DECODE AND FORWARD COOPERATIVE DIVERSITY FOR TSV-MODEL BASED 60 GHZ WPAN SYSTEM

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ABSTRACT

Worldwide opening of tremendous amount of unlicensed spectrum around 60 GHz has created great interest in developing communication system at 60 GHz, especially in the context of WLAN (Wireless Local Area Network) and WPAN (Wireless Personal Area Network) systems for High Data Rate (HDR) wireless communications. The 60 GHz band provides abundance of bandwidth and is unmatched in any of the lower frequency bands. Cooperative communication networks have received significant interests from both academic and industry in the past decade due to its ability to provide spatial diversity without the need of implementing multiple transmit and/or receive antennas at the end-user terminals. These new communication networks have inspired novel ideas and approaches to find out what and how performance improvement can be provided with cooperative communications. This paper deals with providing performance improvement by mitigating detection errors at the relay using decode and forward (DAF) cooperative protocol. Comparison between the amplify-and-forward (AAF) cooperative transmission technique and the Decode and Forward cooperative transmission technique is encompassed. The paper examines a single relay network in which the channels considered are based on TSV model at 60 GHz. Performances based on different combining methods are evaluated. The effect of providing error detection capability at the relay on performance has been studied. The results indicate satisfactory diversity benefits offered by DAF cooperative diversity protocol as compared to single link transmission.

Keywords: AAF, BER, DAF, ESNRC, ERC, FRC, MRC, SNR, SNRC, TSV Model.

INTRODUCTION

Introduction 60 GHz is considered the most promising technology to deliver gigabit wireless for indoor communications. Strong commercial interest in using the 57-66 GHz band (also known as the millimeter wave band or mm wave band in short) for indoor wireless communications is evidenced by the recent industrial and standard development efforts in several international standard bodies. First of all, the abundance of the bandwidth in the unlicensed 60 GHz band is unmatched in any of the lower frequency bands. The fact that this band is unlicensed and largely harmonized across most regulatory regions in the world is a big advantage, in contrast with the meager spectrum available in the lower frequency bands for existing technologies such as Wi-Fi. The 60 GHz band boasts a wide spectrum of up to 9 GHz that is typically divided into channels of roughly 2 GHz each. Such wide channels make it easy to achieve gigabit data rate even with relatively simple modulation and coding schemes [10]. The opening of that big chunk of free spectrum, combined with advances in wireless communications technologies, has rekindled interest in this portion of spectrum once perceived for expensive point-to-point (P2P) links. The immediately seen opportunities in this particular region of spectrum include next-generation wireless personal area networks (WPANs) [11].

Recent generation wireless communication system should be capable of providing high throughput with good reliability under scarce radio spectrum, interference and variation in wireless channel. Similarly this system should also be capable of delivering high data rate multimedia services without affecting the quality of service. In many upcoming wireless applications, such as ad-hoc networks, implementing multiple transmit and/or receive antennas to provide diversity might not be possible due to the size and cost limitations. Cooperative diversity has recently been proposed to overcome the above limitations. The basic idea of the new method is that a source node transmits information data to the destination through single / multiple nodes (or relays). In this way, the destination receives the transmitted data with multiple copies that are generally affected by different and statistically independent fading paths. The destination then combines all the received signals to obtain diversity. Diversity obtained through multi-hop transmissions with the assistance of relays is commonly referred to as cooperative diversity [12].

The cooperative diversity scheme is classified mainly into two categories namely AAF and DAF. With AAF, the relay receives noisy version of the source information, amplifies it and further retransmits to the destination. With DAF, the relay decodes the source information, re-encodes it and retransmits to the destination.

Section II presents the literature review **Section III** presents the system model. S**ection IV** provides SER/BER analysis for cooperative WPAN system. **Section V** simulation environment with result are discussed. **Section VI** concludes the paper.

LITERATURE REVIEW

Recently cooperative diversity has emerged as a promising technique to combat fading in wireless channels. Various cooperative protocols have been proposed by different authors.
Cooperative protocols like AAF and DAF have been proposed in [5, 8] whereas [3] provides the user cooperation protocols. In [2] SER performance and optimum power allocation are provided for cooperative UWB multiband OFDM system with DAF protocols. Cooperative communication using AAF and DAF in Rayleigh fading channel with turbo codes has been discussed in [14]. In [16] DAF performance enhancement using interference cancellation is provided. A parallel relaying network at 60GHz, in the form of 3D pyramid using 3D ray tracing tool is formulated and simulated for better coverage and capacity as discussed in [17].
All these facts provide encouragement to use single relay based AAF and DAF at 60GHz for indoor communication.

