Implementing a Random-Access Protocol for Pilot Allocation in Crowded Massive MIMO Systems

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ABSTRACT

The Massive MIMO (multiple-input multiple output) technology has a great potential to manage the rapid growth of wireless data traffic. Massive MIMO achieves tremendous spectral efficiency by spatial multiplexing of many tens of user equipment (UEs). These gains are only achieved in practice if many more UEs can connect efficiently to the network than today. As the number of UEs increases, while each UE intermittently accesses the network, the random-access functionality becomes essential to share the limited number of pilots among the UEs. In this paper, we revisit the random-access problem in the Massive MIMO context and develop a reengineered protocol, termed strongest-user collision resolution (SUCRe). An accessing UE asks for a dedicated pilot by sending an uncoordinated random-access pilot, with a risk that other UEs send the same pilot. The favorable propagation of Massive MIMO channels is utilized to enable distributed collision detection at each UE, thereby determining the strength of the contenders' signals and deciding to repeat the pilot if the UE judges that its signal at the receiver is the strongest. The SUCRe protocol resolves the vast majority of all pilot collisions in crowded urban scenarios and continues to admit UEs efficiently in overloaded networks.

Keyword: - *Key word1:UE(User Equipment), Key word2:BS(Base Station), Key word3:MIMO(Multiple Input Multiple Output), Key word4: SUCRe(Strongest-User Collision Resolution).*

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1. INTRODUCTION

Wireless technology is the most noteworthy advancement nowadays, with widespread access that has become an integral part of society as crucial as electricity and the connectivity itself impels developments. Wireless communication services are accessible and pervasive in all walks of life of all the people globally, thanks to a cellular wide area, local area networks, and satellite services. The usage of a time-domain rectangular window, leading to miserably poor frequency localization, the communication nodes need to use a lot of time for overhead signals and awaiting transmission. Recently, FBMC technology surpassed all other drawbacks enumerated in conventional OFDM. Besides these advantages, the frequency was split into many sub-bands, this raises the duration of the symbol to perfect fading channels multipaths. Therefore, FBMC in future wireless networking environments is considered a feasible physical layer technique.

2. Prior Work on Random Access in Massive MIMO

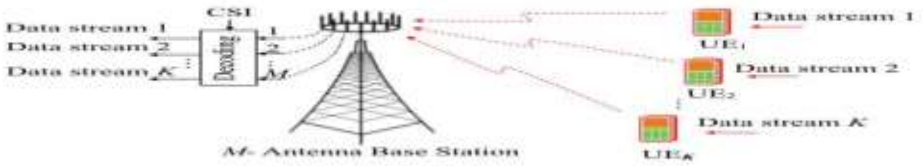
Conventional cellular networks allocate dedicated resources to each active UE; thus, the BS needs to convey the time-frequency positions of these resources. In contrast, Massive MIMO systems allocate all time-frequency resources to all active UEs, and separate them spatially based on their pilot sequences. The number of pilots is limited by the size of the channel coherence block. In the original Massive MIMO concept of the UEs within a cell use mutually orthogonal pilots, while the necessary reuse of pilots across cells causes inter-cell pilot contamination that leads to additional interference.

In this paper, we explore the alternative solution that each UE needs to be assigned a pilot sequence before transmitting payload data, to avoid intra-cell pilot collisions and actualize the payload transmission situation considered in the main body of Massive MIMO research. We focus on urban deployments with small initial timing variations and propose a new RA protocol for UEs that wish to access the network. The protocol can resolve RA collisions in a distributed and scalable way, by exploiting special properties of Massive MIMO channels.

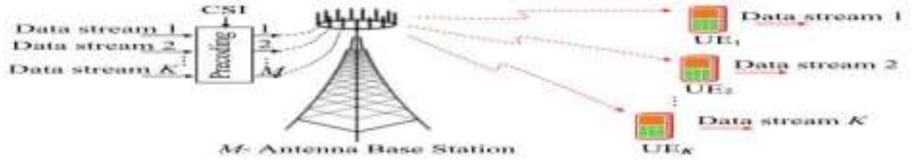
2.1 Introduction to Massive MIMO

In wireless communications, MIMO technology has drawn substantial interest, because it enables substantial changes in data throughput and the connectivity area without increasing bandwidth or transmitting capacity MIMO technology has attained considerable attention in wireless networking since the data output, and connection range has increased considerably, and no need for bandwidth increased, or power transmits. Figure 1 shows the conventional MIMO and massive MIMO with M and K transceiver antennas. Today the Massive MIMO is widely accepted for its distinctive spectral performance, reliability, and overall capabilities in TDD/FDD systems, both in academia and industry.

