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Introduction to Massive MIMO and Random Access Protocol for Pilot Allocation

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Abstract – *This paper presents an overview of Massive MIMO (Multiple Input Multiple Output) system. It further discuss the problems present in Massive MIMO technology implementation. A detailed discussion of Pilot Contamination problem of Massive MIMO is done. Random Access protocols PRACH (Physical Random Access Channel) and SUCR (Strongest User Collision Resolution) has been studied . SUCR Protocol resolves the UE collision to a vast extent. But many other factors are there which are responsible for the failure of these protocols at some point of time. Such factors has been discussed in the paper.*

Key Words: Massive MIMO, PRACH, SUCR, User Equipment, LTE system

1. INTRODUCTION

Multiple-antenna (MIMO) technology is becoming mature for wireless communications and has been incorporated into wireless broadband standards like LTE and Wi-Fi. Basically, the more antennas the transmitter/receiver is equipped with, the more the possible signal paths and the better the performance in terms of data rate and link reliability. The price to pay is increased complexity of the hardware (number of RF amplifier frontends) and the complexity and energy consumption of the signal processing at both ends.

Massive MIMO (also known as Large-Scale Antenna Systems, Very Large MIMO, Hyper MIMO, Full-Dimension MIMO and ARGOS) makes a clean break with current practice through the use of a very large number of service antennas (e.g., hundreds or thousands) that are operated fully coherently and adaptively. Extra antennas help by focusing the transmission and reception of signal energy into ever-smaller regions of space. This brings huge improvements in throughput and energy efficiency, in particularly when combined with simultaneous scheduling of a large number of user terminals (e.g., tens or hundreds). Massive MIMO was originally envisioned for time division duplex (TDD) operation, but can potentially be applied also in frequency division duplex (FDD) operation.

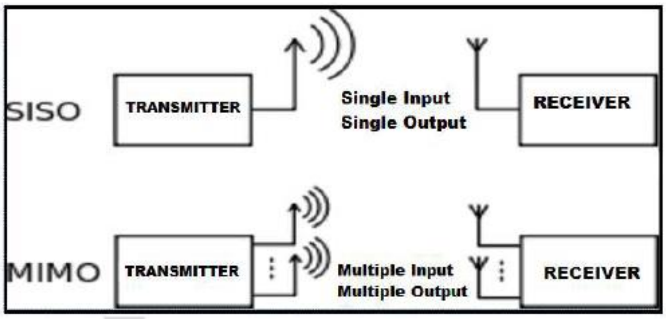

Fig -1: Block Diagram of SISO and MIMO systems

1.1 Benefits of Massive MIMO

Benefits of massive MIMO include high spectrum efficiency due to large multiplexing gain as well as antenna array gain. Massive MIMO system has high reliability due to large diversity gain and also high energy efficiency due to concentration of radiated energy on UE (user equipment). It includes simple scheduling scheme which provide robustness to individual element failure due to large number of antenna array elements. Massive MIMO can be developed using low power and in-expensive components.

1.2 Limitations of Massive MIMO

Pilot Contamination due to limited orthogonal pilot subcarriers as of bounded coherent interval and bandwidth is the most important limitation of Massive MIMO application which is to be considered. Massive MIMO is sensitive to beam alignment, as extremely narrower beam is used which is sensitive to movement of Mobile Station (MS) or swaying of antenna array. Channel State Information Acquisition and channel feedback is also a limiting factor.

2. Pilot Contamination

Pilot Contamination is said to be the limiting factor of Massive MIMO operation. An accessing UE asks for a dedicated pilot by sending an unprotected random access pilot, with a risk that other UEs send the same pilot. This can lead to pilot collision which affects the Massive MIMO operation. Various protocols has been introduced previously to work upon the pilot collision, two of them are going to be discussed here.

2.1 Physical Random Access Channel

First we describe the conventional protocol used on the Physical Random Access Channel (PRACH) of Long Term Evolution (LTE). It consists of four steps [1] as illustrate din Fig 2.

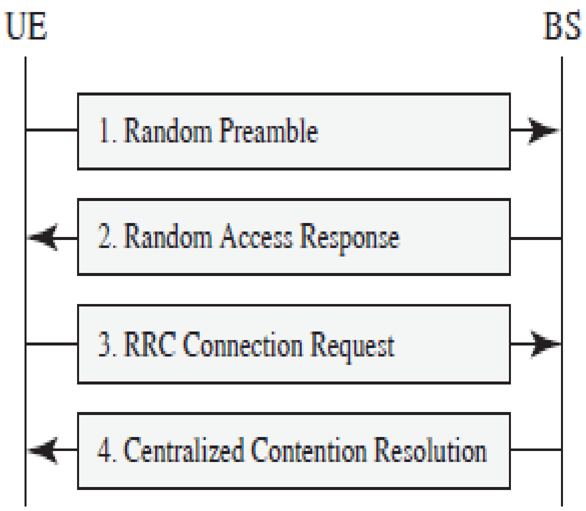

Fig -2: The PRACH Protocol of LTE system [1]

Step- 1: An accessing UE picks randomly a preamble from a pre-defined set. The preamble does not contain any reservation information these are entities that enables the BS to gain synchronization. Collisions can not be detected at this stage. Step 2: Base station (BS) sends a random access response corresponding to each activated preamble to convey physical parameters. It allocate a resource to UE that activated the preamble. Step 3: UE sends a radio resource control (RRC) connection request in order to obtain resources for data transmission. Collision is detected by BS at this stage. Step 4: This step is considered to be the contention resolution step.

