An Industrial Oriented Mini Project Report

on

ESTIMATION OF CHANNEL MULTI CELL MULTI USER IN MIMO-OFDM

Submitted by

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Under the Esteemed Guidance of

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To

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BONAFIDE CERTIFICATE

This is to certify that the mini project entitled "ESTIMATION OF CHANNEL MULTI CELL MULTI USER IN MIMI-OFDM" that is being submitted by P.BALU MAHENDER (21W91A0499), under the guidance of Mr.OWK.SRINIVASULU for the award of B.Tech Degree in ELECTRONICS AND COMMUNICATIONENGINEERING from the MALLAREDDY INSTITUTE OF ENGINEERING & TECHNOLOGY, Maisammaguda (Affiliated to JNTU Hyderabad) is a record of bonafied work carried out by them under our guidance and supervision. The results embodied in this mini project have not been submitted to any other university or institute for the award of any degree.

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DECLARATION

I, P.BALU MAHENDER (21W91A0499), hereby declare that the mini project entitled "ESTIMATION OF CHANNEL MULTI CELL MULTI USER IN MIMI-OFDM" is bonafide work done and submitted under the guidance of Mr.OWK.SRINIVASULU in partial fulfillment of the requirements for the awardof the degree of BACHELOR OF TECHNOLOGY in ELECTRONICS AND COMMUNICATION ENGINEERING.

DEPARTMENT OF ECE

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ABSTRACT

This project investigates the uplink transmission in multi-cell multi-user multiple input multiple output (MIMO) orthogonal frequency division multiplexing (OFDM) systems. The system model considers imperfect channel estimation, pilot contamination (PC), multiple sub-carriers and multi-path channels. It is proposed a simple H-inf channel estimation that achieves good suppression to PC. The approach exploits the space-alternating generalized EM (SAGE) iterative process to decompose multi-cell multi-user MIMO problem into a series of single-cell single-user SISO problems, which reduces the complexity drastically. Analysis on mean square error (MSE) of H-inf in the presence of PC is also presented. The numerical results show that increasing the number of pilot subcarriers cannot mitigate PC, and a clue for relieving PC can be obtained. The H-inf realizes better suppression to PC than the LS and ML algorithms. Its performance is close to the optimal MMSE algorithm and can be improved as the increase in the length of channel impulse response (CIR). By using the SAGE process, the performance of the H-inf does not degrade in case of a large number of antennas at base station (BS).

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Wireless communications require the outstanding capability to combat multipath fading and to offer high spectral efficiency. Multiple-input multiple-output (MIMO) combined with orthogonal frequency-division multiplexing (OFDM) has been widely considered to be a promising candidate. Unlike the point-to-point MIMO, a multiuser MIMO (MU-MIMO) system that has low cost in terminals and better tolerance to wireless propagation environment has been considered for future wireless communications [3]. In a multi cell scenario, it is well known that accurate channel state information (CSI) is critical for achieving high system performance. Since the mobility of users and the limited bandwidth, it is not possible to allocate dedicated pilots for the users in each cell, and therefore, the reuse of pilots is a must for users in different cells.

1.2 WIRELESS COMMUNICATION

Wireless communication is the transfer of information between two or more points that are not connected by an electrical conductor. The most common wireless technologies use radio. With radio waves distances can be short, such as a few meters for television or as far as thousands or even millions of kilometers for deep-space radio communications Wireless operations permit services, such as a long-range communications, that are impossible or impractical to implement with the use of wires. Supporting technologies include Wi-Fi is a wireless local area network that enables portable computing devices to connect easily to the Internet. Standardized as IEEE 802.11 . Wi-Fi approaches speeds of some types of wired Ethernet. Wi-Fi has become the de facto standard for access in private homes, within offices, and at public hotspots. Some businesses charge customers a monthly fee for service, while others have begun offering it for free in an effort to increase the sales of their goods.

1.3 MIMO (MULTIPLE INPUT MULTIPLE OUTPUT)

Multiple-input and multiple-output is a method for multiplying the capacity of a radio link using multiple transmit and receive antennas to exploit multipath propagation, At one time in wireless the term “MIMO” referred to the mainly theoretical use of multiple antennas at both the transmitter and the receiver. In modern usage, “MIMO” specifically refers to a practical technique for sending and receiving more than one data signal on the same radio channel at the same time via multipath propagation as shown in Fig 1.1. MIMO is fundamentally different from smart antenna techniques developed to enhance the performance of a single data signal, such as beam forming and diversity.

Fig.1.1 Multiple Input Multiple Output

MIMO can be sub-divided into three main categories, pre coding, spatial multiplexing or SM, and diversity coding. Pre coding is multi-stream beam forming, in the narrowest definition. In more general terms, it is considered to be all spatial processing that occurs at the transmitter. In (single-stream) beam forming, the same signal is emitted from each of the transmit antennas with appropriate phase and gain weighting such that the signal power is maximized at the receiver input.

1.4 APPLICATIONS FOR MIMO

Spatial multiplexing techniques make the receivers very complex, and therefore they are typically combined with Orthogonal frequency-division multiplexing (OFDM) or with Orthogonal Frequency Division

Multiple Access (OFDMA) modulation, where the problems created by a multi-path channel are handled efficiently. The IEEE 802.16e standard incorporates MIMO-OFDMA. The IEEE 802.11n standard, released in October 2009, recommends MIMO-OFDM.

MIMO is also planned to be used in Mobile radio telephone standards such as recent 3GPP and 3GPP2. In 3GPP, High-Speed Packet Access plus (HSPA+) and Long Term Evolution (LTE) standards take MIMO into account. Moreover, to fully support cellular environments, MIMO research consortia including IST-MASCOT propose to develop advanced MIMO techniques, e.g., multi-user MIMO (MU-MIMO). MIMO technology can be used in non-wireless communications systems. One example is the home networking standard ITU-T G.9963, which defines a power line communications system that uses MIMO techniques to transmit multiple signals over multiple AC wires (phase, neutral and ground).

1.5 MIMO-SPACE TIME WIRELESS SYSTEM

It requires MIMO antenna configuration. In spatial multiplexing, a high-rate signal is split into multiple lower-rate streams and each stream is transmitted from a different transmit antenna in the same frequency channel. If these signals arrive at the receiver antenna array with sufficiently different spatial signatures and the receiver has accurate CSI, it can separate these streams into (almost) parallel channels. Spatial multiplexing is a very powerful technique for increasing channel capacity at higher signal-to-noise ratios (SNR).

Multi-user MIMO beam forming even benefits single spatial stream devices. Prior to MU-MIMO beamforming, an access point communicating with multiple client devices could only transmit to one at a time. With MU-MIMO beamforming, the access point can transmit to up to four single stream devices at the same time on the same channel. The 802.11ac standard also supports speeds up to 6.93 Gbit/s using eight spatial streams in single-user mode. The maximum data rate assumes use of the optional 160 MHz channel in the 5 GHz band and 256 QAM (quadrature amplitude modulation). Chipsets supporting six spatial streams have been introduced and chipsets supporting eight spatial streams are under development.

1.6 MIMO (MU-MIMO)

Multi-user MIMO (MU-MIMO) can leverage multiple users as spatially distributed transmission resources, at the cost of somewhat more expensive signal processing. In comparison, conventional, or single-user MIMO considers only local device multiple antenna dimensions. Multi-user MIMO algorithms are developed to enhance MIMO systems when the number of users or connections is greater than one. Multi-user MIMO can be generalized into two categories: MIMO broadcast channels (MIMO BC) and MIMO multiple access channels (MIMO MAC) for downlink and uplink situations, respectively. Single-user MIMO can be represented as point-to-point, pair wise MIMO.

To remove ambiguity of the words receiver and transmitter we can adopt the terms access point (AP; or, base station), and user. An AP is the transmitter and a user is the receiver for downlink environments, whereas an AP is the receiver and a user is the transmitter for uplink environments. Homogeneous networks are somewhat freed from this distinction.

1.7 SPACE DIVISION MULTIPLE ACCESS

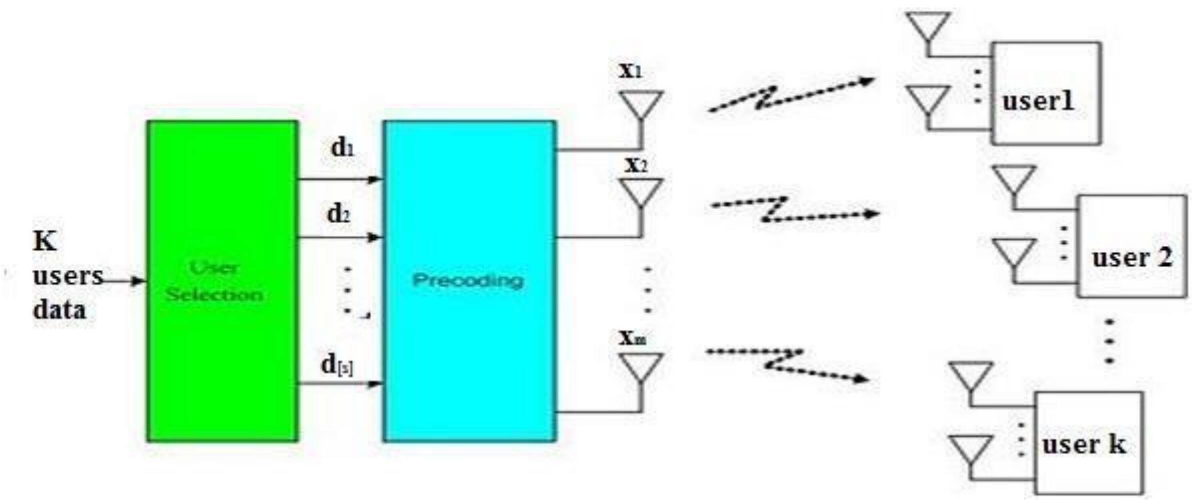

Fig: 1.2 Space Division Multiple Access

MIMO broadcast represents a MIMO downlink case in a single sender to multiple receiver wireless networks. Examples of advanced transmit processing for MIMO BS are interference aware precoding and SDMA-based downlink user scheduling.

