Comparative Analysis of Procedures and Solutions to Improve Energy Efficiency of Massive MIMO

Ritu Singh Phogat, and Rutvij Joshi

Abstract—The blustery growth of high data rate applications leads to more energy consumption in wireless networks to satisfy service quality. Therefore, energy-efficient communications have been paid more attention to limited energy resources and environmentally friendly transmission functioning. Countless publications are present in this domain which focuses on intensifying network energy efficiency for uplink-downlink transmission. It is done either by using linear precoding schemes, by amending the number of antennas per BS, by power control problem formulation, antenna selection schemes, level of hardware impairments, and by considering cell-free (CF) Massive-MIMO. After reviewing these techniques, still there are many barriers to implement them practically. The strategies mentioned in this review show the performance of EE under the schemes as raised above. The chief contribution of this work is the comparative study of how Massive MIMO EE performs under the background of different methods and architectures and the solutions to few problem formulations that affect the EE of network systems. This study will help choose the best criteria to improve EE of Massive MIMO while formulating a newer edition of testing standards. This survey provides the base for interested readers in energy efficient Massive MIMO.

Keywords—EE; Uplink-Downlink Transmission; Power Control; Linear Precoding; CF Massive MIMO

I. INTRODUCTION

THE potential to interface with individuals moving had matured remarkably since 1897, when Guglielmo Marconi first revealed radio's facility to deliver persistent contact with ships cruising the English Channel. Thenceforth, advanced wireless communication services and their methods have been vigorously embraced by people worldwide. Particularly in the past ten years, mobile communication industry has been heightened in magnitude, charged by digital and RF circuit fabrication improvements and other shrinked technologies, making portable radio equipment nanoscopic, economical, and more authentic. If we look back roughly ten years when LTE got deployed for the first time, we had few tens of megabits of capacity distributed amongst all the users in the sector.

Today, with MU-MIMO, we have the capability of reusing that same spectrum with beams to multiple users so rather than sharing networking speeds and several gigabits per second to each of those users.

"The demand for higher data rates and traffic volumes seems never-ending; thus, the quest for delivering the required
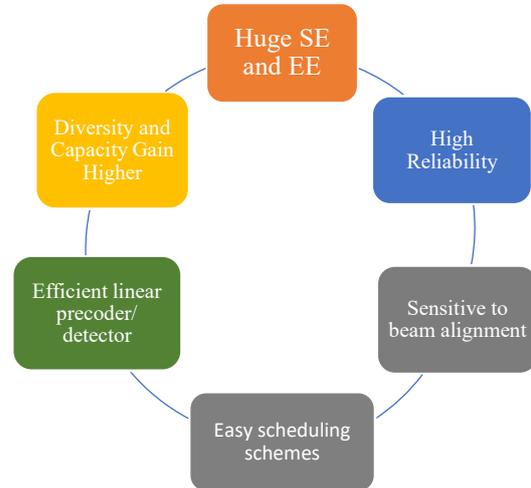

Fig. 1. Features of Massive MIMO

services must also continue. The cellular network technology has evolved from using fixed sector antennas to flexible multiple antenna solutions". With the lively evolution of electronic devices and computer science, numerous transpire applications (viz. simulated 3-D environment, mixed reality and computer mediated reality, massive data analytics, artificial intelligence, UHD transmission video) have set foot in our society and fabricated remarkable exceptional development in the data volume of wireless networks. For the time being, mobile networks have become requisite to our community as a critical service for personal computing devices. Massive MIMO (multiple-input multiple-output) has been recognized as a vital technology to steer orders of magnitude more data traffic. Hundreds of antennas serve tons of UEs simultaneously. Figure.1 shows few massive MIMO features. During every cellular generation, various power usage and factors were made available to have a more efficient system. The user traffic increased in every generation and will increase due to more demand for data in the domain, as shown in Fig.2. The system is said to be absolute if it is enough efficient to provide unmitigated services to users. For massive MIMO system to work in this manner it should be spectrally and energy efficient. There are various factors on which the efficiency depends on and any refashion of these parameters will result in overall system performance. This article focuses on EE of massive MIMO which rely on data throughput and power depletion of system.

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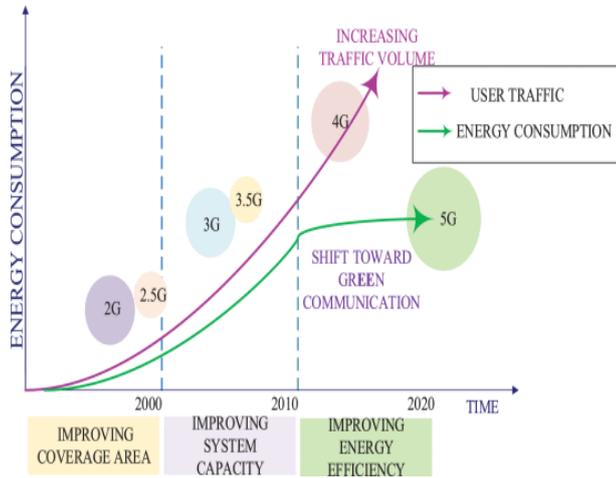Rutvij Joshi is with Parul University, Vadodara, India (e-mail: rutvij.joshi19624@paruluniversity.ac.in).

Fig. 2. Shift towards green communication [4]

A. Modelling Data throughput and Energy Consumption [1]

According to a survey, mobile operators are top energy consumers and are growing fast. BS absorbs a enormous part of the energy, so not just operators but also from the consumer's perspective, obtaining energy efficiency has noteworthy economic advantages. Deciding the adequate energy efficiency metric is of prime importance before analysing a power optimized network.

Energy Efficiency : "Energy Efficiency of a cellular network is the number of bits transmitted per unit of energy." But all imparted data is not factual information, thus, not be covered in throughput. Two viewpoints for EE consideration are as below: [3]

• Network EE: The amount of information bits that are transmitted or received by users per unit of energy consumed by RAN in bit/joule.

