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OPTIMAL DESIGN OF ENERGY-EFFICIENT MULTI-USER DETECTION IN MASSIVE MIMO SYSTEMS

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ABSTRACT

Assume that a multi-user multiple-input multiple output (MIMO) system is designed from scratch to uniformly cover a given area with maximal energy efficiency (EE). What are the optimal number of antennas, active users, and transmit power? The aim of this paper is to answer this fundamental question. We consider jointly the uplink and downlink with different processing schemes at the base station and propose a new realistic power consumption model that reveals how the above parameters affect the EE. Closed-form expressions for the EE-optimal value of each parameter, when the other two are fixed, are provided for zero-forcing (ZF) processing in single-cell scenarios. These expressions prove how the parameters interact. For example, in sharp contrast to common belief, the transmit power is found to increase (not to decrease) with the number of antennas. This implies that energy-efficient systems can operate in high signalto-noise ratio regimes in which interference-suppressing signal processing is mandatory. Numerical and analytical results show that the maximal EE is achieved by a massive MIMO setup wherein hundreds of antennas are deployed to serve a relatively large number of users using ZF processing. The numerical results show the same behavior under imperfect channel state information and in symmetric multi-cell scenarios.

Index Terms—Energy efficiency, massive MIMO, linear processing, system design, downlink, uplink, imperfect CSI, single cell, multi-cell.

Introduction

Monstrous various information different yield otherwise called huge scale reception apparatus frameworks proposed in [1], another exploration zone in remote interchanges, is distinguished as the most ideal approach to expand the unearthly effectiveness of remote correspondence framework. Gigantic MIMO in which the base stations are furnished with extremely enormous number of intelligently working radio wires gives both decent variety addition and multiplexing gain. Gigantic MIMO expands the information rate to an enormous degree on account of the huge number of receiving wires. Every reception apparatus can convey autonomous information streams and progressively number of terminals can be served at the same time giving full band width to every terminal. It can expand the ability to multiple times or more in view of the multiplexing utilized. Monstrous MIMO can be worked with economical, low power parts on the grounds that the costly ultra straight 50W enhancers utilized with regular frameworks are supplanted by several low power speakers of mW range[2], [3]. It lessens the limitations on precision, linearity and RF gain prerequisites of the speakers utilized.

It gives exceptionally upgraded vitality proficiency as the BS can center the transmitted vitality to the spatial headings where the clients are actually found [4], [5]. Since it utilizes the guided shaft toward the terminal it lessens the impedance to different channels. Monstrous MIMO empowers a huge decrease of inertness noticeable all around interface since it depends on the law of huge numbers and pillar shaping so as to abstain from blurring plunges. Monstrous

MIMO rearranges the numerous entrance layer in light of the fact that the channel solidifies so recurrence space booking never again satisfies and furthermore every terminal can be given with the full data transmission, which renders the majority of the physical layer control flagging excess. Enormous MIMO builds the heartiness to deliberate sticking on the grounds that it offers numerous overabundance degrees of opportunity that can be utilized to drop signals from purposeful jammers. These enormous surplus degrees of opportunity can be successfully utilized for equipment agreeable sign forming.

Each one of those phenomenal benefits can be accomplished with extremely low multifaceted nature direct sign preparing strategies [6]–[8]. All the unfriendly results of uncorrelated clamor and quick blurring vanish and the handiest last hindrance in huge MIMO is the between versatile obstruction because of pilot contamination. In this manner, huge MIMO has been considered as one of the most extreme looked for after and imaginative innovation for the fifth innovation remote correspondence frameworks [2], [9]. There is persistently a quickly developing interest for wi-fi records. The best way to cook the developing interest is through providing higher throughput in accordance with unit zone (bits/m2). This can be accomplished by utilizing expanding the cell thickness (all the more wide assortment of cells for a chose area) and by specialized overhauls inside the real layer to give extra ghastly effectiveness. The subsequent plausibility is tried in this paper wherein particular techniques to boost the ghastly exhibition of a gigantic MIMO contraption are considered.

The effect of the amount of BS reception apparatuses, number of fiery clients per cell and lucid square period at the phantom proficiency is all around analyzed through reproduction. Zero driving precoding approach is thought about for our assessment and the results are additionally contrasted and most extreme proportion joining procedure. The end some portion of the paper is sorted out as pursues. Segment II gives a fast writing assessment to legitimize the significance of the proposed canvases. Area III portrays the framework model beneath thought and gives its qualities. Segment IV gives the subtleties of reproduction impacts and the impact of various gadget parameters on SE and stage V abridges the artistic creations and clarifies the bits of knowledge achieved through it.

