Massive MIMO: Energy Efficient Solution for Increasing Coverage and Capacity

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Abstract – **In this paper, the energy efficiency of 32T32R Massive MIMO product has compared with the conventional 2T2R evolved node B (eNB) and identified the improvement in terms of both coverage and capacity. Initial field trial and hardware design analysis indicates that 32T32R massive MIMO will reduce the power consumption per bit by half.**

Keywords – **32T32R massive MIMO, Energy efficiency, Downlink capacity, Power consumption per bit.**

I. INTRODUCTION

Many services such as high-speed internet, video streaming, video conferencing, video downloading, interactive gaming, and group chat, have significantly contributed to the increase in smartphone usage and mobile data traffic in cellular networks in the last few years. In the USA alone, the number of smartphone users increased from 60 million in 2010 to 164 million in 2014 [1]. Additionally, there were 3.9 billion smartphone users worldwide in 2016, and this number is likely to double by 2022 [2]. The concept of fully networked society with applications like augmented reality, virtual reality, and connected homes, and cars, machine to machine communication requires plenty of data. As a result, the amount of mobile data traffic is projected to be eight times the current level by 2022, according to the Ericsson Mobility Report [2].

High channel bandwidth, increase in several sites, deployment of heterogeneous networks are the possible solutions to achieve the desired data capacity in the coming years. Larger channel bandwidth is possible at the high-frequency band which has higher penetration losses and requires a large number of sites to provide the coverage. More sites led to higher operational expenditure (OPEX) and capital expenditure (CAPEX) for the operator. The revenue per customer is decreased in recent years hence operators need a cost-effective solution that fulfills the requirement of data capacity without increasing the sites and without adding the new spectrum. Massive Multiple Input Multiple Output (MIMO) is a pre-5G potential solution to meet the immediate need by replacing the existing sites with massive MIMO eNB that leverage the data capacity by 3-4 times in the field [3]. Massive MIMO is an extension of multi-user MIMO (MU-MIMO) with a large number of antenna elements (AEs) in both vertical and horizontal directions. Several AEs in both directions can provide the 3D beamforming which allows the beam to be sharpened in both azimuth and elevation plane [4]. The narrow beam improves the signal to interference and noise ratio (SINR) by pointing the desired main lobe of an antenna in the direction of users and null lobe in the direction of interferers. Thus, improves the inter-cell interference that enhances the SINR at the user equipment (UE).

Channel reciprocity in the time divisional duplexing (TDD) allows massive MIMO eNB to estimate the sounding reference signal (SRS) in uplink that able to identify the optimal weights for user-specific beamforming. MU-MIMO is defined up to 8 layers in 3GPP release 10 which can be extended to more layers in both downlink and uplink based on the processing capability in the LTE eNB [5, 6]. More number of AEs provide more directivity with a narrow beamwidth which in-turn facilitates less correlation amongst the received signal at UEs. Hence, eNB can transmit multiple layers to the different UEs simultaneously in the same time and frequency slot and increases the physical resource block (PRB) reuse that leads to the enhancement of the capacity of the network [7]. Since massive MIMO can transmit a greater number of layers with the concept of space division multiplexing within the same frequency and time, it increases the spectral efficiency of the network [8].

A large number of AEs can use the multiple low power transceiver chains that allow the use of radio frequency integrated circuit (RFIC) for transceiver and low power amplifier for the front end design. Low power design has several advantages including low cost, low power consumption, distributed heat across multiple low power amplifiers, reducing the insertion losses between the RF port and antenna port by using blind mate connector, etc. Although total power consumption of massive MIMO may increase in comparison with 2T2R and 4T4R macro eNB because of a greater number of transceiver chains, power consumption per bit will reduce significantly due to higher spectrum efficiency supported by massive MIMO eNB.

The remainder of this paper is organised as follows. 3D beamforming using a large number of AEs is explained in Section 2. The hardware design of massive MIMO is described in Section 3. The expected performance comparison of 2T2R conventional macro eNB with 32T32R massive MIMO is described in Section 4. Section 5 provides initial field test results and a comparison of 32T32R massive MIMO with respect to 2T2R. Section 6 concludes the power efficiency per bit for 32T32R massive MIMO.

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II. THEORY

This section describes the design principle of massive MIMO. MU-MIMO systems, where a BS with a few hundred or more antennas simultaneously serves tens (or more) of users in the same time-frequency resource, are known as Massive MIMO systems [8]. It is an extension of 3D beamforming along with MU-MIMO in which M antenna array supports K users where M ≥ 32 and K ≥ 8. 3D beamforming works on the principle of space division multiple access and provides beamforming in both horizontal and vertical direction resulting into a narrow beam as shown in Fig. 1. MU-MIMO allows the simultaneous generation of multiple beams at the same time and frequency slots for different UEs that increases the throughput of the massive MIMO eNB.

