VOL. 10, NO. 17, SEPTEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

CHANNEL ESTIMATION AND BIT ERROR RATE ANALYSIS OF DEMODULATE AND FORWARD WIRELESS RELAY NETWORKS

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ABSTRACT

This paper presents channel estimation techniques for demodulate and forward (DeF) wireless relay networks (WRN) using least squares (LS) algorithm and its variants. Channel estimation is a significant issue in wireless relay networks as it plays a major role in data detection of coherent communication systems. Channel coefficients (or) channel state information (CSI) need to be estimated by algorithms as CSI is not available practically in wireless network environment. Although, LS is an existing algorithm and provides mean square error performance to a lesser extent in comparison to the more powerful minimum mean square error (MMSE) algorithm and maximum likelihood (ML) algorithms, this paper proposes LS algorithm for CSI estimation of DeFWRN with the sole aim of performing data detection with low computational complexity and simplicity which is provided by LS algorithm. Derivation of CSI is done in this paper using least squares algorithm and its performance on mean square error (MSE) is simulated. To address data detection, bit error rate analysis is also carried out to analyze the estimated wireless channel coefficients of demodulate and forward wireless relay networks.

Keywords: *d*emodulate and forward, wireless relay networks, least squares, mean square error, bit error rate and data detection.

INTRODUCTION

As the wireless communication era progresses requirements to support increased data rates, coverage, throughput and spectral efficiency becomes essential for different wireless applications in a network arrangement [1-5]. Data rates, throughput and spectral efficiency are addressed by advanced modulation schemes in PHYSICAL Layer (PHY), throughput in the Network Layer and use of Multiple Input Multiple Output (MIMO) schemes. Coverage of a wireless network is an important parameter related to distance between source node (transmitter) and a destination node (receiver) [1]. In order to improve the coverage capacity of wireless networks, relays or intermediate nodes can be employed [1] and [2]. A relay is a low power device which when placed in a geographical arrangement can provide spatial diversity by acting as virtual antennas and relays information received from the source node further. Relays when placed in a network are referred to as wireless relay networks (WRN). Wireless relay network operate by relaying strategy which can be classified as Amplify and Forward Wireless Relay Networks (AFWRN) [3], Decode and Forward Wireless Relay Networks (DFWRN) [4], Compress and Forward Wireless Relay Networks (CFWRN) and Demodulate and Forward Wireless Relay Networks (DeFWRN) [6-9].

In amplify and forward wireless relaying strategy the information transmitted from the source node is broadcasted to all the relay nodes and in the relays the information is linearly processed (Amplification) which can also be referred as scaling [3]. The amplified signal is further transmitted to the destination node through multiple access channels. This form of amplify and forward relaying strategy is also referred as non-regenerative method of relaying in wireless networks which can increase coverage. In the second type of relaying strategy the decode and forward relaying strategy the information transmitted from the source node is decoded at the relay node and it is retransmitted further to the destination node [4]. In compress and forward relaying strategy the information transmitted from the source node is compressed at the relay node by using techniques such as Wyner Ziv coding. The signal is further transmitted and received at the destination node. In demodulate and forward the signal is demodulated at the relay node which refers retransmission of the information signal used at the source node. The signal is retransmitted towards the destination node from the relay node [6-9]. Both demodulate and forward (DeF) and decode and forward (DF) are regenerative relaying methods concerned with retransmission of signals. This paper resorts to demodulate and Forward wireless relaying strategy as an initiative with no specific attributes but at the same time addresses the issue of estimation of wireless channel coefficients which is essential for data detection in wireless relay networks.

For successful transfer of information in wireless relay networks it is necessary to know the wireless channel fading coefficients so that it plays a role in data detection [5]. Estimation of wireless channel is done by using proper feedback from the destination node to the relay node and from the relay node to the source node. The coefficients are applied with estimation algorithms such as least squares (LS), minimum mean square error (MMSE) and maximum likelihood (ML) approaches [10]. Least squares approach is linear and simple in terms of computational complexity. Minimum mean square error approach depends on the likelihood function which is probability density function (PDF). Maximum likelihood approach is the optimal and best possible estimator with only option of having intensive searching among the possibilities of finding the best equivalent estimate. Though ML and MMSE approaches are considered to be superior in terms of mean square error (MSE) [10] criterion in comparison to LS but it is necessary to sacrifice computational speed for certain wireless applications. With this context, LS channel estimation approach is considered for channel estimation. After estimation of wireless channel coefficients, the estimated wireless channel coefficients can be used for analysing the bit error rate of wireless relay networks.