Literature Survey

A cell base station serves a variety of single-reception apparatus terminals over a similar time-recurrence c programming language. Time-division duplex task mixed with inverse hyperlink pilots allows the base station to evaluate the complementary forward-and turn around connection channels. The conjugate-transpose of the channel appraisals are utilized as a straight precoder and combiner separately on the forward and switch joins. Engendering, obscure to the two terminals and base station, contains quick blurring, log-ordinary shadow blurring, and geometric constriction. In the point of confinement of a boundless scope of recieving wires an entire multi-cell assessment, which obligations for between cell obstruction and the overhead and blunders identified with channel-kingdom insights, yields various numerically genuine decisions and variables to an alluring course nearer to which cell wi-fi ought to develop. In explicit the results of uncorrelated commotion and quick blurring disappear, throughput and the wide assortment of terminals are fair of the components of the phones, otherworldly productivity is free of data transfer capacity, and the ideal transmitted quality as indicated by bit evaporates. The main extreme debilitation is between versatile obstruction due to re-utilization of the pilot successions in various cells (pilot contamination) which does now not evaporate with boundless number of reception apparatuses.

A variety of self-ruling terminals simultaneously transmits certainties streams to a reduced exhibit of recieving wires. The exhibit utilizes blemished channel-nation information got from transmitted pilots to remove the individual data streams. The quality transmitted by means of the terminals can be made contrarily corresponding to the square-foundation of the wide assortment of base station reception apparatuses and not utilizing a decrease in execution. In correlation if perfect channel-nation records had been accessible the vitality may be made conversely relative to the assortment of radio wires. Lower ability limits for max-proportion joining (MRC), zeroforcing (ZF) and insignificant infer rectangular blunders (MMSE) identification are determined. A MRC beneficiary ordinarily performs more awful than ZF and MMSE. Anyway as quality levels are diminished, the cross-talk conveyed by means of the second rate most-proportion beneficiary in this manner falls under the commotion degree and this basic recipient turns into a conceivable alternative. The tradeoff between the quality execution (as estimated in bits/J) and ghostly execution (as estimated in bits/channel use/terminal) is evaluated for a channel model that incorporates little scale blurring yet no longer huge scale blurring. It is demonstrated that the use of genuinely huge recieving wire exhibits can improve the otherworldly and quality execution with requests of significant worth contrasted with an unmarried-reception apparatus gadget.

Existing Method

Maximal Ratio Combining (MRC)

This is the third post in the series discussing receiver diversity in a wireless link. Receiver diversity is a form of space diversity, where there are multiple antennas at the receiver. The presence of receiver diversity poses an interesting problem – how do we use ‘effectively‘ the information from all the antennas to demodulate the data. In the previous posts, we discussed selection diversity and equal gain combining (EGC).

In this post, we will discuss Maximal Ratio Combining (MRC). For the discussion, we will assume that the channel is a flat fading Rayleigh multipath channel and the modulation is BPSK.We use the same constraints as defined in the Selection Diversity and Equal Gain Combining (EGC) post. Let me repeat the same.

1. We have N receive antennas and one transmit antenna.
2. The channel is flat fading – In simple terms, it means that the multipath channel has only one tap. So, the convolution operation reduces to a simple multiplication.
3. The channel experienced by each receive antenna is randomly varying in time. For the receive antenna, each transmitted symbol gets multiplied by a randomly varying complex number. As the channel under consideration is a Rayleigh channel, the real and imaginary parts of are Gaussian distributed having mean and variance.
4. The channel experience by each receive antenna is independent from the channel experienced by other receive antennas. 5. On each receive antenna, the noise has the Gaussian probability density function with

$$p(n) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(n-\mu)^2}{2\sigma^2}} \text{ with } \mu = 0 \text{ and } \sigma 2 = \frac{N_0}{2}.$$

The noise on each receive antenna is independent from the noise on the other receive antennas.
6. At each receive antenna, the channel is known at the receiver.