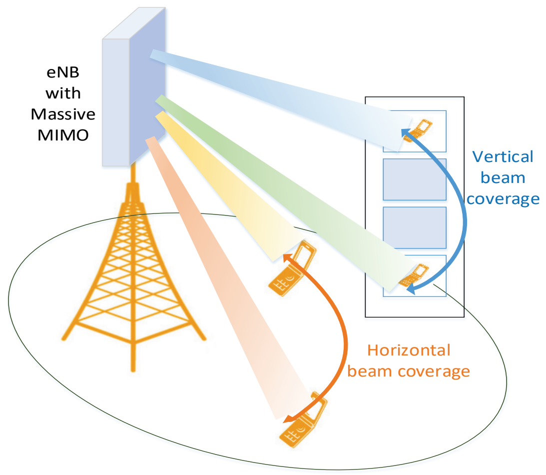

Fig. 1. Three-dimensional beamforming for massive MIMO [4]

A. Three-Dimensional Beam Forming

Three-dimensional beam forming consists of an antenna array both in horizontal and vertical directions with an antenna element spacing greater than or equal to half of the wavelength (λ) as shown in Fig. 2. Uniform rectangular array of M x N AEs positioned along the XY-plane with λ/2 spacing as shown in Fig. 2. The array factor is a multiplication of two plane array of the sum of the individual AEs. The array factor A (θ, Φ) for the rectangular array is described in (1) [9]

$$A(\theta,\Phi)=\sum_{m=1}^{M}A_m \exp^{j(m-1)kd_x Sin\theta\cdot Cos\phi+\beta_x} + \sum_{n=1}^{N}B_n \exp^{j(n-1)kd_y Sin\theta\cdot Sin\phi+\beta_y} \quad (1)$$

where A_m and B_n are the amplitude coefficient of the antenna element in x and y direction respectively; β_x and β_y are the phase shift coefficient of AEs in x and y direction respectively; d_x and d_y is the antenna element spacing in x and y-direction respectively. Amplitude and phase constant of each antenna element is called weight function for the corresponding antenna elements. A combination of weight function for all the AEs determines the radiation pattern for a specific user based on the user location and the direction of the interferers. Calculating the weight function using the SRS for LTE massive MIMO eNB is explained in Section 3. The next subsection explains the concept of MU-MIMO to enable multiple streams to simultaneous users at the same time and frequency slots.

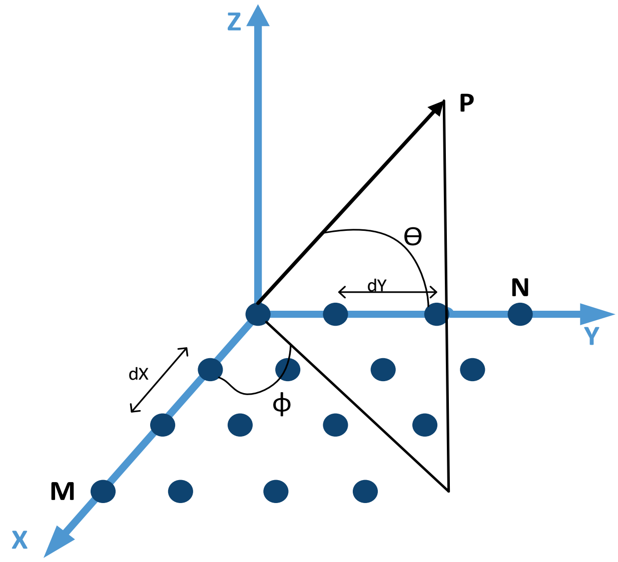

Fig. 2. Antenna array for 3-dimensional beamforming

B. Multi-User MIMO

Massive MIMO is an extension of MU-MIMO along with the 3D beamforming. MU-MIMO scheme is defined from the LTE release 8 to release 10 as per the 3rd generation partnership project (3GPP) [5], [6]. MU-MIMO can provide simultaneous transmissions to several UEs in the same time-frequency resources by exploiting the spatial diversity of propagation channels. MU-MIMO feature as per the 3GPP defined in various releases are described in Table I. Beamforming with MU-MIMO in LTE uses "User-specific reference signal" which is used for demodulating the data and for channel estimation as well. Channel estimation through user-specific reference signal in downlink and the sounding reference signal (SRS) in uplink can identify the user-specific channel information which is very much useful for the beamforming algorithm [11]. Massive MIMO in TDD uses the advantage of channel reciprocity due to the samefrequency in both downlink and uplink [8]. There are different algorithms for calculating the optimum beamforming weights. However, determining the direction of arrival (DoA) or angle of arrival (AoA) of received uplink signal and optimum beamforming through channel estimation by using sounding reference signal is popular for the FDD massive MIMO implementation [4].

