past work in Table 7 also shows that the MMSE precoding scheme is always better than other schemes and ultimately a top choice for a massive MIMO system.

To evaluate the performance (as per Figure 7) of our proposed massive MIMO system precoder over the rest of the schemes, the simulation result of M_MMSE matched with from [24, 25], RZF with from [25, 26], RF with from [20, 22], and MR with from [20–27] are provided in Table 8. The numerical expression and simulation results show the achievable average sum of SE per cell is increased as compared to past work done [24–26] after considering the proposed numerical expression.

The computed results of the proposed models are appropriate to endorse that the massive MIMO systems can enhance SE in a 5G cellular network. The proposed model is applicable for both UL and DL communication while the UL SE with the MMSE estimator is compared with EW-MMSE and LS. In the end, the maximum-ratio (MR) precoding scheme is modelled for the augmentation of DL SE whereas the latest work presented in the [22] has not considered the mentioned points. As mentioned, the SE of a system is gradually increasing with the number of antennas and cells. It demonstrates that the multicell MMSE (M-MMSE) has greater SE than single-cell MMSE(S-MMSE) having an increment in SE with the increasing number of antennas. The results presented in [19] are tested only for M-MMSE where we analyzed and tested for different combining schemes like M-MMSE, S-MMSE, RZF, RF, and MR. On the other hand, we considered 500 antennas although it increases the power consumption but high numbers of M have comparatively high EE as shown in Table 7. As there is a need to design a massive MIMO system where EE performance should be reviewed using practical measurements. In the work presented in [24–26], energy consumption models include only radiated power whereas the power consumption of radio frequency circuits is not included. In our previous work [28], the power consumption modelling for the massive MIMO systems has been demonstrated. We have considered and extended our previous work [28] by modelling the numbers of antenna estimation, assessment of maximum users and the practical effective transmit power and circuit power.

5. Conclusion

In this work, we have augmented an optimal SE per cell in the proposed massive MIMO system and computed MMSE channel estimation with their different combining and precoding schemes. As a first step, we have figured out a multi-cell scenario and computed the expressions for uplink and downlink transmission and then recommended a realistic, efficient and applicable model. We have computed an MMSE channel estimator instead of EW-MMSE and LS that can enhance the achievable average sum of SE per cell based on the above-mentioned schemes. The simulation results have revealed remarkable implications.

The research was fundamentally originated upon MMSE channel estimation after examining EW-MMSE and LS estimators, where MMSE found the more complex but exceptionally improved estimator to enhance the SE per cell. The results of MMSE combining and precoding schemes are produced by monte Carlo simulations in MATLAB. Although the MMSE was the optimum channel estimator among all, it is also observed that MR was less complex at all. In this regard, the complex computations of MMSE are taken into account because the variance in results is relatively small and the improvement in SE is big. M-MMSE, S-MMSE, RZF, ZF, MR combing and precoding schemes for UL and DL are tested with the proposed numerical expressions by taking the same vectors where M-MMSE has found the best option to deal with SE. The results with MR precoding are not much good but it can operate under intercell interference with less complexity in the computation of channel estimation. The conclusions of this work specify that the massive MIMO system can develop by optimizing channel estimation for the augmentation of SE in UL and DL transmissions. We can recapitulate that some complex computations of MMSE channel estimators can augment the average sum of SE per cell as results shown in our model.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare no conflict of interest.

Authors' Contributions

Rao Muhammad Asif, Mustafa Shakir, Ateeq Ur Rehman contributed to actualization, validation, methodology, formal analysis, investigation, software, and initial draft. Muhammad Shafiq, Rehan Ali Khan, Wali Ullah Khan contributed to actualization, validation, methodology, formal analysis, investigation, and initial draft. All authors read and approved the final version.

References

[1] Y. Liu, C. Wang, J. Huang, J. Sun, and W. Zhang, "Novel 3-D nonstationary MmWave massive MIMO Channel models for 5G high-speed train wireless communications," *IEEE Transactions on Vehicular Technology*, vol. 68, no. 3, pp. 2077–2086, 2019.

[2] A. U. Rehman, J. Aimin, A. Rehman, and A. Paul, "Weighted Based Trustworthiness Ranking in Social Internet of Things by using Soft Set Theory," in *IEEE 5th International Conference on Computer and Communications (ICCC)*, pp. 1644–1648, Chengdu, China, 2019.

[3] R. M. Asif, J. Arshad, M. Shakir, S. M. Noman, and A. U. Rehman, "Energy Efficiency Augmentation in Massive MIMO Systems through Linear Precoding Schemes and Power Consumption Modeling," *Wireless Communications and Mobile Computing*, vol. 2020, 13 pages, 2020.

[4] R. Chataut, R. Akl, and U. K. Dey, "Least Square Regressor Selection Based Detection for Uplink 5G Massive MIMO Systems," in *IEEE 20th wireless and microwave technology conference (WAMICON)*, pp. 1–6, Cocoa Beach, FL, USA, 2019.

[5] B. Kang, J. H. Yoon, and J. Park, "Low-complexity massive MIMO detectors based on Richardson method," *ETRI Journal*, vol. 39, no. 3, pp. 326–335, 2017.

[6] A. U. Rehman, R. A. Naqvi, A. Rehman, and A. Paul, "Muhammad Tariq Sadiq, Dildar Hussain A Trustworthy SIoT Aware Mechanism as an Enabler for Citizen Services in Smart Cities," *Electronics*, vol. 9, no. 6, p. 918, 2020.

[7] E. Björnson, J. Hoydis, and L. Sanguinetti, "Massive MIMO has unlimited capacity," *IEEE Transactions on Wireless Communications*, vol. 17, no. 1, pp. 574–590, 2018.