The large-scale MIMO incorporates these architecture principles to make high SE in the coverage level of future wireless systems an effective way. Each base station is fitted with a wide variety of antennas, M, and serves a cell, K. Each terminal usually has a single antenna. Various bases represent different cells. With the possible limitation of power management and pilot allocations, massive MIMO does not depend on base station cooperation. In both uplink and downlink transmissions, all terminals have used the entire time-frequency capabilities simultaneously.



(a) Uplink



(b) Downlink

Fig1:Illustration of the basic Massive MIMO

2.2 MASSIVE MIMO-CHANNEL ESTIMATION

An enormous MIMO channel prediction approach for FDD is proposed in using frequency selection techniques. It is dependent on the message passing algorithm. The original AMP is now expanded to Multiple Measurement Vector (MMV) for FDD/TDD modes called M-AMP. The latest works are investigated in have called for a short training series based on the associated nature of large MIMO. It provides a pilot method for minimizing the MSE in channel evaluation using the Kalman filter. The channel may be measured using an early channel performance or channel statistics training arrangement for such a method. It should be noted that additional feedback is essential to obtain network statistics on massive, non-stationary MIMO channels. The training methods used in are carried out without the transmitter's information or statistical data and are valid only for high-time correlation slow fading networks. These are dependent on filtering adaptations.

CIR between various transmissions and the receiving pairs of antennas has a fragmented block structure. Also, they used the path delays calculated from uplink training to enhance the efficacy of the downlink channel approximations. They suggested the Block Subspace Pursuit (ABSP) auxiliary information-based approach for procuring a few channel parameters. The proposed solution would considerably minimize computational complexity and pilot performance while providing a better MSE than the conventional EE approach.

3. PROPOSED METHOD

3.1 Random Access Functionality in LTE

Before we propose a new highly scalable access protocol, we describe the conventional protocol used on the Physical Random Access Channel (PRACH) of LongTerm Evolution (LTE). It consists of four steps, as illustrated in Fig2. In Step 1, each accessing UE picks a preamble at random from a predefined set. The preamble is an entity that enables synchronization towards the BS. It does not carry specific reservation information or data and thus can be viewed as a pilot sequence. Since UEs that wish to access the network are not coordinated in picking the preambles, a collision occurs if two or more UEs select the same preamble simultaneously. A BS in LTE only detects if a specific preamble is active or not in Step 1. In Step 2, the BS sends a random access response corresponding to each activated preamble, to convey physical parameters (e.g., timing advance) and allocate a resource to the UE (or UEs) that activated the preamble. In Step 3, each UE that has received a response to its preamble transmission sends a RRC (Radio Resource Control) Connection Request in order to request resources for subsequent data transmission. If more than one UE activated the preamble, then all these UEs use the same resource to send their RRC connection request in Step 3 and this collision is detected by the BS. Step 4 is called contention resolution and contains one or multiple steps to resolve the collision. This is a complicated procedure that might result in that all colliding UEs need to make a new access attempt after a random waiting time.

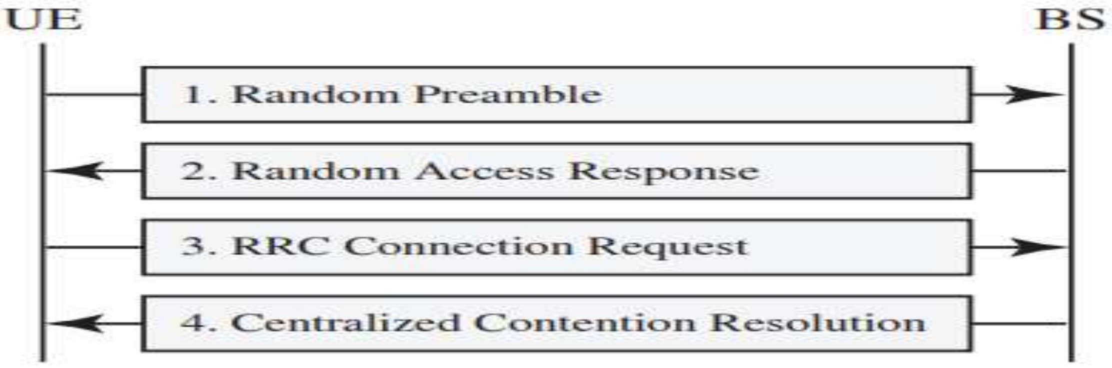


Fig2:The PRACH protocol of the LTE system.