This is a complicated procedure that can cause delay and might cause all the colliding UEs to start the procedure again and make a new request after a random waiting time.

2.2 Strongest User Collision Resolution

Strongest user collision resolution protocol [2] has been proposed to improve collision avoidance probability in comparison to previously proposed protocol.

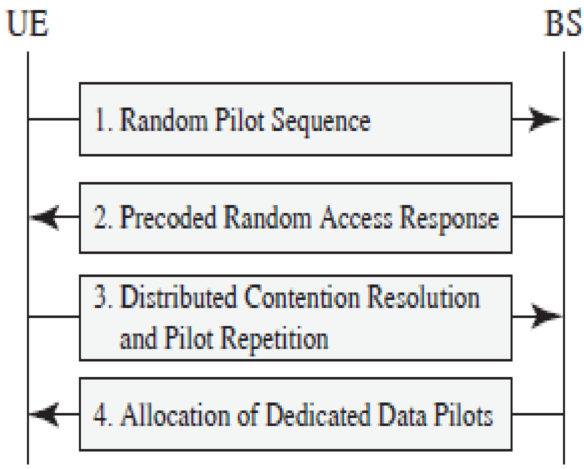

Fig -3: The SUCR Random access protocol [2]

As per illustration in Fig-3, the steps for SUCR protocol are described below.

Step-0: The basic step for this protocol is that BS broadcast a synchronization signal, from this signal each UE estimate its average channel gain to the BS. Step-1: UE selects a pilot sequence from predefined set. Collision can not be detected at this stage. BS selects which pilot sequences that were used and estimates the channel that each pilot has propagated over. The probability that pilot collision occurs is:

$$1-\left(1-\frac{P_a}{\tau_p}\right)^K - K\frac{P_a}{\tau_p}\left(1-\frac{P_a}{\tau_p}\right)^{K-1}$$

where $(1-\frac{P_a}{\tau_p})^K$ is the probability that the pilot is unused ($N=0$) and $K\frac{P_a}{\tau_p}(1-\frac{P_a}{\tau_p})^{K-1}$ that $N=1$ UE uses it.

Step-2: BS send downlink pilot signals that are precoded using channel estimates. Each UE can estimate the sum of channel gains of UEs that picked the same pilot and compare it with its own channel gain obtained in Step 0. Collision can be detected by UE in this step in distributed manner. UE resolve contention by applying local decision rule that only the UE with the strongest channel gain is allowed to retransmit its pilot. Step-3: It resembles the PRACH protocol in LTE RRC connection request. UE informs about its identity and request resources to transmit payload data. Probability of successful transmission increases at this stage. Step-4: At this stage resources are granted or contention resolution started.

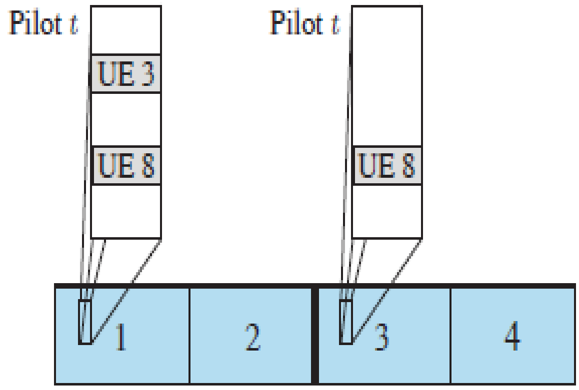

Fig -4: Illustration of a UE collision at RA pilot t resolved by the SUCR protocol, where only the UE with strongest signal gain repeats the pilot in Step 3.

In this protocol TDD Massive MIMO system is considered, coherence blocks are divided into two categories, one for dedicated pilot sequence, another one for random access. Random access protocol enables UE to access the network with low delay and stay active until they run out of data, also uncorrelated Rayleigh fading is considered.

2.3 Shortcomings of SUCR protocol

The proposed protocol has some shortcomings. A collision is resolved if and only if a single UE appoint itself the contention winner. The estimation errors and inter cell interference can cause false positives and negatives. A false negative occurs when none of the UE identifies itself as the contention winner. Exact details depend strongly on the propagation environment and UE distribution which are hard to compute and model. If the decoding fails, the SUCR protocol has failed to resolve the collision.

2.4 Proposed solution for improvement.

SUCR protocol is said to resolve 90% of all collisions and that is robust to inter-cell interference and channel distribution. But as mentioned above a collision is resolved if and only if a single UE appoint itself the contention winner, thus to improve the contention resolving efficiency we need to increase the power gain of receiving antenna so that the corresponding UE with best signal strength can be picked up. Increasing number of antennas at receiving end will increase the probability of less collision. Another way out is to decrease estimation errors and inter-cell interference by proper placing of cells in the receiving section also the hexagon shape of cell reduces the interference most.

3. CONCLUSIONS

From this review paper it is concluded that Massive MIMO is a revolutionary change in telecom sector for 5G technology but it also introduces challenges for cellular system and system design. The pilot sequences are the main factor to be considered as they enable the BS to separate the UEs in spatial domain. The existing protocols for resolving pilot signal collision that is pilot contamination are effective upto 90% , the proposed solutions can be adapted to increase the efficiency so that protocol can work in overloaded Massive MIMO environment with better efficiency.

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