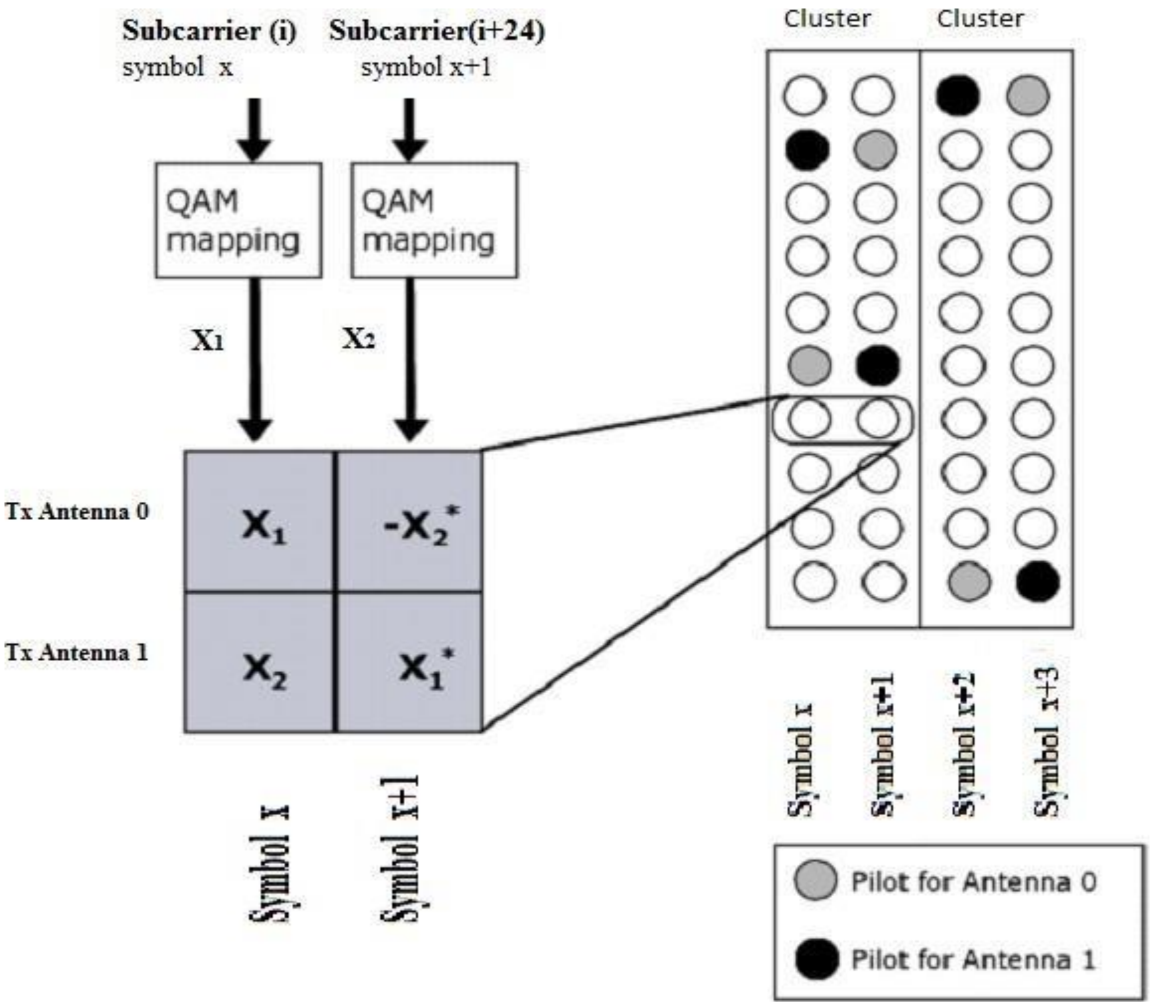

Fig1.3 Space time decoding

Space time codes may be split into two main types

- Space–time trellis codes (STTCs) [1] distribute a trellis code over multiple antennas and multiple time-slots and provide both coding gain and diversity gain.
- Space–time block codes (STBCs) [2][3] act on a block of data at once (similarly to block codes) and also provide diversity gain but doesn't provide coding gain.

STC may be further subdivided according to whether the receiver knows the channel impairments. In coherent STC, the receiver knows the channel impairments through training or some other form of estimation.

1.8 ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

Orthogonal frequency-division multiplexing (OFDM) is a method of encoding digital data on multiple carrier frequencies. OFDM has developed into a popular scheme for wideband digital communication, used in applications such as digital television and audio broadcasting, DSL Internet access, wireless networks, power line networks, and 4G mobile communications. OFDM is a frequency-division multiplexing (FDM) scheme used as a digital multi-carrier modulation method. A large number of closely spaced orthogonal sub-carrier signals are used to carry data[1] on several parallel data streams or channels. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase-shift keying) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth.

Loss of efficiency caused by cyclic prefix/Guard interval orthogonal frequency-division multiplexing (OFDM) is a method of encoding digital data on multiple carrier frequencies. OFDM has developed into a popular scheme for wideband digital communication, used in applications such as digital television and audio broadcasting, DSL Internet access, wireless networks, power line networks, and 4G mobile communications.

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The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions (for example,attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath) without complex equalization filters. Channel equalization is simplified because OFDM may be viewed as using many slowly modulated narrowband signals rather than one rapidly modulated wideband signal.

The orthogonality requires that the sub-carrier spacing is $\Delta f = kTU$ Hertz, where T_U seconds is the useful symbol duration (the receiver side window size), and k is a positive integer, typically equal to 1. Therefore, with N sub-carriers, the total pass band bandwidth will be $B \approx N \cdot \Delta f$ (Hz).

The orthogonality also allows high spectral efficiency, with a total symbol rate near the Nyquist rate for the equivalent baseband signal (i.e. near half the Nyquist rate for the double-side band physical passband signal). Almost the whole available frequency band can be utilized. OFDM generally has a nearly 'white' spectrum, giving it benign electromagnetic interference properties with respect to other co-channel users.

1.8.1 OFDM ADVANTAGES

- Flexibility of deployment across various frequency bands with little needed modification to the air interface.
- Averaging interferences from neighboring cells, by using different basic carrier permutations between users in different cells.
- Interferences within the cell are averaged by using allocation with cyclic permutations.
- Enables Single Frequency Network coverage, where coverage problem exists and gives excellent coverage.
- Offers Frequency diversity by spreading the carriers all over the used spectrum.

1.8.2 OFDM DISADVANTAGES

- Problems with Doppler shift.
- Synchronizing frequencies can be problematic
- Sensitive to frequency synchronization problems.
- High peak-to-average-power ratio (PAPR). This needs linear transmission circuits; they need a lot of power.

1.9 CHANNEL CODING AND INTERLEAVING OFDM

It is invariably used in conjunction with channel coding (forward error correction), and almost always uses frequency and/or time interleaving. Frequency (subcarrier) interleaving increases resistance to frequency-selective channel conditions such as fading. For example, when a part of the channel bandwidth fades, frequency interleaving ensures that the bit errors that would result from those subcarriers in the faded part of the bandwidth are spread out in the bit-stream rather than being concentrated. Similarly, time interleaving ensures that bits that are originally close together in the bit-stream are transmitted far apart in time, thus mitigating against severe fading as would happen when travelling at high speed. However, time interleaving is of little benefit in slowly fading channels, such as for stationary reception, and frequency interleaving offers little to no benefit for narrowband channels that suffer from flat-fading (where the whole channel bandwidth fades at the same time).

The reason why interleaving is used on OFDM is to attempt to spread the errors out in the bit-stream that is presented to the error correction decoder, because when such decoders are presented with a high concentration of errors the decoder is unable to correct all the bit errors, and a burst of uncorrected errors occurs. A similar design of audio data encoding makes compact disc (CD) playback robust.

Newer systems, however, usually now adopt near-optimal types of error correction codes that use the turbo decoding principle, where the decoder iterates towards the desired solution. Examples of such error correction coding types include turbo codes and LDPC codes, which perform close to the Shannon limit for the Additive White Gaussian Noise (AWGN) channel. Some systems that have implemented these codes have concatenated them with either Reed-Solomon (for example on the MediaFLO system) or BCH codes(on the DVB-S2 system) to improve upon an error floor inherent to these codes at high signal-to-noise ratios[16].

1.10 ADAPTIVE TRANSMISSION

The resilience to severe channel conditions can be further enhanced if information about the channel is sent over a return-channel. Based on this feedback information, adaptive modulation, channel coding and power allocation may be applied across all sub-carriers, or individually to each sub-carrier. In the latter case, if a particular range of frequencies suffers from interference or attenuation, the carriers within that range can be disabled or made to run slower by applying more robust modulation or error coding to those sub-carriers.

The term discrete multitone modulation (DMT) denotes OFDM based communication systems that adapt the transmission to the channel conditions individually for each sub-carrier, by means of so-called bit-loading. Examples are ADSL and VDSL. The upstream and downstream speeds can be varied by allocating either more or fewer carriers for each purpose. Some forms of rate-adaptive DSL use this feature in real time, so that the bit rate is adapted to the co-channel interference and bandwidth is allocated to whichever subscriber needs it most.

1.11 OFDM EXTENDED WITH MULTIPLE ACCESS

OFDM in its primary form is considered as a digital modulation technique, and not a multi-user channel access method, since it is utilized for transferring one bit stream over one communication channel using one sequence of OFDM symbols. However, OFDM can be combined with multiple access using time, frequency or coding separation of the users.

In orthogonal frequency-division multiple access (OFDMA), frequency-division multiple access is achieved by assigning different OFDM sub-channels to different users. OFDMA supports differentiated quality of service by assigning different number of sub-carriers to different users in a similar fashion as in CDMA, and thus complex packet scheduling or Media Access Control schemes can be avoided. OFDMA is used in the mobility mode of the IEEE 802.16 Wireless MAN standard, commonly referred to as Wi-MAX .

1.12 SPACE DIVERSITY

OFDM based wide area broadcasting, receivers can benefit from receiving signals from several spatially dispersed transmitters simultaneously, since transmitters will only destructively interfere with each other on a limited number of sub-carriers, whereas in general they will actually reinforce coverage over a wide area. This is very beneficial in many countries, as it permits the operation of national single-frequency networks (SFN), where many transmitters send the same signal simultaneously over the same channel frequency. SFNs utilize the available spectrum more effectively than conventional multi-frequency broadcast networks (MFN), where program content is replicated on different carrier frequencies. SFNs also result in a diversity gain in receivers situated midway between the transmitters. The coverage area is increased and the outage probability decreased in comparison to an MFN, due to increased received signal strength averaged over all sub-carriers.

