MIMO Based Cooperative Communication and Joint Maximum-Likelihood Detection for Cognitive Radio System

D.Damodaram

Abstract**:** ***In this work, novel cooperative communication strategies like Decode and Forward based relay schemes, joint maximum likelihood signal detection in combinational Multiple Input Multiple Output (MIMO) cooperative relay cognitive networks are used. The joint cooperative signal detection using Maximum-Likelihood (ML) detector at each relays, and associated path links improves the quality of services at the destination node, which can be dynamically altered using different relay combinations and associated iterative computational complexity accumulated during ML detection. Here the relay performs ML decoding and transmit the detected symbols to the destination and also to the multiple antennas equipped for cooperative communication. The same ML detection at the destination combines the MIMO based diversity to narrow down the error probability among different orthogonal transmissions. The combination of iterative signal detection and relay assisted decoding scheme shows superior error rate performance when compared to non-iterative hard decoded signal detection. The simulations results proved the influence of MIMO assisted cooperative communication and the associated performance penalty gaps that come with imperfect channel state information at the destination node.***

Keywords: cognitive radio system, Cooperative Communication, Decode-and-Forward protocol, MIMO, ML signal detection Iterative Complexity.

I. INTRODUCTION

Cognitive Radio (CR) improves the radio spectrum utilization and offers highly reliable communication for next generation wireless communication systems. Radio spectrum is very prominent and a scarce resource. Numerous methodologies [1-2] were proposed to maximize the utilization of the spectrum. Cooperative Communication Schemes (CCS) [3] is now widely in many wireless communication applications to overcome the shortage of this limited source. Maximization of spatial diversity gains, surmounting the coverage and enhancing the channel capacity can be achieved with CCS using relay nodes.

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Even though CCS employ relay based nodes, throughput rate in terms of packet delivery ratios and a feasible amount of Quality of Services (QoS) could not be attained due to poor channel links between source to the destination. To address these problems,

CCS deal with diversity gain by forwarding the information to all its relays nodes from source and the once again the same data to the destination for improved QoS services. Relay assisted CCS in CR depends on the collaborative relationship between Secondary Users (SUs) and Primary Users (PUs). Relay based schemes are built upon two basic techniques namely Decode-And-Forward (DF) and Amplify-And-Forward (AF). The AF scheme is a non-regenerative protocol while DF is regenerative one. In the DF relay model, the source transmits data to both the relay node and the destination. The relay node receives the data, demodulates the symbols and retransmits to the destination. Hence, the destination nodes handle two symbols received from different terminals.

At times, the received demodulation symbols at relay are erroneous because of the path link quality and also the desired diversity gain is not achieved in real time. To tackle these gaps, Decode-and-Forward protocol is formulated. This one is complex in nature but it is inbuilt with Forward Error Correction (FEC) coding. In this Decode-and-Forward relay system, the relay node decodes the transmitted data and then routes the re-encoded data to the destination. Because of this reason the Decode-and-Forward relay modes comprises of complex arithmetic units and consume maximum power. The advantage of choosing CCS in CR systems is that it offers increased data rate in wireless communication system by utilizes the same amount of radio resources and channel. In addition to that, Collaborative scheme of communication reaps maximized spectrum utilization and its integration with Multiple Input Multiple Output (MIMO) system allows transmitting the multiple streams of data independently and obtaining a remarkable performance gains in CRNs. To attain a considerable diversity gain at the relay nodes, it is enabled to use virtual MIMO system rather than using multiple antennas and by doing so a stealthy performance metric might be got out with multiple collaborative nodes using AF protocol.

II. RELATED WORKS

It is discussed in [5] about Decode-and-Forward (DF) based relay schemes for an area efficient coherent demodulator at the receiver side using weighted combining technique. In this system the weights are used adaptively to achieve the required QoS with two dedicated travelling path links namely relay based transmission and direct transmission.

The discussed simulation results proved that coherent demodulation at the receiver side received considerable diversity gains irrespective of the corresponding constellation.

At the same time, error rate performance also got improved with maximum-likelihood (ML) detection over DF relaying protocols. With MIMO-based CR some practical issues are also felt during the strategies employed for data transmission by Pus. For this three models are used namely: channel environment conditions, channel state information and rate of data transmission. A model of deep learning for MIMO PU transmission and an algorithm for blind channel estimation is developed in [6] and also cognitive beamforming method is designed to reduce the path interference during PU data transmission. A maximum likelihood detection process was proposed in [7] for a MIMO Alamouti Space-Time Block Coding (STBC) based relay assisted cooperative system using DF protocols.

