Optimization of Bandwidth in Zero - Forcing Beamforming Channel and PU^{2}RC Channel for MIMO Gaussian Broadcast

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Abstract— Although there has been considerable prior work on the MIMO downlink channel feedback, there is a dichotomy between results on systems with a small number of receivers /users (on the order of Nt) and systems with many users. The throughput of systems with the number of users on the order of Nt has been shown to be extremely sensitive to the accuracy of the CSI, and thus many feedback bits are needed from each user in order to achieve a large sum rate. These have been shown from a fundamental information theoretic perspective, as well as in terms of particular transmit strategies. For example, Zero-Forcing (Z-F) beamforming has been shown to require CSI quality that scales proportional to the SNR in dB. At the other extreme, it has been shown that systems can achieve a very large sum rate even with very few feedback bits per user, in the asymptotic limit as the number of users is taken to infinity. But in recent studies the numbers of bits optimized were less and the SNR has been observed for one single value i.e. 10 db. The work in this research paper is focused on high density traffic analysis by choosing a wide sensing environment.

Keywords— Zero – Forcing, Beamforming and PU^{2}RC

I. INTRODUCTION

In telecommunications, a Diversity scheme [19] refers to a method for improving the reliability of a message signal by using two or more communication channels with different characteristics. Multiple versions of the same signal may be transmitted and/or received and combined in the receiver. Alternatively, a redundant forward error correction code may be added and different parts of the message transmitted over different channels. Diversity techniques may exploit the multipath propagation, resulting in a diversity gain, often measured in decibels. The classes of diversity schemes can be identified as Time diversity , Frequency diversity , Space diversity, Polarization diversity , Multiuser diversity and Cooperative diversity.

A. *Multi User Diversity*

The wireless medium is often called fading channel The conventional view suggests that channel fading is an impediment to reliable communication When time scale of communication is much larger than that of channel fluctuations, channel fading turns into an advantage that can be exploited The ability to track the channel in a point-to-point link can increase capacity (opportunistic communication) This insight can be extended to a multiuser scenario, in an effect known as multiuser diversity In addition to the choice of when to transmit, there is an additional choice of which user(s) to transmit to. The cellular system requirements to extract multiuser diversity benefits are: The *base station* (BS) should have access to the channel quality measurements (TDD/FDD systems) The BS should have the ability to schedule transmissions among the users as well as adapt the data rate according to the instantaneous channel quality These features are already present in the designs of many third-generation systems In practice, there are several considerations to take into account before realizing such gains.

B. *Accurate Channel state Information*

In wireless communications, channel state information (CSI) refers to known channel properties of a communication link [20]. 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. CSI needs to be estimated at the receiver and usually quantized and fed back to the transmitter (although reverse-link estimation is possible in TDD systems). Therefore, the transmitter and receiver can have different CSI. The CSI at the transmitter and the CSI at the receiver are sometimes referred to as CSIT and CSIR, respectively.

1) *Different kinds of channel state information*

There are basically two levels of CSI, namely instantaneous CSI and statistical CSI.

- *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.

The CSI acquisition is practically limited by how fast the channel conditions are changing. In fast fading systems where channel conditions vary rapidly under the transmission of a single information symbol, only statistical CSI is reasonable. On the other hand, in slow fading systems instantaneous CSI can be estimated with reasonable accuracy and used for transmission adaptation for some time before being out-dated. In practical systems, the available CSI often lies in between these two levels; instantaneous CSI with some estimation/quantization error is combined with statistical information.

C. Equalization Techniques

Equalization techniques can be subdivided into two general categories—linear and nonlinear equalization. These categories are determined from how the output of an adaptive equalizer is used for subsequent control (feedback) of the equalizer. In general, the analog signal is processed by the decision making device in the receiver. Many filter structures are used to implement linear and nonlinear equalizers. Further, for each structure, there are numerous algorithms used to adapt the equalizer.

