VOL. 10, NO. 19, OCTOBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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ON THE COOPERATIVE AND DOPPLER DIVERSITY FOR AMPLIFY-AND-FORWARD RELAY NETWORK

M. F. Rabbi and Kamarul Hawari Bin Ghazali
Faculty of Electrical and Electronics Engineering, University Malaysia Pahang, Pekan, Pahang, Malaysia
E-Mail: fzrabbi@gmail.com

ABSTRACT

This paper investigates Cooperative and Doppler diversity for Amplify-and-Forward (AF) relay network assuming the channel between Mobile Station (MS)s and Relay Station (RS)s as well as the channel between the RSs and Base Station (BS) are nonstationary. More specifically, this paper analyzes and demonstrates how both the Doppler and cooperative diversities can be achieved to improve the system performance of an AF relay network in high user mobility scenario. To facilitate the analysis, a model for Orthogonal Frequency Division Multiple Access (OFDMA) based AF relay is developed. The time varying channel is modeled using Basis Expansion Model (BEM). Using both models we present efficient signal detection methods which can exploit the Doppler spread to improve Symbol Error Rate (SER) performance. Theoretical analysis together with simulation results is presented to demonstrate the improvement on system performance.

Keywords: amplify-and-forward relay, cooperative diversity, doppler diversity.

INTRODUCTION

In the evolution of mobile communication systems new technologies have been regularly introduced with updated features that require high data rate transmission and reception. The ever increasing demand for high speed data communication has always been a challenge for the researchers. In this sequel, the IEEE standard for wireless broadband communication, (IEEE 802.16 (2012)) has been published providing guidelines on the physical layer (PHY) and Medium Access Control layer (MAC). This standard integrates the previous relay based network with the fixed network to establish a hybrid Metropolitan Area Network (MAN). This standard provides guidelines for high data rate communication with the user mobility for a certain extent. Which means that, the users can enjoy mobile applications with high data rate while they are moving in car, train or other fast vehicles. Current Long Term Evolution (LTE), 3GPP and upcoming LTE-Advance are also designed in the same manner where users are supposed to enjoy high speed internet on their way of daily life (Afif Osseiran *et al.* 2009) (Y. Jiang *et al.* 2010).

However, the user mobility is always an obstacle to provide the high speed data communication especially for the broadband communication. The reason is mainly the Doppler effect that causes the Carrier Frequency Offset (CFO) resulting Inter Carrier Interference (ICI) yields data rate deterioration dramatically. More specifically, the channel between the mobile user and BS (or RS) becomes time varying when user moves faster. This channel variation is not easy to approximate at the receiver end to retrieve data with low error rate. As a result approximation of such time varying channel requires special treatment such as modeling and efficient estimation algorithm to keep more accurate data equalization (J. N. Laneman *et al.* 2004).

With underlying feature of cooperative diversity, the relay based cooperative network can provide very good data communication as investigated by (A. Sendonaris *et al.* 2003), (J. N. Laneman *et al.* 2004), (Fang Liu *et al.* 2008) and (S. S. Ikki and M.H. Ahmed 2009). In first two studies it has been shown that, utilizing the cooperative nature of different users' MS in the network, it is possible to get the cooperative diversity to enhance network capacity as well as the flexibility on the network coverage. (Fang Liu *et al.* 2008) proposed channel estimation algorithm for AF relay based cooperative network. (S. S. Ikki and M.H. Ahmed 2009) proposed a cooperative diversity technique where the channel information between MS-RS is fed back to the RS to improve the system performance at the BS. Note that, all of the above studies consider the stationary channel. The relay nodes can simply amplify the received signals before forwarding to the destination is known as AF relaying. Also relays would decode the signal and then forward to the destination is known to be Decode-and-Forward (DF) relaying. However the AF relaying requires less processing burden on the RS which may be another MS in the network. Recently, OFDMA based AF relay network has been given a lot of attention for spectrum efficiency.

In this paper we consider the AF relay network where the multiple users are moving in very high speed. OFDMA uplink system in such network consists of different users with different CFO due to different Doppler frequency of each user channel. We investigate the cooperative diversity together with Doppler diversity for the relay based network. Considering the high mobility of the user, first an appropriate system model is developed. The system model presents an effective channel model as well as received OFDMA signal structure. Based on the introduced model, we develop signal detection algorithm. Next, we analyze how the proposed methods can achieve both cooperative and Doppler diversity at the same time. Simulation results are provided to demonstrate performance improvement in practical situations.