Although the guard interval only contains redundant data, which means that it reduces the capacity, some OFDM-based systems, such as some of the broadcasting systems, deliberately use a long guard interval in order to allow the transmitters to be spaced farther apart in an SFN, and longer guard intervals allow larger SFN cell-sizes. A rule of thumb for the maximum distance between transmitters in an SFN is equal to the distance a signal travels during the guard interval — for instance, a guard interval of 200 microseconds would allow transmitters to be spaced 60 km apart.

A single frequency network is a form of transmitter macrodiversity. The concept can be further utilized in dynamic single-frequency networks (DSFN), where the SFN grouping is changed from timeslot to timeslot. OFDM may be combined with other forms of space diversity, for example antenna arrays and MIMO channels. This is done in the IEEE802.11 Wireless LAN standard.

1.13 LINEAR TRANSMITTER POWER AMPLIFIER

An OFDM signal exhibits a high peak-to-average power ratio (PAPR) because the independent phases of the sub-carriers mean that they will often combine constructively. Handling this high PAPR requires:

- a high-resolution digital-to-analogue converter (DAC) in the transmitter.
- a high-resolution analogue-to-digital converter (ADC) in the receiver.
- a linear signal chain.
- Any non-linearity in the signal chain will cause intermodulation distortion that raises the noise floor may cause inter-carrier interference generates out-of-band spurious radiation.

The linearity requirement is demanding, especially for transmitter RF output circuitry where amplifiers are often designed to be non-linear in order to minimize power consumption. In practical OFDM systems a small amount of peak clipping is allowed to limit the PAPR in a judicious trade-off against the above consequences. However, the transmitter output filter which is required to reduce out-of-band spurs to legal levels has the effect of restoring peak levels that were clipped, so clipping is not an effective way to reduce PAPR. Although the spectral efficiency of OFDM is attractive for both terrestrial and space communications, the high PAPR requirements have so far limited OFDM applications to terrestrial systems.

CHAPTER 2

LITERATURE SURVEY

It is consider a multi-cell multiple antenna system with precoding used at the base stations for downlink transmission. For precoding at the base stations, channel state information (CSI) is essential at the base stations. A popular technique for obtaining this CSI in time division duplex (TDD) systems is uplink training by utilizing the reciprocity of the wireless medium. This paper mathematically characterizes the impact that uplink training has on the performance of such multi-cell multiple antenna systems. When non-orthogonal training sequences are used for uplink training, the paper shows that the precoding matrix used by the base station in one cell becomes corrupted by the channel between that base station and the users in other cells in an undesirable manner.

2.1 MIMO MAC

Conversely, the MIMO multiple-access-channel or MIMO MAC represents a MIMO uplink case in the multiple sender to single receiver wireless network. Examples of advanced receive processing for MIMO MAC are joint interference cancellation and SDMA-based uplink user scheduling. For advanced receive processing, the receiver has to know the channel state information at the receiver (CSIR). Knowing CSIR is generally easier than knowing CSIT. However, knowing CSIR costs a lot of uplink resources to transmit dedicated pilots from each user to the AP. MIMO MAC systems outperforms point-to-point MIMO systems especially when the number of receiver antennas at an AP is larger than the number of transmit antennas at each user.

2.2 CROSS-LAYER MIMO

Enhances the performance of MIMO links by solving certain cross-layer problems that may occur when MIMO configurations are employed in a system. Cross-layer techniques can be used to enhance the performance of SISO links as well. Examples of cross-layer techniques are Joint

Source-Channel Coding, Adaptive Modulation and Coding (AMC, or "Link Adaptation"), Hybrid ARQ (HARQ), and user scheduling.

2.3 MULTI-USER TO MULTI-USER

The highly interconnected wireless ad hoc network increases the flexibility of wireless networking at the cost of increased multi-user interference. To improve the interference immunity, PHY/MAC-layer protocols have evolved from competition based to cooperative based transmission and reception. Cooperative wireless communications can actually exploit interference, which includes self-interference and other user interference. In cooperative wireless communications, each node might use self-interference and other user interference to improve the performance of data encoding and decoding, whereas conventional nodes are generally directed to avoid the interference.

Cooperative multiple antenna research — apply multiple antenna technologies in situations with antennas distributed among neighboring wireless terminals. Cooperative diversity — Achieve antenna diversity gain by the cooperation of distributed antennas belonging to each independent node. Cooperative MIMO — Achieve MIMO advantages, including the spatial multiplexing gain, using the transmit or receiver cooperation of distributed antennas belonging to many different nodes.

Cooperative relay Apply cooperative concepts onto relay techniques, which is similar to cooperative diversity in terms of cooperative signalling. However, the main criterion of cooperative relay is to improve the tradeoff region between delay and performance, while that of cooperative diversity and MIMO is to improve the link and system performance at the expense of minimal cooperation loss. Store-and-forward (S&F), Amplify-and-forward (A&F), Decode-and-forward (D&F), coded cooperation, spatial coded cooperation, Compress-and-forward (C&F), Non-orthogonal methods.

2.4 COOPERATIVE MIMO (CO-MIMO)

CO-MIMO, also known as Network MIMO (Net-MIMO), or ad hoc MIMO, uses distributed antennas which belong to other users, while conventional MIMO, i.e., single-user MIMO, only employs antennas belonging to the local terminal. CO-MIMO improves the performance of a wireless network by introducing multiple antenna advantages, such as diversity, multiplexing and beamforming. If the main interest hinges on the diversity gain, it is known as cooperative diversity. It can be described as a form of macro-diversity, used for example in soft handover.

Space-Division Multiple Access (SDMA) enables creating parallel spatial pipes next to higher capacity pipes through spatial multiplexing and/or diversity, by which it is able to offer superior performance in radio multiple access communication systems. In traditional mobile cellular network systems, the base station has no information on the position of the mobile units within the cell and radiates the signal in all directions within the cell in order to provide radio coverage. This results in wasting power on transmissions when there are no mobile units to reach, in addition to causing interference for adjacent cells using the same frequency, so called co-channel cells. Likewise, in reception, the antenna receives signals coming from all directions including noise and interference signals. By using smart antenna technology and by leveraging the spatial location of mobile units within the cell, space-division multiple access techniques offer attractive performance enhancements. The radiation pattern of the base station, both in transmission and reception is adapted to each user to obtain highest gain in the direction of that user. This is often done using phased array techniques.

In GSM cellular networks, the base station is aware of the mobile phone's position by use of a technique called Timing Advance (TA). The Base Transceiver Station (BTS) can determine how distant the Mobile Station (MS) is by interpreting the reported TA. This information, along with other parameters, can then be used to power down the BTS or MS, if a power control feature is implemented in the network. The power control in either BTS or MS is implemented in most modern networks, especially on the MS, as this ensures a better battery life for the MS and thus a better user experience (in that the need to charge the battery becomes less frequent). This is why it may actually be safer to have a BTS close to you as your MS will be powered down as much as possible. For example, there is more power being transmitted from the MS than what you would receive from the BTS even if you are 6 m away from a mast. However, this estimation might not consider all the MS's that a particular BTS is supporting with EM radiation at any given time.

Space–time code (STC) is a method employed to improve the reliability of data transmission in wireless communication systems using multiple transmit antennas. STCs rely on transmitting multiple, redundant copies of a data stream to the receiver in the hope that at least some of them may survive the physical path between transmission and reception in a good enough state to allow reliable decoding.

The problem of channel estimation in multi-cell interference-limited cellular networks. We consider systems employing multiple antennas and are interested in both the finite and large-scale antenna number regimes (so called ”massive MIMO”). Such systems deal with the multi-cell interference by way of per-cell beam forming applied at each base station. Channel estimation in such networks, which is known to be hampered by the pilot contamination effect, constitutes a major bottleneck for overall performance. We present a novel approach which tackles this problem by enabling a low-rate coordination between cells during the channel estimation phase itself. The coordination makes use of the additional second-order statistical information about the user channels, which are shown to offer a powerful way of discriminating across interfering users with even strongly correlated pilot sequences. Importantly, we demonstrate analytically that in the large-number-of-antennas regime, the pilot contamination effect is made to vanish completely under certain conditions on the channel covariance. Gains over the conventional channel estimation framework are confirmed by our simulations for even small antenna array sizes

This project describes a least squares (LS) channel estimation scheme for multiple-input multiple-output (MIMO) orthogonal frequency division multiplexing (OFDM) systems based on pilot tones. We first compute the mean square error (MSE) of the LS channel estimate. We then derive optimal pilot sequences and optimal placement of the pilot tones with respect to this MSE. It is shown that the optimal pilot sequences are equi powered, equispaced, and phase shift orthogonal. To reduce the training overhead, an LS channel estimation scheme over multiple OFDM symbols is also discussed. Moreover, to enhance channel estimation, a recursive LS (RLS) algorithm is proposed, for which we derive the optimal forgetting or tracking factor. This factor is found to be a function of both the noise variance and the channel Doppler spread. Through simulations, it is shown that the optimal pilot sequences derived in this paper outperform both the orthogonal and random pilot sequences. It is also shown that a considerable gain in signal-to-noise ratio (SNR) can be obtained by using the RLS algorithm, especially in slowly time-varying channels.

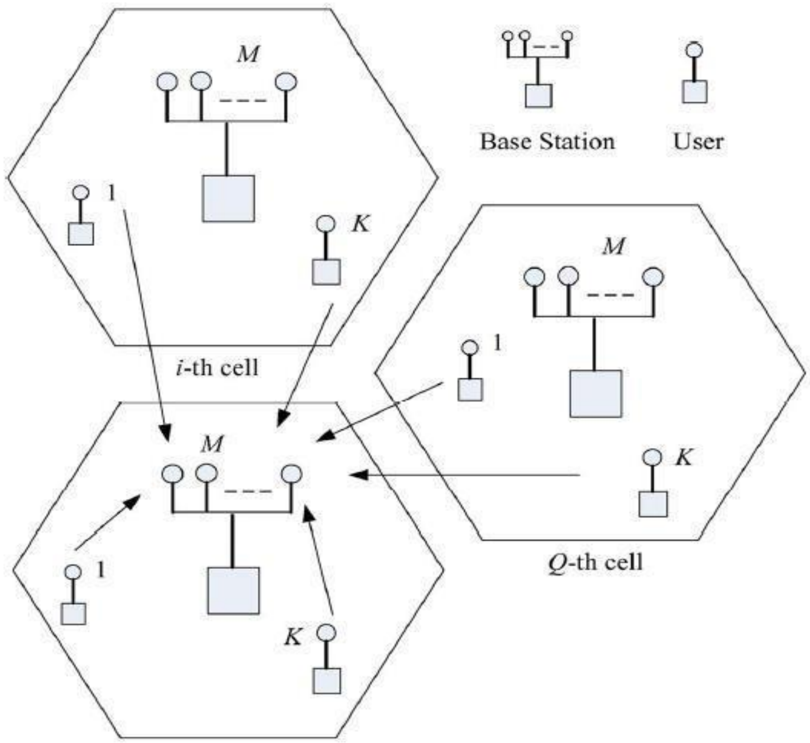

Fig. 2.1 Uplink transmission in multicell MU-MIMO systems.