This paper proposes to enhance the performance of WPAN systems operating at 60GHz using both the cooperative protocols. The BER performance analysis is provided for cooperative WPAN systems employing AAF and DFF protocols. The enhancement in BER performance by using pseudo error detection at the relay station for DAF protocol is provided. The proposed cooperative scheme has an improved performance as compared to non-cooperative scheme for WPAN system.

SYSTEM MODEL

A. Channel Model

The Complex impulse response is given as [1]

$$h(t)=\beta\,\delta(t)+\sum_{l=0}^{L-1}\sum_{m=0}^{M_l-1}\alpha_{l,m}\,\delta\left(t-T_l-\tau_{l,m}\right)\delta\left(\varphi-\Psi_l-\psi_{l,m}\right) \tag{1}$$

$$\overline{|\alpha_{l,m}|^2} = \Omega_0 e^{-T_l/\Gamma}\, e^{-\tau_{l,m}/\Upsilon-k[1-\delta(m)]}\sqrt{G_r(0,\Psi_l+\psi_{l,m})}, \angle\,\alpha_{l.m} \propto Uniform[0,2\pi] \tag{2}$$

PL_d: Path loss of the first impulse response; *t:* time[ns] ; *d(・): Delta function*

l = cluster number, *m* = ray number in *l*-th cluster, *L* = total number of clusters;

M_l = total number of rays in the *l*-th cluster;

T_l = arrival time of the first ray of the *l*-th cluster;

$\tau_{l,m}$ = delay of the *m*-th ray within the *l*-th cluster relative to the firs path arrival time, T_l;

W$_0$ = Average power of the first ray of the first cluster

Y_l ∝Uniform [0,2π); arrival angle of the first ray within the l^{th} cluster

$y_{l,m}$ = arrival angle of the m-th ray within the l^{th} cluster relative to the first path arrival angle, Y_l

The Two-path response is given as

$$\beta\,[\mathrm{dB}] = 20\cdot\log_{10}\left[\left(\frac{\mu_d}{d}\right)\left|\sqrt{G_{t1}G_{r1}}+\sqrt{G_{t2}G_{r2}}\Gamma_0\exp\left[j\frac{2\pi}{\lambda_f}\frac{2h_1h_2}{d}\right]\right|\right]-PL_d\left(\mu_d\right) \tag{3}$$

$$PL_d\left(\mu_d\right)[\mathrm{dB}] = PL_d\left(d_0\right)+10\cdot n_d\cdot\log_{10}\left(\frac{d}{d_0}\right) \tag{4}$$

$$PL_d\left(d_0\right)[\mathrm{dB}] = 20\log_{10}\left(\frac{4\pi d_0}{\lambda_f}\right)+A_{NLOS} \tag{5}$$

A_{NLOS}: Constant attenuation for NLOS

Path number of G_{ti} and G_{ri} (1 : direct, 2 : refrect)

d ∝ Uniform : Distance between Tx and Rx, h_1 ∝ Uniform : Height of Tx

h_2 ∝ Uniform : Height of Rx , μ_d ∝ Average of distance between Tx and Rx

$|\Gamma_0|$: Reflection coefficien t

$|\Gamma_0| \cong 1$: LOS Desktop environment (incident angle $\cong \pi/2$)

$|\Gamma_0| \cong 0$: Other LOS/NLOS environment

Arrival rate: It is described as a Poisson process and given as

$$p\left(T_l \mid T_{l-1}\right) = \Lambda \exp\left[-\Lambda\left(T_l - T_{l-1}\right)\right], \quad l > 0 \tag{6}$$

$$p\left(\tau_l \mid \tau_{l,(m-1)}\right) = \lambda \exp\left[-\lambda\left(\tau_l - \tau_{l,(m-1)}\right)\right], \quad m > 0 \tag{7}$$

Where
Γ : *cluster* decay factor
$1/\Lambda$: *cluster* arrival rate
γ : *ray* decay factor
$1/\lambda$: *ray* arrival rate
σ_1 : *cluster* lognormal standard deviation
σ_2 : *ray* lognormal standard deviation
σ_ϕ : Angle spread of ray within cluster (Laplace distribution)