[8] J. Singh and D. Kedia, "Spectral efficient precoding Design for Multi-cell Large MU-MIMO system," *IETE Journal of Research*, pp. 1–16, 2020.

[9] J. Arshad, A. Rehman, A. U. Rehman, R. Ullah, and S. O. Hwang, "Spectral efficiency augmentation in uplink massive MIMO systems by increasing transmit power and uniform linear array gain," *Sensors*, vol. 20, no. 17, p. 4982, 2020.

[10] H. Yang and T. L. Marzetta, "Performance of conjugate and zero-forcing beamforming in large-scale antenna systems," *IEEE Journal on Selected Areas in Communications*, vol. 31, no. 2, pp. 172–179, 2013.

[11] S. Hassan, N. Tariq, R. A. Naqvi, A. U. Rehman, and M. K. A. Kaabar, "Performance Evaluation of Machine Learning-Based Channel Equalization Techniques: New Trends and Challenges," *Journal of Sensors*, vol. 2022, 14 pages, 2022.

[12] A. Thakur and R. C. Mishra, "Performance Analysis of Energy-Efficient Multi-Cell Massive MIMO System," in *10th International Conference on Computing, Communication and Networking Technologies (ICCCNT)*, Kanpur, India, 2019.

[13] S. Al-Mogren, "Energy Adaptive Approach In a Multi-Channel Dissemination-Based Network," in *New Technologies, Mobility and Security*, pp. 1–6, Tangier, Morocco, 2008.

[14] R. Mubashar, M. A. B. Siddique, A. U. Rehman, A. Asad, and A. Rasool, "Comparative performance analysis of short-range wireless protocols for wireless personal area network," *Iran Journal of Computer Science*, vol. 4, no. 3, pp. 201–210, 2021.

[15] H. B. Almelah and K. A. Hamdi, "Spectral efficiency of distributed large-scale MIMO systems with ZF receivers," *IEEE Transactions on Vehicular Technology*, vol. 66, no. 6, pp. 4834–4844, 2017.

[16] A. Ahmed, Q. Z. Ahmed, A. Almogren, S. K. Haider, and A. U. Rehman, "Hybrid precoding aided fast frequency-hopping for millimeter-wave Communication," *Access*, vol. 9, pp. 149596–149608, 2021.

[17] Y. Wang, G. Zhu, M. Li et al., "Water pollutants p-cresol detection based on au-ZnO nanoparticles modified tapered optical fiber," *IEEE Transactions on Nanobioscience*, vol. 20, no. 3, pp. 377–384, 2021.

[18] A. G. Leal-Junior, A. Frizera, C. Marques et al., "Polymer optical fiber for angle and torque measurements of a series elastic actuator's spring," *Journal of Lightwave Technology*, vol. 36, no. 9, pp. 1698–1705, 2018.

[19] V. Chien, C. M. Trinh, and E. Björnson, "Large-scale-fading decoding in cellular massive MIMO systems with spatially correlated channels," *IEEE Transactions on Communications*, vol. 67, no. 4, pp. 2746–2762, 2019.

[20] H. Q. Ngo, E. Larsson, and T. Marzetta, "Energy and spectral efficiencyof very large multiuser MIMO systems," *IEEE Transactions on Communications*, vol. 61, no. 4, pp. 1436–1449, 2013.

[21] X. Chen, X. Wang, and X. Chen, "Energy-Efficient optimization for wireless information and power transfer in large-scale MIMO systems employing energy beamforming," *IEEE Wireless Communications Letters*, vol. 2, no. 6, pp. 667–670, 2013.

[22] Y. Xin, D. Wang, J. Li, H. Zhu, J. Wang, and X. You, "Area spectral efficiency and area energy efficiency of massive MIMO cellular systems," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 5, pp. 3243–3254, 2016.

[23] W. Tan, W. Huang, X. Yang, Z. Shi, W. Liu, and L. Fan, "Multiuser precoding scheme and achievable rate analysis for massive MIMO system," *EURASIP Journal on Wireless Communications and Networking*, vol. 2018, no. 1, 2018.

[24] X. Li, E. Bjornson, E. G. Larsson, S. Zhou, and J. Wang, "A Multi-Cell MMSE Detector for Massive MIMO Systems and New Large System Analysis," in *IEEE global communications conference (GLOBECOM*, pp. 1–6, San Diego, CA, USA, 2015.

[25] H. V. Nguyen, V.-D. Nguyen, S. K. Sharma, S. Chatzinotas, B. Ottersten, and O.-S. Shin, "On the spectral and energy efficiencies of full-duplex cell-free massive MIMO," *IEEE Journal on Selected Areas in Communications*, vol. 38, no. 8, pp. 1698–1718, 2020.

[26] A. Riadi, M. Boulouird, and M. M.'. R. Hassani, "Least Squares Channel Estimation of an OFDM Massive MIMO System for 5G Wireless Communications," in *International conference on the Sciences of Electronics, Technologies of Information and Telecommunications*, Genoa, Italy and Hammamet, Tunisia, 2018.

[27] O. Ozdogan, E. Bjornson, and E. G. Larsson, "Uplink spectral efficiency of massive MIMO with spatially correlated Rician fading," in *IEEE 19th International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)*, Kalamata, Greece, 2018.

[28] R. M. Asif, M. Shakir, J. Nebhen, A. U. Rehman, M. Shafiq, and J. G. Choi, "Energy efficiency trade-off with spectral efficiency in MIMO systems," *CMC-COMPUTERS MATERIALS & CONTINUA*, vol. 70, no. 3, pp. 5889–5905, 2022.