3.2 PROPOSED RANDOM ACCESS PROTOCOL

We consider cellular networks where each BS is equipped with M antennas. The system operates in TDD mode and the time-frequency resources are divided into coherence blocks of T channel uses, dimensioned such that the channel responses between each BS and its UEs are constant and frequency flat within a block, while they vary between blocks. This can be implemented using orthogonal frequency-division multiplexing (OFDM). We let U_i denote the set of UEs that reside in cell i. At any given time, only a subset $A_i \subset U_i$ of the UEs are active in the sense that they are transmitting and/or receiving data. Note that in the scenarios relevant for Massive MIMO deployment, we typically have a very large UE set: $|U_i|$ T. However, the active UEs satisfy $|A_i| < T$, thus the BS can temporarily assign orthogonal pilot sequences to these UEs and reclaim them when their respective transmissions are finished.

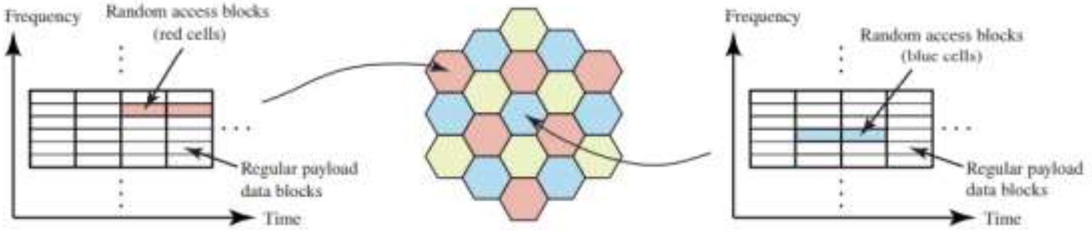


Illustration of the proposed transmission protocol

3.3 Strongest-user collision resolution (SUCRe)—Overview

The key contribution of this paper is the strongest user collision resolution (SUCRe) protocol, which is an efficient way to operate the RA blocks in beyond-LTE Massive MIMO systems. There is also a preliminary Step 0 in which the BS broadcasts a control signal. Each UE uses this signal to estimate its average channel gain and to synchronize itself towards the BS. In OFDM, the UE and the BS need to be synchronized in frequency, and the timing delay can be neglected if it is shorter than the cyclic prefix. The roundtrip time determines the maximum timing delay, thus the normal CP in LTE allows for 750 m cell radius and the extended CP allows for 2.5 km—these are substantially larger than the 250–500 m cell radius typical in urban deployments.

In Step 1, a subset of the inactive UEs in cell wants to become active. Each such UE selects a pilot sequence at random from a predefined pool of RA pilots. BS estimates the channel that each pilot has propagated over. If multiple UEs selected the same RA pilot, a collision has occurred and the BS obtains an estimate of the superposition of the UE channels. The BS cannot detect if collisions occurred at this point, which resembles the situation in LTE.

In Step 2, the BS responds by sending DL pilots that are precoded using the channel estimates, which results in spatially directed signals toward the UEs that sent the particular RA pilot. The DL signal features an array gain of M that is divided between the UEs that sent the RA pilot. Due to channel reciprocity, the share of the array gain is proportional to their respective UL signal gains, particularly when M is large, which enables each UE to estimate the sum of the signal gains and compare it with its own signal gain (using information obtained in Step 0).

3.4 Detailed Description of the SUCRe Protocol

Next, we describe and analyze the proposed RA protocol in detail. Without loss of generality, we focus on an arbitrary cell, say cell 0, and consider how interference from other cells impacts the operation. Let $K_0 = U_0 \setminus A_0$ denote the set of inactive UEs in cell 0 in a given RA block. Hence, there are $K_0 = |K_0|$ inactive UEs in cell 0. These are assumed to share τ_p mutually orthogonal RA pilot sequences $\psi_1 , . . . , \psi_{\tau_p} \in C^{\tau_p}$ that span τ_p UL channel uses and satisfy $k\psi_t k^2 = \tau_p$. The inactive UEs are not fully time-synchronized, but the pilot orthogonality is maintained at the receiver since we consider urban scenarios where the roundtrip delays are smaller than the cyclic prefix. We typically have τ_p K_0, but there is no formal constraint. Each of the K_0 UEs picks one of the τ_p pilots uniformly at random in each RA block: UE k selects pilot $c(k) \in \{1, 2, . . . , \tau_p\}$. Furthermore, each UE would like to become active in the current block with probability $P_a \leq 1$, which is a fixed scenario-dependent parameter that describes how often a UE has data packets to transmit or receive. An access attempt by UE k consists of transmitting the pilot $\psi_{c(k)}$ with a non-zero power $\rho_k > 0$, otherwise it stays silent by setting $\rho_k = 0$. Hence, each inactive UE will transmit a particular pilot sequence ψt (using non-zero power) with probability Pa/τp. The set St = {k : c(k) = t, ρk > 0} contains the indices of the UEs that transmit pilot t. Based on this model, the number of UEs, |St|, that transmits ψt has a binomial distribution:1

$$|\mathcal{S}_t| \sim B\left(K_0, \frac{P_a}{\tau_p}\right). \qquad (1)$$

We notice that pilot t is unused (|St| = 0) with probability (1 − Pa τp) K0 and selected by only one UE (|St| = 1) with probability K0 Pa τp (1 − Pa τp) K0−1 . Consequently, an RA collision (|St| ≥ 2) occurs at this arbitrary pilot with probability

$$1-\left(1-\frac{P_a}{\tau_p}\right)^{K_0} - K_0\frac{P_a}{\tau_p}\left(1-\frac{P_a}{\tau_p}\right)^{K_0-1}. \qquad (2)$$

These collisions need to be detected and resolved before any UE can be admitted into the payload blocks.