• Device EE: The amount of information bits per unit of energy consumption of the communication module in bit/Joule.
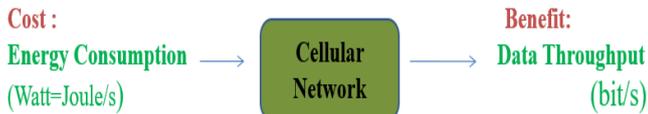
According to the above definition, EE is:

$$EE = \frac{Throughput[\frac{bit}{s}{cell}]}{Power\ Consumption[W/cell]} \qquad (1)$$

EE is counted in bit/Joule and visualized as a benefit-cost Ratio comparing the quality of ser-vice(throughput) with associated costs (power absorption) is done.
Average uplink sum rate per cell:
Data Throughput $= K\,(1 - \tau K/U)\,B log_2(1 + SINR)$
K is multiplexed active users, (1-τk/U) is data fraction per frame used for pilots, and the last term is data rate per user. SINR depends on different parameters and can be derived in different ways for different setups.

$$SINR = \frac{M}{\left(K+\frac{BN_0}{\rho}\right)\left(1+\frac{2}{\tau(\alpha-2)}+\frac{BN_0}{\rho}\right)+\frac{2K}{\alpha-2}\left(1+\frac{BN_0}{\rho}\right)+\frac{K}{\tau}\left(\frac{4}{(\alpha-2)^2}+\frac{1}{\alpha-1}\right)+\frac{M}{\tau(\alpha-1)}} \qquad (2)$$

where M: number of BS antennas, α: path-loss component.

Energy Consumption strongly depends on the hardware of the system. Below mentioned model is very general, and it depends on the number of variables μ, $C_{0,0}$, $C_{1,0}$, $C_{0,1}$, $C_{1,1}$, A.

Energy Consumption =

$$K\frac{\rho\omega\Gamma}{\mu}\frac{\left(\frac{\alpha}{2}-1\right)}{(\pi\lambda)^{\frac{\alpha}{2}}}\left(1-\frac{\tau K-1}{U}\right) + C_{0,0} + C_{0,1}M + C_{1,0}K \\ + C_{1,1}MK + A.DataThroughput \qquad (3)$$

where,
μ is linear power amplifier efficiency; the complete first term is transmitted power with amplifier efficiency, $C_{0,0}$ is fixed circuit power, $C_{0,1}M+C_{1,0}K$ models power per transceiver chain, $C_{1,1}MK$ models for power consumed by signal processing task at BS except for coding/decoding/backhaul, modelled by last term throughput. This modelling is characterized by μ, $C_{0,0}$, $C_{0,1}$, $C_{1,1}$, A, which changes over time, and the model remains fixed.

This paper contains sections such as Section II describing different solutions to design the energy-efficient networks, summarizing diverse techniques to improve EE of Massive MIMO, and some misconceptions regarding Massive MIMO in literature. Section III and IV describe system models and compare the numerical results of different precoding schemes and outcomes of different architectures to design energy efficient massive MIMO. Finally, section V presents some concluding remarks.

II. HOW TO DESIGN ENERGY EFFICIENT NETWORKS?

As shown in "(1)", to increase this ratio, one possible solution is increasing the throughput and decreasing power consumption. Another one is to let the data decay, but the energy wears faster than the ratio. The last one enables the data to grow, along with the energy, but not at the same pace. The last one is the most viable solution for the future network. With this option definitely, there will be more energy consumption but also a more energy-efficient system.
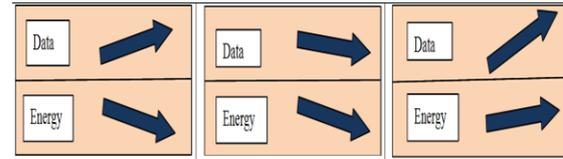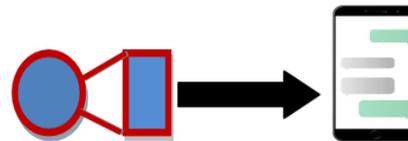

Fig. 3. Trade-off between data throughput and Energy efficiency

A. Power Control

Power Control includes controlling the transmit power.
Point to point transmission from UE to BS end appeared as:

$$\frac{Data\ Throughput}{Energy\ Consumption} = \frac{B\log_2(1+\frac{P_{tx}\beta}{BN_0})}{\frac{P_{tx}}{\mu} + P_{circuit}} \qquad (4)$$

Data throughput includes B bandwidth in product with spectral efficiency. Here P_{tx} is the transmit power, βis path-

loss, BN0 is noise power spectral density. The energy consumption part includes two parts: transmit power and circuit power. μ is amplifier efficiency, P$_{circuit}$ is circuit power that takes care of all types of analog and digital circuits and radio and basement processing. Here transmits power is divided by amplifier efficiency. Because power amplifiers can be very inefficient if power gets transmitted at a certain rate, then probabilities can be four times more power consumption. The below fig.4 shows the general behaviour of energy efficiency when transmit power is changed.
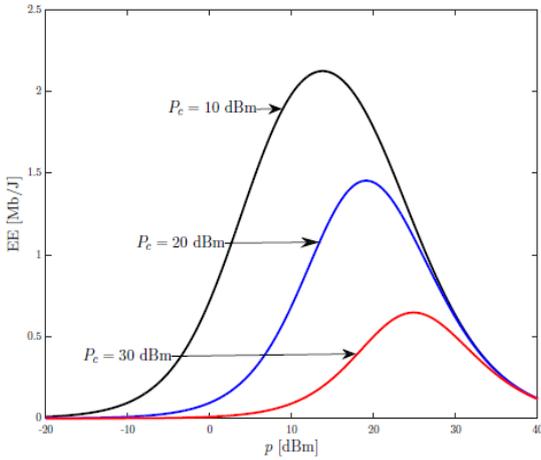

Fig. 4. Energy efficiency changes with transmit power [4]

The transmit power is low, energy efficiency increases upto a certain point, and decreases (unimodal function). As the radiated power increases, the EE drops, and the amount of power used to be maximally energy efficient also grows. So, if the circuit power is significant, it can be afforded by paying more for higher transmit power, which will still be a better option and more efficient. Eventually, they all go down because of log function of transmit power grows logarithmically, and the power term grows linearly.

