Journal of Engineering Sciences
Vol 13, Issue 04, APRIL /2022
ISSN NO:0377-9254

Robust Analysis of Adaptive Pilot Pattern for Massive MIMO Systems

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Abstract- This work proposes a new adaptive pilot design utilized for the pilot course of action at the portable station and another channel assessment at the base station. It tends to the cycle blunder rate (BER) execution improvement of remote direct assessment in huge various information numerous result frameworks. To start with, we propose another versatile pilot design (APP) that offers a lower BER than the traditional pilot designs. Then, we recommend another channel assessment calculation in light of the APP. It Is called the shifted APP-channel estimation (SACE). As a result, APP guarantees an optimal BER performance for the different system con_gurations, channel models, and carrier frequencies. It offers better BER performance than conventional
pilot patterns, such as the long-term evolution (LTE) pilot pattern. Moreover, the shifted APP-based channel estimation algorithm solves the error _oor caused by the usage of multiple subcarriers. It also offers a signal-to-noise ratio (SNR) improvement that reaches 17 dB at BERD10-2 compared to the conventional minimum mean square error (MMSE) channel estimation.

Index Terms: communication, MIMO-OFDM, Antenna

I. Introduction

Hypothetical exploration works ordinarily expect an ideal channel state data (CSI) [1], [2]. However, in down-to-earth frameworks, one ought to think about the channel assessment and the blunders that accompany it. There are three CSI assessment techniques: blind, semi-visually impaired, and pilot-supported [3]. To begin with, blind assessment procedures depend on factual channel properties [4], [5]. They are frightfully ef_cient. Nonetheless, they experience the ill effects of imprecision and high intricacy. Second, semi-blind assessment is a blend of factual channel properties and known pilot images [6]. Even though they cover a portion of the visually impaired procedure's weaknesses, they are not appropriate for high versatility frameworks. Third, the pilot-supported channel assessment (PACE) depends on multiplexing some known pilot images with the sent information [7]. It is the most involved procedure for remote frameworks with high portability due to its effortlessness and accuracy.

PACE parts into two sections. The initial segment is at the transmitter, where a pilot succession is doled out to every client. Then, at that point, it is embedded in the accessible assets among the information following a particular example [8]. The subsequent part is at the recipient. Channel coefficients that compare to the pilots' positions are assessed utilizing a few calculations like least-square (LS) [9], least mean-square mistake (MMSE) [9], and vigorous channel assessment [8]. At long last, they are inserted among the obscure coefficients that compare to the information positions. There are numerous addition calculations [10] like straight insertion, second-request interjection, low-pass introduction, spline cubic interjection, and time-space insertion. Cutting edge remote frameworks require the utilization of basic and straight calculations [11]. Thus, in this paper, we think about the straight introduction method. We can arrange research works that examine the PACE method into three fundamental tomahawks.