VOL. 10, NO. 19, OCTOBER 2015 ISSN 1819-6608
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CHANNEL MODEL AND DIVERSITY TECHNIQUES

Cooperative channel model for high doppler spread

There are several studies on modeling the fast fading channels in mobile communication environment. In (G. B. Giannakis and C. Tepedelenlioğlu, 1998) Basis Expansion Model (BEM) based channel model was first proposed for time varying channel approximation. Later, (X. Ma and G. B. Giannakis, 2003), (I. Barhumi, *et al*. 2006), (Y. Ma and R. Tafazolli, 2007) and (H. Shengwei and C. C. Ko, 2009) also investigated the nature of time variation of the channel to approximate it more efficiently. However, all those studies are for fixed network only. Specifically, channel condition between the MS-RS and RS-BS were not considered explicitly. Channel model considering MS and/or RS moving in a faster manner has not received much attention yet.

Let us consider a cooperative network where multiple MSs are communicating with BS through multiple RSs. We consider no line of sight communication available between the MS and BS. As an example configuration is shown in Figure-1, in first time slot the signal transmitted from MS is reached to RS while the signal is amplified and relayed to the BS in the second time slot. Similar to the BEM in (X. Ma and G. B. Giannakis, 2003) the time varying channel between MS-RS link can be presented by a discrete time model as given by

$$h(n,l)=\sum_{q=-Q}^{Q} a_q(l)\exp\left(\frac{j2\pi nq}{gN}\right),\ 0\le n\le N-1,\ 0\le l\le L-1, \quad (1)$$

where $a_q(l)$ is the q-th BEM coefficient for l-th path and q determines the sampling resolution in Doppler domain. Note that g is the oversampling index and the relation between g and q can be shown as

$$f_q=\frac{q}{gT},-\lceil gf_dT\rceil\le q\le\lceil gf_dT\rceil, \quad (2)$$

where f_q and f_d are the q-th sampled and maximum Doppler frequency respectively. With T being the OFDMA block period, it is possible to approximate the channel for a fixed Doppler frequency which has a relation with user speed as $f_d=\upsilon f_c/C$ where υ, f_c and C are the relative speed, carrier frequency and speed of light respectively. In this channel model diversity technique can be employed to combat the fading effects. For example, as it can be seen in (1), there are multiple (L >1) independent fading channels with the total power constant by transmitting at a lower power in each channel. This issue can be demonstrated using theoretical Bit Error Rate (BER) simulation. The BER is simulated for both white Gaussian noise (AWGN) and fading channels with several values of multipath component (L) in Figure-2. As shown in the figure, increasing the value of L can improve the system performance in terms of BER. It implies that, the more copy of the channel coefficients received by the receiver, the more improvement in the error rate can be provided. This is also known as multipath diversity (Sayeed and Aazhang, 1999).

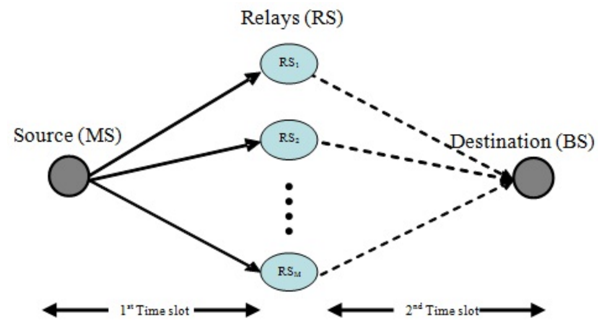

Figure-1. Cooperative communication between MS and BS via relay station (RS_1-RS_M).

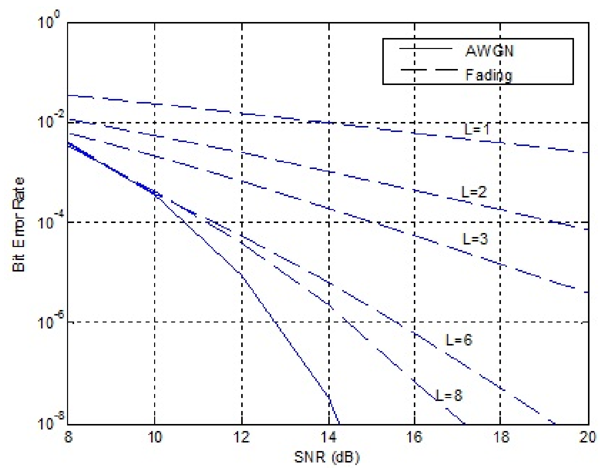

Figure-2. The system performance improvement by multipath channel modeling.