The received $N \times 1$ signal vector on all N subcarriers at the rth antenna at the jth BS can be expressed as

Yj=XHj+Zj (1)

Where $Y_j = [Y_j(0), \ldots, Y_j(N-1)]^T$, $X = [X_1, \ldots, X_Q]$,X_q is a diagonal matrix containing the transmit signal from the qth cell, and $Z_j = [Z_j(0), \ldots, Z_j(N-1)]^T$ is a vector of independently and identically distributed (i.i.d.) complex zero-mean Gaussian noise variables with variance σ^2. $H_j = [H^T_{j1}, \ldots, H^T_{jQ}]^T$, H_{jq} is the frequency response of the channel between the jth and qth cells,$\sqrt{}H_{jq} = [H^T_{jq1}, \ldots, H^T_{jqK}]^T$, $\mathrm{H}_{jqk} = F_{N,L}C_{jqk}$, $F_{N,L}$ is $1/N$ times the first L columns of discrete Fourier transform (DFT) matrix, $F^{H}_{N,L}F_{N,L} = I_L$ and $\boldsymbol{C}jqk$ is the $L \times 1$ propagation coefficients between the jth BS and the kth user in the qth cell and is given as follows:

Cjqk=Djqk1/2+Gjqk (2)

Where $\boldsymbol{G}jqk$ denotes the $L \times 1$ fast-fading coefficient vector, which has an exponentially decaying multipath power-delay profile. The maximum tap delay is assumed shorter than the OFDM cyclic prefix (CP). Let $gjqkl$ be the lth element of $\boldsymbol{G}jqk$, and it is normalized to unity, i.e. is an $L \times L$ diagonal matrix whose diagonal elements $djqkl$ denote path loss and shadow fading, which are assumed to be independent over l and k.1 Since $djqkl$ changes slowly, we rewrite it as djq for notational simplicity, and djq is assumed to be less than 1.

Rewrite the received vector at the jth BS as

Yj=q=1Qk=1KXqk Hjqk+Zj. (3)

Let $\boldsymbol{X}qk = \boldsymbol{S}qk + \boldsymbol{B}qk$, where $\boldsymbol{S}qk$ is an arbitrary $N \times N$ data diagonal matrix, and $\boldsymbol{B}qk$ is an $N \times N$ pilot diagonal
matrix. Model (3) could be further rewritten as

Yj=q=1QTq Cjq+q=1QAq Cjq+Zj (4)

where $\boldsymbol{T}\ q$ =[$\boldsymbol{S}q1\boldsymbol{F}N,L$, . . . ,$\boldsymbol{S}qK\boldsymbol{F}N,L$],$\boldsymbol{A}q$ =[$\boldsymbol{B}q1\boldsymbol{F}N,L$....., $\boldsymbol{B}qK\boldsymbol{F}N,L$], and $\boldsymbol{C}jq$ = [$\boldsymbol{C}Tjq1$, . . . ,$\boldsymbol{C}TjqK$]T .

2.5 RELATED WORK

There are few researches specifically focused on channel estimation algorithms in the presence of PC in multicell MU-MIMO systems, although single-carrier and flat-fading transmission scenario has been considered. In [6], a blind channel estimation algorithm based on Eigen value decomposition was proposed; however, it requires a long-data record and employs the prior knowledge of stochastic information and high computational complexity. In [7], a coordinated channel estimation approach with correlated pilot sequences was developed to tackle the problem of PC; however, the complexity due to applying second-order statistical information is high. In [8], the asymptotic analysis on the impact of channel aging on both the uplink and the downlink achievable rates was provided, and a finite-impulse-response Wiener predictor was proposed to overcome channel aging effects. Linear least squares is a method of solving mathematics/statistical problems. It uses least squares algorithmic technique to increase accuracy of solution approximations, corresponding with a particular problem's complexity. Linear least squares (mathematics); also ordinary least squares (mathematics), or numerical methods for linear/ordinary least squares; concerning the mathematics and computational aspects of the corresponding optimization problem

- Linear regression, concerning the statistical context in which linear least squares often arises. Special cases are:
- Simple linear regression or straight line regression
- Ordinary least squares (statistics) or Linear least squares (statistics)
- Weighted least squares

Mathematically, linear least squares is the problem of approximately solving an over determined system of linear equations, where the best approximation is defined as that which minimizes the sum of squared differences between the data values and their corresponding modeled values. The approach is called linear least squares since the assumed function is linear in the parameters to be estimated. Linear least squares problems are convex and have a closed-form solution that is unique, provided that the number of data points used for fitting equals or exceeds the number of unknown parameters, except in special degenerate situations

In statistics, linear least squares problems correspond to a particularly important type of statistical model called linear regression which arises as a particular form of regression analysis. One basic form of such a model is an ordinary least squares model. The present article concentrates on the mathematical aspects of linear least squares problems, with discussion of the formulation and interpretation of statistical regression models and statistical inferences related to these being dealt with in the articles just mentioned. See outline of regression analysis for an outline of the topic. Least squares (LS) channel estimation, by using many pilot subcarriers, is usually considered an initial estimator without requiring any prior knowledge [14]. When the transmit symbols are known, the LS algorithm becomes maximum likelihood (ML) estimation [12]. To obtain optimal performance, minimum mean square error (MMSE) estimation, using channel correlation matrix and transmit data, has been investigated in [3]. However, the complexity of the MMSE algorithm is high. By avoiding the drawbacks of conventional algorithms, the H-infinity (H-inf) method is introduced into MIMO-OFDM systems. It has been proven that this algorithm has almost the same performance as MMSE but is much less complex.

Different from the existing researches, our system model considers imperfect channel estimation, PC, multicarrier, and multipath channels. In this paper, we first discuss the impact of the PC on two classical LS and MMSE algorithms. Analytical expressions on the mean square error (MSE) are derived.

In statistics, the mean squared error (MSE) or mean squared deviation (MSD) of an estimator measures the average of the squares of the errors or deviations, that is, the difference between the estimator and what is estimated. MSE is a risk function, corresponding to the expected value of the squared error loss or quadratic loss. The difference occurs because of randomness or because the estimator doesn't account for information that could produce a more accurate estimate.[1]

The MSE is the second moment (about the origin) of the error, and thus incorporates both the variance of the estimator and its bias. For an unbiased estimator, the MSE is the variance of the estimator. Like the variance, MSE has the same units of measurement as the square of the quantity being estimated. In an analogy to standard deviation, taking the square root of MSE yields the root-mean-square error or root-mean-square deviation (RMSE or RMSD), which has the same units as the quantity being estimated; for an unbiased estimator, the RMSE is the square root of the variance, known as the standard deviation.

It is shown that MMSE is more resistant to the PC than the LS due to the use of prior information. Increasing the number of pilot subcarriers in both algorithms does not increase suppression capability to the PC. From the results given here in, a clue for mitigating PC can be obtained. Taking the advantage of the H-inf into account, the H-inf approach is introduced, and the effect of PC is analyzed. By applying the space-alternating generalized expectation–maximization (SAGE) iterative process, the complexity due to multicell MU-MIMO estimation problem can be simplified. Moreover, detailed analysis of its MSE in presence of PC is presented.

According to the given expressions, we can conclude that the H-inf algorithm, by adjusting the scalar factor, is more resistant to PC than LS and ML. The performance of the H-inf is close to optimal MMSE when the length of CIR is large. Meanwhile, when the number of antennas at the BS is large, no performance degradation for H-inf is seen during the iterative process.

CHAPTER 3

EXISTING SYSTEM

This project considers a multi-cell multiple antenna system with precoding used at the base stations for downlink transmission. Channel state information (CSI) is essential for precoding at the base stations. An effective technique for obtaining this CSI is time-division duplex (TDD) operation where uplink training in conjunction with reciprocity simultaneously provides the base stations with downlink as well as uplink channel estimates. This project mathematically characterizes the impact that uplink training has on the performance of such multi-cell multiple antenna systems. When non-orthogonal training sequences are used for uplink training, the project shows that the precoding matrix used by the base station in one cell becomes corrupted by the channel between that base station and the users in other cells in an undesirable manner. This project analyzes this fundamental problem of pilot contamination in multi-cell systems. Furthermore, it develops a new multi-cell MMSE-based precoding method that mitigates this problem. In addition to being linear, this precoding method has a simple closed-form expression that results from an intuitive optimization. Numerical results show significant performance gains compared to certain popular single-cell precoding methods.

This project considers a multi-cell multiple antenna system with precoding at the base stations for downlink transmission. To enable precoding, channel state information (CSI) is obtained via uplink training. This project mathematically characterizes the impact that uplink training has on the performance of multi-cell multiple antenna systems. When non-orthogonal training sequences are used for uplink training, it is shown that the precoding matrix used by the base station in one cell becomes corrupted by the channel between that base station and the users in other cells. This problem of pilot contamination is analyzed in this project. A multi-cell MMSE-based precoding is proposed that, when combined with frequency/time/pilot reuse techniques, mitigate this problem.

3.1 PILOT CONTAMINATION (PC)

One of the main consequences of pilot reuse is pilot contamination (PC), which is caused by using non orthogonal pilots to the users in different cells. PC has a more severe impact on the system performance than channel noise. When the system is deployed with an increasing number of antennas at the base station (BS) and serves a multiplicity of single-antenna terminals, the effects of fast fading and uncorrelated interference will vanish [4]–[13]. However, PC due to the reuse of non orthogonal pilots in other cells does not vanish. In such a multi cell MU-MIMO system, it has been shown in [4] that, with perfect CSI at the BS, the potential benefits in throughput, reliability, and power efficiency will be obtained. These benefits are analyzed mainly based on single-carrier and flat-fading system model; however, a more realistic performance analysis that considers multicarrier and frequency-selective fading channels for future cellular mobile systems is important [14]. Since the BS cannot have perfect CSI in practice, it is crucial to consider the effect of PC on channel estimation based on a multicarrier multipath system model.