B. Smaller Cells

Depending on the position of UEs from BS, the data rate varies a lot because of pathloss. So, if the distance between UE and BS gets reduced, the signal can be transmitted with much less power and lower loss. Below fig.5 shows that the data rate declines as the distance increases or the user moves far from BS.
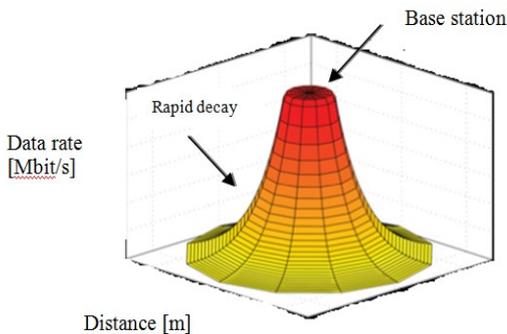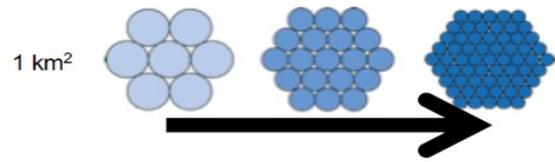
In practical implementation, the decay will be much faster. But since there is a trade off between transmit power and circuit power, using a denser network reduces transmit power. Still, circuit power consumption will grow because hardware implementation increases as in each km, more cells require the deployment of more hardware.

C. Massive MIMO (Multiple Input Multiple Output) [5]

Here the objective is to guide the signals from BS towards the UEs, focussing on where the user is present. So the system of today includes a wide beam from antenna panels covering specific sectors. But if there are massive antennas, the signals can be directed narrowly towards the UE without the need of sector anymore and massive quantity of users can be served, at once. By leading the signal, higher received power can be achieved, corresponding to the units of antennas. It means ten times more antenna means ten times higher received signal power. So, more antennas will reduce the transmit power along with multiplexing several users.
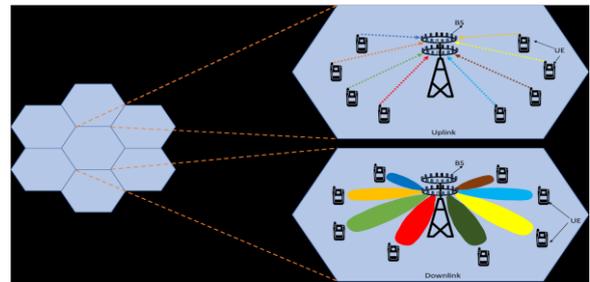

Fig. 6. Massive MIMO uplink and downlink

Uplink Transmission

In uplink channel, information and the pilot signals are tranmitted from the client terminal to the basestation. Allow us to consider a massive MIMO uplink framework that is outfitted with M antennas in the base station and at the same time communicates with individual antenna users N (M>>N). On the off chance that the signal communicated by the client or the deterministic pilot signal to approximate the channel is x∈C^N, the signal got at the BS during uplink transmission is modeled as [5]:

$$y = Hx + n_{uplink}$$

where $y \epsilon \mathbb{C}^M$: signal received at the BS, H: channel vector in the middle of the client terminal and the base station, and elements of $H \in \mathbb{C}^{M \times N}$, do not rely and are identically distributed with zero mean and unit variance,i.e., $H \sim \mathcal{CN}(0,1)$. $nuplink \ \epsilon \mathbb{C}^M$, is summation of intrusion from several transmissions and the receiver sound. The intrusion adjoined does not rely on the user signal x, but it can rely on the channel H.

$$n_{uplink} = n_{uplink} - interference + n_{noise}$$

Downlink Transmission

In downlink channel data is transmitted from base station to user end. The base station makes use of training pilots to estimate the channel—a downlink transmission with multiple UEs and a BS. Let's consider a downlink massive MIMO

system, where the BS is provided with M antennas, and it serves N users who have one antenna at the same time. The base station send on independent information to multiple users at once. The received signal, $y_k \in \mathbb{C}^{M \times 1}$ at the kth user is given as [5]:

$$y_k = h_k x_k + n_{downlink}$$

where h_k: channel vector between kth user and BS, of which elements are independent and identically distributed with zero mean and unit variance, i.e. $h \sim \mathcal{CN}(0,1)$. $x_k \in \mathbb{C}^M$: signal transmitted by a BS for kth user, $n_{downlink}$: additional noise that is framed with the receiver noise $n_{noise} \sim \mathcal{CN}(0, \sigma^2 I)$ and the interference during downlink ($n_{downlink-interference}$) due to transmitting at once to other clients and is given as:

$$n_{downlink} = n_{downlink-interfernce} + n_{noise}$$

To design an energy-efficient future cellular network, we can densify the network to a few hundred meters between BS (this will make the transmit power negligible of the total consumed power of the system). Now, the circuit power matters. Massive MIMO can be deployed, which will suppress the interference spatially so the SNR for users can be improved without causing interference to other cells. Since the users are multiplexed, the circuit power can be shared between them, making the system more energy efficient. This setup can be used for both uplink and downlink.

Optimal Solution: Combination of small cells and Massive MIMO

Massive MIMO is promising technology that can be commonly used for wireless Base stations. However, it has been surrounded by various misunderstandings.