Following (1), it can be easily realized that, the $(2Q+1)L$ BEM coefficients in MS-RS link will be different from that of the RS-BS link. However, the exponential bases will remain same as long as the maximum Doppler frequency is fixed. Also, (2) implies that, the time variation of the channel can be captured more accurately by setting the value of oversampling index high. This is demonstrated by the simulation results shown in Figure-3. In this figure, we plot the modeling mean square error (MSE) against the oversampling index, g. The modeling MSE is obtained from $\varepsilon=\left\{\left|h_{Jake}-h\right|^2\right\}$, where h_{Jake} is the original channel generated by Jake's model in (W.C. Jakes, 1974) and h corresponds to the modeled channel constructed by using BEM as given in (1). From the result shown in Figure-3, it is clear that a larger g can produce less modeling error and thus can capture the time variation of the channel more precisely compare to smaller value of g.

In Figure-4 we illustrate the modeling error performance as a function of maximum Doppler

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frequency. As shown in the figure the BEM method can approximate the fast time varying channel very well. Despite requiring more complexity, the increment of Q also improves the performance in high Doppler spread. Note that, the BEM channel modeling can exploit the multipath diversity as well as the Doppler diversity. Also note that, as implied by (1) and (2) the modeling performance depends on the normalized Doppler frequency, $f_d T$ rather than the symbol period, T itself. Accordingly, BEM can be applied for the channel modeling in future mobile communication standards using high carrier frequency. Now, to get the cooperative diversity we have to work out through the received signal model and signal detection algorithms.

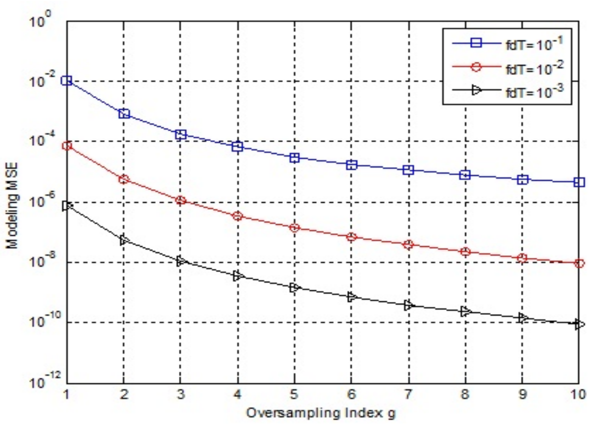

Figure-3. BEM modeling mean square error versus oversampling index.

SIGNAL MODEL AND DETECTION METHODS

Received signal model

The multi user received OFDMA signal at i-th RS can be given by

$$\boldsymbol{r}_i = \boldsymbol{\Gamma}\boldsymbol{a}_{SR}^i + \boldsymbol{z}, \tag{3}$$

where subscript SR implies the MS-RS link and

$$\boldsymbol{\Gamma} = [\boldsymbol{\Gamma}_1 \quad \boldsymbol{\Gamma}_2 \quad \dots \quad \boldsymbol{\Gamma}_U],$$

$$\boldsymbol{a}_{SR}^i = [\boldsymbol{a}_{SR,-Q}^i \quad \boldsymbol{a}_{SR,-Q+1}^i \quad \dots \quad \boldsymbol{a}_{SR,Q}^i]$$

with

$$\boldsymbol{\Gamma}_u = \sqrt{N}[\boldsymbol{D}_{-Q}\boldsymbol{\xi}(x_u) \quad \dots \quad \boldsymbol{D}_Q\boldsymbol{\xi}(x_u)],$$

$$\boldsymbol{D}_q = \mathrm{diag}\left[1 \quad e^{\frac{j2\pi q}{gN}} \quad \dots \quad e^{\frac{j2(N-1)\pi q}{gN}}\right],$$

$$\boldsymbol{a}_{SR,q}^i = [a_u(0,q) \quad a_u(1,q) \quad \dots \quad a_u(L-1,q)],$$

and

$$\boldsymbol{\xi}(\boldsymbol{x}_u) = \boldsymbol{F}\mathrm{diag}[\boldsymbol{M}_u\boldsymbol{X}]\boldsymbol{F}^H(:,1:L)$$

$$= \begin{bmatrix} x_u(0) & x_u(N-1) & \dots & x_u(N-L+1) \\ x_u(1) & x_u(0) & \dots & x_u(N-L+2) \\ \dots & \dots & \dots & \dots \\ x_u(N-1) & x_u(N-2) & \dots & x_u(N-L) \end{bmatrix}$$

is a $N \times L$ matrix formed by circularly shifting time domain data symbol $\boldsymbol{x}_u$, M_u is a masking variable that determines which subcarrier is used by user u, $\boldsymbol{X}$ is the complex IFFT modulated data, $\boldsymbol{F}$ is the inverse Fourier matrix with entry

$$[\boldsymbol{F}]_{x,y} = 1/\sqrt{N}\exp(j2xy/N),$$

and $\boldsymbol{z}$ represents the complex additive white Gaussian noise (AWGN) with zero mean and variance σ^2 in MS-RS link.