The SUCRe protocol is a distributed method to resolve pilot collisions at the UE side by utilizing properties of Massive MIMO channels. The channel vector between UE k ∈ K0 and its BS is denoted by hk ∈ CM. We adopt a very general propagation model where the channels are assumed to satisfy the following two conditions (almost surely):

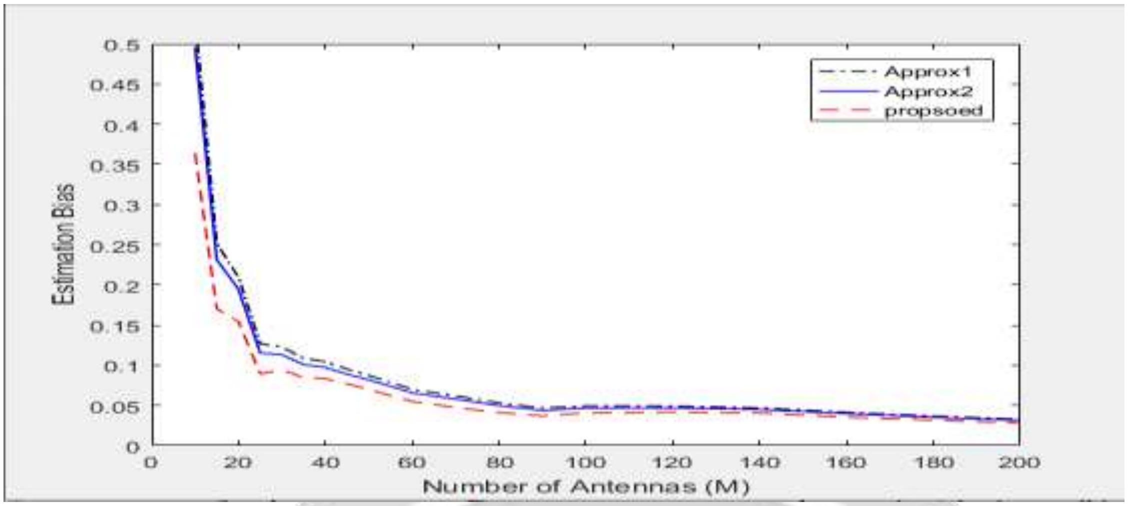
$$\frac{\|\mathbf{h}_k\|^2}{M} \xrightarrow{M\to\infty} \beta_k, \quad \forall k, \qquad (3)$$

$$\frac{\mathbf{h}_k^{\mathrm{H}}\mathbf{h}_i}{M} \xrightarrow{M\to\infty} 0, \quad \forall k,i,\ k \neq i, \qquad (4)$$