The main hatchet is the pilot task which alludes to relegating a bunch of pilot successions to the associated clients. Its motivation is to lessen the obstruction between pilot groupings of clients from various cells. In this way, it assists with relieving the pilot tainting issue [12]-[15]. The subsequent hatchet is the pilot game plan which alludes to orchestrating a pilot succession of a given client in the accessible recurrence, time, and space assets. It comprises of planning a pilot example to either upgrade the phantom proficiency [16], [17] or further develop the framework's dependability [18]-[20]. The last hatchet is the channel assessment which alludes to examining the channel coefficients recognition in light of the got pilot signal. It means to upgrade the framework's unwavering quality [8], [9] or to lessen the computational intricacy. In this work, we are for the most part keen on the subsequent hatchet. Exactly, we are examining the pilot design variation to upgrade the framework's BER execution Existing norms and frameworks, for example, 5G new radio (NR), long haul advancement (LTE), and overall interoperability for microwave access (WiMax) IEEE 802.16 are utilizing fixed pilot designs autonomously from the pre-owned recurrence band. Notwithstanding, that across-the-board approach is not generally fit for the up-and-coming age of remote frameworks. Each channel has its different rationality transmission capacity and time whereas the CSI has very nearly a consistent worth. Consequently, to have an exact assessment, each channel ought to have its relating pilot design. In addition, the framework's setup, for example, the quantity of subcarriers, number of information streams, and image's time, influences the number of assets in every soundness time and transmission capacity. Henceforth, every framework's design likewise requires a relating pilot design. Many works were keen on planning a versatile pilot example to ensure greater adaptability and better dependability. Nonetheless, they are either founded on the channel sparsity [16]-[19] for recurrence division duplex (FDD) frameworks or read up for single-input single-yield (SISO) structures [20]. There is no question that sparsity exists. Nonetheless, not every one of the channels is destined to be meager. Plus, the handset equipment will annihilate the sparsity except if a bunch of necessities is fulfilled. Subsequently, innovations depending on channel sparsity are bound to disfunction for certain clients. As an answer works in embraced the uplink channel assessment. It comprises of sending symmetrical pilots from the portable station to the base station, then, at that point, taking advantage of the channel correspondence to involve the assessed coefficients for the downlink correspondence. That requires the supposition of channel correspondence, the utilization of time division duplex (TDD), and an adequately long intelligence time for two-way transmission. Regardless of a few arrangements proposed in the writing, FDD is certainly not a favored choice for executing monstrous MIMO. Along these lines, this article takes on the TDD-based arrangement. In this work, we propose another versatile pilot design (APP) for enormous MIMO frameworks. We plan to improve the BER execution autonomously of the channel, the recurrence, and the framework's boundaries. In addition, we put together it concerning the arrangement, so it doesn't rely upon the channel sparsity. We additionally offer a hypothetical examination of the APP's effect on the channel assessment's BER execution. At long last, we propose another channel assessment at the base station called the moved APP-based channel assessment (SACE). It means to determine the mistake floor issue caused on the off chance that the APP requires different subcarriers for one CSI grid. To sum up, the main contributions are:

• The proposal of a new adaptive pilot pattern at the mobile station (APP).

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Vol 13, Issue 04, APRIL /2022

ISSN NO:0377-9254

• The suggestion of a new APP-based channel estimation at the base station. To analyze and justify these contributions, we led the following works:

• A comparative study of the APP and the conventional fixed pilot patterns.

• A BER performance’s theoretical study of the APP-based channel estimation.

• A numerical study of the APP and the SACE algorithms using MATLAB simulation.

II. System Overview

This section is a general overview of the techniques and architectures used in this manuscript. First, we give an overview of the PACE channel estimation to distinguish its different features. Then, we describe the system’s architecture that we are using in this work.

A. CHANNEL ESTIMATION OVERVIEW Channel estimation includes three main procedures: pilot arrangement, pilot assignment, and channel estimation. In this section, we are going to distinguish these different meanings.

1) PILOT ARRANGEMENT It consists of arranging the assigned pilot sequence in the available resources. In single-antenna orthogonal frequency division multiplexing (OFDM) systems, pilots are designed in a 2-dimension-arrangement (frequency and time dimensions) following two main patterns. The first one is the bloc-type pilot arrangement [10], in which pilots are inserted in all the subcarriers of one OFDM symbol every coherence time. The second one is the comb-type pilot arrangement, in which pilots are inserted in one subcarrier every coherence band of all the OFDM symbols. For MIMO-OFDM systems, 3-dimension (3D) pilot patterns are needed.