After amplifying and relaying by the RS, the received signal at the BS from i-th RS can be written as

$$\tilde{\boldsymbol{r}}_i = \boldsymbol{\beta}\boldsymbol{r}_i\boldsymbol{h} + \boldsymbol{z}, \tag{4}$$

where $\boldsymbol{\beta}$ is a $N \times N$ diagonal matrix containing analog gain factors of the relay (I. Hammerstroem *et al.* 2003), $\boldsymbol{h}$ refers to the channel matrix for RS-BS link and $\mathbf{z}$ represents the complex AWGN similar to MS-RS link. Using the BEM in (1) we have

$$\boldsymbol{h}_{RD} = \boldsymbol{D}\boldsymbol{a}_{RD}^i, \tag{5}$$

where

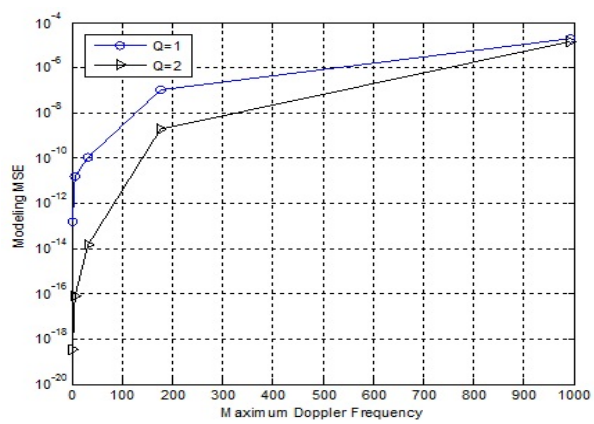

Figure-4. BEM modeling mean square error versus maximum doppler frequency with g =10.

$$\boldsymbol{D} = [\boldsymbol{D}_{-Q} \quad \boldsymbol{D}_{-Q+1} \quad \dots \quad \boldsymbol{D}_Q],$$

$$\boldsymbol{a}_{RD}^i = [\boldsymbol{a}_{RD,-Q}^i \quad \boldsymbol{a}_{RD,-Q+1}^i \quad \dots \quad \boldsymbol{a}_{RD,Q}^i],$$

and RD refers to the RS-BS link. Substituting (3) and (5) into (4), the OFDMA block received at the destination from i-th RS can be written as

$$\tilde{\boldsymbol{r}}_i = \boldsymbol{\Gamma}'\boldsymbol{a}' + \boldsymbol{\beta}\boldsymbol{D}\boldsymbol{a}_{RD}^i\boldsymbol{z} + \boldsymbol{z}, \tag{6}$$

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where $\boldsymbol{\Gamma}' = \boldsymbol{\beta}\boldsymbol{\Gamma}\boldsymbol{D}$ and $\boldsymbol{\alpha}'$ is a circulant matrix with first column $\left[\boldsymbol{a}_{SR}^{i} \otimes \boldsymbol{a}_{RD}^{i} \quad \boldsymbol{o}_{1,N-2(2Q+1)}\right]$. Note that $\otimes$ stand for the Kronecker product and matrix $\boldsymbol{\alpha}'$ determines the required number of BEM coefficients to be estimated. By introducing a variable $\boldsymbol{\eta}$, we can write all effective noise together as

$$\boldsymbol{\eta} = \boldsymbol{\beta}\boldsymbol{D}\boldsymbol{a}_{RD}^{i}\boldsymbol{z} + \boldsymbol{z},$$

so that, (6) becomes

$$\tilde{\boldsymbol{r}}_i = \boldsymbol{\Gamma}'\boldsymbol{\alpha}' + \boldsymbol{\eta} \tag{7}$$

Using (7) the received signal model for all RS signal at the BS can be given by

$$\boldsymbol{r} = \left[\tilde{\boldsymbol{r}}_1 \quad \tilde{\boldsymbol{r}}_2 \quad \cdots \quad \tilde{\boldsymbol{r}}_M\right] \tag{8}$$