D. Multiple Input Multiple Output (MIMO)

In radio, multiple-input and multiple-output, or MIMO (commonly pronounced my-moh or me-moh), is the use of multiple antennas at both the transmitter and receiver to improve communication performance. It is one of several forms of smart antenna technology. Note that the terms *input* and *output* refer to the radio channel carrying the signal, not to the devices having antennas. MIMO technology has attracted attention in wireless communications, because it offers significant increases in data throughput and link range without additional bandwidth or increased transmit power. It achieves this goal by spreading the same total transmit power over the antennas to achieve an array gain that improves the spectral efficiency (more bits per second per hertz of bandwidth) and/or to achieve a diversity gain that improves the link reliability (reduced fading).

Because of these properties, MIMO is an important part of modern wireless communication standards such as IEEE 802.11n (Wi-Fi), 4G, 3GPP Long Term Evolution, WiMAX and HSPA+. MIMO can be sub-divided into three main categories - Precoding , Spatial multiplexing or SM, and Diversity coding. *Precoding* is multi-stream beamforming, in the narrowest definition. In more general terms, it is considered to be all spatial processing that occurs at the transmitter. In (single-stream) beamforming, 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. The benefits of beamforming are to increase the received signal gain, by making signals emitted from different antennas add up constructively, and to reduce the multipath fading effect. In line-of-sight propagation, beamforming results in a well defined directional pattern. However, conventional beams are not a good analogy in cellular networks, which are mainly characterized by multipath propagation. When the receiver has multiple antennas, the transmit beamforming cannot simultaneously maximize the signal level at all of the receive antennas, and precoding with multiple streams is often beneficial. Note that precoding requires knowledge of channel state information (CSI) at the transmitter and the receiver. *Spatial multiplexing* 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). The maximum number of spatial streams is limited by the lesser of the number of antennas at the transmitter or receiver. Spatial multiplexing can be used without CSI at the transmitter, but can be combined with precoding if CSI is available. Spatial multiplexing can also be used for simultaneous transmission to multiple receivers, known as space-division multiple access or multi-user MIMO, in which case CSI is required at the transmitter. The scheduling of receivers with different spatial signatures allows good separability. *Diversity Coding techniques* are used when there is no channel knowledge at the transmitter. In diversity methods, a single stream (unlike multiple streams in spatial multiplexing) is transmitted, but the signal is coded using techniques called space-time coding. The signal is emitted from each of the transmit antennas with full or near orthogonal coding. Diversity coding exploits the independent fading in the multiple antenna links to enhance signal diversity. Because there is no channel knowledge, there is no beamforming or array gain from diversity coding.

Diversity coding can be combined with spatial multiplexing when some channel knowledge is available at the transmitter.

E. Applications of 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).

F. Beamforming

Beam forming or spatial filtering is a signal processing technique used in sensor arrays for directional signal transmission or reception. This is achieved by combining elements in a phased array in such a way that signals at particular angles experience constructive interference while others experience destructive interference. Beamforming can be used at both the transmitting and receiving ends in order to achieve spatial selectivity. The improvement compared with omnidirectional reception/transmission is known as the receive/transmit gain (or loss). Beamforming can be used for radio or sound waves. It has found numerous applications in radar, sonar, seismology, wireless communications, radio astronomy, acoustics, and biomedicine. Adaptive beamforming is used to detect and estimate the signal-of-interest at the output of a sensor array by means of optimal (e.g., least-squares) spatial filtering and interference rejection. Satellite receivers with a dish antenna receive signals that fall within the so-called beam of the antenna. Every antenna has a characteristic beam pattern, which is determined by the mechanical construction of the dish antenna. When using an array of antenna elements, the beam-pattern can also be defined electronically. Such beamforming can be realized via an antenna array combined with electronics, making the array direction sensitive via phase shifters or time delays. Until now, beamforming is mainly applied in military applications, and more recently in base stations for telecommunication. Applications in consumer electronics are scarce, despite of the many potential advantages (see utilization summary). This is because beamforming is typically implemented using specialized microwave and Radio Frequency (RF) technologies with hybrid module assembly techniques, and many RF-cables and connectors, unsuitable for cost-effective mass production. For consumer electronics, a high level of integration, preferably in mainstream CMOS technology, is desired.

