MIMO-IoT Connectivity for Next Generation Advanced Wireless System

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***Abstract*—This paper gives brief introduction of massive MIMO with IoT used for various wireless systems. Also massive MIMO concept like antenna selection for MIMO, performance of MIMO systems, various channels for better utilization of MIMO and their research is described in detail. IEEE 802.11n standard is given to MIMO. Various architectures of MIMO systems and corresponding features are discussed. Large scale antenna system is also massive MIMO. For getting high spectral efficiency and high data rates large number of DoFs are exploited. To support high rates there are many methods and researches for designing communication for utilizing the massive MIMO for IoT. mMTC, eMBB and URLLC are the three generic types for 5G IoT connections. MIMO uses low-power components, reduced latency, simplified version of MAC layer and robustness against jamming. Acquiring acquisition and synchronization for low-cost low-precision components to work together effectively is a challenge for massive MIMO.**

***Keywords*—** eMBB, H-S/MRC, mMTC, Massive MIMO, MPSK, Spatial Multiplexing, URLLC.

1.INTRODUCTION

eMBB, mMTC and URLLC are the three types of connectivity for the future 5G radio networks that will support heterogeneous requirements of connections. eMBB is a part of LTE is useful to increase the network spectral efficiency and data rates. It provides the services like broadband access, video streaming with ultrahigh-quality, virtual reality and augmented reality. With high-reliability small data packets are transmitted by URLLC with error probability [1] Latency requirement for plane user must be 1ms including uplink-downlink transmission [2]. It enables safety systems, wireless industrial robots, autonomous vehicles etc.

Service for large number of devices is provided by mMTC in which only a fraction of devices is active at a given time. Length of mMTC are comparable with URLLC in terms of packets. Within a given frequency-time interval, the performance of mMTC in terms of number of devices can be served is assessed. For LTE network, SE becomes critical because of small sporadic payloads.

The term massive MIMO means thousands of antenna arrays are arranged in a system serving simultaneously at tens of terminals in the same frequency-time resource [3]. Or simply means all the benefits of MIMO are reap but at a larger scale. For the future broadband networks that may be fixed or mobile massive MIMO is an enabler for such networks which can be robust, secure, energy-efficient and spectrum efficiently. Each antenna unit preferably fed by optical or electric digital bus that would be small and active. Spatial multiplexing is used in massive MIMO for that base station should have good channel knowledge for both uplink and downlink. By sending the pilots to the terminals for the uplink is easy to determine the channel responses. Downlink is more difficult. In LTE that is a conventional MIMO systems, the pilot waveforms are sent by base station so that channel responses are estimated and are back feed by base station. When operating in a high-mobility environment, massive MIMO is not feasible for two reasons:

- Between antennas, optimal downlink pilots should be mutually orthogonal. Massive MIMO systems require 100 times than a conventional system so that amount of time-frequency resources with number of antennas needed for downlink pilots scales
- Number of base station antennas is proportional to the number of channel responses each terminal must eliminate. Hence, on compare with conventional systems channel responses should be 100 times that is informed by uplink resources to the base station.

A. *Services of Massive MIMO*

In the context of next-generation wireless system, a massive antenna array is seen as a distinctive technology [4], [5]. Channel hardening and favorable propagation are two important features achieved by large number of DoFs that are spatial dimension [6], [7]. The transformation of multi-antenna i.e., massive into deterministic, this whole process is called channel hardening. Growing the size of antenna array and more separation between the propagation channel is called favorable propagation. Massive MIMO enables high user throughput and high SE for eMBB [8], [9]. Massive MIMO is beneficial for URLLC and mMTC but not directly transferable it is directly used by eMBB.

For attaining high reliability low latency spatial DoFs are required in URLLC. DoFs in large number helps in channel hardening. DoFs also combined with favorable propagation in large number for spatial multiplexing with efficiency. Channel estimation process depends on the efficient use of spatial DoFs in large number. To estimate the full channel eMBB should be fully optimized. In URLLC, massive MIMO either operate in non-coherent process or shorten estimation process. Inter-user interference is affected by imperfect channel estimation. Different sets of problem are possessed by the requirements like collision resolution[14].[15],[16],[z17], activity detection[10],[11],[12],[13]and low-rate wide-area coverage.

