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Massive MIMO

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1. ABSTRACT:

Every new network generation needs to make a leap in area data throughput, to manage the growing wireless data traffic. The Massive MIMO technology can bring at least ten-fold improvements in area throughput by increasing the spectral efficiency (bit/s/Hz/cell), while using the same bandwidth and density of base stations as in current networks. These extraordinary gains are achieved by equipping the base stations with arrays of a hundred antennas to enable spatial multiplexing of tens of user terminals. This Paper explains the basic motivations and communication theory behind the Massive MIMO technology, and provides implementation related design guidelines.

2. Introduction:

Nowadays, Massive MIMIO technique is going to be well known throughout the world because of demanding for network technologies are increasing year by year the uses of people, organizations, companies …etc. are growing day by day, and they need much higher data rates to achieve all this flowing in data, mobile communication are now evolving towards the fifth generation (5G) in the near future.

5G enables a new kind of network that is designed to connect virtually everyone and everything together including machines, objects, and devices.

5G wireless technology is meant to deliver higher multi-Gbps peak data speeds, ultra-low latency, more reliability, massive network capacity, increased availability, and a more uniform user experience to more users. Higher performance and improved efficiency empower new user experiences and connects new industries.

5G will bring wider bandwidths by expanding the usage of spectrum resources, from sub-3 GHz used in 4G to 100 GHz and beyond. 5G can operate in both lower bands (e.g., sub-6 GHz) as well as mm Wave (e.g., 24 GHz and up), which will bring extreme capacity, multi-Gbps throughput, and low latency.

5G is designed to not only deliver faster, better mobile broadband services compared to 4G LTE, but can also expand into new service areas such as mission-critical communications and connecting the massive IoT. This is enabled by many new 5G NR air interface design techniques, such as a new self-contained TDD sub frame design.

3. **Massive MIMO:**

Massive MIMO (MaMi) is MU-MIMO technique where the numbers of base station antennas are much greater than the number of receiving terminals, which are typically assumed to be single-antenna devices. The extra antennas help by providing antenna gain, diversity and eliminating inter-user interference, bringing huge improvements in throughput and radiated energy efficiency. An increase of ten times or more in system capacity can be achieved with MaMi.

Unlike many other techniques, MaMi is well employed in rich scattering environments where the number of propagation paths is large. This makes MaMi well suited for urban environments, with many obstacles.

Another great benefit of MaMi systems is the opportunity for extensive use of inexpensive low-power components. MaMi-system has a great ability to average out errors over all the antennas which makes low complexity hardware a feasible solution for energy and cost reductions in MaMi-systems. This concept is the main core of this work.

Furthermore, thanks to the excessive number of base station antennas, simple linear signal processing can be used in the base station in place of more complex non-linear processing without significant loss of performance. This lowers base station complexity and improves energy reductions.

3.1 **Frame structure:**

The TDD frame structure, used here, and in which massive MIMO data is divided, is shown in Figure 1 below, one frame of 10 milliseconds (ms) consists of 10 sub frames, each containing two time slots of 0.5 ms. Every time slot consist of seven OFDM symbols, where the first three are used for uplink-transmission and the last three for downlink-transmission. The middle symbol is left empty to act as a guard interval to separate uplink-data from downlink-data; allowing transceivers to switch between transmit and receive.