TABLE I
LTE RELEASE AND BEAMFORMING FEATURES

LTE Release	Downlink Beam Forming feature with MU-MIMO
R8.0	Single-layer beamforming can be made using Transmit Mode 7 (TM 7). User-specific reference signal will be decoding the data and reference signals both.
R9.0	Dual-layer beamforming is supported with TM 8.
R10.0	8 single layer or 4 Dual-layer beamforming is supported in TM 9. Downlink channel state information for a reference signal (CSI-RS) is measured and UE will send these details to eNB in the uplink for channel estimation.

DoA based algorithm requires an antenna array with a distance between the individual AEs of $d \leq \lambda/2$. It can be difficult to determine DoA if the angular spread is not small or if there is no dominant direction in the DoA. Alternatively, it is possible to determine the optimum beamforming weights from the channel estimation using the uplink SRS [11]. This can be used directly to estimate the channel, which can derive the weight for the downlink beamforming in the TDD system. In this case, the beamforming vector is determined by channel estimation and not from the DoA calculation. The beamforming calculation is based on the uplink measurement, making calibration of the antenna array and of the RF front end a major factor in the accuracy of the beamforming. The detailed algorithm for TD-LTE eNB is discussed in the next subsection.

C. Calculation of Weight Function

TD-LTE massive MIMO eNB uses the SRS for channel estimation in uplink and determines the weights for downlink accordingly. Fig. 3 shows two UE scenario to simplify the explanation. N number of AEs are assumed in this analysis for massive MIMO eNB [8]. Both UE transmits the SRS periodically in the uplink. eNB receives an SRS signal from both UEs through N antennas. The received vectors are

$$\widetilde{R_1} = [r_{11}, r_{12}, \ldots\ldots, r_{1N}] \tag{2}$$

from UE_1 and

$$\widetilde{R_2} = [r_{21}, r_{22}, \ldots\ldots r_{2N}] \tag{3}$$

from UE_2. eNB has the expected sounding reference signal from both UEs as

$$\widetilde{R'}_1 = [r'_{11}, r'_{12}, \ldots\ldots r'_{1N}] \tag{4}$$

$$\widetilde{R'}_2 = [r'_{21}, r'_{22}, \ldots\ldots r'_{2N}] \tag{5}$$

Using the individual difference of received and expected SRS, eNB estimates the channel response for both UEs and channel response corresponding to N antenna elements is

$$\widetilde{H_1} = [h_{11}, h_{12}, \ldots\ldots, h_{1N}] \tag{6}$$

$$\widetilde{H_2} = [h_{21}, h_{22}, \ldots\ldots, h_{2N}] \tag{7}$$

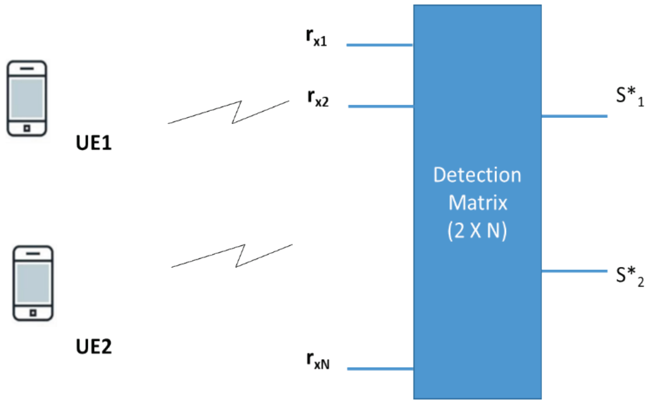

Fig. 3. Two UE uplink scenario for massive MIMO eNB

The received signal corresponing to N antennas ($r_{x1}, r_{x2}, \ldots, r_{xN}$) for two single users UE1 and UE2 can be written as

$$\begin{bmatrix} r_{x1} \\ r_{x2} \\ \vdots \\ r_{xN-1} \\ r_{xN} \end{bmatrix} = H_{uplink} \cdot \begin{bmatrix} X1 \\ X2 \end{bmatrix} \tag{8}$$

where H_{uplink} is the uplink channel response matrix and has Nx2 dimensions and X_1 and X_2 are the signal transmitted by the UE_1 and UE_2 respectively. The transpose of the channel matrix is used for calculating the precoding or weight function for the downlink as shown in Fig.4. Hence, the precoding matrix or weight function for downlink will be 2xN as per Eq. (9).