Several research papers have been putforth so far for demodulate and forward wireless relay networks (DeF). In [6] retransmissions of multiple packets are considered in wireless demodulate and forward wireless relay channels where the relay is limited to perform demodulation and re-modulation to mitigate large decoding delay necessity in DF relays. [7] Studies the impact of uncertainty in channel state information on the performance of demodulate-and-forward relaying with higher order modulation formats such as pulse amplitude modulation (PAM) and rectangular quadrature amplitude modulation (QAM). Regenerative wireless relay networks can be decode and forward and demodulate and forward and [8] presents space time coding in distributed form for DeF. Derivation of Bound and decoding procedures for demodulate-and-forward wireless relay networks using distributed Alamouti space time block coding (STBC) is analyzed in [9].

In this paper channel estimation for demodulate and forward wireless relay networks using least squares algorithm is proposed. As DeF is a regenerative transmission methodology it is sufficient to have channel estimation using simple approaches with less computational complexity. Hence, the optimal solution is least squares for consideration. Mean square error performance of DeFWRN is simulated against signal to noise ratio (SNR) for different lengths of the training sequences.

Notations and representations: Bold face small case is represented by vectors and small case is used to represent scalars. +, and H represents the pseudo inverse, and Hermitian, of the respective elements. $N(\mu, \sigma^2)$ represents a normally distributed random variable with mean μ and variance σ^2.

SYSTEM MODEL - DeFWRN

The system model for demodulate and forward wireless relay network has a single source node S, a single destination node D with M randomly placed relays $R_i \ i = 1,2....M$ The wireless fading channels are Rayleigh flat fading in which signal bandwidth is less than the channel bandwidth. The broadcast wireless channel from source node S to i^{th} relay node R_i is p_i, channel from i^{th} relay node R_i to destination node D as q_i. The wireless fading channel coefficients are complex Gaussian following normal distribution. Data information is transmitted from the source node to the destination node through relay nodes. The operation takes place in two phases given as Phase I and Phase II.

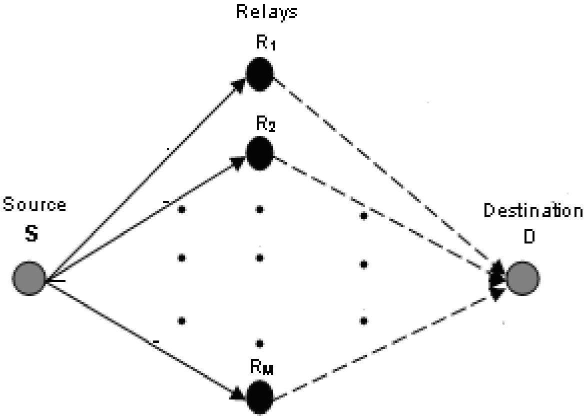

Figure-1. Demodulate and forward wireless relay network.

The $N \times 1$ received signal vector at the relay nodes $R_i \ i = 1,2....M$ is represented by

$$\mathbf{r}_{iDEMF} = p_i \mathbf{d} + \mathbf{n}_{reli} \tag{1}$$

where $\mathbf{d}$ is the transmitted information signal from R_i during phase I and $\mathbf{n}_{ri}$ is the white complex Gaussian noise at the i^{th} relay. During phase II, R_i transmits the data signal by also retransmitting the original data signal of the same length N and destination node D receives it as

$$\mathbf{y}_{iDEMF} = \mathbf{r}_{iDEMF} + \sum_{j=1}^{M} q_j \mathbf{s}_j + \mathbf{n}_{DEMF} \tag{2}$$

where $\mathbf{r}_{iDEMF}$ is $N \times 1$ received signal vector at the relay nodes, $\mathbf{s}_j$ is the original transmitted signal vector which is retransmitted from the relay nodes as it is a regenerative relaying strategy or demodulated and forward relaying strategy, $\mathbf{n}_{DEMF}$ is $N \times 1$ complex Gaussian noise vector at the Destination node. Also $N \times N$ noise covariance matrix at the destination node is