"The Massive MIMO technology uses a nearly infinite number of high-quality antennas at the base stations. By having at least an order of magnitude more antennas than active terminals, one can exploit asymptotic behaviors that some special kinds of wireless channels have. This technology looks great at first sight, but unfortunately, the signal processing complexity is off the charts, and the antenna arrays would be so huge that it can only be implemented in millimeter-wave bands." [6]. The above statement is not valid. The following table shows some misconceptions about Massive MIMO and a summary of why they are invalid.

TABLE I:
COMMON MISCONCEPTIONS OF MASSIVE MIMO [6]

S.N	Misconceptions	Reality
1.	We can turn off inactive BS to save energy	It degrades network coverage(Discontinuous transmission i OK)
2.	We normalize the bandwidth to B = 1 Hz and the noise power to 1 without loss of Generality	**No**, the noise power is BN_0. One cannot normalize anything. Actual transmit power matters!
3.	The radiated energy efficiency of Massive MIMO goes to infinity as I (no. of BS.Antennas)$\rightarrow \infty$	Yes, but the actual energy efficiency goes to zero since circuit power grows with M
4.	Massive MIMO is only worthy for millimeter wave bands	Massive MIMO for cellular band and mm band are two sides of same coin. The same theory can be applied in both bands.

5.	Massive MIMO requires highly accurate hardware	• **Low hardware accuracy can be managed than in the current system since additive distortions are repressed during the process.** • **Can attain exceptional SE by transmitting low order modulations to a multitude of terminals**
6.	Resource assignment and power control (PC) is tricky with a large number of Antennas	• Admission control: no need for selective frequency allocation when there is no frequency-selective fading. • Long term (PC): the complexity of power control scales with several terminals but is liberated of the units of antennas and subcarriers.
7.	The order of magnitude of an antenna (M) is more than users (K)	• No harsh condition on the relation between M and K. • Specifying certain ratio M/K should be avoided as it depends on many parameters

To make the network more energy efficient many techniques/methods are described in the literature. Some of them are presented in the table below.

TABLE II:
TECHNIQUES TO IMPROVE ENERGY EFFICIENCY
IN MASSIVE MIMO

S.N.	Energy Efficiency based onResource Management [1]	• **Joint Power and resource allocation** • **SISO v/s MIMO with packetscheduling**
1.	Energy Efficiency based on Architecture [1],[16], [7], [8], [9]	• Optimization of cell size: small v/s large cell deployment • Network Deployment: Centralized, Network, and cell-free massive MIMO • Overlay source: microcell,picocell and femtocell • Relay and co-operative communications • Reflect array and Transmit array communication • Hybrid Architecture: Phase shifters
2.	Energy-Efficient Radio Technologies [10], [11]	• Heterogeneous network deployment (Multi-RAT) • SWIPT • CRN • SDN • Multimeter wavelength
3.	Energy efficiency by power Control [12]	• Power control : with fixed and variable SIR. • Joint Power Control and Beamforming • Joint Power Control and BS assignment • Joint Power Control and spectral, temporal scheduling
4.	Energy Efficiency by Antenna selection [13], [14], [15], [16]	• Symbol level and channel level antenna selection • Antenna set: Full switching and Binary switching • Conventional, Capacity centric and EE centric energy-efficient antenna selection

These techniques mentioned above have improved EE of Massive MIMO network, having their prons and cons.

Numerical data of few methods are shown in Table III.

TABLE III
STATISTICS OF FEW TECHNIQUES IN TERMS OF EE [1]

S.N	Techniques	Energy Efficiency
1.	S.W.I.P.T.	30%
2.	Beamsteering (Four antennas)	55%
3.	C-RAN	21.2%
4.	Small Cells	11.1%
5.	Massive MIMO (ZF)	31 Mbit/J
6.	Massive MIMO (MMSE)	30 Mbit/J
7.	Massive MIMO (MRC/MRT)	9.87 bit/J

III. COMPARISON OF EE BASED ON PRECODING SCHEMES

A. Power Consumption Model [17]

The system's energy efficiency rely on many factors like architecture of the network, transmission protocol, SE, radiated transmit power, and circuit power absorption. As per literature, power consumption is calculated as radiated transmitted power and constant amount for circuit power absorption. But this prototype might be fallacious because the user rate grows unboundedly as the units of antennas increases to infinitude. Even though attaining infinite EE is physically impracticable, it holds theoretical significance due to how it relates to the power consumption of analog and digital circuits. The overall EE of massive MIMO framework is influenced by various criterias or parameters like units of BS antennas, number of UEs, transmit power for distinct linear precoding schemes at BS. Channel Model and linear processing.

Channel vector entry among user (l^{th}), and BS (i^{th})
$h_{il} \sim CN(0, \beta_{il} I_m)$
Precoding schemes for uplink detection

$$G = \begin{cases} H & \text{MRC} \\ H(H^H H)^{-1} & \text{ZF} \\ \left(HP^{(ul)}H^H + \sigma^2 I_M\right)^{-1} H & \text{MMSE} \end{cases} \quad (5)$$

where,
H = [h_1, h_2...hK] carry all the channels of users, σ^2 indicates the noise variance (in Joule/symbol), $P^{(ul)}$=diag(P1$^{(ul)}$, P2$^{(ul)}$......PK $^{(ul)}$) and the design criteria Pi $^{(ul)}$ >=0 describes the transmitted uplink power of user end for i= 1,2,...,K.
Likewise, precoding scheme for downlink transmission is

$$V = \begin{cases} H & \text{MRT} \\ H(H^H H)^{-1} & \text{ZF} \\ \left(HP^{(ul)}H^H + \sigma^2 I_M\right)^{-1} H & \text{MMSE} \end{cases} \quad (6)$$

Average data rate: "It is a sum of attainable data rate for downlink and uplink communication." The total achievable data rate is:

$$R_i^{tot} = R_i^{UL} + R_i^{DL} \quad (7)$$

With Gaussian codebook, the attainable data rate in uplink is:

$$R_i^{UL} = \bar{R}_{UL}\left(\gamma^{UL}\left(1 - \frac{L^{UL}N}{S_{CB}\gamma^{UL}}\right)\right) \quad (8)$$