3.2 CHANNEL ESTIMATION

In wireless communications, channel state information (CSI) refers to known channel properties of a communication link. This information describes how a signal propagates from the transmitter to the receiver and represents the combined effect of, for example, scattering, fading, and power decay with distance. The CSI makes it possible to adapt transmissions to current channel conditions, which is crucial for achieving reliable communication with high data rates in multi antenna systems. There are basically two levels of CSI, namely instantaneous CSI and statistical CSI.

3.2.1 DIFFERENT KINDS OF CHENNEL ESTIMATION

Instantaneous CSI (or short-term CSI) means that the current channel conditions are known, which can be viewed as knowing the impulse response of a digital filter. This gives an opportunity to adapt the transmitted signal to the impulse response and thereby optimize the received signal for spatial multiplexing or to achieve low bit error rates. Statistical CSI (or long-term CSI) means that a statistical characterization of the channel is known. This description can include, for example, the type of fading distribution, the average channel gain, the line-of-sight component, and the spatial correlation. As with instantaneous CSI, this information can be used for transmission optimization.

3.3 LEAST SQUARE AND MINIMUM MEAN SQUARE ERROR

Impact of pilot contamination on classical least squares and minimum mean square error algorithms in multicell multiuser mimo systems. Massive MIMO communication systems, by virtue of utilizing very large number of antennas, have a potential to yield higher spectral and energy efficiency in comparison with the conventional MIMO systems. In this project , we consider uplink channel estimation in massive MIMO-OFDM systems with frequency selective channels.

Each user communicates with the BS using OFDM and transmits uplink pilots for channel estimation. We assume that all users in a particular cell are assigned orthogonal frequency tones so that there is no intra-cell interference. However, due to necessary reuse of pilots, there are users in the neighboring cells that transmit pilots at the same frequency tones, resulting in an inter-cell interference or pilot contamination. Since only the user in a particular cell of interest will experience.

In this section, we present three different techniques for channel estimation in massive MIMO-OFDM based on the well-known LMMSE and LS estimators and discuss their limitations. For now, we assume that estimates are corrupted only by the white noise. Hence, without loss of generality, we consider a single-cell single-user scenario for the approach

$$\mathrm{MSEO}=\mathrm{j}=1\mathrm{Ri}=1\mathrm{Lnj}\delta\mathrm{i}/1+\rho\mathrm{Knj}\delta\mathrm{i}$$

better MSE performance than the localized strategy, however, it has the following two major drawbacks: 1) Realization of optimal strategy requires global sharing of information to/from the central processor that results in communication overhead (as it requires complex signalling which can be very expensive). 2) As evident from (12), the computation of optimal LMMSE requires inverting a non-trivial matrix of very high dimension (RK ×RK) that leads to computational complexity of order O R3L 3 , which is cubic in number of BS antennas. In massive MIMO scenario where R is of the order of few hundreds, both of the above mentioned operations are very expensive and possibly impractical.

CHAPTER 4

PROPOSED SYSTEM

In statistics and signal processing, a minimum mean square error (MMSE) estimator is an estimation method which minimizes the mean square error (MSE), which is a common measure of estimator quality, of the fitted values of a dependent variable. In the Bayesian setting, the term MMSE more specifically refers to estimation with quadratic cost function. In such case, the MMSE estimator is given by the posterior mean of the parameter to be estimated. Since the posterior mean is cumbersome to calculate, the form of the MMSE estimator is usually constrained to be within a certain class of functions. Linear MMSE estimators are a popular choice since they are easy to use, calculate, and very versatile. It has given rise to many popular estimators such as the Wiener-Kolmogorov filter and Kalman filter.

In many real-time application, observational data is not available in a single batch. Instead the observations are made in a sequence. A naive application of previous formulas would have us discard an old estimate and recompute a new estimate as fresh data is made available. But then we lose all information provided by the old observation. When the observations are scalar quantities, one possible way of avoiding such re-computation is to first concatenate the entire sequence of observations and then apply the standard estimation formula as done in Example 2. But this can be very tedious because as the number of observation increases so does the size of the matrices that need to be inverted and multiplied grow. Also, this method is difficult to extend to the case of vector observations. Another approach to estimation from sequential observations is to simply update an old estimate as additional data becomes available, leading to finer estimates. Thus a recursive method is desired where the new measurements can modify the old estimates.

Design and analysis of space-alternating generalized expectation–maximization-based h-inf algorithm in multicell multiuser multiple-input multiple-output systems. Earlier, we have shown that the MMSE algorithm can obtain optimal performance by using prior information and better suppression to PC. Although the use of SVD of channel correlation matrix is able to reduce the number of multiplications with negligible performance loss, its complexity is still quite high since obtaining the SVD itself has high computational complexity on the order of O (N^3). Here, we introduce the H-inf algorithm, which were proposed in and to multicell MU-MIMO systems.

4.1 H-INF CHANNEL ESTIMATION

H-infinity loop-shaping is a design methodology in modern control theory. It combines the traditional intuition of classical control methods, such as Bode's sensitivity integral, with H-infinity optimization techniques to achieve controllers whose stability and performance properties hold good in spite of bounded differences between the nominal plant assumed in design and the true plant encountered in practice. Essentially, the control system designer describes the desired responsiveness and noise-suppression properties by weighting the plant transfer function in the frequency domain; the resulting 'loop-shape' is then 'robustified' through optimization. Robustification usually has little effect at high and low frequencies, but the response around unity-gain crossover is adjusted to maximize the system's stability margins[14]. H-infinity loop-shaping can be applied to multiple-input multiple-output (MIMO) systems..

H-infinity loop-shaping has been successfully deployed in industry Easy to apply – commercial software handles the hard math.

- Easy to implement – standard transfer functions and state-space methods can be used.
- Plug and play – no need for re-tuning on an installation-by-installation basis.

As an alternative to the classical MMSE estimation, an H-inf filter can achieve an acceptable estimation performance without accurate knowledge of the statistical information of the involved signals. The idea of the H-inf filtering is to construct a filter that guarantees the H-inf norm of the estimation error is less than a prescribed positive value

$$\text{Zjsup=Cj\^{}-Cj2wZj2<s} \qquad (12)$$

Where _ˆ***C**j* − ***C**j*_2 ***W*** = (ˆ***C*** *j* − ***C****j*)*H**W***(ˆ***C*** *j* − ***C****j*); ˆ***C*** *j* is a *LQK* × 1 vector, denoting the channel response vector to be estimated; ***C**j* = [***C**Tj*1, . . . ,***C**TjQ*]*T* ; ***C**jq* = [***C**Tjq*1, . . . ,***C**TjqK*]*T* ; and ***W*** > **0** is a weighting matrix. The H-inf channel estimation in multi cell MU-MIMO systems can be described as

Cj^=ηjεj-1T†Yj (13)

Where $\boldsymbol{T} = [\boldsymbol{T}1, \ldots, \boldsymbol{T}Q]$, $\boldsymbol{T}q = [\boldsymbol{T}q1, \ldots, \boldsymbol{T}qK]$, $\boldsymbol{T}qk = \boldsymbol{X}qk\boldsymbol{F}N,L$, and $\boldsymbol{\varepsilon}j = \boldsymbol{M}1,1 + \boldsymbol{M}1,2\boldsymbol{\xi}j$ and $\boldsymbol{\eta}j$ $= \boldsymbol{M}2,1 +$

$\boldsymbol{M}2,2\boldsymbol{\xi}j$, are both $LQK \times LQK$ matrices. $\boldsymbol{\xi}j$ is a $LQK \times 1$vector, satisfying _$\boldsymbol{\xi}j$_∞ = max($|\xi 1|, \ldots,$ $|\xi LQK|$) < 1, and$\xi 1 = \cdot\cdot = \xi LQK$. $\boldsymbol{M}1,1$, $\boldsymbol{M}1,2$, and $\boldsymbol{M}2,1$, $\boldsymbol{M}2,2$ can be expressed

M1,1=ΩR12+R- 12

M1,2=s- 12ΩW12

M2,1=ΩR12

M2,2=s- 12ΩW12-s12W12 (14)

where $R = T^{\dagger}T = I_{LQK}$ if QPSK is adopted, $\Omega = \Omega_1\Omega^{1}{}_{2}^{/2} - \Omega_2$, $\Omega_2 = (R - s^{-1}W)^{-1}$, and Ω_1 can be easily obtained by the canonical factorization of $I_{LQK} + \Omega_2$.

4.2 H-INF CHANNEL ESTIMATION VIA SAGE PROCESS

A direct solution to (13) will result from intense calculation of the matrix inversion and multiplication operations for each OFDM symbol of all users in Q cells over L paths, and the complexity is on the order of $O(L^3Q^3K^3)$. In the case of large values of L, K, and Q, computational complexity load will be high. In multicell MU-MIMO systems, propagation vectors between the BS antenna arrays and different terminals often could be considered uncorrelated [4]. Since the SAGE can decompose the spatially multiplexed channels, we can apply this iterative algorithm to deal with the problem of high complexity [11]. Generally, the SAGE process is developed to avoid matrix inversion of the ML estimator; therefore, we first assess the feasibility by applying SAGE. Equation (13) can be rewritten as follows.

Cj^=ηjεj-1T†Yj

=γCj^ML (15)

The numerator of (12) is considered to be the whole estimation error between the jth BS and K users in each cell. Thus, the denominator of (12) will be AWGN Z_j . However, if the local estimation error is considered, (e.g., between the jth and K users in the qth cell), the signal, except for that from the qth cell, will be the interference, which will finally change the establishment of the objective function. Where $\gamma = \eta_j \varepsilon^{-1}_j$. Equation (15) can be interpreted as a filter matrix γ applied to the ML estimation, indicating some links between the H-inf and ML estimators. Thus, we can develop an H-inf estimator by combining the SAGE process. Instead of solving (13) directly, the SAGE algorithm converts a multicell MU-MIMO channel estimation problem into a series of single-cell single-user SISO channel estimation problems, making the dimensions of Ω, W, and R involved in the computation of ε_j, η_j much smaller. Thus, the calculation is simplified drastically.