$$\widetilde{H}_{downlink} = \begin{bmatrix} h_{11} & h_{12} & \ldots\ldots & h_{1N} \\ h_{21} & h_{22} & \ldots\ldots & h_{2N} \end{bmatrix} = \widetilde{H}^{T}_{uplink} \tag{9}$$

Maximum ratio transmission (MRT), zero-forcing (ZF) and minimum mean square error (MMSE) are the techniques used for calculating the weights in the downlink. These techniques are similar to those used for the channel estimator for the receiver. For example, MRT is exactly similar to the maximal ratio combiner (MRC) used for channel estimation in the receiver. All three techniques are recommended for the different applications in [12].

1. MRT – recommended for noise-limited channel and not for multi-user scenario because of the interference channel
2. ZF – recommended for the interference-limited channel [13].
3. MMSE – recommended for both noise-limited and interference-limited channels. However, its implementation is complex considering the UE receiver [14].

Either MMSE or ZF techniqueis are used for LTE eNB to take care of inter-cell interference issues.

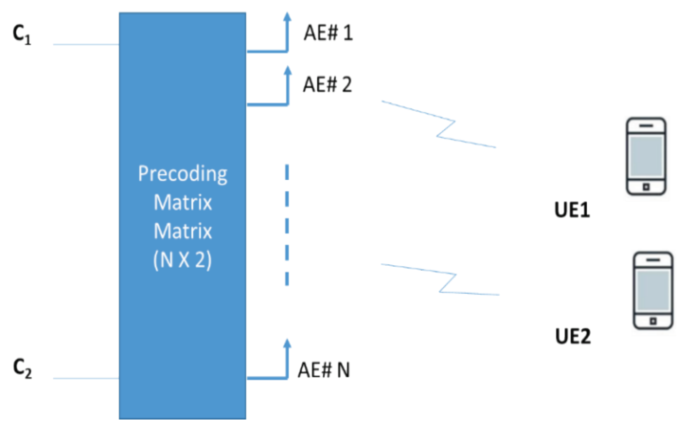

Fig. 4. Two UE downlink scenario for massive MIMO eNB

It is assumed that both UEs are separated in the space and isolated in such a way that the received signals at UE are not correlated. Two streams (C_i) are transmitted from the N antennas using the weight function (W_i) and baseband signals as per Eq. (10)

$$\bar{S} = \bar{W} \cdot \bar{C} \tag{10}$$

and

$$\bar{W} = \bar{H}^{*}_{uplink} \cdot (\bar{H}^{T}_{uplink} \cdot \bar{H}^{*}_{uplink})^{-1}$$

Here, ^{T} denotes the transpose and * denotes the complex conjugate. W_1 and W_2 are Nx1 weight matrix for individual UE corresponing to N antennas.

S_1 and S_2 are down-link signals transmited by the eNB for the UE1 and UE2 corresponding to the baseband C_1 and C_2 respectively as per the below equations

$$S_1 = w_{1,1}.C_1 + w_{1,2}.C_2 \quad for\ \mathrm{UE}_1$$

$$S_2 = w_{2,1}.C_1 + w_{2,2}.C2 \quad \mathrm{for\ UE}_2.$$

III. Hardware Design of Massive MIMO eNB

In the conventional LTE macro eNB, Remote radio head (RRH) is directly connected to the antenna through RF cable as shown in Fig. 5(a). Macro eNB delivers high power in the order of 10 watts (40 dBm) to 40 watts (46 dBm) to antenna port using high power amplifiers (HPA). Such a high power from the antenna port is divided into N AEs by using passive splitters in the transmitter. The passive phase shifter is also used to have different phases at different AEs to support remote electrical tilt. The number of AEs depends on the specifications of vertical beamwidth, horizontal beamwidth, and the gain of the antenna [16]. A half-wave dipole is considered as the basic antenna element. The radiation pattern