Signal detection

As described in (H. Shengwei *et al.* 2009) not all signal detection algorithms are able to give desirable output in fast fading channel. Considering the fact that the received signal in (8) consists of carrier frequency offsets mixed into data subcarriers due to the high Doppler spread, we consider pilot aided detection algorithms for signal detection using interference cancellation method. Note that, the channel coefficients in (8) can be estimated by using appropriate estimation methods as described in (M.F. Rabbi *et al.* 20015). We rewrite the received signal model as

$$\boldsymbol{y} = \boldsymbol{W}\boldsymbol{r} = \boldsymbol{W}\boldsymbol{H}\boldsymbol{X} + \boldsymbol{W}\boldsymbol{\eta}, \tag{9}$$

where $\boldsymbol{W} = [\boldsymbol{w}_0 \quad \boldsymbol{w}_1 \quad \ldots \quad \boldsymbol{w}_{N-1}]^H$ is the interference suppression weight matrix, $\boldsymbol{H}$ is the channel matrix and $\boldsymbol{X}$ consists of all user data.

Matched filtering

In matched filtering, each received OFDMA block is simply filtered by using

$$\boldsymbol{W} = \boldsymbol{H}^H. \tag{10}$$

Zero-forcing

Zero-forcing is a least square technique that attempts to remove the interference from a mixed signal. Based on (9), using zero-forcing interference suppression yields the least square problem $\min_{\boldsymbol{W}} \mathrm{E}\left\{\left\|\boldsymbol{W}\boldsymbol{H}\boldsymbol{X} - \boldsymbol{X}\right\|^2\right\}$. It is easy to show that the solution is

$$\boldsymbol{W} = \left(\boldsymbol{H}^H\boldsymbol{H}\right)^{-1}\boldsymbol{H}^H, \tag{11}$$

which corresponds to the Moore-Penrose pseudo inverse of matrix $\boldsymbol{H}$. Accordingly, from (9) the detector output can be given by

$$\boldsymbol{y} = \boldsymbol{X} + \boldsymbol{W}\boldsymbol{\eta}. \tag{12}$$

(12) implies that, ICI can be completely removed after ZF detection. However, since noise suppression is not considered in the design, a price paid by using zero forcing is noise enhancement. Moreover, noise enhancement becomes more severe as channel variations become faster.

MMSE

The Minimum Mean Square Error (MMSE) technique attempts to remove both interference and noise, and therefore avoids severe noise enhancement. In this paper, we will develop the MMSE scheme by calculating and maximizing Signal-to-Interference plus Noise power Ratio (SINR). From the studies presented in (S. N. Diggavi *et al.* 1997), the achievable rate in an OFDMA system can be maximized if the SINR, γ_k is maximized for subcarrier k=0, 1, …, *N*-1. From the signal model given by (9), the SINR on subcarrier *m* (supposing it is used by user *u*) can be easily derived as follows.

The desired signal power on subcarrier *m* is given by

$$\begin{aligned} p_m &= \mathrm{E}\left\{\boldsymbol{w}_m^H\boldsymbol{H}\boldsymbol{e}_m\boldsymbol{e}_m^T\boldsymbol{X}\boldsymbol{X}^H\boldsymbol{e}_m\boldsymbol{e}_m^T\boldsymbol{H}^H\boldsymbol{w}_m\right\}, \\ &= \boldsymbol{w}_m^H\boldsymbol{H}\boldsymbol{e}_m\mathrm{E}\left\{\boldsymbol{e}_m^T\boldsymbol{X}\boldsymbol{X}^H\boldsymbol{e}_m\right\}\boldsymbol{e}_m^T\boldsymbol{H}^H\boldsymbol{w}_m \end{aligned} \tag{13}$$

where $\boldsymbol{e}_m$ is the unity basis vector whose elements are zero except the *m*-th entry. Next, the ICI power on subcarrier *m* is given by (14) where S_u is the set of subcarriers used by user *u*. Note that, we assume both type of powers are uniformly allocated on all the subcarriers. With σ_s^2 being the power allocated on each of the subcarriers, the signal and ICI powers given by (13) and (14) become.