The SAGE-based H-inf estimation can be iteratively implemented as follows;
Initialization:

For $q = 1, . . . , Q$,

For $k = 1, . . . , K$

Yjqk^(0)=Tqkεjqkηjqk-1Cjqk^(0) (16)

Where ε_{jqk} and η_{jqk} of dimension $L \times L$ are the simplified versions of ε_j and η_j, respectively. The initial value of channel estimation C_{jqk} is 1_L, where 1_L is an $L \times 1$ vector whose elements are all 1.by using iterations… finally solving equation is

Cjqk^(i+1)=ηjqkεjqk-1Tqk†πjqk^(i) 19

Yjqk^(i+1)=Tqkεjqkηjqk-1Cjqk^(i+1) (20)

while for $1 \leq k \leq K$ and k _= k

Yjqk^(i+1)=Yjqk.^(i) (21)

4.3 PERFORMANCE ANALYSIS

Analysis of Matrix γ: To find a solution for the H-inf, we assume $R - s{-}1W > 0$ [22], [23], where R is an identity.Matrix because QPSK is adopted,3 s is a positive scalar factor, and W is also a diagonal matrix that have equal dimensions. Thus, M1, 1, M1, 2, M2,1, and*M*2,2 are all diagonal matrices, respectively. Finally, matrix γ is a real diagonal matrix with equal diagonal elements.

Since the diagonal matrix γ is needed to estimate the performance of the H-inf, we will find the relation between $\boldsymbol{\gamma}$ and the identity matrix. First, it is assumed that

γ<ILQK. (22)

Note that $\boldsymbol{R}$ will not be an identity matrix if 16-QAM, 64-QAM, or other modulations are adopted. However, $\boldsymbol{\gamma}$ is always a diagonal matrix. The proposed algorithm is valid for the different modulations. To satisfy (22), one has $\boldsymbol{\varepsilon} - \boldsymbol{\eta} > 0$. By applying (14), we can get

ε- η=M1,1+M1,2ξj-M2,1+M2,2ξj

=R- 12+s12W- 12ξj>0. (23)

Therefore, our hypothesis is valid. Intuitively, when W is fixed, a smaller s is made, a smaller γ is obtained, and a better performance is achieved, which is the intrinsic characteristic of the H-inf algorithm, as will be discussed in the following.

4.4 IMPACT OF PC ON H-INF

Since the estimation errors in cells are independent of each other, we analyze the channels from the K users in the jth cells. The following assumptions are made: 1) All subcarriers have equal power; 2) phase-shift orthogonal pilot sequences are used for different users within each cell; and the same pilot sequences are reused in other cells.

The channel estimation of the H-inf can be rewritten as

Cjj^H-inf=γTj†Yj

=γTj†q≠jQTqCjq+γCjj+γTj†Zj. (24)

The MSE expression of the H-inf algorithm for multicell MU-MIMO systems in the presence of PC is given as follows:

$$\mathrm{MSEH\text{-}inf}=1Lrnn2q\neq jQdjq+1Lrnn2\sigma 2+1L(1\text{-}rnn)2 \qquad (25)$$

4.5 COMPLEXITYANALYSIS

Considering the number of complex multiplications for each OFDM symbol as a complexity Metric, the inversion of an $n \times n$ matrix requires $n3$ operations, the pseudo inverse of an $n \times r$ matrix requires $2r2n + r3$ operations, and the product of an $m \times r$ matrix with an $r \times n$ matrix requires $m*n$ operations. Let Kit denote the number of iterations that should not be too large due to the superior convergence property of SAGE [20]. A comparison of complexity between the LS, MMSE, and proposed H-inf algorithms is given in Table I. As expected, the H-inf estimation has less complexity than the MMSE algorithm, and the complexity can be further reduced by using the SAGE iterative process

TABLE-4.1

COMPLEXITY OF CHANNEL ESTIMATION ALGORITHMS

Algorithm	Number of operations per OFDM symbol
LS	2(LK)2+LK)N+(LK)3
MMSE	(2LK)2+LKN+(LK)3+2N3+LN2+LN
H-inf	(3LKQ)2+LKQN+3(LKQ)3
SAGE-based	Kit(3L2+LN+3L3)

CHAPTER 5

RESULTS

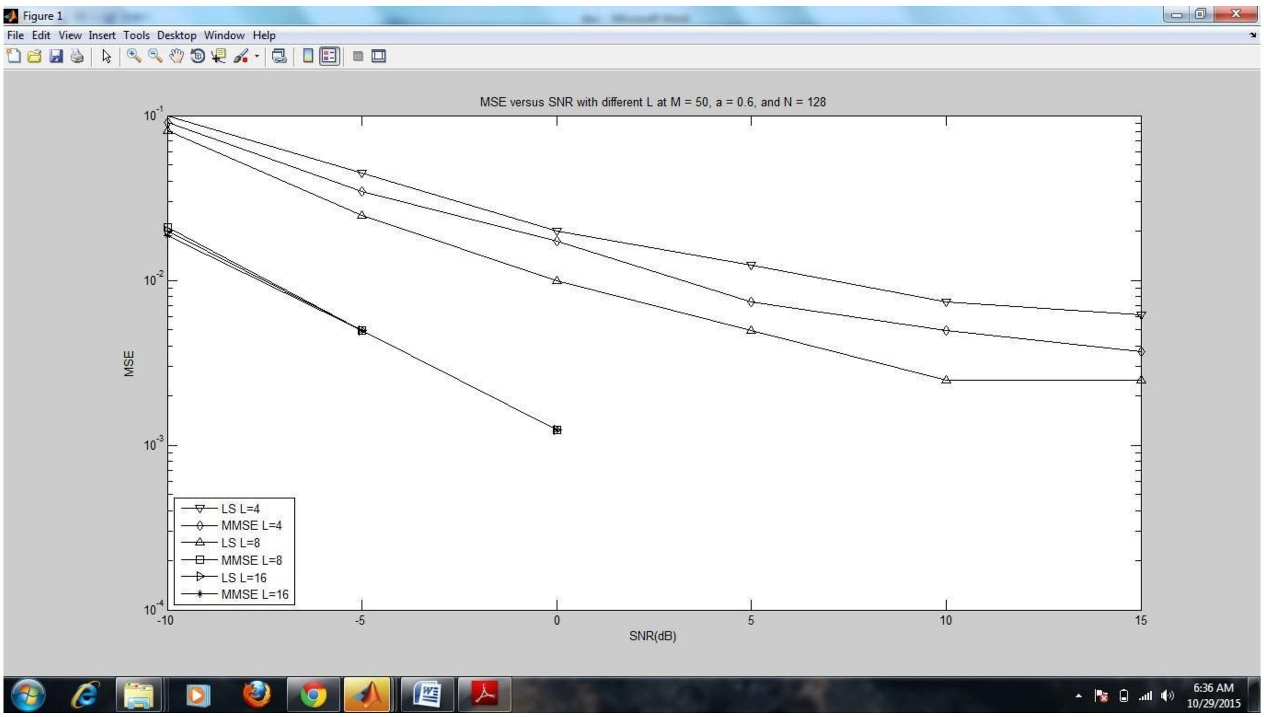

Fig.5.1 MSE versus SNR with different *L* at *M* = 50, *a* = 0.6, and *N* = 128.

- ✓ It shows the MSE Performance of LS and MMSE versus the SNR for different values of L at M=50,a=0.6 and N=128
- ✓ In this figure MMSE is more resistant to PC than LS
- ✓ This is because LS just utilizes few pilot sub carriers than, whereas MMSE makes use of more prior information .
- ✓ The performance of LS can be improved by increasing the length of CIR.

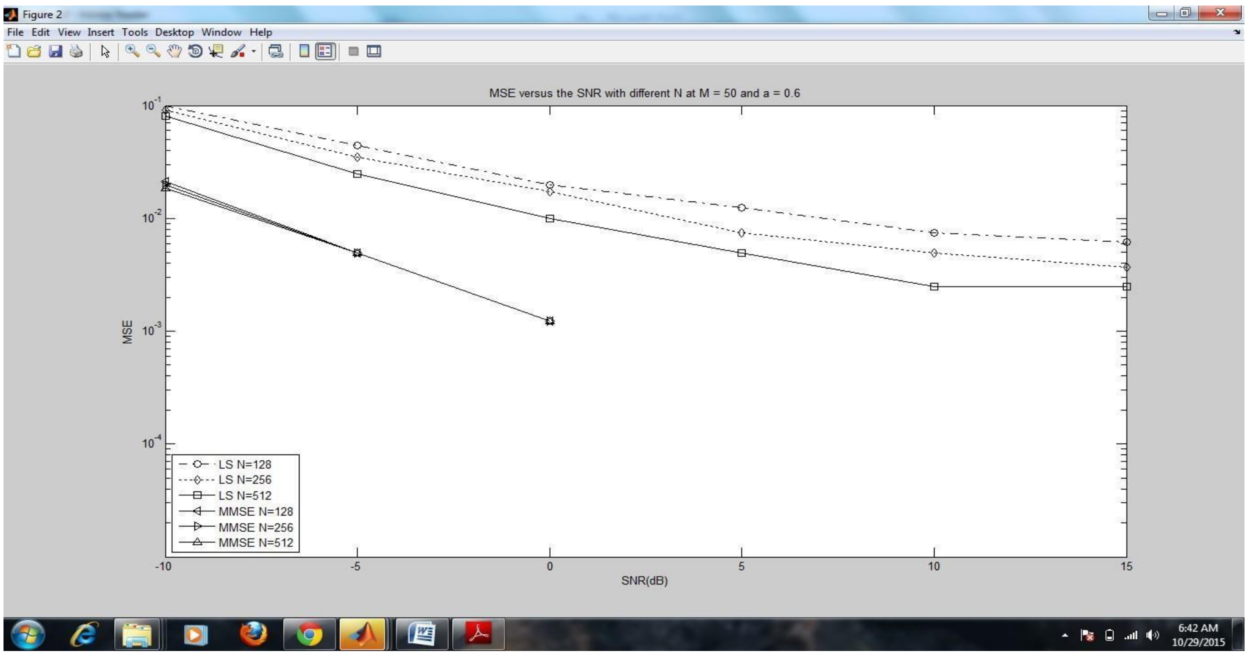

Fig.5.2 MSE versus the SNR with different N at M = 50 and a = 0.6.