G. Zero-forcing Beamforming (ZF-BF)

It is a spatial signal processing in multiple antenna wireless devices. For downlink, the ZF-BF algorithm allows a transmitter to send data to desired users together with nulling out the directions to undesired users and for uplink, ZF-BF receives from the desired users together with nulling out the directions from the interference users. The concept of interference users in the receive mode is information theoretically dual to undesired users in the transmit mode. In this paper work, a generalized greedy (G-greedy) algorithm based on zero-forcing beamforming (ZFBF) for the multiple-input multiple-output (MIMO) broadcast channel has been proposed. This algorithm serves as a general mathematical framework that includes a number of existing greedy user selection methods as its realizations. As previous results only give the scaling law of the sum rate of dirty paper coding (DPC), with the help of the G-greedy structure, we are able to obtain the exact limit of the DPC sum rate for a large number of users. We also prove that the difference between the sum rates obtained by G-greedy user selection and by DPC goes to zero as the number of users increases. In addition to this, we investigate one particular greedy user selection scheme called sequential water-filling (SWF). For this algorithm, a complexity reduction is achieved by an iterative procedure based on an LQ decomposition, which converts the calculation of the Moore-Penrose matrix inverse to one vector-matrix multiplication. A sufficient condition is given to prune the search space of this algorithm that results in further complexity reduction. With the help of the G-greedy algorithm, we prove that SWF achieves the full DPC sum rate for a large number of users. For a moderate number of users, simulation demonstrates that, compared with other user selection algorithms, SWF achieves a higher sum rate that is close to the maximal sum rate achievable by ZFBF with the same order of complexity.

H. PU^{2}RC (Per – User Unitary Rate Control)

Per-User Unitary Rate Control (PU^{2}RC) is the advanced multi-user MIMO technique which utilizes the concept of both pre-coding matrices and scheduling to enhance the system performance of multiple antenna wireless networks. A single-user MIMO was initially developed to improve the spectral efficiency of point-to-point wireless transmission link. A multi-user MIMO was developed for cellular systems where the base station simultaneously communicates with multiple users. Per-User Unitary Rate Control (PU^{2}RC) is the first practical multi-user MIMO scheme. In this scheme different data may simultaneously be transmitted to multiple users from the base station. Users to be served are selected from the set of service-requesting users by the base station using the information provided by users. Data transmitted to mobile users are multiplied by a pre-coding matrix selected from the set of predefined matrices before transmission. The selection of a pre-coding matrix is made based on the information provided by users. The selection of users and a pre-coding matrix using the information provided by mobiles enables the utilization of multi-user diversity and reduces feedback overhead from users to the base station. Pre-coding matrices used in this scheme is unitary. The use of unitary pre-coding matrices facilitates the estimation of interference from other users data to the unintended user.

II. PRESENT WORK

A. Problem formulation

Although there has been considerable prior work on the MIMO downlink channel feedback, there is a dichotomy between results on systems with a small number of receivers /users (on the order of Nt) and systems with many users. The throughput of systems with the number of users on the order of Nt has been shown to be extremely sensitive to the accuracy of the CSI, and thus many feedback bits are needed from each user in order to achieve a large sum rate. These have been shown from a fundamental information theoretic perspective, as well as in terms of particular transmit strategies. For example, Zero-Forcing (ZF) beamforming has been shown to require CSI quality that scales proportional to the SNR in dB. At the other extreme, it has been shown that systems can achieve a very large sum rate even with very few feedback bits per user, in the asymptotic limit as the number of users is taken to infinity. But in recent studies the numbers of bits optimized were less and the SNR has been observed for one single value i.e. 10 db. So the present research work is focused on high density traffic analysis by choosing a wide sensing environment. This has been achieved by increasing the number of bits to manage the high density traffic, increasing the SNR to provide wide sensing environment for communication and to find out the optimized bits for Varied Feedback bits and SNR for ZF and PU^{2}RC