The following two features shows the efficient use of massive MIMO to support mMTC are as follows:

- For large number of devices, MUD enabled by favorable propagation property.
- SNR is boosted by array gain to extend the coverage.

Abbreviations

AAS	Active Antenna system
CSI	Channel State Information
DoF	Degree of Freedom
eMBB	Extended Mobile Broad Band
FEC	Forward Error Correction
HARQ	Hybrid Automatic Request
LTE	Long Term Evolution
MF	Matched filtering
MIMO	Multiple Input Multiple Output
mMTC	Massive Machine Type Communication
MRC	Maximum Ratio Combining
MRT	Maximum Ratio Transmission
MUB	Multi User Detection
PMI	Pre coder Matrix Indicator
PSK	Phase Shift Keying
RAN	Radio Access Network
SE	Spectral Efficiency
SNR	Signal to Noise Ratio
SRS	Sounding Reference Symbols
URLLC	Ultra-Reliable Low Latency Communication
ZF	Zero Forcing

B. Research Literature

1) eMBB and Massive MIMO: The motivation for massive MIMO is to maximize the SE [5], [8]. For spatially multiplexed users, careful optimization is required to achieve high SE along with channel overhead hardening is also considered. Channel hardening is more effective for increasing number of antenna [18]. From the achievable rate of view, there must be trade-off between array size and number of DoFs per user [9]. The most severe limiting factor in achieving high SE in a multi-cell massive MIMO is Pilot contamination [19], [20], [21]. In the presence of pilot contamination when number of antennas increases MIMO systems becomes unbounded in case of correlated channels [22].

2) URLLC and Massive MIMO: URLLC has requirement for internet and number of antennas for given users using MRT and ZF beamforming assuming ideal channel estimation. Imperfections or pilot contamination affects the estimation of channel. In order to assign unique user signatures FEC are exploited for separating the pilot-interacting users.

In [23], author compares coherent and non-coherent transmission for multi-antenna BS and single or two antennas at the transmitting side. Author concludes that higher SNR is required for non-coherent transmission.

3) mMTC: Author discuss to tackle the problem in mMTC for massive number of access attempts in broad sense that the different physical and medium access techniques.

Following are the techniques for physical layer:

- Compressive sensing used by multi-user detection
- Physical layer network code for Collision resolution and harnessing of inference
- Relaxed time-alignment for non-orthogonal access.

C. *Potential of massive MIMO*

Phase coherent is relied by massive MIMO but at the base station from all the antennas processing of signals is simple. Here are some advantages of MIMO systems:

- *Capacity increases about 10 times and efficiency of radiation energy is increases about 100 times via massive MIMO.* Capacity increases when massive MIMO uses spatial multiplexing. Efficiency increases when energy is focused in a small region through large number of antennas. There must be trade-off between energy efficiency and spectral efficiency. Energy efficiency is related in terms of transmission of total number of bits per joule divided by receiving service of energy spent. MRC more works well than ZF for massive MIMO. MRC receiver is so useful that it can operate in noise-limited regime of information theory i.e., rate of 1b/complex dimension (1b/s Hz) is given to each terminal. For uplink, MRC receiver and for downlink its MF.
- *Massive MIMO can be built with low-powered inexpensive components.* With regard to theory, systems and implementations massive MIMO is a game changing technology.
- *Multiple access layer is simplified by massive MIMO.*
- *Robustness increases due to massive MIMO against man-made interference that is unintended and international jamming.* Degree of freedom is given by massive MIMO to cancel the signals from jammers i.e., international jammers.
- *Latency reduces due to massive MIMO.* Fading limits, the performance of wireless communication. Received signal strength is affected by fading Fading is done when signal travels through multiple paths.