2) 3D PILOT PATTERN It consists of arranging the assigned pilots in the time, frequency, and space dimensions. As a requirement, intersymbol interference should be eliminated. Therefore, the most common technique is to use orthogonal resources. One pilot is sent from a single antenna per frequency/time resource while the other antennas are silent. Consequently, one needs as many frequency/time resources as the number of transmit antennas. However, in massive MIMO downlink communication, this is very hard to achieve because of the large number of transmit antennas. Hence, several works are interested in resolving this pilot overhead problem. They are mainly divided into two approaches. The TDDbased approach continues using orthogonal pilots. However, it sends them from the mobile station to the base station. In this case, the number of pilots is proportional to the number

Vol 13, Issue 04, APRIL / 2022
ISSN NO:0377-9254

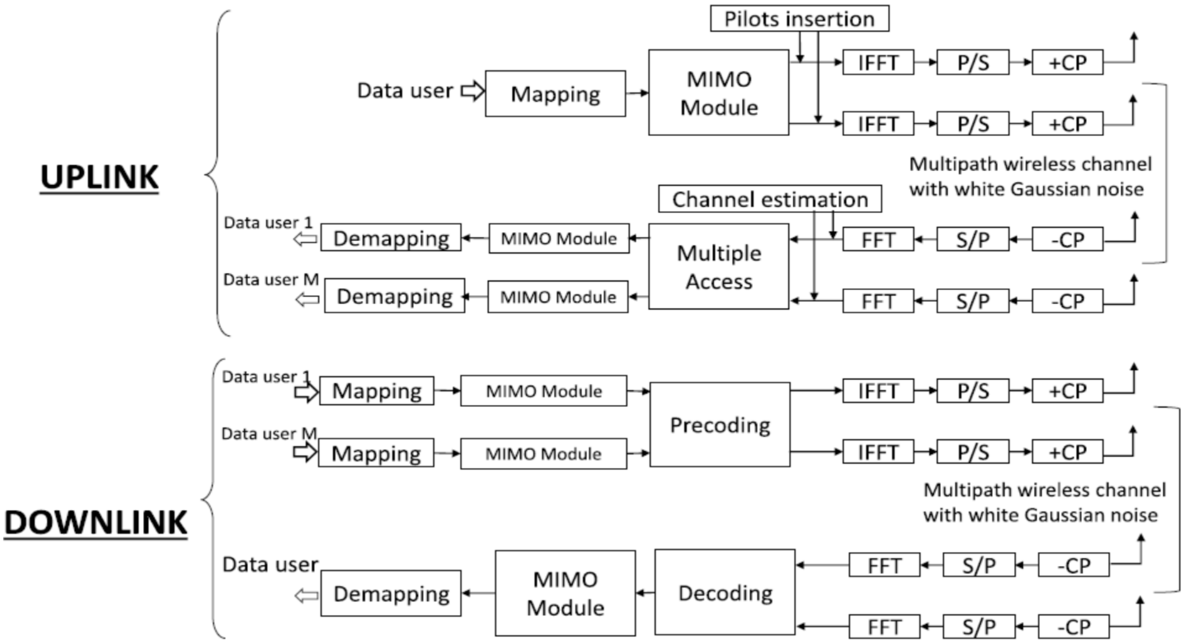

FIGURE 1. System model.

of antennas at the mobile station, which is much smaller than the number of antennas at the base station. That requires the assumption of channel reciprocity, the usage of TDD, and a long enough coherence time for two-way transmission. The second approach gives up on using orthogonal pilots and is based on designing non-orthogonal pilot training to reduce the pilot overhead problem, use compressed sensing to reduce the training and feedback overhead, but the performance relies highly on the channel's sparsity. In this work, we are interested in the TDD-based solution.

B. SYSTEM's ARCHITECTURE

This paper considers the massive MIMO-OFDM system illustrated in Fig. 1. First, the modulated signal goes through a MIMO encoder where the MIMO technique (diversity or spatial multiplexing) is applied. Then, the pilot symbols are inserted to ensure the estimation of the channel coefficients. After that, the OFDM samples are computed via the inverse fast Fourier transform (IFFT) and a cyclic prefix is appended. In the next stage, the signal goes through a multi-path channel with additional white Gaussian noise. The received signal in the kth antenna corresponds to the data's time and frequency slots signal of the).

$$y_k = \sum_{i=1}^{N_t} h_{k,i}(f,t)x_i(f,t) + n_k$$

where yk is the received signalHKf t K^{th} receive antenna, hk,i(f , t)I the channel coefficient of the ,receive antenna and the i th transmit antenna corresponding to the f th subcarrier and the t th time slot. Moreover, xi(f , t) is the symbol transmitted from the i^{th} antenna corresponding to the f^{th} subcarrier and the i^{th} time slot. Finally, nk is the white Gaussian noise. Based on the received signal, the base station estimates the channel matrix of each user. Then, it uses it to ensure the downlink communication. This paper proposes the pilot pattern mapping on uplink communication and analyzes its performances after being used for downlink communication.