$$\begin{aligned} J_m &= \mathrm{E}\left\{\sum_{p\neq m, p\in S_u}\boldsymbol{w}_m^H\boldsymbol{H}\boldsymbol{e}_p\boldsymbol{e}_p^T\boldsymbol{X}\boldsymbol{X}^H\boldsymbol{e}_p\boldsymbol{e}_p^T\boldsymbol{H}^H\boldsymbol{w}_m\right\} + \mathrm{E}\left\{\sum_{v\neq u}\sum_{p\in S_v}\boldsymbol{w}_m^H\boldsymbol{H}\boldsymbol{e}_p\boldsymbol{e}_p^T\boldsymbol{X}\boldsymbol{X}^H\boldsymbol{e}_p\boldsymbol{e}_p^T\boldsymbol{H}^H\boldsymbol{w}_m\right\} \\ &= \boldsymbol{w}_m^H\boldsymbol{H}\left[\sum_{p\neq m, p\in S_u}\boldsymbol{e}_p\mathrm{E}\left\{\boldsymbol{e}_p^T\boldsymbol{X}\boldsymbol{X}^H\boldsymbol{e}_p\right\}\boldsymbol{e}_p^T\right]\boldsymbol{H}^H\boldsymbol{w}_m + \boldsymbol{w}_m^H\boldsymbol{H}\left[\sum_{v\neq u}\sum_{p\in S_v}\boldsymbol{e}_p\mathrm{E}\left\{\boldsymbol{e}_p^T\boldsymbol{X}\boldsymbol{X}^H\boldsymbol{e}_p\right\}\boldsymbol{e}_p^T\right]\boldsymbol{H}^H\boldsymbol{w}_m \end{aligned} \tag{14}$$

$$p_m = \sigma_s^2\boldsymbol{w}_m^H\boldsymbol{H}\boldsymbol{e}_m\boldsymbol{e}_m^T\boldsymbol{H}^H\boldsymbol{w}_m, \tag{15}$$

$$J_m = \sigma_s^2\boldsymbol{w}_m^H\boldsymbol{H}\left(\boldsymbol{I}_N - \boldsymbol{e}_m\boldsymbol{e}_m^T\right)\boldsymbol{H}^H\boldsymbol{w}_m. \tag{16}$$

Finally, the noise power on subcarrier *m* is given by

$$\eta_m = \boldsymbol{w}_m^H\mathrm{E}\{\boldsymbol{Z}\boldsymbol{Z}\}\boldsymbol{w}_m = \sigma_n^2\boldsymbol{w}_m^H\boldsymbol{w}_m. \tag{17}$$

From (15), (16) and (17), the SINR on subcarrier *m* is

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$$\gamma_m = \frac{\boldsymbol{w}_m^H \boldsymbol{H}\boldsymbol{e}_m \boldsymbol{e}_m^T \boldsymbol{H}^H \boldsymbol{w}_m}{\boldsymbol{w}_m^H \left[\frac{\sigma_n^2}{\sigma_s^2} \boldsymbol{I}_N + \boldsymbol{H}\left(\boldsymbol{I}_N - \boldsymbol{e}_m \boldsymbol{e}_m^T\right)\boldsymbol{H}^H \right] \boldsymbol{w}_m}. \tag{18}$$

As pointed out in (A. Stamoulis *et al.* 2002) an optimization problem to maximize the SINR, γ_m can be expressed as $\max\{\boldsymbol{w}_m^H \boldsymbol{H}\boldsymbol{e}_m \boldsymbol{e}_m^T \boldsymbol{H}^H \boldsymbol{w}_m\}$, subject to

$$\boldsymbol{w}_m^H \left[\frac{\sigma_n^2}{\sigma_s^2} \boldsymbol{I}_N + \boldsymbol{H}\left(\boldsymbol{I}_N - \boldsymbol{e}_m \boldsymbol{e}_m^T\right)\boldsymbol{H}^H \right] \boldsymbol{w}_m = 1. \tag{19}$$

This optimization problem is a standard generalized eigenvalue problem, with the solution given by

$$\boldsymbol{w}_m = \left(\frac{\sigma_n^2}{\sigma_s^2} \boldsymbol{I}_N + \boldsymbol{H}\boldsymbol{H}^H \right)^{-1} \boldsymbol{H}\boldsymbol{e}_m, \quad m = 0,1 \ldots N-1. \tag{20}$$

Consequently, the weight matrix $\boldsymbol{W}$ can be written as

$$\boldsymbol{W}_{\text{MMSE}} = \left(\frac{\sigma_n^2}{\sigma_s^2} \boldsymbol{I}_N + \boldsymbol{H}^H \boldsymbol{H} \right)^{-1} \boldsymbol{H}^H. \tag{21}$$

SIMULATION RESULTS

Here we present some simulation results to verify the theoretical analysis done in the previous sections. We use MATLAB program to simulate a practical mobile communication environment with high Doppler spread. Note that, the Monte Carlo method is used in this simulation where the channel coefficients are random in each run. The Symbol Error Rate (SER) is evaluated in a fast time-varying channel, with, for example, a normalized Doppler frequency of $f_d T$ = 0.1 or a vehicle speed of 216 km/hr at a carrier frequency of f_c = 5GHz. Simulation parameters are given in table below.