7. In the presence of channel, the instantaneous bit energy to noise ratio at receive antenna is . For notational convenience, let us define,

$$\gamma_i = \frac{|h_i|^2 E_b}{N_0}.$$

Effective Eb/No with Maximal Ratio Combining (MRC)

Earlier, we noted that in the presence of channel, the instantaneous bit energy to noise ratio at receive antenna is

$$\gamma_i = \frac{|h_i|^2 E_b}{N_0}.$$

Given that we are equalizing the channel with , with the receive antenna case, the effective bit energy to noise ratio is,

$$\begin{aligned}\gamma &= \sum_{i=1}^{N} \frac{|h_i|^2 E_b}{N_0} \\ &= N\gamma_i\end{aligned}$$

Effective bit energy to noise ratio in a N receive antenna case is N times the bit energy to noise ratio for single antenna case.

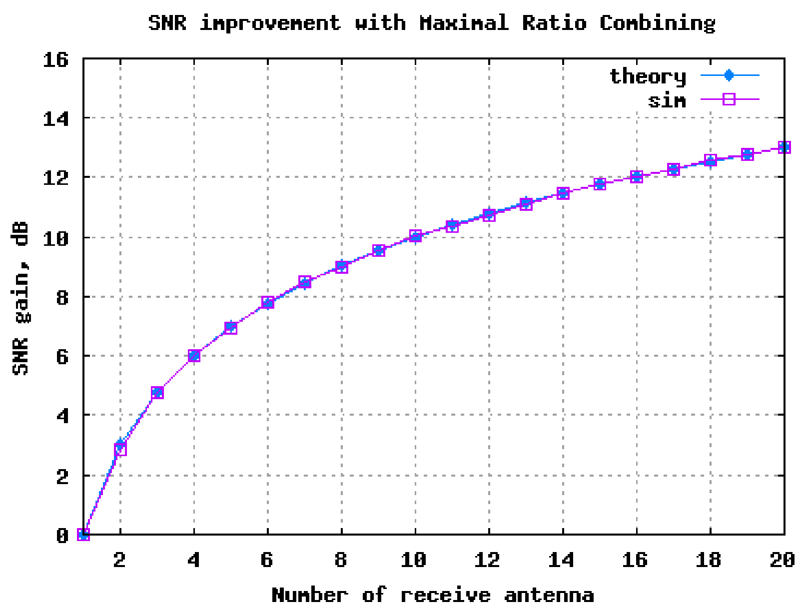


Figure 3.1 Effective SNR with Maximal Ratio Combining in Rayleigh fading channel

Error rate with Maximal Ratio Combining (MRC)

From the discussion on chi-square random variable, we know that, if is a Rayleigh distributed random variable, then is a chi-squared random variable with two degrees of freedom. The pdf of is

$$p(\gamma_i) = \frac{1}{(E_b/N_0)} e^{\frac{-\gamma_i}{(E_b/N_0)}}$$

Since the effective bit energy to noise ratio is the sum of such random variables, the pdf of is a chi-square random variable with degrees of freedom. The pdf of is,

$$p(\gamma) = \frac{1}{(N-1)!(E_b/N_0)^N} \gamma^{N-1} e^{\frac{-\gamma}{(E_b/N_0)}}, \quad \gamma \geq 0$$

Zero Forcing Equalizer

We had discussed three Single Input Multiple Output (SIMO also known as receive diversity) schemes – Selection combining, Equal Gain Combining, Maximal Ratio Combining and a Multiple Input Single Output (MISO, also known as transmit diversity) scheme – Alamouti 2×1 STBC. Let us now discuss the case where there a multiple transmit antennas and multiple receive antennas resulting in the formation of a Multiple Input Multiple Output (MIMO) channel. In this post, we will restrict our discussion to a 2 transmit 2 receive antenna case (resulting in a 2×2 MIMO channel). We will assume that the channel is a flat fading Rayleigh multipath channel and the modulation is BPSK.

2×2 MIMO channel

In a 2×2 MIMO channel, probable usage of the available 2 transmit antennas can be as follows:

1. Consider that we have a transmission sequence, for example

$$\{x_1, x_2, x_3, \ldots, x_n\}$$

2. In normal transmission, we will be sending I_1 in the first time slot, I_2 in the second time slot, I_3 and so on.
3. However, as we now have 2 transmit antennas, we may group the symbols into groups of two. In the first time slot, send I_1 and I_2 from the first and second antenna. In second time slot, send I_3 and I_4 from the first and second antenna; send I_5 and I_6 in the third time slot and so on.
4. Notice that as we are grouping two symbols and sending them in one time slot, we need only time slots to complete the transmission
5. This forms the simple explanation of a probable MIMO transmission scheme with 2 transmit antennas and 2 receive antennas.