Where,
γ^{UL}: fraction of uplink transmission,

L^{UL}: pilot length of uplink, fraction $\left[1 - \frac{L^{UL}N}{S_{CB}\gamma^{UL}}\right]$: pilot overhead value
$\bar{R}_{UL}$: gross rate
Similarly, the downlink rate for perfect CSI is:

$$R_i^{DL} = \bar{R}_{DL}\left(\gamma^{DL}\left(1 - \frac{L^{DL}N}{S_{CB}\gamma^{DL}}\right)\right) \quad (9)$$

Where
γ^{DL}:fraction for downlink transmission,
L^{DL}: pilot length of downlink,
fraction $\left[1 - \frac{L^{DL}}{S_{CB}\gamma^{DL}}\right]$:pilot overhead value
$\bar{R}_{DL}$:: gross rate.
So, the total attainable data rates for duplex communication is:

$$R_i^{tot} = \left(N - \left(\frac{N(L^{UL}+L^{DL})}{S_{CB}}\right)\bar{R}\right) \quad (10)$$

B. Computation of Power consumption

"The total power consumption/absorption is the sum of power dissipated by a Power Amplifier (PA) and also used by circuit parts of UEs and BS".It is modeled as:

$$P_{total} = P_{PA} + P_{cir}^{tot} \quad (11)$$

Where,
P_{PA} is power consumption by the power amplifier
P_{cir}^{tot} is circuit power consumption.
In pieces of literature, circuit power is a constant value of power absorption computed for backhaul which do not rely on load, signal control, and power required for the cooling system and baseband processor, which is not a proper way of power consumption calculation. In the system, as units of transmit antennas (M) increases, the circuit power consumption also increases proportional to M. The uplink and downlink PA's power [2] is:

Uplink PA power $$P_{PA}^{UL} = \frac{\rho K B \sigma^2 \gamma^{UL}}{\eta^{UL}}\left(\frac{r^{\varphi+2}-d_m^{\varphi+2}}{\omega\left(1+\left(\frac{\varphi}{2}\right)\right)(r^2-d_m^2)}\right)$$

Downlink PA power $$P_{PA}^{UL} = \frac{\rho K B \sigma^2 \gamma^{DL}}{\eta^{DL}}\left(\frac{r^{\varphi+2}-d_m^{\varphi+2}}{\omega\left(1+\left(\frac{\varphi}{2}\right)\right)(r^2-d_m^2)}\right)$$
(12)

ηpa is an efficiency of PA. Mathematical model for total circuit power consumption is:

$$P_{cir}^{tot} = P_t + P_b + P_{c/d} + P_e + P_l + P_s \quad (13)$$

where,
Pt - power consumed in transceiver chains
Pc/d - power consumption while coding/decoding
Pb - load-dependent backhaul
Pl - power distributed while applying linear processing schemes
Pe - power used in channel state estimation
Ps - fixed power required for baseband, cooling, and control signaling
In literature, there is a list of precoding schemes, which are in two categories:
a) Non-linear precoding Schemes: They can achieve the optimal channel capacity by utilizing successive encoding and decoding to eliminate the interferences. However, the non-linear precoding schemes usually involve high complexity when the dimension of the MIMO system is large or the modulation order is tall. This fact makes them challenging to use for large-scale MIMO.

b) Linear Precoding Schemes: By contrast, the linear precoding schemes utilize the linear precoding matrix to eliminate the multi-user interferences. Their complexity is much lower than the non-linear schemes. Also, when the units of BS antennas N is much massive than the number of users K, linear precoding schemes can achieve the near-optimal capacity. Types of power measured in linear processing : the first type is needed to calculate G and V, (5) and (6), respectively. The second type is required for matrix-vector multiplication by each data symbol. [2] The precoding/decoding matrices are computed in each coherent block, while its entanglement is unpredicted on the type of precoding.

Hence Power consumption for three types of liner schemes are:

Power consumption for MRC/MRT=

$$P_l^{\overline{\frac{MRC}{MRT}}} = \left\{ \frac{2MNB}{\Psi_{BS}}\left(1 - \left(\frac{L^{UL}+L^{DL}}{3S_{CB}}\right)\right) + \left(\frac{3BMN}{S_{CB}\Psi_{BS}}\right)\right\} \quad (14)$$

Power consumption for ZF=

$$P_l^{ZF} = \left\{\left(\frac{BN^3}{3S_{CB}\Psi_{UE}}\right) + \left(\frac{BM(3N^2+N)}{\Psi_{BS}}\right)\right\} \quad (15)$$

Power consumption for MMSE=

$$P_l^{MMSE} = \left\{\left(\frac{BN^3}{3S_{CB}\Psi_{UE}}\right) + \left(\frac{BM(3N^2+N)}{\Psi_{BS}}\right)\right\} \quad (16)$$

where Ψ_{UE} =12.8, and Ψ_{BS}= 5Gflops/W are computational efficiency symbols for UE and BS.

C. Modeling of EE

As defined before, "EE is a ratio of average data rate to average power dissipation". Total EE metric computing for both uplink and downlink is:

$$EE = \frac{\sum_{i=1}^{M}(R_i^{tot})}{P_{TX}^{(UL)}+P_{TX}^{(DL)}+P_{cir}^{tot}} \quad (17)$$

Precise modelling of P_{cir} is of supreme significance to deal with the layout of an energy-efficient communication system. P_{cir} is to be optimized with three design parameters which are: number of BS antennas (M), number of UEs (k), and the gross rate $\bar{R}$.