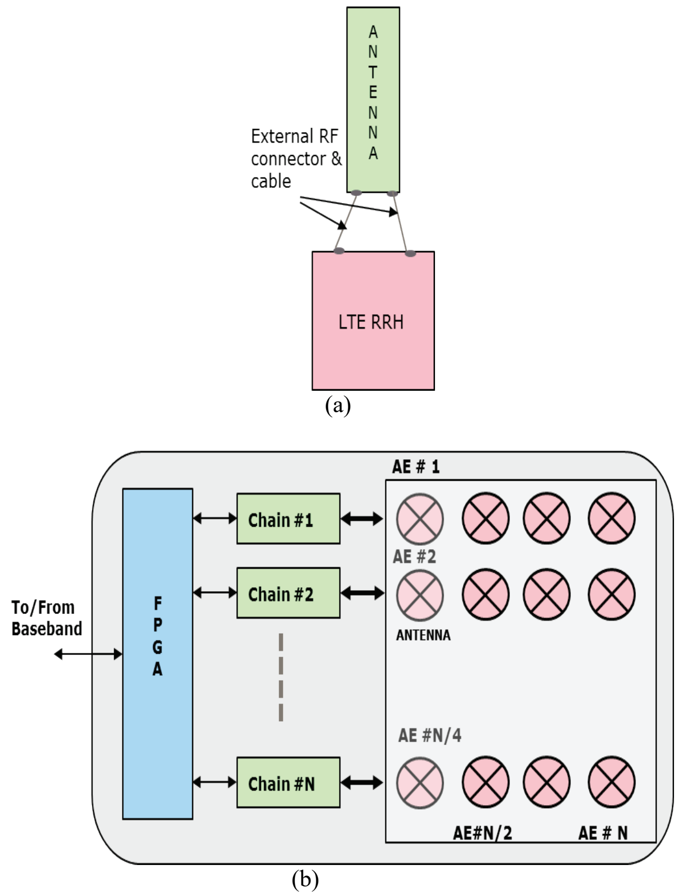

Fig. 5. Connection between LTE RRH and antenna: (a) Conventional approach, (b) Using active antenna array

of the antenna is the multiplication of the array pattern and the radiation pattern of the basic antenna element. Hence, antenna array comprises several antenna elements in the horizontal and vertical direction and decides the overall radiation pattern for user data for massive MIMO eNB. Recent trends in telecom industries favour the deployment of RRH on top of the tower. As RRH is very close to the antenna, the insertion loss of RF cables reduces, which in turn reduces the requirement of the peak power of HPA [17]. Later, active antenna array (AAA) introduces the concept of using low power transceiver chains in place of HPA and feeds individual chain output to the corresponding dipole directly [18]. AAA enables the use of the single IC for RF transceiver chain and matched p-HEMT devices for low power amplifiers which are used for high power class devices like outdoor CPE [18]. The concept of AAA is extended in the massive MIMO eNB where AEs are placed in both horizontal and vertical directions. Accordingly, the number of transceiver chains are also increased in the massive MIMO eNB. N transceiver chains and the same number of AEs are shown in Fig. 5(b) and they are directly connected through blind mate RF connectors without RF cable. In the next subsection RRH for 32T32R massive MIMO eNB is discussed.