Having said this, some of you will wonder – the two transmitted symbols interfered with each other. Can we ever separate the two out? The rest of the post attempts to answer this question.

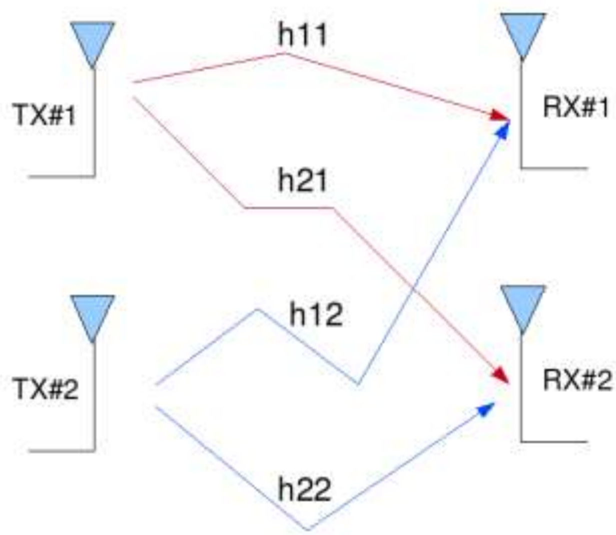


Figure 3.2 Transmit 2 Receive (2×2) MIMO channel

3.2.2 Zero forcing (ZF) equalizer for 2×2 MIMO channel

Let us now try to understand the math for extracting the two symbols which interfered with each other. In the first time slot, the received signal on the first receive antenna is,

$$y_1 = h_{1,1}x_1 + h_{1,2}x_2 + n_1 = [h_{1,1} \ h_{1,2}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1.$$

The received signal on the second receive antenna is,

$$y_2 = h_{2,1}x_1 + h_{2,2}x_2 + n_2 = [h_{2,1} \ h_{2,2}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2.$$

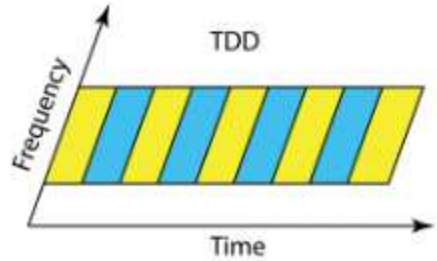
Where

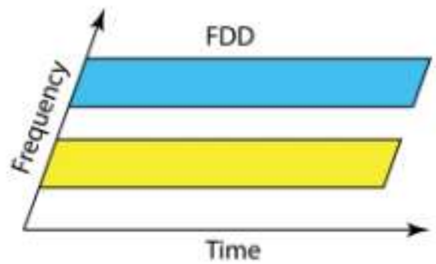
y_1, y_2 are the received symbol on the first and second antenna respectively,
$h_{1,1}$ is the channel from 1^{st} transmit antenna to 1^{st} receive antenna,
$h_{1,2}$ is the channel from 2^{nd} transmit antenna to 1^{st} receive antenna,
$h_{2,1}$ is the channel from 1^{st} transmit antenna to 2^{nd} receive antenna,
$h_{2,2}$ is the channel from 2^{nd} transmit antenna to 2^{nd} receive antenna,
x_1, x_2 are the transmitted symbols and
n_1, n_2 is the noise on 1^{st},2^{nd} receive antennas.

We assume that the receiver knows $h_{1,1}$, $h_{1,2}$, $h_{2,1}$ and $h_{2,2}$. The receiver also knows y_1 and y_2. The unknown s are x_1 and x_2.

Drawbacks in Massive MIMO with TDD

LTE was designed to work equally well in time-division duplex (TDD) and frequency division duplex (FDD) mode, so that operators could choose their mode of operation depending on their spectrum licenses. In contrast, Massive MIMO clearly works at its best in TDD, since the pilot overhead is prohibitive in FDD (even if there are some potential solutions that partially overcome this issue).