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ISSN NO:0377-9254

Algorithm 1 APP Mapping Algorithm

Input: B_s : bandwidth; T_s : number of subcarriers delay spread; N_r: antennas number; p:sequence of kn pilots
Output: $P(a_r, f, t)$: mapping grid
calculate the coherence bandwidth B_c
calculate the coherence time T_c
calculate the best frequency spacing $\delta_f = \left\lfloor \frac{B_c}{B_s} \right\rfloor$
calculate the best time spacing $\delta_t = \left\lfloor \frac{T_c}{T_s} \right\rfloor$
calculate $\left\lfloor \frac{N_r}{\delta_t} \right\rfloor + r$
extract the number of subcarriers to be used $N_{sc} = \lfloor$
extract the time slots number in the last subcarrier N_t
for each cluster of δ_t time slots and δ_f subcarriers **do**
  start the mapping with the first antenna $a_r \leftarrow 1$
  while $f \leq N_{sc}$ **do**
    while $t \leq \delta_t$ **do**
      $P(a_r, f, t) \leftarrow p(a_r)$
      $a_r = a_r + 1$
    end while
  end while
  if $r > 0$ **then**
    while $t \leq r$ **do**
      $P(a_r, N_{sc} + 1, t) \leftarrow p(a_r)$
      $a_r = a_r + 1$
    end while
  end if
end for

Comparison With Conventional Pilot Patterns

This section offers a comparison between the APP and the conventional fixed pilot patterns like LTE and WIMAX pilot patterns. It is done in terms of BER, pilot overhead, system flexibility, and complexity. The summary of this comparison is given in Table 1.

III. Numerical Study

TABLE 1. Comparison between APP and conventional fixed pilot patterns.

BER	APP offers better or equal BER performance than conventional pilot patterns
Pilot overhead	APP offers a better or equal pilot overhead performance in case it has similar BER performance as the fixed pilot patterns. Fixed pilot patterns can offer better pilot overhead performance at the cost of a higher BER
Flexibility	APP is more flexible than conventional pilot patterns
Complexity	APP is more complex than conventional pilot patterns

Conventional pilot patterns have fixed clusters of frequency/time resources in which the pilot symbols are reinserted to estimate a new CSI matrix. For example, the LTE pilot pattern has a fixed cluster of 6 subcarriers and 4 time slots. WiMAX IEEE 802.16e has a fixed cluster of 5 subcarriers and 4 time slots. In this work, we are referring to this cluster as the conventional pilot pattern cluster. To compare the APP and the conventional fixed pilot patterns BER performance, two use cases should be investigated. The first use case is when the system's channel is constant over a larger bandwidth or time period than a conventional pilot pattern cluster. In this case, the APP and the conventional fixed pilot pattern both give similar BER performances since the CSI is accurate for both of them. The second use case is when the channel is variable over the conventional pilot pattern cluster. In this case, the fixed pilot pattern can no longer guarantee an accurate CSI because the channel changed during the estimation of the same channel matrix. Therefore, the APP offers a better BER performance since it takes into consideration the channel's coherence time and frequency.

To compare the pilot overhead performance, three use cases should be investigated. The first use case is when the channel is constant over exactly the same bandwidth and time period as the conventional pilot pattern cluster. In this case, both the APP and the fixed pilot pattern offer the same pilot overhead. The second use case is when the channel is constant over a larger bandwidth or time period than the conventional pilot pattern cluster. In this case, the APP offers better pilot overhead performance since it sends pilots only when the channel changes. The third use case is when the channel is variable over the conventional pilot pattern cluster. In this case, the conventional pilot pattern offers better pilot overhead but at the cost of a BER performance degradation. In terms of flexibility, APP can be

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ISSN NO:0377-9254

implemented with any architecture while the conventional fixed pilot patterns are limited to a given set of architectures.