- ✓ The MSE performance of LS and MMSE algorithms is shown in above graph for different values of N in the case of a=0.6 as a function of SNR.
- ✓ The MSE of MMSE can be improved by increasing the number of sub carriers.

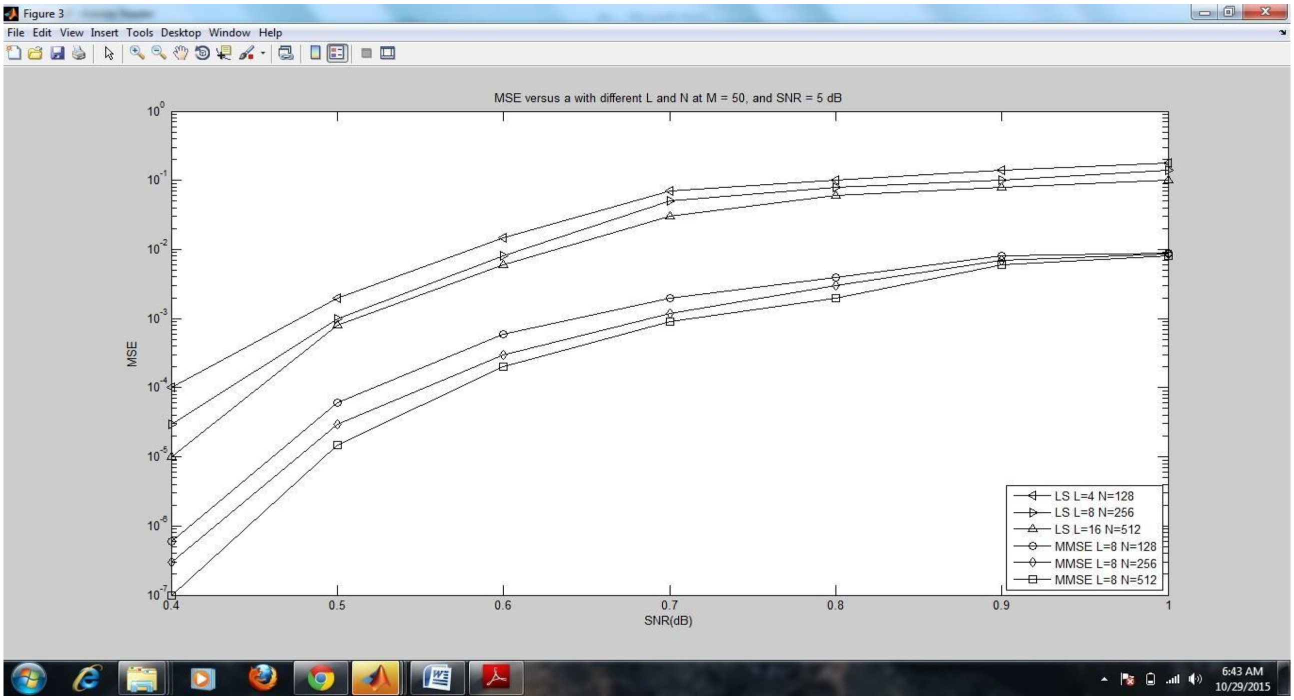

Fig.5.3 MSE versus *a* with different *L* and *N* at *M* = 50, and SNR = 5 dB.

- ✓ This fig shows that the MSE performance of the LS and MMSE algorithms as a function of a for different values of L and N at SNR=sdB.
- ✓ In this graph the performance of LS and MMSE generally degrades due to increasing cross gain a.

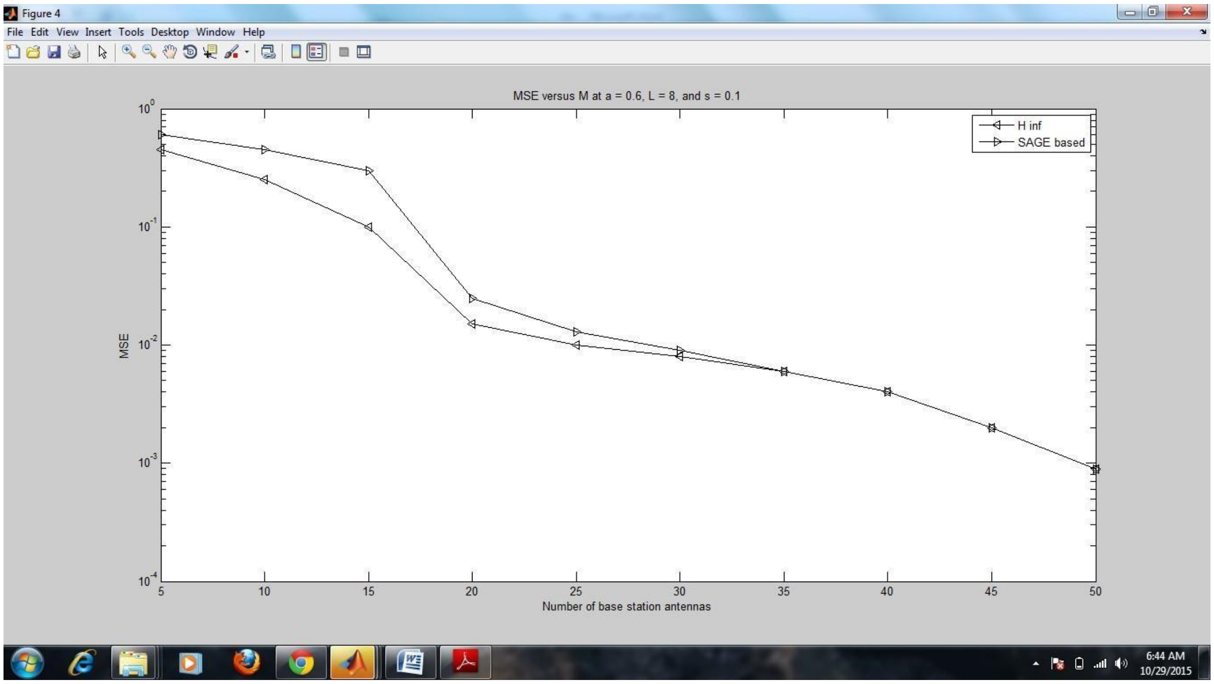

Fig.5.4 MSE versus *M* at *a* = 0.6, *L* = 8, and *s* = 0.1

- ✓ The graph shows the MSE performance of H-inf and SAGE based algorithms versus M for a=0.6, L=8,and s=0.1
- ✓ It is shown that the performance of the SAGE based algorithm is almost same as that of H-inf when M>30

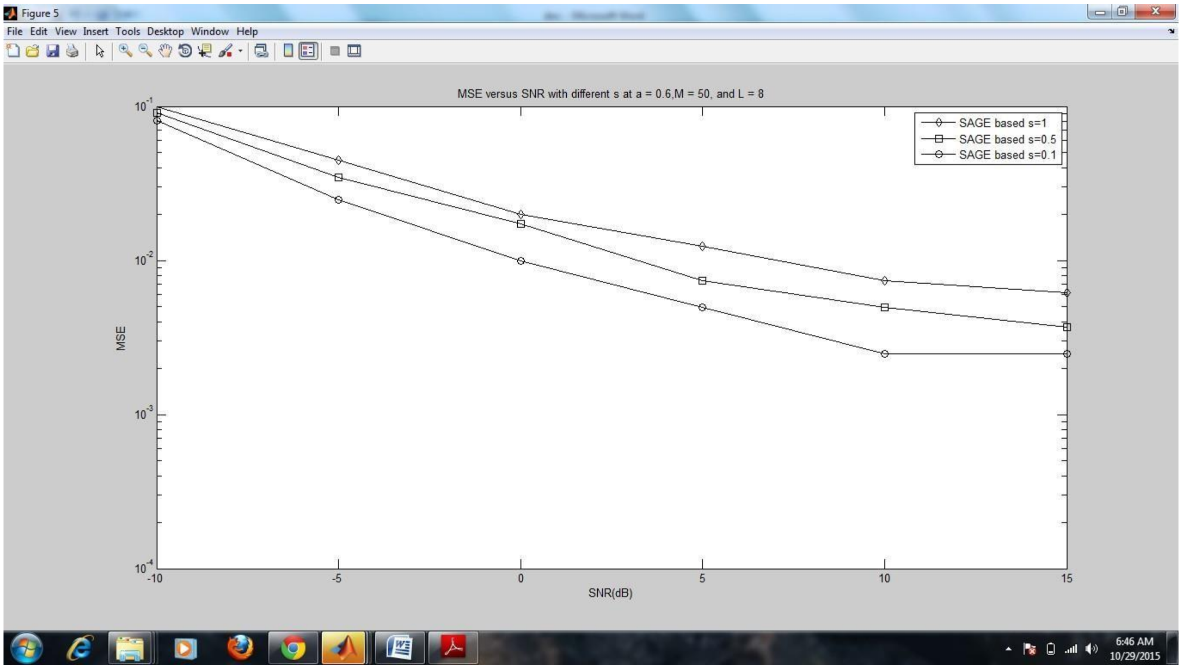

Fig.5.5 MSE versus SNR with different *s* at *a* = 0.6, *M* = 50, and *L* = 8

- ✓ Its shows the MSE performance of the SAGE based algorithm verses SNR for different values of s for a=0.6,M=50, and L=8.
- ✓ It is shown that the MSE performance is gradually enhanced when s decreases.