From this it is also pointed out that a piece-wise linear (PL) decoder for the MIMO systems proposes almost same error rate performance that was got with complex ML detection used in most of the relay schemes.

In some cognitive radio environments where MIMO transmission model and Orthogonal Frequency Division Multiplexing is employed, it is difficult to channel allocation. In this case, a novel cooperation model is proposed among the SUs and a DF relay for each user in [8] and also dual decomposition technique to determine optimal subcarrier spacing and relay selection during cooperative transmission. In [9], spectrum access scheme for high data rate during PU data transmission and optimal resource sharing for SUs were proposed by making a particular relaying protocols and a specific time slot for transmission through channel. In [10], it is discussed about MIMO cooperative communication in cognitive radio relay network is systematized by using multiple antennas at the site of Secondary User Transmitter (ST) and operating Amplify-and-Forward transmission in a half-duplex mode. In this data transmission scheme factorable constellation pairs were brought in to make ST to transmit its own data as well as PU's. From the results it is studied that in noise-free channel condition, both PU and SU data are decoded individually and in case of Gaussian noise channel, improvement in reliability is achieved with full diversity.

For IoT applications, it is noted that the spectrum depletion problems arises because of the issues related to existing spectrum allocation. The problems were addressed in [11] with the help of machine learning-based CCS methodologies which don't even consider the node placement for spectrum sensing. In [12] a mechanism called Contract theory is introduced for OFDM-based cognitive IoT system for studying channel characteristics and data transmission. Here a compromise is done in channel access between PUs and SUs and precedence are given accordingly. In [13] different modes of CCS relaying protocols and their related parametric metrics that are required for proper relay selection in the CR network were discussed. In addition, the system requirements for data propagation in 5G networks and the leverage of cooperative communication systems are also discussed. Some of the common threats to information security such as eavesdropping and jamming are also overcome with secure data communication and considerable amount of diversity gain with cooperative communication.

A novel cooperative technology called hybrid cooperative relaying method [14] was used to establish a secured transmission path link between source and destination nodes and also elaborates the finite error rate performances. Under network interference management proposal [15] discussed the demarcation between non cooperative and cooperative relaying schemes. The generated interference power from an each individual SU using Nash bargaining solution based on the dual decomposition method is accumulated. This solution will suppress the influence of the interferences in CCS and maximize the network performance rate. The impact of imperfect Channel State Information (CSI) on the cooperative Non-Orthogonal Multiple Access (NOMA) transmission model is analyzed in [16]. During Decode-and-Forward based relaying Simultaneous Wireless Information and Power Transfer (SWIPT) model is co-opted to decide the energy level requirements for data transmission. Considering the channel conditions and using the robust beamforming, the power splitting, the minimum data requirement for a far user is achieved.

A Multi-User Multiple-Input And Multiple-Output (MU-MIMO) transmission model for cognitive radio system is proposed in [17]. For spectrum sensing, Weighted-Eigen Value Detection (WEVD) model is used for high data rate transmission and time bounds for each transmission is calculated. In [18] a joint channel allocation and adaptive mode selection schemes for MIMO-based multi-modal cognitive radio systems were discussed. Based on dynamic accessing capabilities of each cognitive radio devices the optimal MIMO modes multiplexing and/or diversity gains are provided in order to attain reliability and also the system performance is improved significantly. Finally the network performance is investigated over different level of data traffic and channel conditions.

III. PROPOSED FRAMEWORK

The efficiency of CCS is got out by incarnating the relay schemes as per the design necessities and the mode of communication. In CCS high performances is attained by using optimal relay node (RN) and suitable signal detection techniques. The CCS is evaluated for metrics like Signal to Noise Ratio (SNR), Channel State Information (CSI), and Error Rate Performance (BER) and for high diversity gain, the system should be prepared with multiple relays, MIMO Space-Time Block Codes (STBCs) over CR networks.