D. *Standards for 3GPP*

Massive MIMO included by 5G NR i.e., advanced antennas with complex digital beamforming or hybrid analog/digital beamforming and large arrays.5G NR specification is first froze by 3GPP. eMBB is a subset of 5G requirements and focused on early commercial deployments in release 15[24]. Maximum 256 antennas is supported by 5G NR on comparing with 64 elements in release 13. To focus the power in a particular direction, multiple antennas is required that is called massive MIMO.

At the end of 2019, the second phase of the standardization is finalized to fulfill the targets of 5G requirements. in Multi-user MIMO and multi-beam multi-transmission point operation are the enhancements in massive MIMO. On-going work includes URLLC physical layer enhancements and industrial IoT. AAS uses FD-MIMO for 2-D planar structure in which large number of antennas are packed. Adaptive electronic beamforming is another important possibility to form a beam in both horizontal and vertical direction and cover any point in the 3D space.

To support a heterogeneity and services of 5G,5G frame has been designed [25]. The principle of general design is that there must be static and strict timing relation. Instead of using predefined retransmission time, asynchronous HARQ is used. For subcarriers up to 60kHz, a slot of 7or 14 OFDM symbols are assigned. More than 14 OFDM symbols are assigned for more than 60kHz frequency. Multiple slots for data transmission can be spanned to increase the coverage or reduce the overhead due to switching and control information. For LTE, the TDD UL/DL scheme is much more flexible. A slot may contain either DL or UL or combination of DL/UL and pattern can be changed in each slot or sub frame. For more flexible capacity allocation, a faster TDD switching is allowed. For more efficient massive MIMO there must be SRS in every slot may be possible that allowed a more optimized TDD channel reciprocity. In each slot, ACK should be scheduled to make faster TDD switching turn-around. A mini-slot is given for low latency transmissions purpose which can be start with any time and slot is also shorter than regular slots duration. Mini-slot is the smallest scheduling unit and can be short as one OFDM symbol.

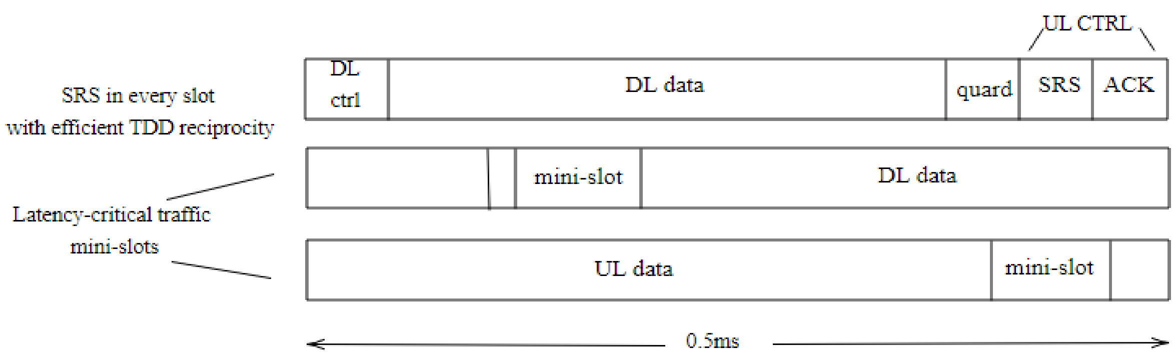

Figure 1 TDD 5G Frames

E. Antenna Selection for MIMO system

Multiple antenna presents at both transmitter side and receiving side are known as multiple input multiple output i.e., MIMO [26]. These systems are used in 3rd generation cellular systems i.e., W-CDMA. For high-performance of wireless local area networks that have standard IEEE 802.11 are also discussed for MIMO.

There are two different ways of exploitation of MIMO systems, one is creation of antenna diversity system with highly effectiveness other is to increase the capacity of system for that parallel transmission is done by multiple antennas.

In wireless systems, effects of fading are combat by antenna selection. The combination of independent multiple copies of same signal are available and then added into a total signal. Secondly, different signal copies are linearly combined with weighted and added. Demodulation and decoding of resulting signal at the combiner output is done through MRC (mentioned above). For MRC, weights must be matched with wireless systems and weights must be optimum.