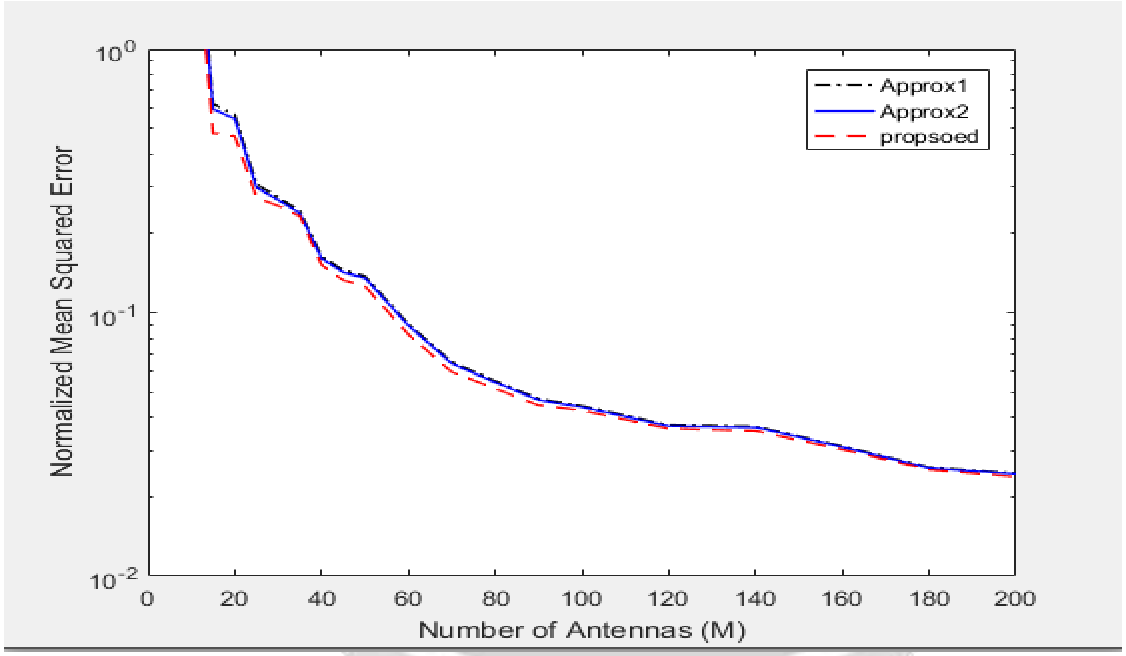
for some strictly positive value of βk that is known to UE k (it was estimated in Step 0). Such channels are said to offer channel hardening and asymptotic favorable propagation. The properties are satisfied (almost surely) by a variety of stochastic channel models; for example, when hk = R 1/2 k xk where Rk ∈ CM×M is a positive semi-definite matrix with bounded spectral norm and xk ∈ CM has i.i.d. entries with zero mean and bounded eighth-order moment. In this case we have tr(Rk)/M → βk. Asymptotic favorable propagation can also be obtained for deterministic lineof-sight channels; for example, for uniform linear arrays (ULAs) where the UEs have distinct angles with respect to the BS array.

4.SIMULATION RESULTS:

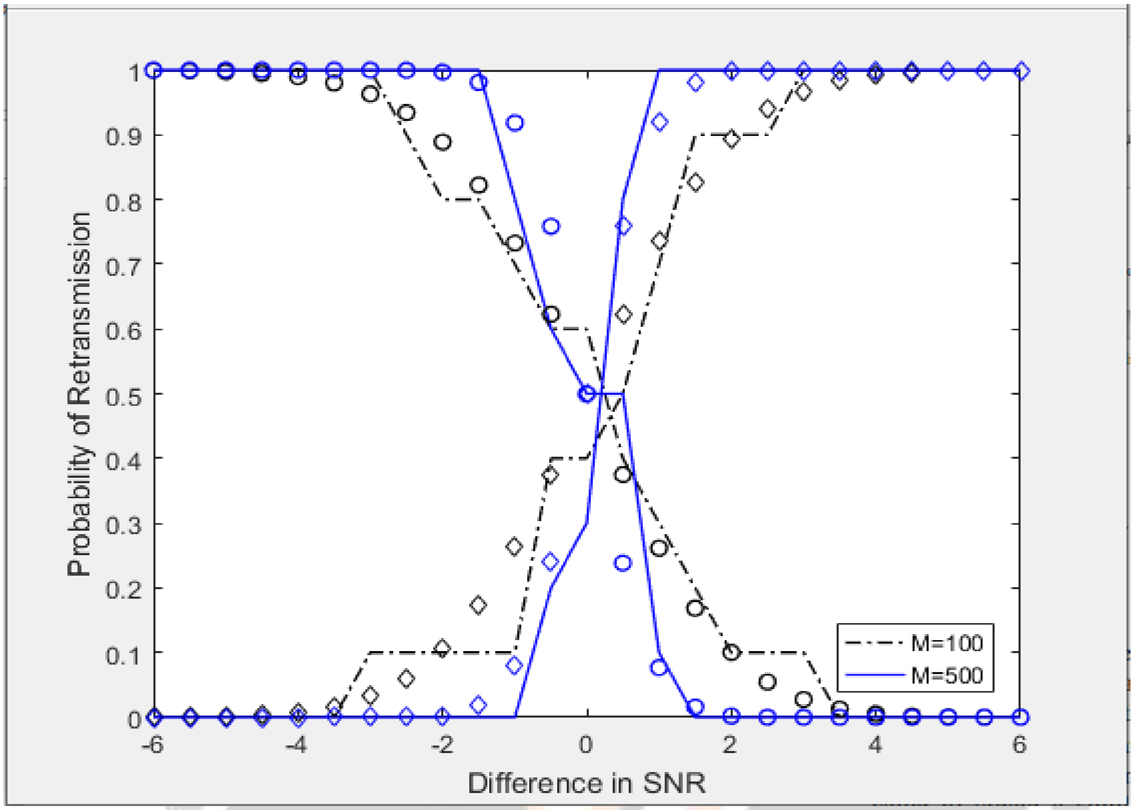
This section gives the detailed simulation outcomes of the proposed method and existing method, all the simulations are conducted by using the MATLAB software.