So eq.3 can be modelled as:

$$(EE) = \frac{\sum_{i=1}^{M}(R_i^{tot})}{P_{TX}^{(UL)}+P_{TX}^{(DL)}+P_{cir}^{total}} \quad (18)$$

Max M, K ϵ Z,
$\bar{R}$ >=0

By plugging all previously computed values, EE is:

$$EE = \left[\frac{\left(K-\left(K(L^{UL}+L^{DL})/S_{CB}\right)\bar{R}\right)}{\left(\left(\rho kB\sigma^2/\eta_{PA}\right)\left(\left(r^{\varphi+2}-\frac{d_m^{\varphi+2}}{\omega\left(1+\frac{\varphi}{2}\right)}\right)(r^2-d_m^2)\right)\right)P_{cir}^{total}}\right] \quad (19)$$

Max M, K ϵ Z, $\bar{R}$ >=0

This relationship is the trade-off between data rate and total power dissipation. EE improves by surging the antennas where the entire power disperses, and it additionally develops relatively.

D. Results and Discussions of Precoding Schemes

This section gives the simulation outcomes obtained in the literature of EE performance comparison. Fig.7 shows EE v/s number of transmit antennas in a single cell. It portrays that more energy-efficient system can be made by reducing the cell dimension and fixed power needed for baseband
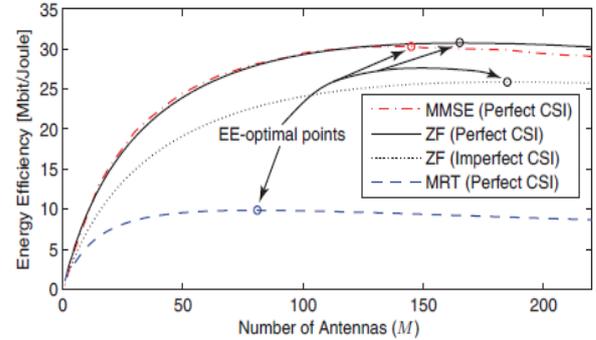

Fig. 7. Comparison of EE of different precoding schemes [2]

TABLE IV
Numerical comparison results of [2] and work in [18],[19]

LINEAR PROCESSING SCHEME	RESULTS IN [2]		RESULTS [18], [19]	
	EE (MBIT/J)	M (NO. OF BS ANTENNA)	EE (MBIT/J)	M (NO. OF BS ANTENNA)
MMSE-PERFECT CSI	38.1	122	30.0	165
ZF-PERFECT CSI	39.1	141	31.0	165
ZF-IMPERFECT CSI	31.0	155	26.1	185
MRT/C PERFECT CSI	10.0	82	8.0	85

When compared the results of [2] with [18,19], it gives 15% improved results with the small magnitude of M. It also portrays that a more energy-efficient system can be developed by reducing cell dimension and fixed power needed for baseband.
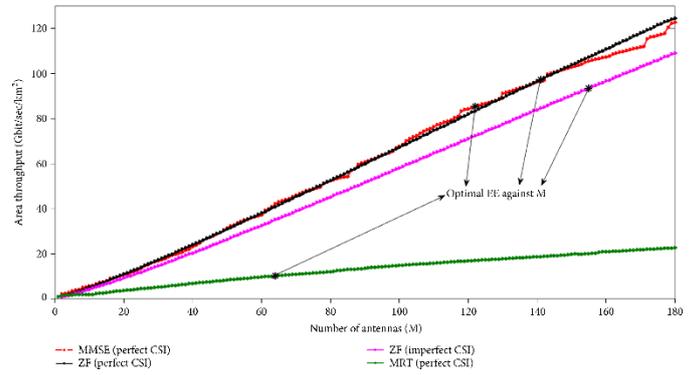

Fig. 8. Comparison of area throughput [2]

Fig.8 shows the results of area throughput. It shows that with interference mitigation linear precoding schemes, Massive MIMO can attain better area throughput, and EE Table 2 compares the numerical value of area throughput.

TABLE V
NUMERICAL RESULT COMPARISON OF AREA THROUGHPUT

Linear Processing Scheme	Results in [2] EE	Results [18],[20] EE
Zero-Forcing -perfect CSI	21.1	15.1
Zero Forcing - imperfect CSI	80.2	62.0
MMSE Processingperfect CSI	81	60
MRT Processing - perfect CSI	97.0	72

Even though the MMSE is the optimal for achieving high throughput gains, ZF processing provides better efficiency gain and the main reason is complex computations of MMSE. The MMSE scheme has the advantage of steering the system where the value of M is less than N. The Zero Forcing-imperfect CSI performs similar as MMSE and Zero Forcing -with perfect CSI. The outcome with MRT/C are not that much adequate, but it operates below excessive IUI, that is why the rate/U.E. is less.The circuit power absorption will lessen with time, demonstrating that the higher EE is achievable using less UEs, fewer BS antennas, faded power, and innovative precoding strategies. The survey suggests that the massive MIMO framework can be fabricated by utilizing a low-power transceiver (consumer-grade) equipment at coverage-tier BS as an druthers for conservative processed - grade high-power ingesting equipment. The decrement in power dispersal brings step forward effects, and it is far feasible by contracting the circuit power absorption. The proportion of reducing cell dimension is likewise carried out as furnished in [21] in articulation (13). Lowering cell radius lessens the network capacity of the system, now with standing, it expands the EE. Decisively, the results show that cutting the maximum distance of a cell helps increasing the EE. When the cell radius is reduced essentially, transmit power is reduced ultimately, that brings outcomes in terms of perfected EE of a massive MIMO framework.

TABLE VI
COMPARISON BETWEEN DIFFERENT LINEAR PRECODING SCHEMES

Performance Metric	ZF Precoding	MMSE Precoding	MRC/MRT Precoding
Rate Attained	Optimal	Moderate	Less
Performance With Reference To Power	Better At High Tx Power	Best Performance At High Andlow Tx Power	Better At Low Tx Power
At High SNR	Finer	Converges To ZF	Less
At Low SNR	Less	Satisfactory	Satisfactory
Units Of Antennas	Requires More Antenna	Ok With Fewer Antennas	More Is Better
Number Of Served Users	Low	Highest	High

Numerous low price and low complicated techniques for precoding, unearthing, channel estimation and user scheduling have been put forward to lessen power absorption at BS, in which the main focussed vicinity is antenna and power amplifier structure. In [22], the method to lessen the mutual coupling precipitated distortion is defined but they're computationally inexpedient for massive MIMO framework.