Suppose the diversity order for N antenna elements that describes the effectiveness of diversity in avoiding deep fades is also N. Diversity order is related with signal-to-noise ratio at the combiner. At the combiner output, average SNR increases through multiple antennas.

Space-time-coding or delay diversity is used in case when channel is unknown at the transmitter side. But in this case, average SNR is not improved instead high diversity order is gain. Transmitting diversity and receiving diversity is combine is the next step.

If $N_{transmit}$ are transmitter antennas and $N_{receive}$ are the receiving antennas then $N_{transmit}N_{receive}$ are the diversity order is achieved[27].

Spatial Multiplexing is another way to exploit the multiple antennas [28]. Spatial multiplexing is also known as BLAST [29] approach. From different transmitting antennas, data stream is also transmitted in parallel that also are different. Different data streams are separated at the receiver through multiple receive antenna elements.

Received signals $N_{receive}$ are represented by linearly independent signals if channel is well behaved. If $N_{transmit} \leq N_{receive}$ then transmit signals can also be recovered. Without requiring more spectrum, by the factor of $N_{transmit}$ data rate is increased.

Complexity and the cost are the main drawback of MIMO systems.

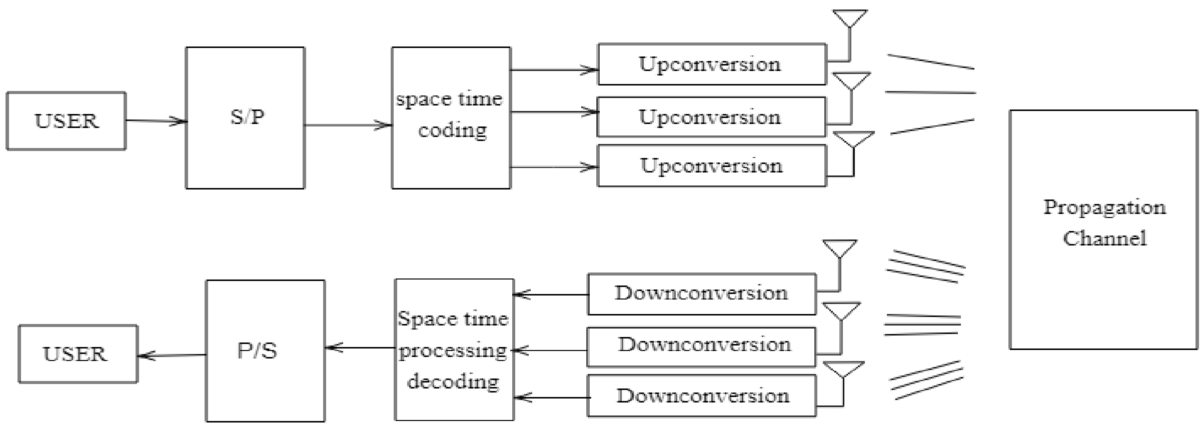

Figure 2 Spatial Multiplexing Principle

Hybrid selection/maximum-ratio-combining(H-S/MRC) or generalized selection combining is used for diversity purposes for multiple antennas.

Notation

In this article , an alphabet with arrow denotes vector i.e.,$\vec{x}$, an alphabet with underline $\underline{X}$, complex conjugate denotes by * and Hermitian transpose is denoted byX^T.

2.SYSTEMMODEL

Vector encoder and modulator sends bit stream as shown in figure. Stream of complex symbols are denoted by $L_{transmit}$ that is parallel and that are converted into a single bit stream by encoder. Same information is present in all streams. From available antenna branches, best $L_{transmit}$ modulated signals out of $N_{transmit}$ are switched by multiplexer. Complex weights are multiplied with signal whose value depends on channel realization.