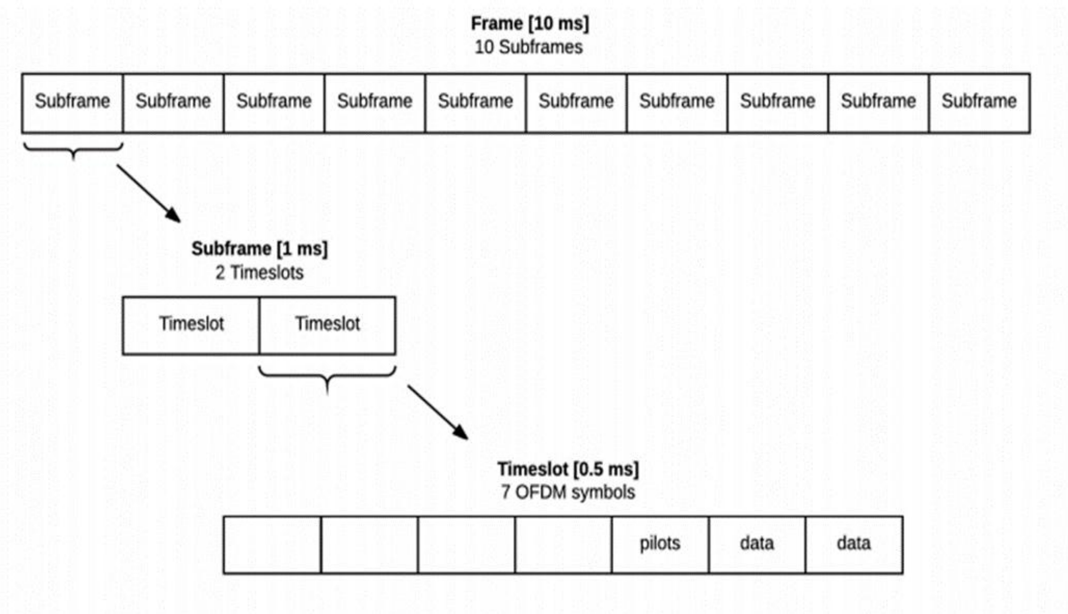

Figure (1): Massive MIMO frame structure.

3.2 Massive MIMO preceding:

Massive MIMO preceding can be described as a generalized form of Beamforming. That aims to minimize the error in the receiver output. A signal processing technique is performed in the base station, exploiting transmits diversity by weighting information streams based on the CSI estimated in the uplink. In massive MIMO systems, linear preceding techniques have turned out to be near optimal even if less complex than non-linear approaches. First of all, a general expression for the down-link transmission on one of the subcarriers can be described as

$y = Hz + n$……… (1)

Where y is a vector of the received signals at the K terminals, H the KxM channel matrix between the M base station antennas and the K single-antenna terminals, z the transmitted signals on the M base station antennas and n is the channel noise.

Now using a linear precode W to calculate the transmit signals on the M base station antennas, from the vector of data points x intended for the K terminals, we have

$z = W x$……… (2)...

3.2 linear precoding techniques

The most common linear precoding techniques used in massive MIMO are maximum ratio transmission (MRT) and zero-forcing (ZF). For a single-cell downlink massive MIMO system, ZF has been shown to achieve higher data rates than MRT.

3.3 Zero-forcing precoding

In ZF precoding, the multiple transmit antennas can cancel out the inter user interference. Hence, ZF is referred to as null-steering. The ZF-processing in the base station can be expressed as:

$$W_{\mathrm{ZF}} = H^H(HH^H)^{-1} = W_{\mathrm{MRT}}(HH^H)^{-1} \quad ..(3)$$

Where H is the estimated channel matrix, W an MxK matrix, M is referring to the number of transmit antennas and K to the number of receiving single-antenna users.

3.4 Maximum ratio transmission (MRT):

MRT is one technique of linear precoding which maximizes the signal gain at the intended user. The MRT precoding employed by the BS is written as

$$W = H^H \quad \ldots\ldots\ldots\ldots\ldots (4)$$

For large values of M and K, the related signal-to-interference-plus-noise ratio of the kth user is given as

$$SINR_K^{mrt} = \frac{P_d M}{K(P_d + 1)} \quad \ldots.. (5)$$

it is obvious that for the same available downlink transmit power and same value of M and K in ZF and MRT cases, the two schemes have different signal-to- interference-to-noise ratio.

Therefore, the same value should not be assigned to it (SINR) for both precoders for a good performance comparison.