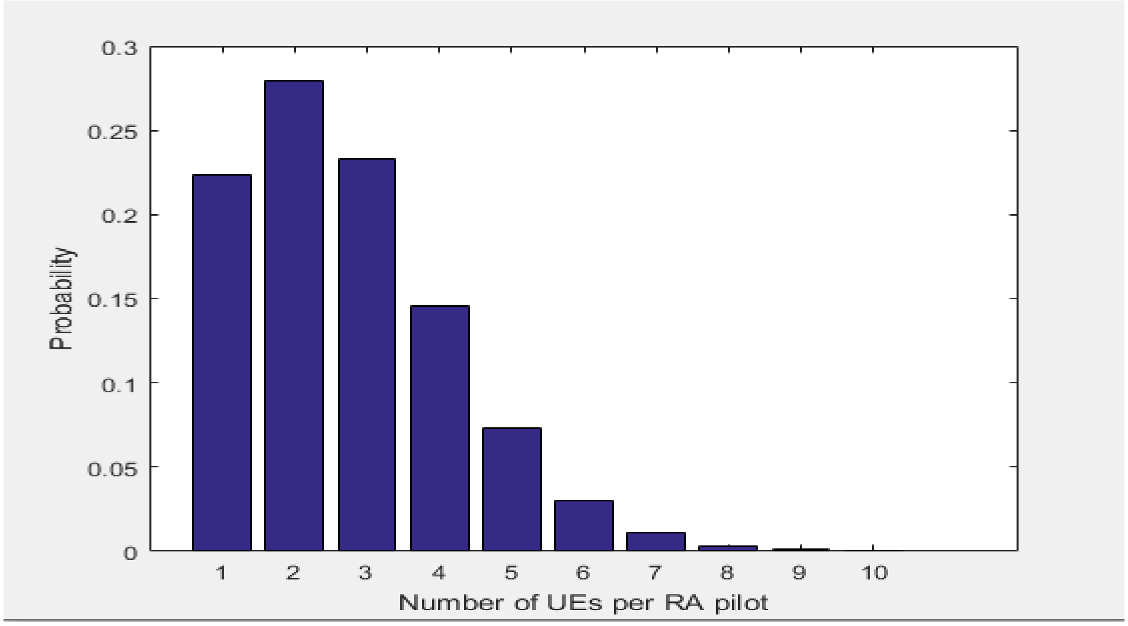
Normalized bias



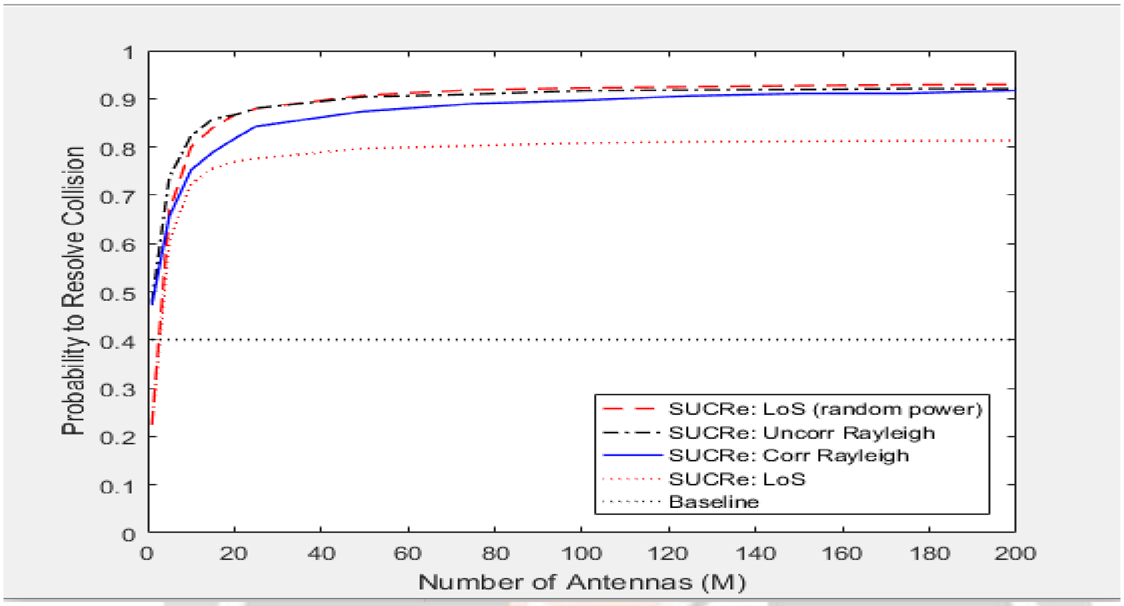
Normalized Mean Square Error



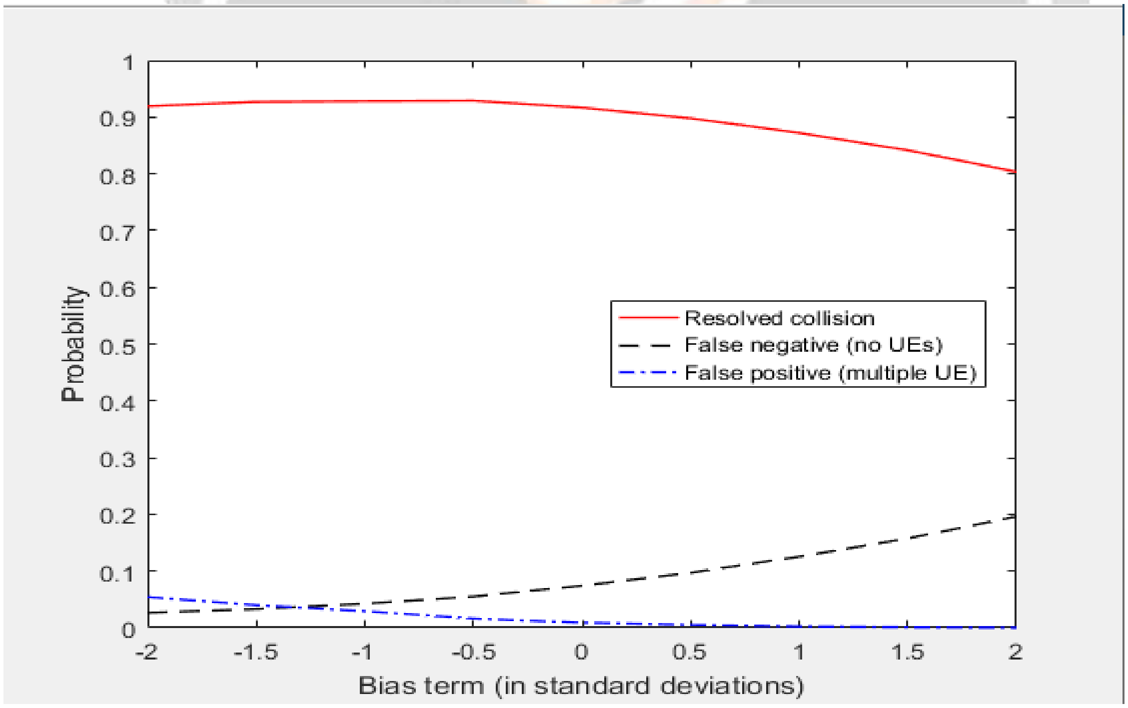