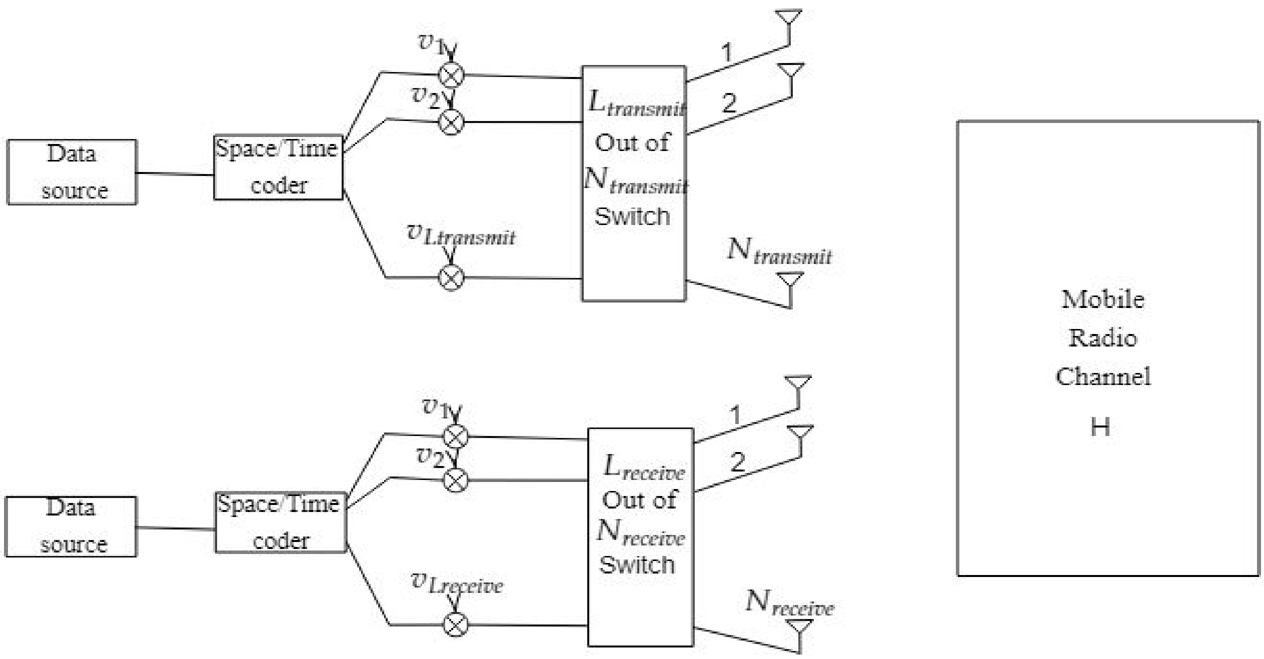

Figure 3 Block Diagram of considered system

Through quasistatic flat-fading channel, signal is transmitted.

We denote the $N_{transmit} \times N_{receive}$ matrix of the channel $\underline{H}$. Suppose pth is the transmit antenna and qth is the receive antenna and $h_{p,q}$ denotes the attenuation. Due to the Additive Gaussian Noise(AGN) output channel is polluted and assume to be independent at all receiving antenna. From $N_{receive}$ antenna $L_{receive}$ are the best one at all the receiver for further processing these are selected and down converted. Complex weights $\vec{w}^*$ are included in further processing and also linear combining or space-time-processing and decoding.

Following are the assumptions:

1) Independent Identically Distributed (i.i.d.) Rayleigh Fading is assumed for fading is assumed for different antenna elements. And this is done if transmitter or receiver components from direction of multipath components are uniform [30].
2) Assuming frequency flat fading so that channel coherence bandwidth is larger than bandwidth of transmission significantly
3) Receiver must have perfect channel knowledge, there may/ may not need of channel knowledge for transmitter side.
4) Assuming channel is Gaussian means long coherence time of the channel may be approx. infinite so that many bits can transmitted within this time. Shannon-AWGN is the channel realization. Cumulative distribution function is used for capacity as it is a random variable.

   So for input-output relationship expression is establish

$$\vec{y}=\underline{H}\vec{s}_t + \vec{\eta} \qquad (1)$$

where $\vec{s}_t$is the transmit signal and $\vec{\eta}$ is the noise vector.