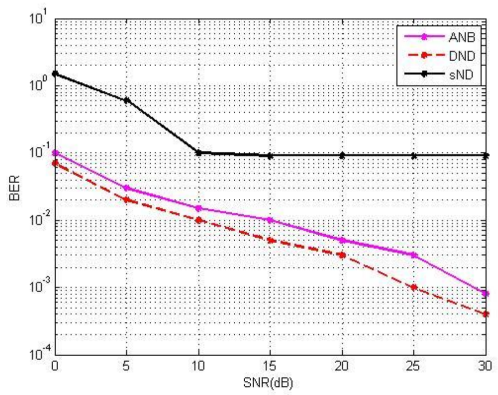

Figure 2. BER comparison of APP and LTE pilot pattern with 20 Mhz bandwidth.

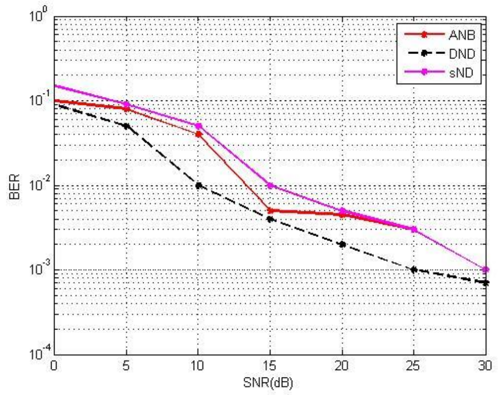

FIGURE 3. BER comparison of APP and LTE pilot pattern with 4 Mhz bandwidth.

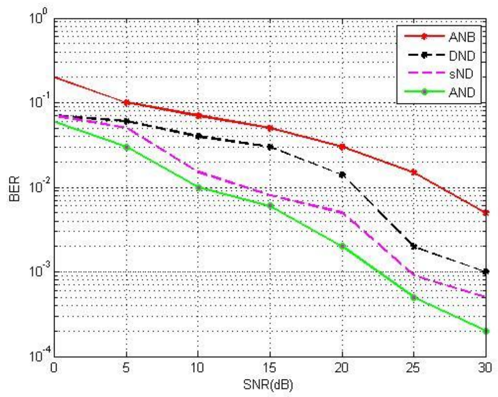

FIGURE 4. BER performances of SACE.

Fig. 2,3,4 shows the result of the BER versus SNR comparison between the APP and the LTE pilot pattern while giving the perfect channel case as a referee The final result shows that the APP reaches a BER = 10−3 for 30 dB while the LTE pilot pattern did not exceed BER = 10−1 . To discuss this result we analyzed the BER and the pilot overhead performances.

IV. Conclusion

This paper addresses the pilot pattern optimization issue to ensure its BER optimization. It offers primarily five commitments. In the first place, it proposes a versatile pilot design called APP. Then, at that point, it thinks about it to regular fixed pilot designs. Then, it examines its BER execution. From that point forward, it proposes another channel assessment called SACE. At long last, it offers a numerical study of the proposed techniques. The main founded results are:

• APP guarantees a channel estimation within the coherence time and bandwidth independently from the channel model and the system's configuration.

• APP offers equal or better BER than the conventional fixed pilot patterns.

• APP offers equal or lower pilot overhead than conventional pilot patterns without any cost in terms of BER.

• SACE suppresses the error floor caused by the use of more than one subcarrier at the pilot pattern design.

• SACE offers an SNR amelioration of 17dB at BER = 10−2 compared to the MMSE channel estimation.

This APP design considers only the TDD mode. However, several communication technologies are based on the FDD mode. Therefore, further work is needed to use APP combined with the FDD.

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