Probability to repeat the pilot transmission in a two-UE collision



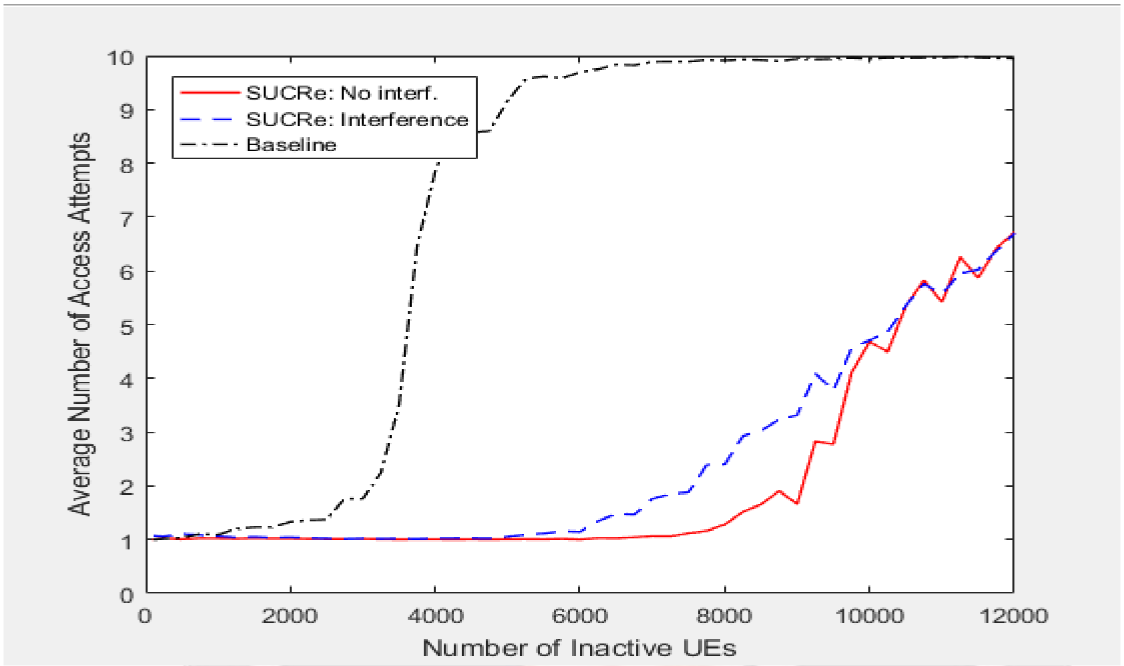
Example of a distribution of the number of UEs that selects each RA pilot.