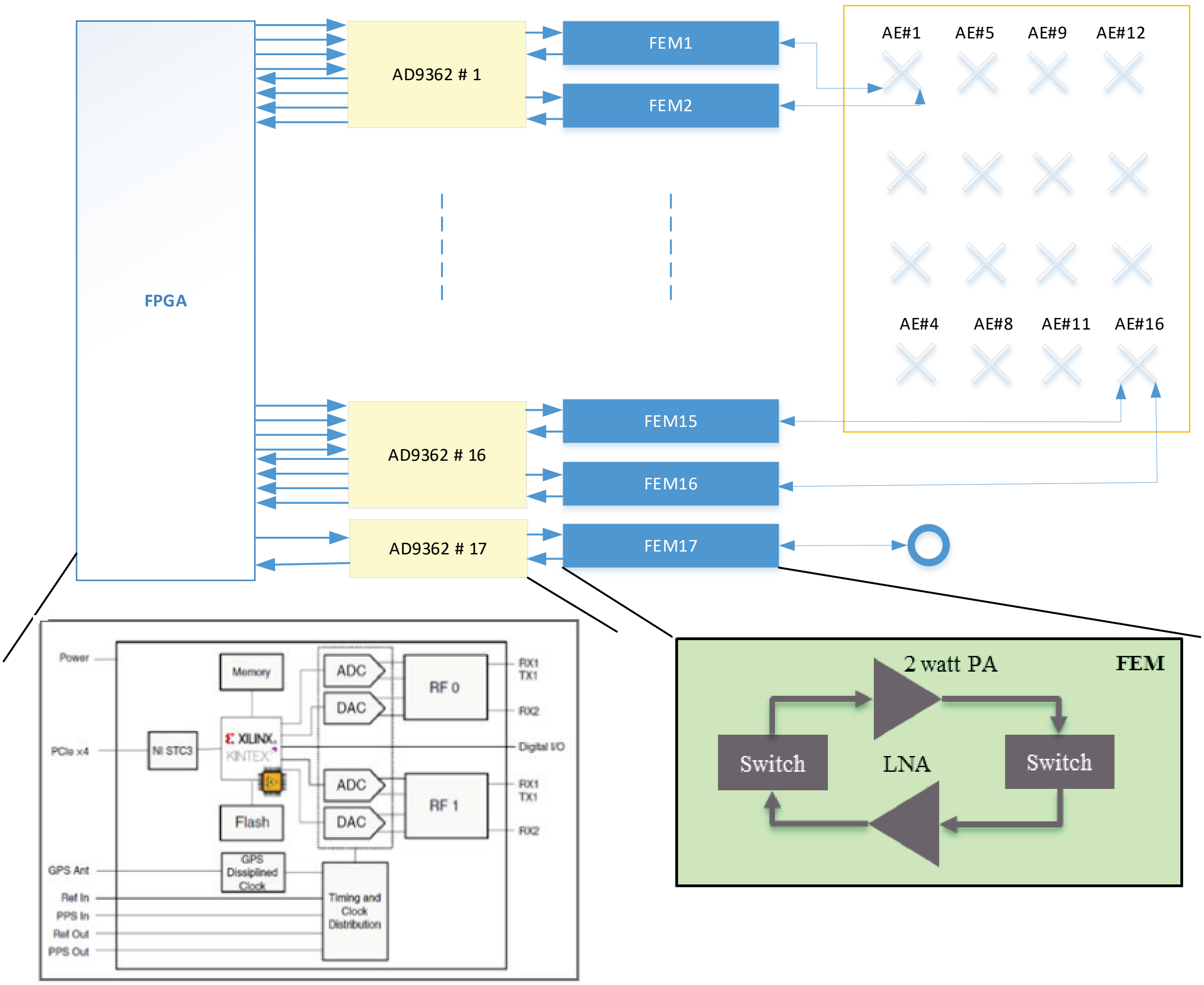

Fig. 6. Block Diagram of Massive MIMO RRH

A. 32T32 RRH Design for Massive MIMO

Integrated low power RFIC and low power amplifiers are key components in the massive MIMO eNB design. The block diagram of hardware design is shown in Fig. 6. Analog Devices AD9362 is a single-chip transceiver IC which consists of analog to digital converter (ADC), digital to analog converter (DAC), low pass filter, RF up and down converter and PLL synthesizer.

RFIC has mainly two data interfaces: One towards the front-end module (FEM) and the second towards the FPGA. Interface towards the FEM connects to the antenna through HPA in the TX chain and LNA in the RX chain. Another interface will be connected to the baseband processing unit (BBU) through FPGA where the Common public radio interface (CPRI) and other glue logic is implemented. BBU connects to RRH through the CPRI interface. Calibration between TX chains and RX chains required to achieve the same gain and phase response of all the TX and RX chains which are essential to meet the reciprocity assumption in TDD. An additional one transceiver chain is required for calibrating the TX and RX chains [19]. AD9362 supports two transceiver chains in a single RFIC. 32T32R massive MIMO RRH requires 33 transceiver chains. Therefore, 17 AD9362 (RFIC) chips are required for the massive MIMO RRH design. Fig. 6 shows the hardware design for 32T32R Massive MIMO RRH. PA, LNA, and TDD switch comprise of FEM. Here, the antenna unit comprises of total 16 AEs, where each AE is made of two cross-dipoles and one FEM is connected to each dipole. Thus, a total of 32 FEMS are connected to 16 AEs as shown in Fig. 6. One FEM is connected to the calibration port which is used for the initial calibration of each transmit/receive chain for lab test.

B. Power Consumption Details

The power consumption analysis is carried out for 20 MHz channel bandwidth in TDD band 40, frame configuration 2, and special subframe configuration 7 have been considered in this analysis [7]. 32 transceivers along with 2 watts PA per chain has been designed in this analysis to achieve 64 watts (48 dBm) total power at the output of PA. 2 dB is the insertion loss in FEM due to TDD switch, filter and blind mate RF connectors which reduces the total transmit power

TABLE II
POWER CONSUMPTION DETAILS FOR MASSIVE MIMO ENB

Component	Unit	Power Consumption (W) each unit	Total Power Consumption (W)
Baseband Unit for 20 MHz per Sector			
Baseband/Sector/20 MHz RRH	1	50	50
TRX Module and PA Module			
RFIC (AD9362)	33	1.2	39.6
Gain block (MGA-30789)	33	0.55	18.15
2 Watt Power Amplifier	33	4.8	158.4
FPGA	1	12	12
+28 V to 12 V DC-DC Converter + LDO	4	4.4 + 1.6	24
LNA (MGA-64606)	33	0.024	0.792
Power Supply module			
48 V to +28 V DC-DC Converter	1	14	14
Total Power Consumption (W)			**310**

to 40 watts (46 dBm). 2 watt (33 dBm) power amplifier has been designed considering the dual balanced configuration with Avago’s four MGA-43040. It is a matched p-HEMT device and provides linear output up to 27 dBm for LTE signal as per the above configurations.