$$\mathbf{R}_n = E\{\mathbf{n}_d \mathbf{n}_d^H\} \tag{3}$$

LEAST SQUARE BASED CHANNEL ESTIMATION

To derive LS algorithm [10] consider (2), where the $N \times 1$ received signal vector $\mathbf{y}_{iDEMF}$ at the destination node is considered to be

$$\mathbf{y}_{iDEMF} = \mathbf{r}_{iDEMF} + \sum_{j=1}^{M} q_j \mathbf{t}_j + \mathbf{n}_{DEMF} \qquad (4)$$

where $\mathbf{r}_{iDEMF}$ is the $N \times 1$ received signal vector at the relay node, t_j is the $N \times 1$ training signal vector and n_{DEMF} is the $N \times 1$ noise vector at the destination node. To derive the LS estimate for $N \times 1$ received signal vector in (4), consider the objective function Q to determine the scalar channel coefficient q_j. To derive the estimate of q_j, consider Q to be the objective function

$$Q = \left(\mathbf{y}_{iDEMF} - \mathbf{r}_{iDEMF} - \sum_{j=1}^{M} q_j \mathbf{t}_j \right)^2 \qquad (5)$$

Now, partially differentiating (5) with respect to q_j it results in

$$\frac{\partial Q}{\partial q_j} = 2\left(\mathbf{y}_{iDEMF} - \mathbf{r}_{iDEMF} - \sum_{j=1}^{M} q_j \mathbf{t}_j \right)\left(-\sum_{j=1}^{M} \mathbf{t}_j \right) \qquad (6)$$

Equating the resultant to the least value which is zero in (6) it is rewritten as

$$0 = 2\left(\mathbf{y}_{iDEMF} - \mathbf{r}_{iDEMF} - \sum_{j=1}^{M} \hat{q}_{LS\,j} \mathbf{t}_j \right)\left(-\sum_{j=1}^{M} \mathbf{t}_j \right) \qquad (7)$$

Further (7) is rearranged and it is given as

$$0 = \mathbf{y}_{iDEMF} - \mathbf{r}_{iDEMF} - \sum_{j=1}^{M} \hat{q}_{LS\,j} \mathbf{t}_j \qquad (8)$$

Further, rearranging (8) it results in the LS estimator as given by (7) and (8)

$$\sum_{j=1}^{M} \hat{q}_{LS\,j} \mathbf{t}_j = \mathbf{y}_{iDEMF} - \mathbf{r}_{iDEMF} \qquad (9)$$

$$\hat{q}_{LS} = \frac{\mathbf{y}_{iDEMF} - \mathbf{r}_{iDEMF}}{\mathbf{t}_j} \qquad (10)$$

The LS estimate of q_j is determined for a single relay node channel coefficient is found to be as

$$\hat{q}_{LS} = \left(\mathbf{y}_{iDEMF} - \mathbf{r}_{iDEMF} \right)\left(\mathbf{t}_j \right)^{+} \qquad (11)$$

SIMULATION RESULTS

In this section, the mean square error performance of LS channel estimation algorithm for demodulate and forward wireless relay networks is obtained using all one vector training sequence. The wireless fading channel p_i, q_i and noise is complex Gaussian random variable having mean zero and variance equal to one. Signal power is $SNR = (P_S \times 1)/N_0 = P_S$. Simulations are carried out in MATRIX Laboratory (MATLAB) with 1000 Monte-Carlo iterations for determining one value of mean square error.