In CR networks each relay node will transmit STBC encoded data as non orthogonal transmission among the relays. Therefore, for a cooperative communication it is important to use highly distributed STBC to reduce the performance deterioration due to poor channel links. MIMO with relaying AF protocol is better than DF assisted MIMO system as given below:

$$R_D = \min(\alpha R_{SR}, (1-\alpha)R_{RD}) \quad (1)$$

Where α time measure for data propagation R_D, R_{SR}, R_{RD} are received symbols of destination, source to relay and relay to destination respectively. While transmitting the data to SU the error rate performance is tried to minimize with the help of MIMO.

In this scenario SU transmitter is equipped with two antennas and PU transmitter is equipped with a single antenna and the data transmission is carried in a half-duplex model. During cooperation AF protocol is followed in two phases, and proceeds over to successive time slots. During initial phase, PU transmit antenna transmits data to its own destination and also to SU and in second phase SU integrates both the PU data and received PU data as factorable constellation pair and then, Amplifies and Forwards the received signals to both primary destination node and SU terminal using the MIMO Alamouti coding scheme.

IV. SIGNAL DETECTION

The relays involved in CCS perform repeated ML detection for demodulating all the received symbols before transmitting them to the destination. The relay nodes assimilated with Demodulate-and-Forward scheme would strangle the gathered erroneous symbols and decrease the respective performance reduction at the receiver. Maximum Likelihood (ML) decoder derived from different CSI models improved the system performance at the destination side.

During collaborative relay communication, the symbols received at the destination node can be represented as

$$Y_{R,D} = H_{R,D}.\hat{X} + E_{R,D} \quad (2)$$

$\hat{X}$ denotes decoded data by the relay, $H_{R,D}$ refers channel gain

Let $Y = (Y_{S,D}, Y_{R,D})$ is equal to the orthogonal combinations of all data received at the destination node.

The log likelihood ratio (LLR) finding for ML detection is formulated as follows:

$$\hat{X}^{d}_{l,m} = \ln\left(\frac{P_y\, |H_{S,D}, H_{R,D}, x = X_l, x\epsilon C}{P_y\, |H_{S,D}, H_{R,D}, x = X_m, x\epsilon C}\right), l, m = 1,2,3, \ldots .X \quad (3)$$

From the above equation P_y terms belong to conditional joint probability density function of received vector y from both S-D and R-D communication path links. As shown in Fig.1. the relay assisted for SR received all the signals from PT as well as ST and jointly detects all transmitted signals using iterative maximum likelihood (ML) detector. The relay node also decodes the erroneous symbols from ST for improved system performance.

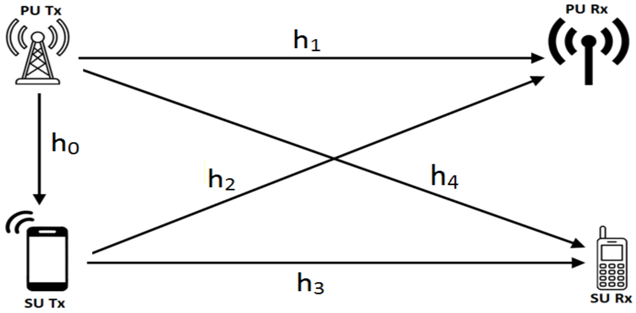

Fig.1. Relay assisted cooperative communication system in CR networks

V. SIMULATIONS

Simulations are performed using higher order M-QAM with 16 order of constellations and Rayleigh fading channels for validating the performance of relay assisted MIMO based cooperative communication systems. It is assumed that the normalized SNR range of all metrics evaluation is considered to be same and simulations are obtained accordingly.