Table II provides detailed power consumption to break up for major components. Approximately 300 watt is the power consumption of single sector massive MIMO eNB as per the above analysis which is 200 watt for 2T2R with 2 X 20 watt macro eNB [19]. Transceiver design along with PA is designed using Keysight"s Advance Design System tool (ADS) and validated for end-to-end RF performance. Power consumption details are taken from the datasheet of the individual components and exact efficiency is considered as per the operational point.

IV. EXPECTED IMPROVEMENT IN PERFORMANCE

Massive MIMO improves performance in both coverage and capacity. Since there are multiple antenna elements, it provides array gain in downlink and uplink as well. Array gain reduces the power rating of amplifier in the transmit chain that improves the overall power consumption of massive MIMO eNB as discussed in the previous section. Array gain in the uplink increases the coverage which is very much required because of the uplink limitation in the cellular network.

MU-MIMO in the massive MIMO can provide the data capacity in both downlink and uplink [20]. Since, the data capacity is more important in the downlink, in the beginning, tier 1 infrastructure manufacturers are more focused on the downlink. However, uplink data capacity is also possible to increase by adding the extra baseband processing capacity in BBU. Both uplink coverage and downlink data capacity improvement have been analysed with reference to 2T2R macro eNB.

A. *Coverage Improvement in the Uplink*

To understand the coverage advantages because of massive MIMO with respect to 2T2R macro eNB, antenna specifications are required to understand for both types of eNB. Antenna specifications are listed in Table III. The conventional antenna used in 2T2R Macro eNB is of 17 dBi gain while the gain of the Antenna element recommended for massive MIMO is in the range of 7- 10 dBi. We have taken 8 dBi in this analysis. 2T2R macro eNB has only two antennas which lead to a maximum array gain of 3 dB while massive MIMO eNB has 64 antenna elements which increase array gain to 17 dB. This corresponds to the overall gain of 2T2R macro eNB of 20 dB whereas 32T32R massive MIMO will have 25 dB. Considering the gain of the individual antenna and array gain, it can be seen that massive MIMO eNB will have 5 dB more gain in uplink which results in 35 % of high uplink coverage.

B. Improvement in DL Throughput

In this analysis, the TM-7 mode, single layer MU-MIMO is considered. The improvement in DL throughput mainly depends on the PRB reuse factor in the massive MIMO. PRB reuse factor is determined based on the orthogonality of the received signal at the UEs. If the UEs are separated in space, the correlation between received signals at different UEs is less that allows the massive MIMO to create several streams simultaneously. Considering a maximum of eight simultaneous streams in an ideal scenario, data capacity can be increased theoretically by eight times in comparison with SU-MIMO. For example, if SU-MIMO can deliver 50 Mbps peak throughput in the downlink, 400 Mbps throughput can be achieved in the ideal scenario with 32T32R Massive

MIMO [12]. However, it is very difficult to achieve similar results in the field due to nLOS, mobility, and spatial separation. SRS periodicity determines the massive MIMO throughput in the presence of mobility. In this paper, lab test results with the cabled environment and field tests with LOS/nLOS/mixed-mode scenarios are discussed in the next section.

TABLE III
ANTENNA GAIN ENHANCEMENT IN MASSIVE MIMO

Parameter Details	Unit	Conventional Antenna for 2T2R Macro eNB	Massive MIMO Antenna
Horizontal BW	degree	65	90
Vertical BW	degree	7	40
Gain	dBi	17	10
No of Antenna (N)		2	32
Array Gain ($A= 10\cdot Log_{10} N$)	dBi	3	15
Overall Gain (N +A)	dBi	20	25

V. FIELD TEST RESULTS

We carried out an initial field test along with 32T32R massive MIMO eNB to identify the capacity gain in the real scenario where LOS and nLOS both types of UE were present. The test was conducted in an outdoor scenario in Mumbai city. Eight Samsung Galaxy phones were used in this testing and were kept at least 10-meter distance from each other. Three different configurations were tested in the field to understand the gain in various scenario as listed below:

- All 8 UEs in LOS
- All 8 UEs nLOS and
- mixed scenario (4 UEs in LOS and 4 UEs in nLOS)

Table IV provides the details of RF parameters including RSRP, SINR, and DL-Throughput for all three scenarios along with 8 different UE locations. It is seen that massive MIMO eNB provides better downlink (DL) throughput when all 8 UEs are in LOS and provides least DL throughput in case of all UEs are in near-LOS. Massive MIMO eNB is also able to provide a gain in a mixed scenario where 4 UEs are in LOS and the remaining 4 UEs are in nLOS. DL Throughput was achieved in the range of 176 to 308 Mbps in medium to good RF nLOS condition which is around 2-4 times in comparison with conventional 2T2R macro eNB. If one or two users would be at the extreme cell edge, the performance may deteriorate. Such an extensive field test with extremely poor RF condition (Users at indoor with SINR less than 0 dB) would be carried out further to understand the performance when all UEs are at the cell edge.

VI. SUMMARY

This paper has explained the advantages of massive MIMO eNB in terms of uplink coverage, downlink capacity, and power consumption. Summary of our analysis is as follows:

1. Massive MIMO can replace HPA with more number of low power amplifiers with matched p-HEMT devices which reduces the power consumption, cost, and overall development time of the product.
2. Transceiver directly connects to the antenna without the need of any cable reduces the insertion loss in front end module which leads to the improvement in both power efficiency and RX sensitivity.
3. 35% of uplink coverage may be improved by using massive MIMO eNB with respect to 2T2R macro eNB.
4. 8 times data capacity in a downlink can increase in comparison with 2T2R macro eNB with transmit diversity in an ideal scenario. Similarly, 4 times data capacity increases in comparison with spatial multiplexing (SM) mode considering the ideal scenario.
5. As per the initial filed trial, DL throughput can be achieved between 200-300 Mbps in the different RF conditions which is around 2-4 times in comparison with conventional 2T2R macro eNB.
6. Combining the data power consumption and data capacity, power consumption per megabits is calculated as shown in Table V. 32T32R Massive MIMO eNB increases the power efficiency around 2 times in comparison with 2T2R macro eNB.

TABLE V
COMPARISON OF POWER CONSUMPTION PER MBPS FOR 2T2R CONVENTIONAL ENB AND 32T32R MASSIVE MIMO ENB

Parameter Details	Unit	Conventional Antenna for 2T2R Macro eNB	Massive MIMO Antenna
Power Consumption	Watts	200	310
Data throughput as per the field data	Mbps	80	280
Power consumption	Watts/Mbps	2.4	1.11

TABLE IV
FIELD MEASUREMENT REPORTS WITH 32T32R MASSIVE MIMO ENB

RF Parameter Details	**Unit**	**UE1**	**UE2**	**UE3**	**UE4**	**UE5**	**UE6**	**UE7**	**UE8**	**DL Throughput (in Mbps)**
8 UEs placed in Line of Sight (LoS) locations										
RSRP	dBm	-65	-64	-58	-65	-65	-65	-77	-77	308
SINR	dB	30	30	26	28	26.6	25	21	18.6	
DL-Throughput	Mbps	41.2	35	37	42.5	37	38	38	39.2	
8 UEs placed in Near Line of Sight (nLOS)										
RSRP	dBm	-87	-86	-84	-90	-90	-87	-89	-87	176
SINR	dB	19	19.6	23.8	27.2	25	23.2	19.6	23.6	
DL-Throughput	Mbps	19	17	16	19	19	17	22	21	
4 UEs are in LOS and 4 UEs are in nLOS										
RSRP	dBm	-64	-64	-68	-69	-86	-86	-84	-85	280
SINR	dB	27	24	26	26	21.6	21.3	22.8	21.8	
DL-Throughput	Mbps	38	42	38	40	30	30	32	30	

VII. FORWARD PATH

Massive MIMO product is in the initial stage of development and many more features are yet to be developed. The following points are yet to be addressed for considering the 5G deployment.

a) TDD Massive MIMO is easy to implement by using the channel reciprocity however for FDD direction of arrival (DoA) based algorithm needs to be used.
b) Massive MIMO in TDD is a digital Beamforming which increases the data rate demand between BBU and RRH (CPRI Interface). There will be a large number of transceiver chains in 5G in the order of 256 to1024. Digital Beamforming is not going to work for these many chains. Hence hybrid Beamforming may be used for 5G Radio with suboptimal performance.
c) 5G radio for above 6 GHz band requires to transmit signal up to 800 MHz bandwidth. Power-efficient linear Power amplifier design with 800 MHz channel bandwidth will also be a challenge.

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