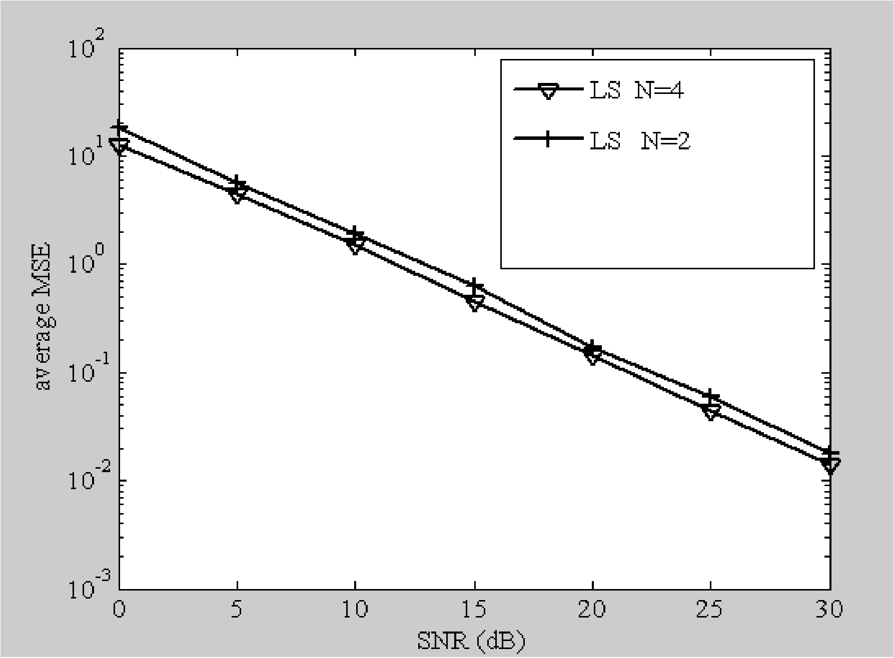

Figure-2. Average Mean Square Error (MSE) Vs SNR (dB) for DeFWRN.

Figure-2, shows MSE performance of least squares algorithm for demodulate and forward wireless relay network when the length of the training sequence is *N*=2 and N=4. MSE performance of LS estimator increases as the length of the training sequence increases which is obvious due to increased signal power value. It is observed that the LS algorithm results in an MSE of 10^{-1} at 22 dB when the training sequence length is 2 and it increases by 1 dB to 23 dB when the length of the training sequence is doubled.

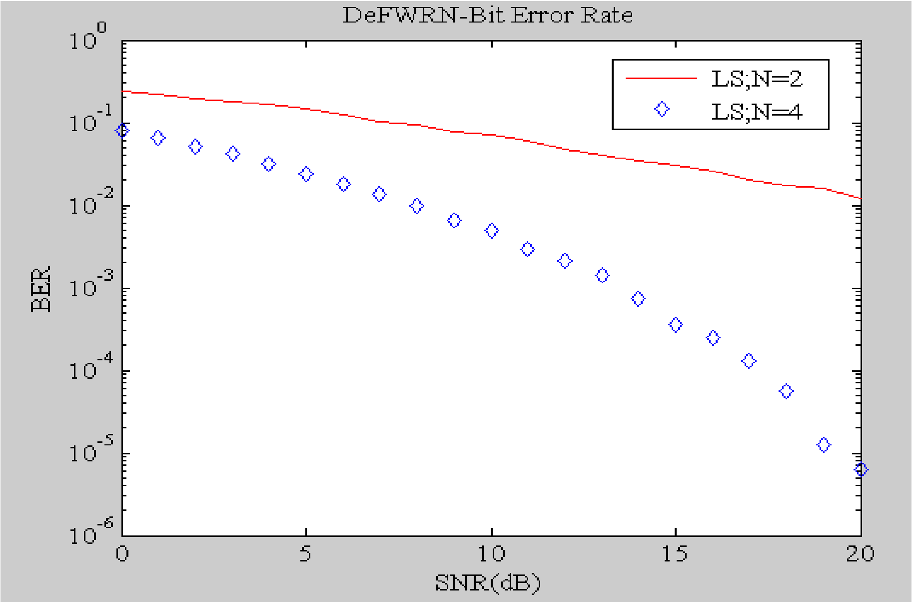

Figure-3. BER of DeFWRN using estimated channel coefficients using LS algorithm.

Figure-3, shows the bit error rate (BER) performance of LS algorithm for the training sequence lengths of *N*=2 and 4. BER performance of LS estimator for N=4 is 8 dB and N=2 is greater than 20 dB which stresses the importance of increasing training sequence length than increasing the number of relay nodes which involves infrastructure cost.

CONCLUSIONS

Demodulate and Forward wireless relay networks are a form of regenerative relaying networks which significantly increase the coverage area. Increased communication coverage can be obtained by DeFWRN due to its relaying strategy. Channel estimation acts as an important issue in DeFWRN pertaining to data detection in wireless networking applications. The obtained results portrayed in this paper can act as a benchmark for coverage related aspects of wireless relay networks.

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