3.Performance of Single Input Multiple Output (SIMO) systems

To optimize the performance i.e., to achieve largest possible SNR at each instant for the case L out of N antennas output SNR of MRC is the algebraic sum of SNRs at the different receive antenna elements.

$$y_{output_{H-S/MRC}} = \sum_{x=1}^{L} y(x) \qquad (2)$$

For output SNR for H-S/MRC, mean and variance is given as:

$$\mu_{H-s/MRC} = L\left(1+\sum_{\eta=L+1}^{N}\frac{1}{\eta}\right)\bar{\mu} \qquad (3)$$

and

$$\sigma^2_{H-S/MRC} = L\left(1+\sum_{\eta=L+1}^{N}\frac{1}{\eta^2}\right)\bar{\mu}^2 \qquad (4)$$

Symbol error probability (SEP) for M-ary phase-shift keying (MPSK) with H-S/MRC is derived [x13] as

$$P_{e_{H-S/MRC}}^{MPSK} = \frac{1}{\pi}\int_0^{\Theta}\left[\frac{\sin^2\theta}{c_{MPSK}\bar{\mu}+\sin^2\theta}\right]^L \times \prod_{\eta=L+1}^{N}\left[\frac{\sin^2\theta}{c_{MPSK}\bar{\mu}\frac{L}{\eta}+\sin^2\theta}\right] d\theta \qquad (5)$$

where $\Theta = \frac{\pi(M-1)}{M}$ and $c_{MPSK} = \sin^2(\pi/M)$

4.Spatial Multiplexing in MIMO

Consider transmitter has no channel knowledge and for spatial multiplexing data streams that different are transmitted from different antenna elements.

For channel matrix $\underline{\widetilde{H}}$, combination of antenna elements is associated with its own channel.
To optimize the information-theoretic capacity

$$\mathbb{C}_{H-S/MIMO} = max_{S(\widetilde{H})}\left(log_2\left[det\underline{I}_{N_{receive}} + \frac{\bar{\mu}}{N_{transmit}}\underline{\widetilde{H}\widetilde{H}^T}\right]\right) \quad (6)$$

$\underline{I}_{N_{receive}}$ is the $N_{receive} \times N_{receive}$ identity matrix.

5.Limiting Factors of Massive MIMO

Reciprocity of channel

TDD is affected due to reciprocity of channel, if magnetic properties affect the materials then propagation channel is reciprocal. However, between the uplink and downlink, hardware chains in the base station and terminal transceivers may not be reciprocal.
If base station is properly calibrated then there, is not need of calibration for terminal uplink and downlink chains. But some mismatch within the receiver chain is present which limits the MIMO systems.

Pilot Contamination

In massive MIMO systems, every terminal is assigned with sequence orthogonal uplink pilot maximum of it is exist upper-bounded for the duration of coherence internal divided by the channel delay spread.
Pilot contamination is referred to those when pilot are reuses from one cell to another which produces negative consequences. In [31], it is mentioned that pilot contamination constitutes the limit on performance when number of antennas increases.

Radio Propagation

Favorable propagation is the important characteristic of radio environment i.e., for different terminals propagation channel responses should sufficiently different.
Using realistic antenna arrays, performance of channel measurements is studied for the behavior of MIMO systems.

6.Research problems in MIMO

1) There is challenge for fast processing. This processing must be simple and linear for that such researches must be invested[y19]
2) Low-cost hardware is a challenge, as many numbers of RF chains, up/down converters, A/D and D/A are requiring.
3) Internal power consumption is an issue as MIMO reduces up to 1000 times the radiated power. So there is a vast opportunity to have research on power consumed including baseband signal processing.
4) There is a need of calibration for reciprocity of TDD.
5) Pilot contamination is the challenge that limits the performance of massive MIMO.

7.Conclusions

In this paper, massive MIMO is highlighted as a key of future generation cellular systems especially for5G systems. Energy efficient, spectral efficiency, robustness and reliability are some advantages provided by MIMO. At both base station and mobile unit side it allows for the low-cost hardware. At base station, low-power efficient devices are used to operate coherently together. In terms of computational complexity, realization of distributed processing algorithm are the challenges and the part of research.

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