3.5 **Differences between Multiuser MIMO and Massive MIMO**

Table (1): differences between multiuser MIMO and massive MIMO

3.6 Area Throughput:

	Multiuser MIMO	Massive MIMO
M_j and K_j	$M \approx K$ and both are small (e.g., < 10)	$M \gg K$ and typically large (e.g., $M = 100$, $K = 20$).
Duplexing	Designed to work in both TDD and FDD	Designed for TDD and exploits channel reciprocity
CSI acquisition	Mainly based on codebooks with set of predefined angular beams	Based on sending uplink pilots and exploiting channel reciprocity
Link quality	Varies rapidly due to frequency-selective and small-scale fading	Small variations over time and frequency, thanks to channel hardening
Resource allocation	Changes rapidly due to link quality variations	Can be planned since the link quality varies slowly

The area throughput of a cellular network is measured in bit/s/km2
Area throughput = B [Hz] · D [cells/km2] · SE [bit/s/Hz/cell]… (6)
Where B is the bandwidth, D is the average cell density, and of information transferred per second over a unit bandwidth.

To increase the area throughput they are three ways which are:

1. Allocate more bandwidth.

2. Density the network by adding more BSs.

3. Improve the SE per cell.

3.7 Spectral Efficiency:

The spectral efficiency (SE) of an encoding/decoding scheme is a number of bits of information, per complex-valued sample, that can be reliably transmitted over the channel under consideration.

3.7.1 Equivalent units:

3.7.1.1 Bit per complex-valued sample

3.7.1.2 Bit per second per Hertz (bit/s/Hz)

3.8 Canonical Massive MIMO Network:

Network is a multicarrier cellular network with L cells that operate according to a synchronous TDD protocol.1 BS j is equipped with Mj 1 antennas, to achieve channel hardening. BS j communicates with Kj single-antenna UEs simultaneously on each time/frequency sample, with antenna-UE ratio Mj/Kj > 1. Each BS operates individually and processes its signals using linear receive combining and linear transmit preceding.

3.9 Deployment strategies:

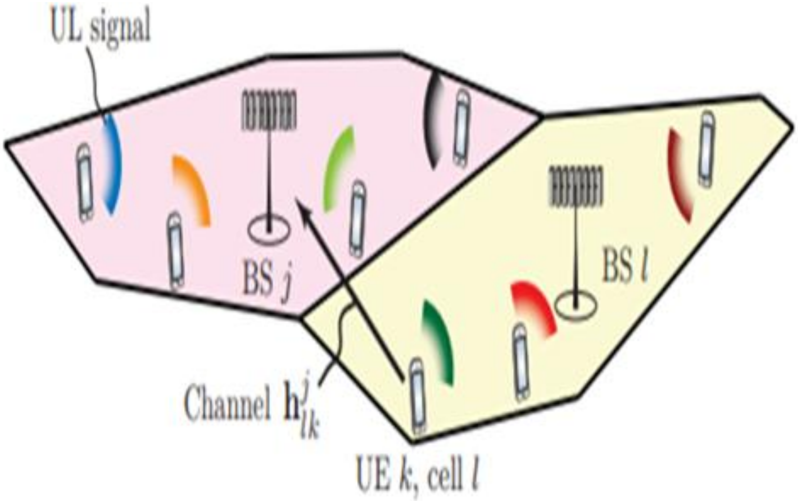

Figure (2): Canonical Massive MIMO Network.

3.9.1 One or multiple cell sectors

3.9.2 One or multiple arrays per cell

3.10 Massive in numbers, not in size:

3.10.1 BSs in LTE have hundreds of radiating elements, but few RF chains

3.10.2 Novelty Every radiating element is an antenna with an RF chain

3.11 Radiating Element, Antenna, and Antenna Array:

An antenna consists of one or more radiating elements (e.g., dipoles) which are fed by the same RF signal. An antenna array is composed of multiple antennas with individual RF chains

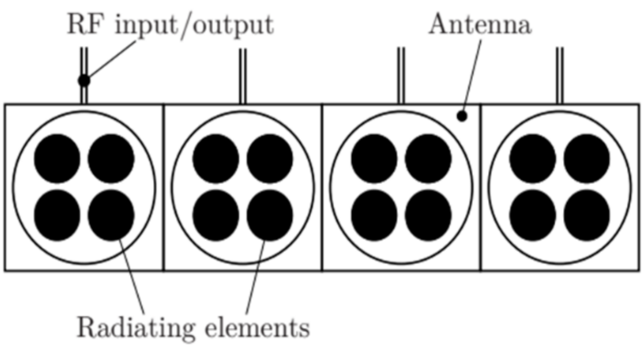

Figure (3): radiating element, antenna, and antenna array.