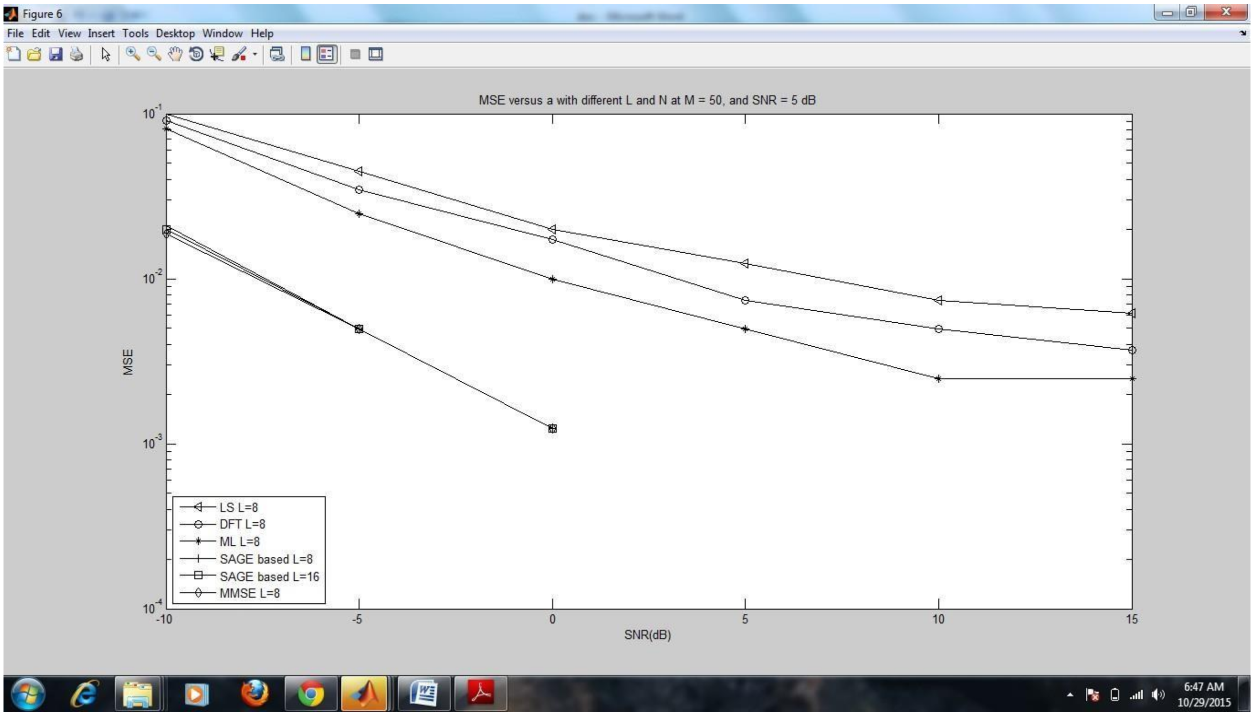

Fig.5.6 MSE versus SNR with different L at a = 0.6, M = 50, and s = 0.1.

- ✓ The MSE performance of LS,DFT,ML,MMSE and SAGE based algorithms versus SNR for different values of L at a=0.6,M=50and s=0.1.
- ✓ The SAGE based algorithm is more resistant to PC than LS,DFT and ML.
- ✓ This is because the SAGE based algorithm utilizes other information, such as transmitted data and scalar factor s.
- ✓ The performance of SAGE based algorithm can be improved by increasing the length of CIR.

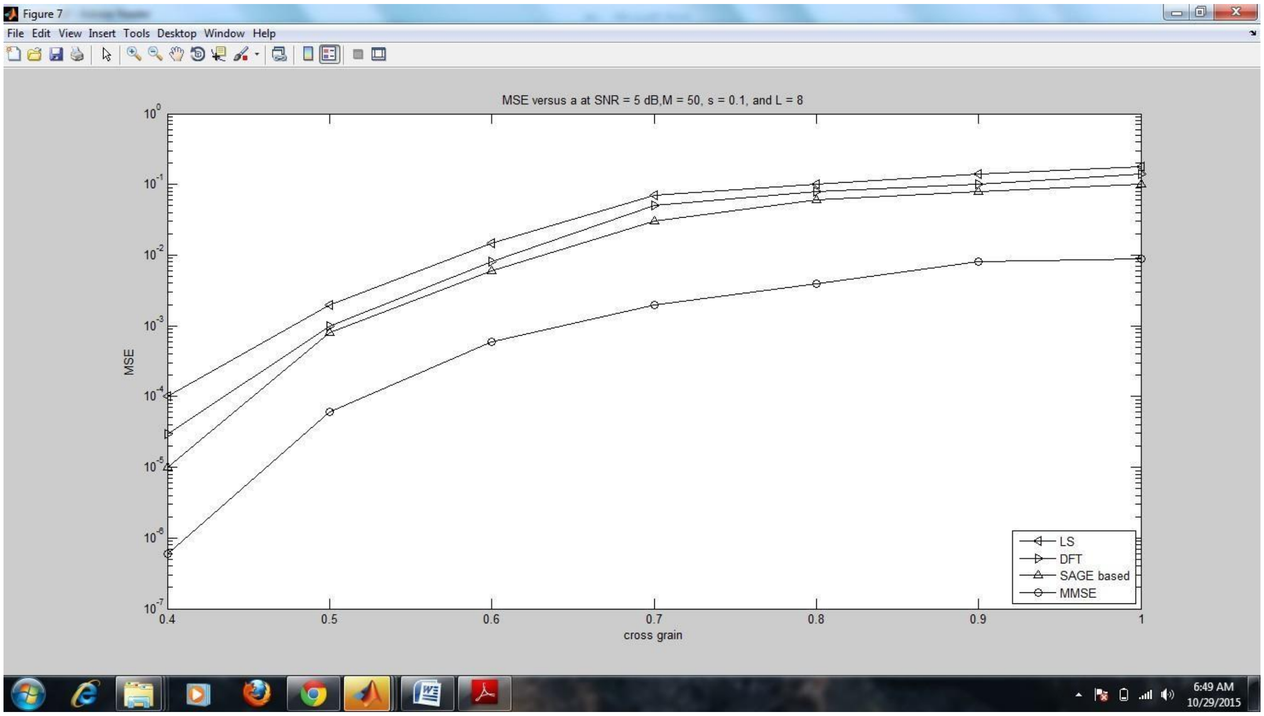

Fig.5.7 MSE versus *a* at SNR = 5 dB, *M* = 50, *s* = 0.1, and *L* = 8.

- ✓ It shows the MSE performance of LS, DFT ,MMSE and SAGE based algorithms for SNR=5dB,
- ✓ M=50,s=0.1 and L=8 as a function of a.
- ✓ It is shown that the performance of all the algorithms degrades much when cross gain a is large.
- ✓ The performances have obvious improvement when the value of a decreases.

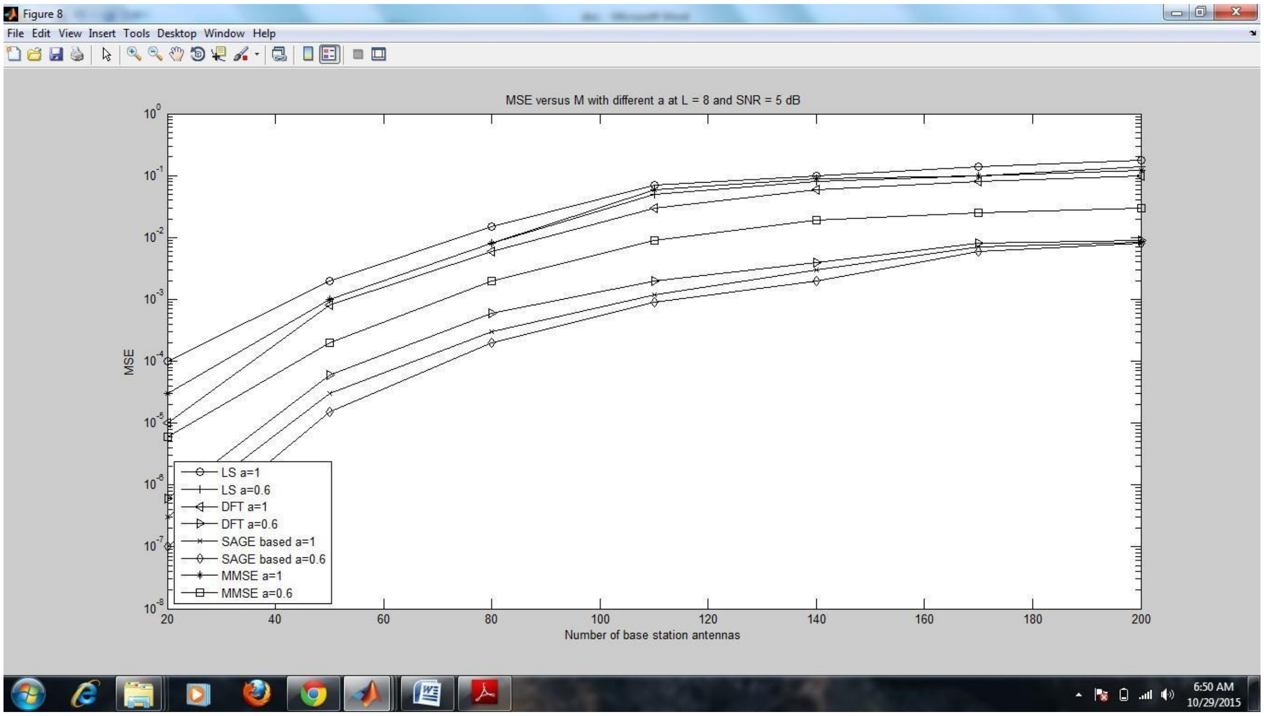

Fig.5.8 MSE versus *M* with different *a* at *L* = 8 and SNR = 5 dB

- ✓ Finally, the MSE performance of LS,DFT,MMSE and SAGE based algorithms is shown in the above graph as a function of M with different values of a for SNR=5dB and L=8.
- ✓ The performance of DFT,MMSE and SAGE based algorithms improve significantly as M increases when a=0.6.

CHAPTER 6

CONCLUSION

It have analytically investigated the impact of PC on the several pilot-based channel estimation algorithms, including classical LS, MMSE algorithms, and our proposed H-inf algorithms in multicell MU-MIMO systems under a realistic system model that considers imperfect channel estimation, PC, multicarrier, and multipath channels. Analytical expressions were derived, and comparisons were made. It has been shown that, of all the algorithms, the optimal MMSE is most resistant to PC with high complexity. By slightly increasing the number of OFDM subcarriers, PC suppression can be achieved in the MMSE. In addition, by increasing the number of pilot subcarriers for all channel estimation algorithms, PC cannot be mitigated. For the proposed H-inf algorithms, proper length increment of CIR is helpful for the suppression of PC. Simulation results have shown that the proposed H-inf algorithm has almost the same performance as MMSE, and it leads to better suppression to PC than LS, DFT, and ML. In addition, the H-inf via the SAGE iterative process does not introduce any performance loss when the number of antennas is large at each BS in multi cell MU-MIMO systems.

CHAPTER 7

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