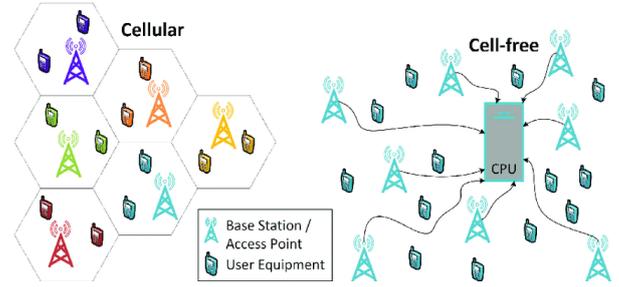## IV. COMPARISON OF EE BASED ON ARCHITECTURE

Fig. 9. Cell-free v/s cellular networks [23]

As shown in the figure above, there are BS with massive antennas in the cellular network. The coverage area is splitted into many different cells, each having BS with several multiple antennas. The user in a particular cell will be served by BS present in that cell, which means users surround each BS. Cell free architecture consists of numerous wireless AP that cooperate to serve users together, in spite of building independent cells. The station is controlled by these types of antennas to serve users coherently in downlink and uplink transmission. It is far terrible move to keep an objective to optimize EE unconditionally as it frequently results in a relatively unfeasible outcomes of using low power for low throughput. SE and EE are competing goals such that one ought to be sacrificed so that the other can be improved. In truth, [23] dis-plays that cell free Massive MIMO using Max-Min power control strategy is obviously energy-efficient without the forfeit of spectral efficiency and authors quantify its upgrades over massive MIMO.

A. System Model and Processing

For cell free massive MIMO, m^{th} service antenna and k^{th} user have channel between them which is modeled as:

$$g_{m,k} = \sqrt{\beta_{m,k}} h_{m,k} \qquad (20)$$

where $h_{m,k}$ is for small scale fading which manages random scattering and $\beta m,k$ is for the large scale fading which manages geometric attenuation and shadow fading. "The downlink effective SINR for cell free massive MIMO with conjugate beamforming precoding is given by" [23]

$$\text{SINR}_k^{\text{cellfree}} = \frac{\rho_d \left(\sum_{m=1}^{M} \sqrt{\alpha_{m,k} \eta_{m,k}} \right)^2}{1 + \rho_d \sum_{m=1}^{M} \beta_{m,k} \sum_{k'=1}^{K} \eta_{m,k'}}. \qquad (21)$$

where $\alpha_{m,k} = \frac{\rho_u \tau \beta_{m,k}^2}{1 + \rho_u \tau \beta_{m,k}}$ indicates the mean square of the channel estimate, ρ_d, and ρ_u, are normalized downlink and uplink SNR, respectively. τ indicates the range of the uplink pilot sequence used for channel estimation. $\eta_{m,k}$ indicates power control for downlink. Let Pd, be full downlink radiated power per access point, then the radiated EE for cell-free system is modelled as:

$$EE^{\text{cell-free}} = \frac{B \sum_{k=1}^{K} \log_2 \left(1 + \text{SINR}_k^{\text{cellfree}} \right)}{P_d \sum_{m=1}^{M} \sum_{k'=1}^{K} \eta_{m,k'}} \qquad (22)$$

where B is carrier spectral BW. Here EE of a cell-free system depends on downlink power control $\eta_{m,k}$.

Two downlink power strategies are under consideration:

Equal power control strategy: It means the allocation of same power to every user in each Access Point.

Max-Min control strategy: Minimum SINR_k among all k active users is maximized using this strategy.

The channel model using same basic supposition and the channel with same uplink pilot operation, es-timation with all M number of antennas collocated in an array at a BS,the large scale fading co-efficient may be presumed to be the same for M number of antennas. So, for a single-cell massive MIMO system having conjugate beamforming precoding, the downlink effective SINR can be modelled as:

$$\text{SINR}_k^{\text{cellular}} = \frac{\rho' M^M \gamma k \eta k}{1 + \rho' d \beta_k \sum_{k'=1}^{K} \eta_{k'}} \quad (23)$$

where, $\gamma_k = \frac{\rho_u \tau \beta_k^2}{1 + \rho_u \tau \beta_k}$ channel estimate mean square, and the power control , ηk do not rely on service antenna index m. The radiated EE of the cellular framework is modelled as:

$$EE^{\text{cellular}} = \frac{B \sum_{k=1}^{K} \log_2 \left(1 + \text{SINR}_k^{\text{cellular}}\right)}{P_{d'} \sum_{k'=1}^{K} \eta_{k'}} \quad (24)$$

where, Pd' is total available radiated downlink power of massive MIMO BS. For a fair comparison, assume that the total available downlink power is same for both the systems.
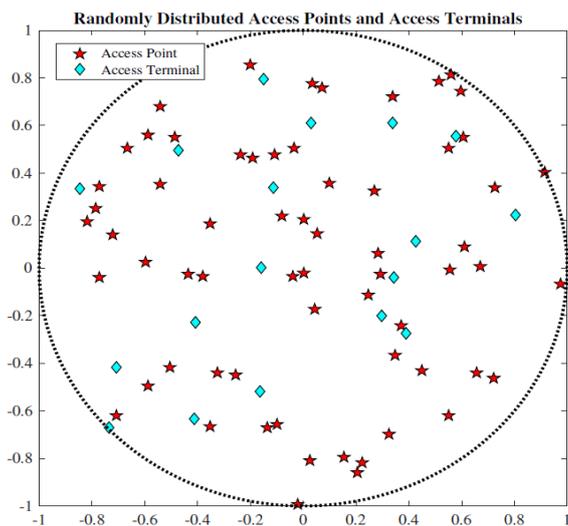
$$P_{d'} = MP_d$$