3.12 Uplink Channel Estimation:

In the uplink, the channel vector to an unlimited number of antennas can be learned from a single pilot transmission. If there are K single-antenna UEs, then K pilot signals are required.

The UE sends a single pilot signal s ∈ C that is known at the BS

$$y = hs + n…….. (7)$$

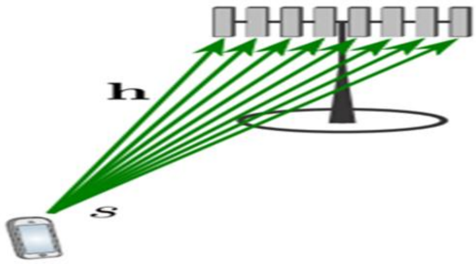

Figure (.4): uplink channel estimation.

3.13 Downlink Channel Estimation:

The BS sends a known pilot signal s subsequently from each antenna, Received signal at the UE:

ym = hms + nm m = 1. . . M…….. (8)

•Simple estimate of hm.

• The **UE** feeds hˆ back to the BS.

M pilot transmissions (plus feedback) are needed to estimate the downlink channel.

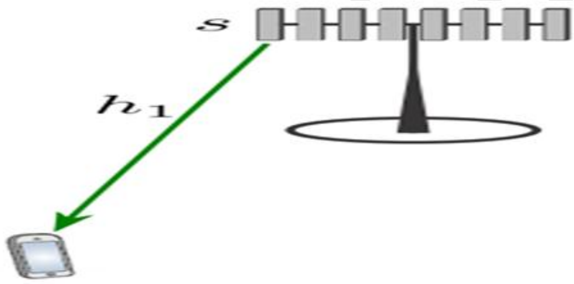

Figure (5): downlink channel estimation.

3.14 Channel Coherence Block:

A coherence block consists of a number of subcarriers and time samples over which the channel response is approximately constant and flat-fading. If the coherence bandwidth is Bc and the coherence time is Tc, each coherence block contains:

$$\tau c = BcTc…….. (9)$$

Complex-valued samples.

• Tc and BC depend on carrier frequency, UE speed, delay spread, etc.

•Typical values for Tc and Bc are in the range from 1–50 ms and 0.2–1 MHz: a coherence block contains 200–50000 samples.

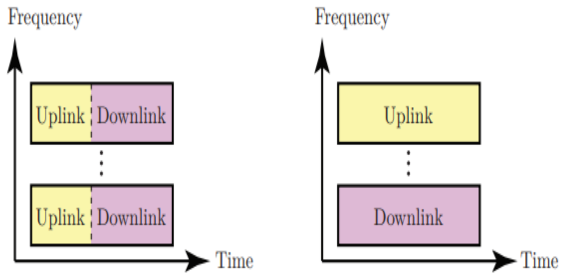

Figure (6): Channel coherence block.

Different ways to assign UL and DL to coherence blocks:

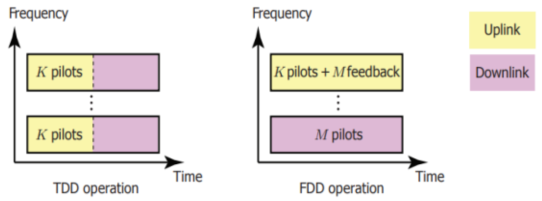

Figure (7): ways to assign UL and DL to coherence blocks.

3.14.1 Time-division duplex (TDD):

Overhead per block: K pilots.