Table-1. Simulation parameters and values.

Parameter	Value
Modulation scheme	QPSK
# of subcarriers (N)	64
# of users (U)	4
length of CP (N_g)	8
OFDMA block duration	100.8 μ sec
Sampling interval (T_s)	1.4 μ sec
# of OFDMA block	50
delay spread (L)	3
path delay	[0, T_s, 2*T_s]
avg. path gain (in dB)	[0,-5,-10]
oversampling index, g	5

Note that, we consider the pilot scheme in (T. Cui *et al.* 2005) where data and pilots are mounted separately in different time so that the length of the pilot block can be different from the data block. Apparently pilot block must have a length at least equal to the number of BEM coefficients to be estimated in the received signal model of (8). Note that, we consider the fixed relay gain allocation such that, the total power transmitted by relays will remain constant regardless the number of relays (I. Hammerstroem *et al.* 2003). As shown in (C. S. Patel *et al.* 2007), the receiver (BS in this case) possesses the knowledge of SNR and noise variance as these values are long-term properties. In the simulation we fix the gain as 3 dB unless otherwise stated.

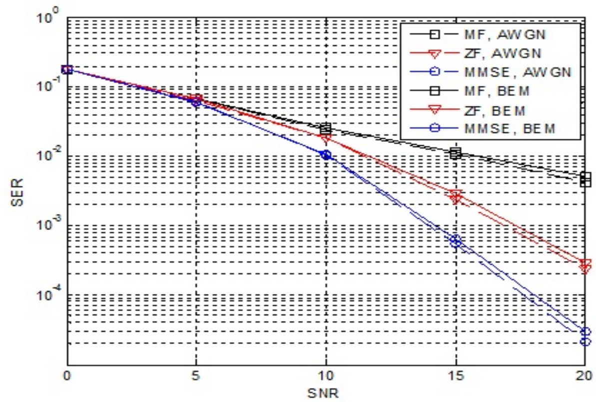

Figure-5. SER comparison in static and fading channel.

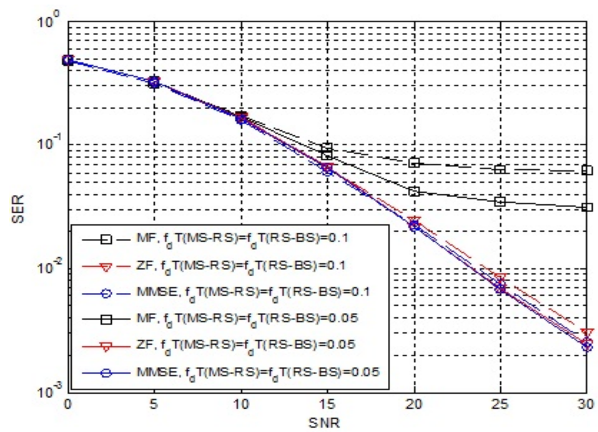

Figure-6. SER versus SNR in high doppler scenario, single relay.

Example 1: Static channel vs fading channel

First we simulate the SER performance for static channel and slow fading channel to justify the compatibility of the proposed signal detection methods. The static channel was also used in (Sayeed and Aazhang, 1999). Specifically, the AWGN channel is assumed for this static condition. On the other hand Rayleigh fading channel, modeled using BEM, with a normalized Doppler spread of 0.001 is assumed for slow fading channel case. As depicted in Figure-5, the proposed MF, ZF and MMSE symbol detection methods can give very close performances in both static and nonstationary channel condition.

VOL. 10, NO. 19, OCTOBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Example 2: Blind amplification and relay

In the first example, we consider single RS which will amplify the received signal blindly. This implies that, the received signal in a RS will be amplified together with the received noise in the RS as well. As shown in the Figure-6, the MMSE method has the best performance in the given high Doppler scenario. The ZF method cannot perform as good as MMSE method while MF scheme suffers from an error floor as it is more vulnerable to the amplified noise than others.