Fig. 10. Cell free Massive MIMO: M=64 AP and K=18 AT [23]

As displayed in fig.10, the circle with radius R consist of ATs and APs that are irregularly scattered. "The same circular ring structure is used for service region of cellular framework for better juxtaposition. Access Terminals are desultorily distributed inside this ring structure and Massive MIMO BS having M service antennas is located at the core of this ring structure. Access Terminals close to the core of the service region are statistically not same as the Access Terminal close to the edge for both frameworks".[23]

B. Numerical Results and Discussion

AP and AT are parted by utmost level of distance i.e., 2R. The path loss between them is large. As shown in fig.11, with Max-Min power control, over 60% of APs in cell-free framework do not send with full energy, the radiated energy productivity is generously better compared to the cellular frame-work in spite of having low spectral efficiency. [23]

shows equal power, and max-min power techniques show the similar SE of the cellular network.
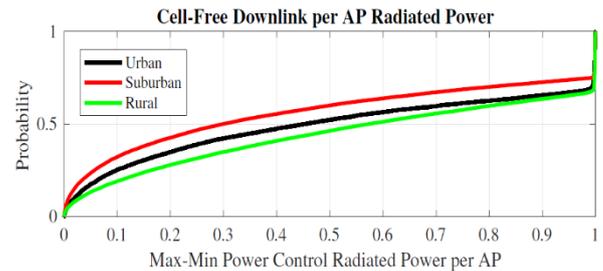

Fig. 11. Cell-free Massive MIMO with Max-Min power control strategy having transmit power normalized per AP [23]
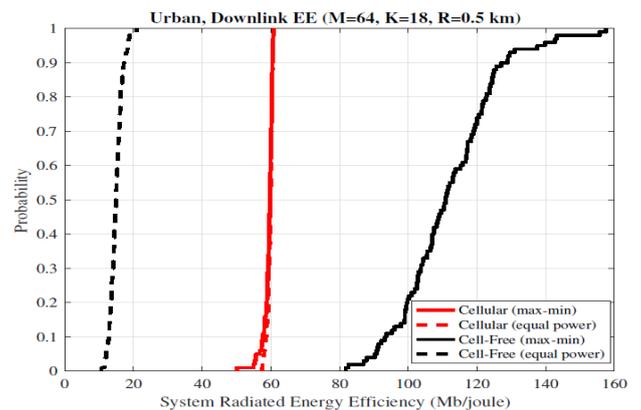

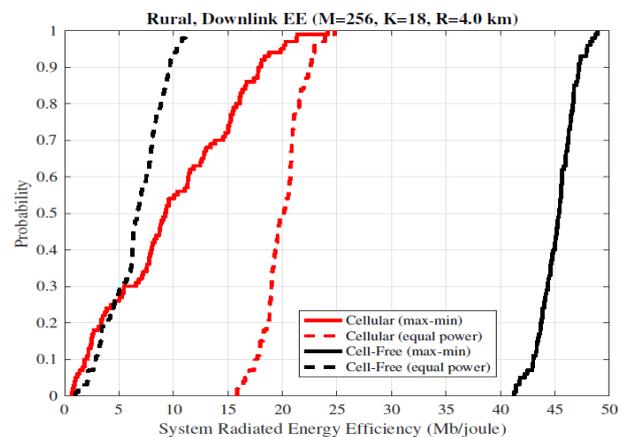Fig. 12. Massive MIMO in Urban development [23]

Fig. 13. Massive MIMO in Rural Development [23]

Still, there is a large opening between cell-free systems, divulging the tremendous inadequacy of similar power strategies in cell-free. There are variations in large-scale fading service antennas and a user AT in a cell-free system. It also shows that significant path loss results in more negligible interference, and median SE increases in all cases. "Path loss for the cellular framework is more substantial, and large-scale fading is demanding for cell-edge clients." [23] It is shown in the figure that Max-Min power in a cellular framework performs unfortunate than equivalent power in terms of median throughput. Cell-free framework using Max-Min power strategy performs the best among all in EE. Table 7. shows the comparison of different parameters of three different architectures that affect the EE of the system.

TABLE VII
COMPARISON BETWEEN CENTRALIZED, NETWORK, AND CELL-FREE
MASSIVE MIMO [24]

Architecture	Centralized framework	Network framework	CF framework
Quantity of Antennas	Huge	Medium	Huge
Implementation cost	Costly	costly	economical
Macro Diversity	Small	Medium	Large
Channel hardening	robust	dull	Medium
Favorable propagation	robust	dull	Medium
Uniform coverage	Bad	Medium	Good
EE	Large	Small	highest
Estimation of Channel	broad	broad	restricted
Fronthaul Resource	Small	Large	Medium

An equivalent power strategy for a cell-free framework conveys the most exceedingly terrible energy efficiency by huge sum in all scenarios. Thus, streamlining energy efficiency unequivocally can bring about pointless arrangements.

CONCLUSION

Foregoing discussion reveals that Massive MIMO is very advantageous scheme for developing energy efficient system. From a detailed study of various techniques, it is found that the cellular communication system must be first spectrally efficient to perform well. Massive MIMO delivers higher order of spectral efficiency, which makes it naturally energy efficient. The detailed study of precoding schemes showed that MMSE and ZF carry maximum EE gain. Based on architecture, cell-free systems contribute to a significant increase in radiated EE as this setup has a path loss advantage over a cellular structure, also a huge number of APs don't communicate with full influence with max-min power control strategy. This paper reviews various techniques to further develop the EE of massive MIMO framework. It also compares their results and articulates that, though theoretically better results are achievable, it is not necessary that the same improvement can be seen in real time because hardware works differently depending on environment, availability of resources, and demand. So, new calculations algorithms are under measure by combined work of industrial and researchers to obtain better EE performance. Hope this paper and those referenced in this publication will assist to make headway along this journey.

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