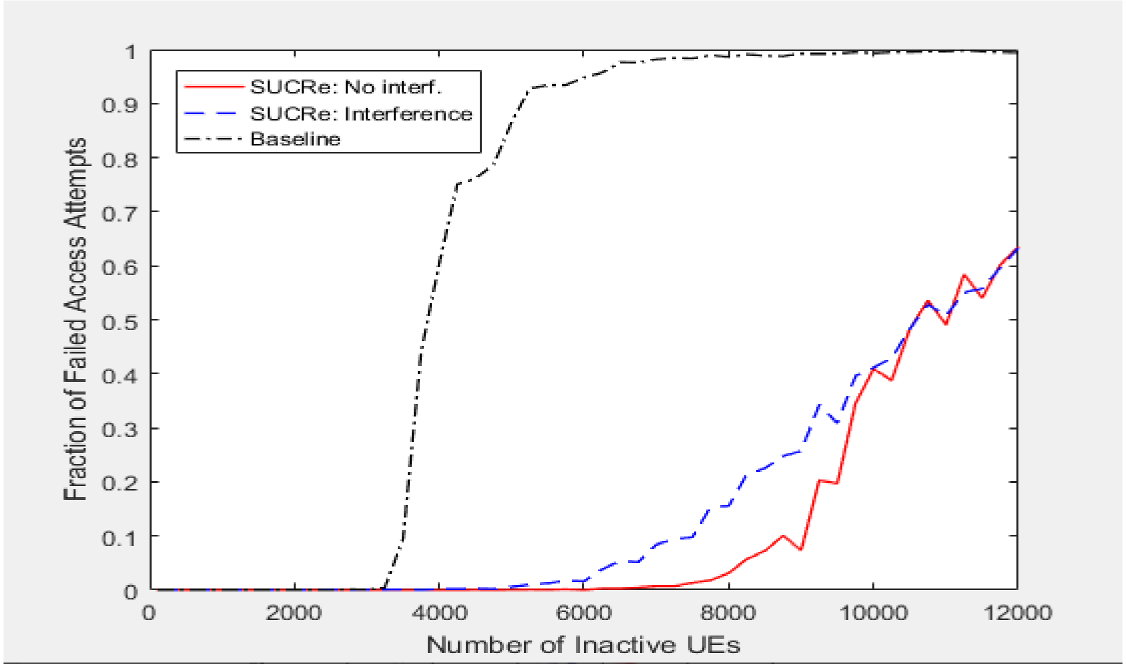
With interference from adjacent cells



With interference from adjacent cells



Average number of RA attempts



Probability of failed RA attempt (more than 10 attempts)

4. CONCLUSION

The pilot sequences are precious resources in Massive MIMO since they enable the BS to separate the UEs in the spatial domain. In future urban scenarios, the number of UEs that resides in a cell is much larger than the number of available pilots, thus the pilots need to be temporally allocated only to the UEs that have data to transmit or receive. The proposed SUCRe random access protocol provides an efficient way for UEs to request pilots for data transmission, and is well-suited for beyond-LTE Massive MIMO systems and crowded urban deployment scenarios. The protocol exploits the channel hardening and favorable propagation properties to enable distributed collision detection and resolution at the UEs, where the contender with the strongest signal gain is the one being admitted. The numerical results demonstrate that the SUCRe protocol can resolve around 90% of all collisions and that it is robust to inter-cell interference and choice of channel distribution. The protocol does not break down in overloaded situations, where more UEs request pilots than there are RA resources, but continues to admit a subset of the accessing UEs.

5. FUTURE SCOPE

This work described the effectiveness of Massive MIMO system with the enhancement of SE and UE in presence of AWGN and frequency selective Rayleigh fading channel. A combined scheme of Doubly EM based equalizer-with ICI mitigation approach is employed for enhancing the performance of Massive MIMO system. In addition, this algorithm reduced the complexity and processing delay by improving BER performance of Massive MIMO system. However, the weights utilized in SE and UE expression are not optimal and further there is a lack of translation invariance. Thus, it is required to address these issues to maximize the performance of Massive MIMO system for 5G wireless networks.

6. REFERENCES

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