Example 3: Amplification with SNR improvement

In this case we consider single RS which will amplify the received signal with SNR improvement. Specifically, RS will calculate SNR from the received signal and then, only the symbol power will be amplified to improve the SNR. Note that, the pilot symbols are considered to be known to the RS in this case. As demonstrated in Figure-7 overall SER performance of all the detection methods is improved. The MMSE method outperforms two other detection schemes in very high Doppler spread scenario. The reason is, unlike others MMSE can exploit the improved SNR during symbol detection.

Next, we will present simulation results for the relay network with multiple RS. Note that, the relay gain will be distributed to the RSs to maintain the total gain fixed.

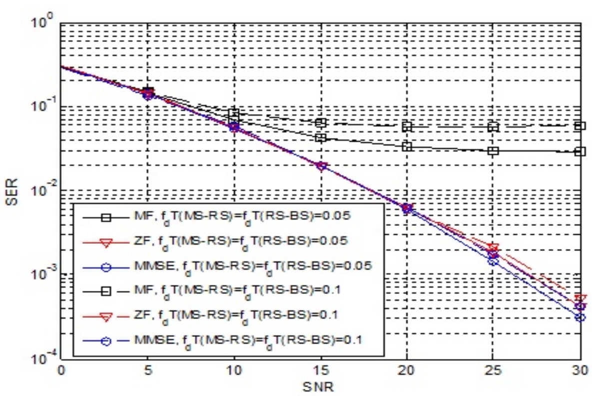

Figure-7. SER performances with SNR improvement, single relay.

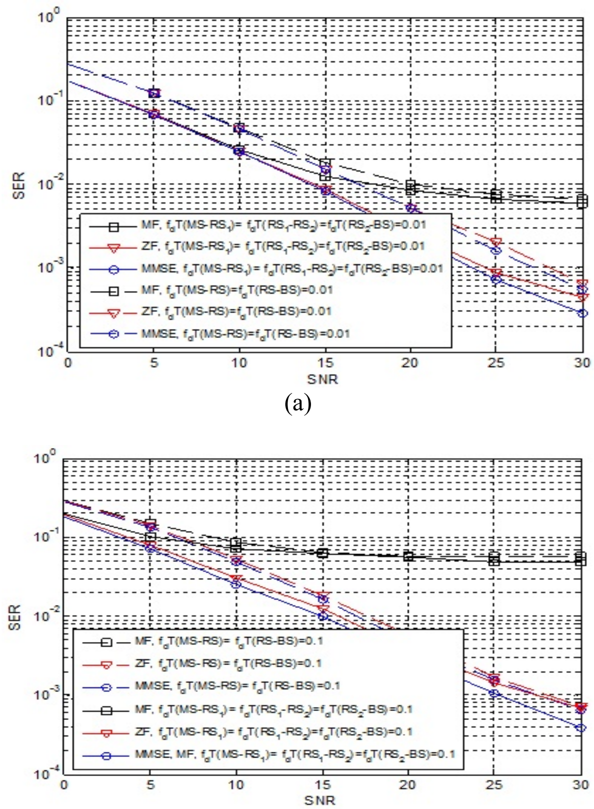

Figure-8. SER performance in (a) slow and (b) high mobility in two RS relay network.

Example 4: Cooperative diversity achievement

The dominant cooperative diversity in the SER performance is shown in the Figure-8, where using two RSs improves SER compare to using single RS. At the same time this figure compares slow and high mobility of MS and RS. For single RS two links of MS-RS and RS-BS with normalized Doppler spread [0.01, 0.01] and [0.1, 0.1] are considered for slow and high mobility respectively. While for two RSs case, there are three links of MS-RS1, RS1-RS2 and RS2-BS with normalized Doppler spread [0.01, 0.01, 0.01] and [0.1, 0.1, 0.1]. As illustrated in the figure, using two relays improves the SER performance compare to using single relay. However, the increment of Doppler frequency degrades the performance. This result implies that, using the proposed MMSE detector along with multiple relays may be a good choice for signal detection to improve system performance in very high mobility scenario.

CONCLUSIONS

In this paper we investigate two diversity techniques known as Cooperative diversity and Doppler diversity for relay based network. It has been shown that, by using an appropriate channel model, the Doppler diversity can be achieved for high mobility channel. In addition to the channel model, exploiting the cooperative

VOL. 10, NO. 19, OCTOBER 2015 ISSN 1819-6608
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nature of the AF relay network three different symbol detection methods have been proposed. It has been found that, MMSE detection method can exploit the relay gain of RS and, can provide best SER performance in very high Doppler spread condition. Also, all three detectors can improve their respective SER performance in multiple RS relay network compare to single RS case.

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