• UL/DL channels are reciprocal.

• Only BS needs to know full channels.

3.14.2 Frequency-division duplex (FDD):

Overhead per block: M + K 2.

• K pilots + M feedback in UL.

• M pilots in DL.

Feasible Operating Points Illustration of operating points (M, K) supported by using τp = 20 pilots, for different TDD and FDD protocols. The shaded area corresponds to operating points that are preferable in SDMA systems. Only TDD and the resulting channel reciprocity allow for very large M**.**

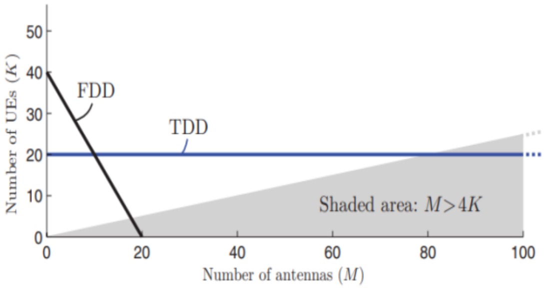

Figure (8): shaded area

3.15 Channel Parameterizations:

In some propagation scenarios, the M-dimensional channels can be parameterized using much less than M parameters.

• Key example: LoS propagation.

• Mainly depends on the angle between the BS and the UE.

• Instead of transmitting M DL pilots, select a set of equally spaced angles and send precoded DL pilot signals only in these directions.

• If the number of angles is much smaller than M, then this method can enable FDD operation with potentially good estimation quality but:

• LoS channel parameterizations depends on array geometry.

• UE channels are likely a mixture of NLoS and LoS components TDD operates efficiently in any kind of propagation environment.

3.16 Energy Efficiency:

The EE of a wireless communication system is the number of bits that can be reliably transmitted per unit of energy [bit/Joule]

1Power

$$\mathrm{EE} = \frac{\text{Throughput [bit/s/cell]}}{\text{Power consumption [W/cell]}}$$ … (10)

Consumption:

$$\underbrace{\mathrm{PC}}_{\text{Power consumption}} = \underbrace{\mathrm{ETP}}_{\text{Effective transmit power}} + \underbrace{\mathrm{CP}}_{\text{Circuit power}}$$ **..(11)**

3.17 Circuit Power for Massive MIMO:

Transceiver hardware at the BS and UE are not the only contributions A CP model for a generic BS j in a Massive MIMO network is

$$\mathrm{CP}_j = \underbrace{P_{\mathrm{FIX},j}}_{\text{Fixed power}} + \underbrace{P_{\mathrm{TC},j}}_{\text{Transceiver chains}} + \underbrace{P_{\mathrm{CE},j}}_{\text{Channel estimation}} + \underbrace{P_{\mathrm{C/D},j}}_{\text{Coding/Decoding}} + \underbrace{P_{\mathrm{BH},j}}_{\text{Load-dependent backhaul}} + \underbrace{P_{\mathrm{LP},j}}_{\text{Linear processing}}$$

…… (12)

• Before Massive MIMO, the CP of these operations was negligible compared to PFIX, j

• A tractable and "realistic" model for each term is now needed

• Economical expenses can be potentially added — by dividing the network cost rate (in $/s) with the energy price (in Joule/$).

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4. Modeling of massive MIMO:

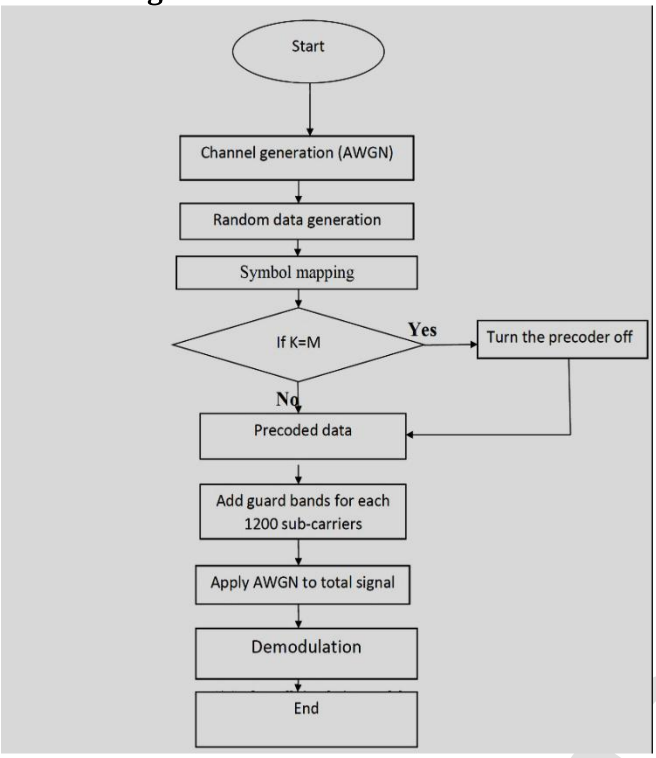

Figure (9)

Result of Simulation:

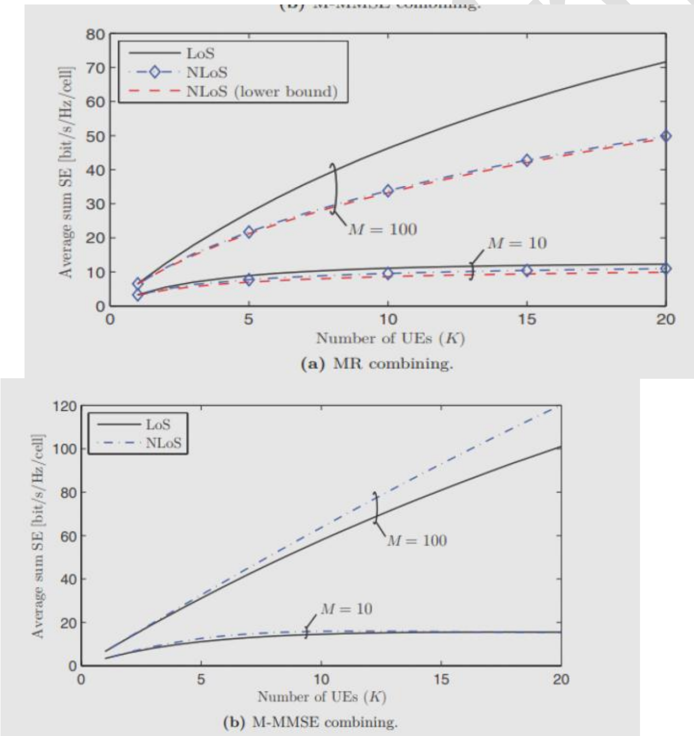

Figure (10)

Figure (10) Average UL sum SE as a function of the number of UEs per cell for different combining schemes, different channel models, and either M = 10 or M = 100 BS antennas.

The SNR is SNR0 = 0 dB and the strength of the inter-cell interference is $\bar{\beta}$ = −10 dB. The sum SE grows linearly with K as long as M/K remains large. M-MMSE rejects interference more efficiently than MR.

Figure (11): Average DL sum SE as a function of the number of BS antennas for different precoding schemes. There is K = 10 UEs per cell and the same K pilots are reused in every cell.

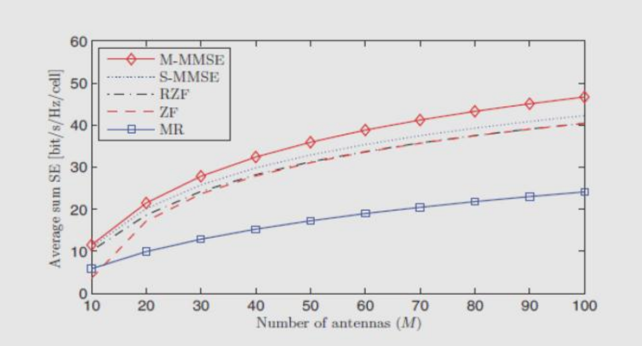

Figure (11)

Figure (12): Average DL sum SE as a function of the number of BS antennas for different precoding schemes. There are K = 10 UEs per cell and either 2K or 4K pilots that are reused across cells.