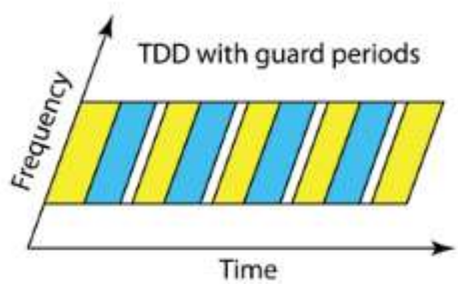




Clearly, we will see a larger focus on TDD in future networks, but there are some traditional disadvantages with TDD that we need to bear in mind when designing these networks. I describe the three main ones below.

Guard Period

Everyone in the cell should operate in uplink and downlink mode at the same time in TDD. Since the users are at different distances from the base station and have different delay spreads, they will receive the end of the downlink transmission block at different time instances. If a cell center user starts to transmit in the uplink immediately after receiving the full downlink block, then users at the cell edge will receive a combination of the delayed downlink transmission and the cell center users' uplink transmissions. To avoid such uplink-downlink interference, there is a guard period in TDD so that all users wait with uplink transmission until the outmost users are done with the downlink.



In fact, the base station gives every user a timing bias to make sure that when the uplink commences, the users' uplink signals are received in a time-synchronized fashion at the base station. Therefore, the outmost users will start transmitting in the uplink before the cell center users. Thanks to this feature, the largest guard period is needed when switching from downlink to uplink, while the uplink to downlink switching period can be short. This is positive for Massive MIMO operation since we want to use uplink CSI in the next downlink block, but not the other way around.

Inter-cell synchronization

We want to avoid interference between uplink and downlink within a cell and the same thing applies for the inter-cell interference. The base stations in different cells should be fairly time-synchronized so that the uplink and downlink take place at the same time; otherwise, it might happen that a cell-edge user receives a downlink signal from its own base station and is interfered by the uplink transmission from a neighboring user that connects to another base station.

Proposed Method
System Model

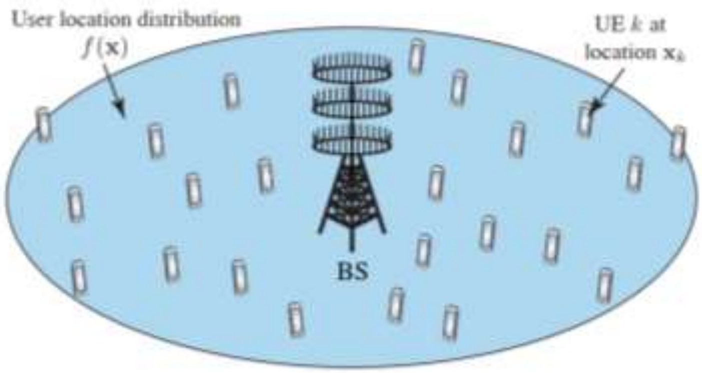


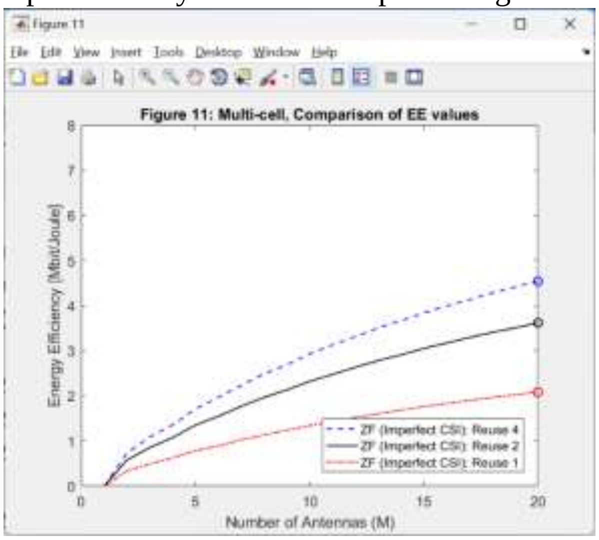
Illustration of a generic multi-user MIMO scenario: A BS with M omnidirectional antennas communicates with K single-antenna UEs in the uplink and downlink. The user locations are selected from an arbitrary random user distribution f(x).
This section uses simulations to validate the system design guidelines obtained in Section V under ZF processing and to make comparisons with other processing schemes. We provide numerical results under both perfect and imperfect CSI, and for both single-cell and multi-cell scenarios. Analytic results were used to simulate ZF, while Monte Carlo simulations with random user locations and small-scale fading were conducted to optimize EE with other schemes