B. Proposed Algorithm

For the problem stated the equalization technique which has been used for optimization is Zero-forcing Beamforming. Following Tasks were performed:

- Analyzed the code in MATLAB.
- Find out the different objective function for optimizing the equalization technique.
- Understanding the ZF – BF function code
    - Increased the number of bits
    - Increased the SNR bits for the ZF- BF
    - Checked whatever the outcomes of it were after optimization of the ZF – BF
    - Plotted sum rate vs T
    - Plotted the sum rate for the ZF and PU^{2}RC for T = 100 , 200,300,400,500,600 and 700 at various per user feedback loads
    - Plotted the sum rate for the ZF and PU^{2}RC for B

- Got the final optimized table after changing the SNR, feedback budget bits for the ZF, PU^2 RC for the optimized bits.

III.RESULTS AND CONCLUSIONS

In the present research work, generalized greedy (G-greedy) algorithm based on Zero-forcing Beamforming (ZFBF) for the multiple-input multiple-output (MIMO) broadcast channel has been used. This algorithm serves as a general mathematical framework that includes a number of existing greedy user selection methods as its realizations. As previous results only give the scaling law of the sum rate of dirty paper coding (DPC), with the help of the G-greedy structure, we were able to obtain the exact limit of the DPC sum rate for a large number of users. We also proved that the difference between the sum rates obtained by G-greedy user selection and by DPC goes to zero as the number of users increases. Per-User Unitary Rate Control (PU^{2}RC) is the advanced multi-user MIMO technique which utilizes the concept of both pre-coding matrices and scheduling to enhance the system performance of multiple antenna wireless networks. A single-user MIMO was initially developed to improve the spectral efficiency of point-to-point wireless transmission link. A multi-user MIMO was developed for cellular systems where the base station simultaneously communicates with multiple users. Following are the results obtained:

- The proposed technique was tested on a range of 100 – 700 bits with the values for SNR - 5, 10 , 15 , 20 and 25.

- The values of the optimized bits have reduced from 33. 333 to 30. 4348 by increasing the feedback budget bits from 100 to 700 with changing the SNR.

The table for various readings of Feedback budget Bits (B), SNR and corresponding values of Z-F and PU^{2}RC is given below.

TABLE I
OPTIMIZATION TABLE FOR Z-F AND PU^{2}RC

S. No	Feedback budget bits	SNR	Optimization bits Z-F	Optimization bits PU^{2}RC
1	100	5	16.6667	2
	100	10	20	2
	100	15	25	6
	100	20	25	2
	100	25	25	2
2	200	5	15	2
	200	10	25	2
	200	15	25	2
	200	20	28.5714	2
	200	25	33.333	2
3	300	5	17.6471	2
	300	10	23.0769	2
	300	15	22.222	2
	300	20	33.333	2
	300	25	33.333	2
4	400	5	19.0476	2
	400	10	26.6667	2
	400	15	25	2
	400	20	30.7692	2
	400	25	36.3636	2
5	500	5	20	2
	500	10	31.25	2
	500	15	28.5714	2
	500	20	33.333	2
	500	25	41.6667	2
6	600	5	20	2
	600	10	27.2727	2
	600	15	28.5714	2
	600	20	35.2914	2
	600	25	35.2914	2
7	700	5	19.4444	2
	700	10	30.4348	2
	700	15	30.4348	2
	700	20	30.4348	2
	700	25	30.4348	2

Now for almost any number of antennas N(t) , average SNR , Feedback budget Tfb , sum rate is maximized by choosing B (feedback bits per user) such that near perfect CSI is obtained for each of the Tfb / B users that do feedback. In other words, accurate CSI is more valuable than multi user diversity. It is also worth emphasizing that the results do not imply that multi-user diversity is worthless. On the contrary, multi-user diversity does provide a significant benefit. However, the basic design insight is that feedback resources should first be used to obtain accurate CSI and only afterwards be used to exploit multi-user diversity. Given the increasing importance of multi-user MIMO in single cell and multi-cell (i.e., network MIMO) settings, it seems that this point should be fully exploited in the design of next-generation cellular systems such as LTE

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