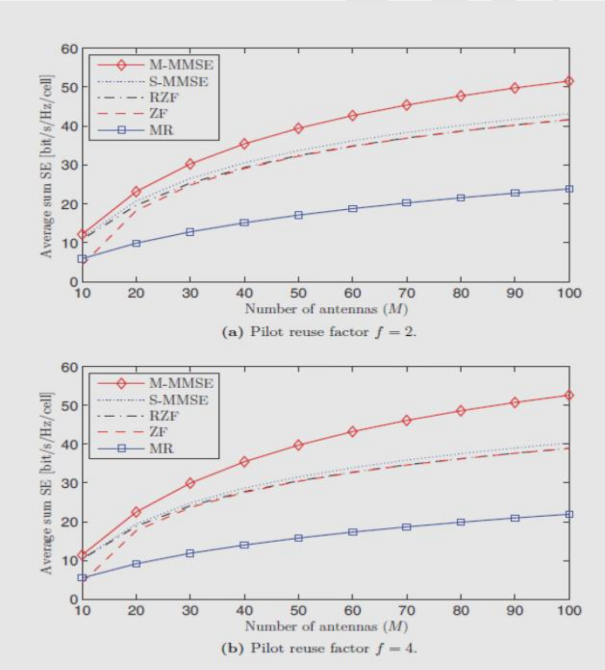

Figure (12)

5. Conclusions:

Users of future networks will demand wireless connectivity with uniform service quality, anywhere at any time

- .The demand for data traffic increases rapidly and calls for higher area throughput in future cellular networks. This can be achieved by cell densification, allocating more frequency spectrum, and/or improving the SE [bit/s/Hz/cell]
- .Current and future network infrastructure consists of two key parts: the coverage tier and the hotspot tier. The area throughput needs to be improved in both tiers
- .The coverage tier takes care of coverage, mobility, and guaran-tees a minimum service quality. To increase the area through-put of this tier, it is preferred to increase the SE, since densification or the use of spectrum at higher frequencies degrade the mobility support and coverage
- .The hotspot tier offloads traffic from the coverage tier, for example, from low-mobility indoor UEs. Densification and the use of new spectrum at higher frequencies are attractive ways to increase the area throughput of this tier, but the SE can be also improved by an array gain
- .The SE of a single UE is a slowly increasing, logarithmic function of the SINR. Only modest SE gains are possible by increasing the SINR (e.g., by using higher transmit power or deploying multiple antennas at the BS)

.

- AK-fold SE gain is achievable by serving KUEs per cell, on the same time/frequency resources, using SDMA. The number of BS antennas is preferably increased with K to get an array gain that compensates for the increased interference.
- Each BS should have more antennas, M, than UEs, leading to an antenna-UE ratio M/K >1. This makes linear UL receive combining and DL transmit pre coding nearly optimal since each interfering UE contributes with relatively little interference.
- When the number of BS antennas is large, the effective channels to the desired UEs are almost deterministic after combining/ pre coding, although the channel responses are random. This phenomenon is called channel hardening.

CSI is used by the BS to spatially separate the UEs in UL and DL. The channels are most efficiently estimated with a TDD protocol that utilizes channel reciprocity, since only UL pilot signals are required and no feedback is needed.

6. Recommendations:

- Make Massive MIMO work in FDD mode
- Channel measurements, channel modeling, data track modeling.

Required for system level simulations, Cross-layer system design, Protocols for random access and system information broadcast, Spatial resource allocation, Power control balancing sum SE and fairness, Estimation of spatial correlation properties under mobility, Information theory advances, Tighter lower bounds on ergotis capacity, without channel hardening, Non-trivial upper bounds on capacity, New deployment characteristics, Multi-antenna users, distributed arrays, cell-free (network MIMO).

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