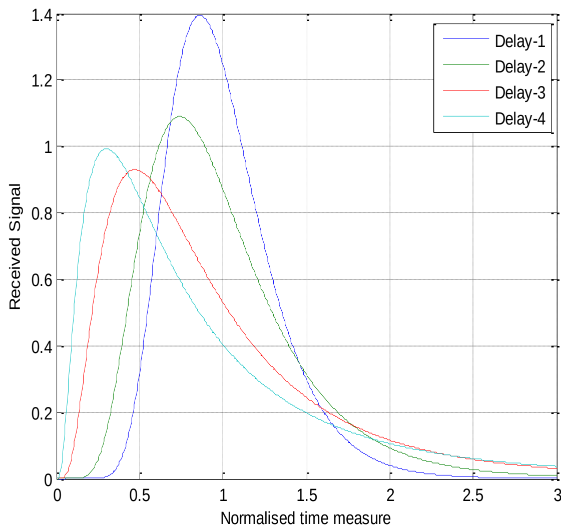

Fig.2. Signal measures of various path links to the destination

Fig. 2 shows the measurement of signal strength related to each path links and decides the hard decision on ML detection at the destination and accordingly narrows down the error rates. As per the system model described the path links are dynamically varying as per the number of relays chosen and associated antenna elements participating in collaborative data communication. It can be seen from above results that the inclusion of a DF relay to the CR system can considerably tolerate the channel non linearity but by adding extra relays the diversity gain will diminish the error tolerable error rate performance.Fig .3 depicts that with the addition of relays it is found that diversity gains have improved the quality of services, with proper mode of protocols for relay path links BER performance was achieved to the required level and also some of the valuable resources in the cooperative CR networks were saved.

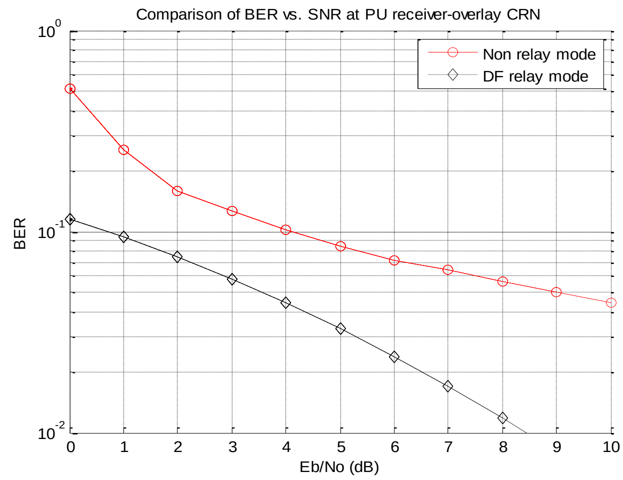

Fig.3. Performance comparison between Non relay vs. DF relaying protocols

The combination of highly iterative ML symbol detection and Decoding and Forward scheme at the receiver side outperforms other competitive counterpart models in terms of accessing the channel environmental conditions. This work considered soft decision information for each iteration during mAP (mean Average Precision) detection and incorporates relay link selection strategies into the iterative processing detector.

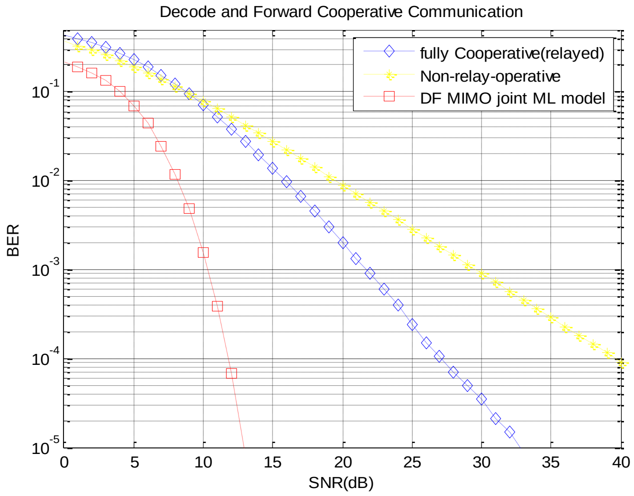

Fig.4. BER performance tradeoff analyzes between DF relay vs. DF MIMO joint ML protocols

As shown in Fig. 4 even with the limited Channel State Information (CSI) and by applying the relay diversity selection models to the identically available relay nodes diversity enabled cooperative transmission could be further improved

Further work on this research can be extended based statistical and mathematical analysis of diversity gain and associated error rate analysis for relay selection and cooperative MIMO/ML signal detection, which is excluded in this work which would require several statistical information.

VI. CONCLUSION

The impact of joint ML signal detection and Decode and Forward (DF) based distributed MIMO model has improved overall system performance of cooperative communication system. The factors affecting performance with complex-valued higher order M-ary constellations for high data rate is successfully reduced at the destination side. Further the proposed ML detection not only enables reliable data transmission but also significantly outperform an existing AF based Alamouti STBC when channel state information is not accurately estimated at the receiver side. The conditional ML detection that is applied for MIMO system and symbol detection from different set of constellation orders is analysed.

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