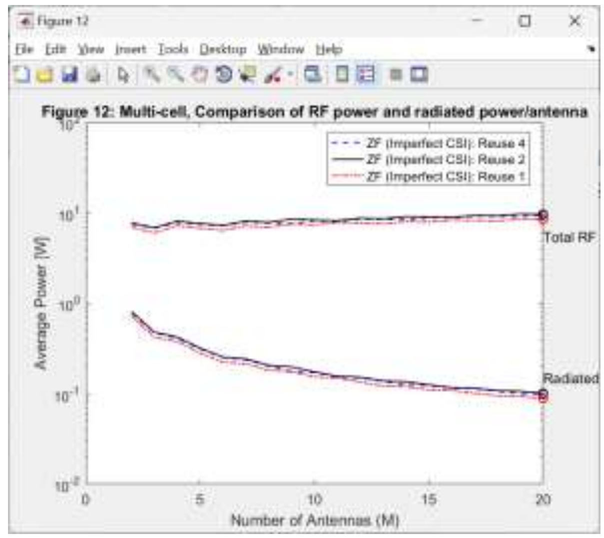
MMSE (Perfect CSI)

The Minimum Mean Square Error (MMSE) estimation technique, under the assumption of perfect Channel State Information (CSI), is a fundamental concept in wireless communication systems. In this context, "perfect CSI" implies that the receiver has complete and accurate knowledge of the channel characteristics, including channel gains, phase shifts, and noise statistics.
The MMSE estimator aims to minimize the mean square error between the transmitted signal and its estimate at the receiver.

Results And Discussions

This section uses simulations to validate the system design guidelines obtained in Section V under ZF processing and to make comparisons with other processing schemes. We provide numerical results under both perfect and imperfect CSI, and for both single-cell and multi-cell scenarios. Analytic results were used to simulate ZF, while Monte Carlo simulations with random user locations and small-scale fading were conducted to optimize EE with other schemes. To compute the total power consumption in a realistic way, we use the hardware characterization described in Section IV. We first consider the single-cell simulation scenario in Example 1 (i.e., a circular cell with radius 250 m) and assume operation in the 2 GHz band. The corresponding simulation parameters are given in Table II and are inspired by a variety of prior works: the 3GPP propagation environment defined in [20], RF and baseband power modeling from [1], [27], [28], [33], backhaul power according to [34], and the computational efficiencies are from [15], [35]. The simulations were performed using Matlab and the code is available for download at https://github.com/emilbjornson/ is-massive-MIMO-the-answer, which enables reproducibility as well as simple testing of other parameter values.





Conclusion

This paper analyzed how to select the number of BS antennas M, number of active UEs K, and gross rate $\bar{R}$ (per UE) to maximize the EE in multi-user MIMO systems. Contrary to most prior works, we used a realistic power consumption model that explicitly describes how the total power consumption depends non-linearly on M, K, and $\bar{R}$. Simple closed form expressions for the EE-maximizing parameter values and their scaling behaviors were derived under ZF processing with perfect CSI and verified by simulations for other processing schemes, under imperfect CSI, and in symmetric multi-cell scenarios. The applicability in general multi-cell scenarios is an important open problem that we leave for future work. The EE (in bit/Joule) is a quasi-concave function of M and K, thus it has a finite global optimum. Our numerical results show that deploying 100–200 antennas to serve a relatively large number of UEs is the EE-optimal solution using today’s circuit technology. We interpret this as massive MIMO setups, but stress that M and K are at the same order of magnitude.

Energy-efficient systems are therefore not operating in the low SNR regime, but in a regime where proper interference-suppressing processing (e.g., ZF or MMSE) is highly preferably over interference ignoring MRT/MRC processing. The radiated power per antenna is, however, decreasing with M and the numerical results show that it is in the range of 10–100 mW. This indicates that massive MIMO can be built using low-power consumer grade transceiver equipment at the BSs instead of conventional industry-grade high-power equipment. The analysis was based on spatially uncorrelated fading, while each user might have a unique non-identity channel covariance matrices in practice (e.g., due to limited angular spread and variations in the shadow fading over the array). The statistical information carried in these matrices can be utilized in the scheduler to find statistically compatible users that are likely to interfere less with each other [37]. This basically makes the results with imperfect CSI and/or with MRT/MRC processing behave more like ZF processing with perfect CSI does.

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