Antenna parameters

$$G(\theta, \emptyset) = Gexp[-\alpha(\theta^2 + \emptyset^2)] \tag{8}$$

$Gt\left(\theta, \phi\right)$: Antenna gain of Tx
$Gr\left(\theta, \iota\right)$: Antenna gain of Rx

Rician factor k: Ray Rician effect is given as

$$K = \frac{\beta^2}{\sum_{l=0}^{L-1} \sum_{m=0}^{M_l - 1} \left|\alpha_{l,m}^2\right| \delta\left(t - T_l - \tau_{l,m}\right) \delta\left(\varphi - \Psi_l - \psi_{l,m}\right) G_r\left(0, \Psi_l + \psi_{l,m}\right)} \tag{9}$$

B. Block Fading

In a fast fading channel, the channel characteristic changes within one burst of data. The block fading channel model takes this into consideration. The burst is broken up into smaller chunks called blocks, and thus can be assumed to have more or less a constant channel characteristic for block duration. Similarly in order to allow perfect estimation of channel characteristics the block length has to be long enough. The magnitude and the phase of the fading coefficient of the block are assumed to be known by the receiver. The possibility of high burst error cannot be ruled out in a block fading channel. Error correcting codes may not be capable of correcting this burst errors. The signal can be interleaved to get the errors distributed uniformly over the whole signal to prevent such occurrences. It is assumed that block interleaving and the coding exist. The only thing that is of interest is the average bit error ratio (BER). In order to reduce the computing time the block length of one is assumed without loss of generality.

C. Non Cooperative Model (Direct Transmission)

In a non cooperative UWB system, the source transmits data directly to the destination. In order to establish base-line performance under direct transmission the source transmits over channel (1). The signal is modulated using binary phase shift keying (BPSK). The signal quality received at the destination depends on the SNR of the channel and the way the signal is modulated. Theoretical BER for a single link transmission is defined as

$$P_b = \frac{1}{2}\left(1 - \sqrt{\frac{\overline{\gamma_b}}{1+\overline{\gamma_b}}}\right) \quad (10)$$

$\overline{\gamma_b}$ denotes the average signal-to-noise ratio, defined as $\overline{\gamma_b} = \frac{\xi}{2\sigma^2}\mathrm{E}(a^2)$, where $\mathrm{E}(a^2)=a^2$

D. Cooperative Model

To benefit from diversity, an interesting approach might be to build an ad-hoc network using another wireless device/ terminal as a relay**.** The cooperative AAF model of such a system is illustrated in Fig.III.1. Consider two-user cooperation over a WPAN system. Each user can act as a source or a relay. The cooperation strategy comprises two phases. In Phase 1, the source(S) sends the data to its destination (D), and the data is also received by the relay (R) as it is listening to this transmission. In Phase 2, the source is silent, while the relay helps forward the source data to the destination after processing. At the destination the two received signals are combined. Orthogonal channels are used for the two transmissions. Without loss of generality, this can be achieved using time divided channels, which is done in all the simulations in this paper.

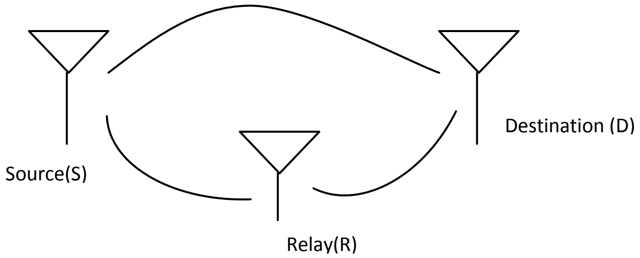


Fig. III.1: Direct data transmission and transmission through relay

SER/BER ANALYSIS FOR COOPERATIVE WPAN SYSTEM

A. Amplify and Forward (AAF) Protocol

The general relaying allows sophisticated joint encoding in transmitting signal of the source and relay as well as intricate processing and decoding of the source signals at the relay and destination. Amplify and forward protocol is used when, the relay has only limited computing time/power available or the time delay, caused by the relay to de- and encode the message, has to be minimized. As expected the signal received at the relay is attenuated and hence required to be amplified before retransmission. This forms the basic idea behind AAF protocol. The disadvantage of this protocol is that the noise in the signal is amplified as well. Block wise amplification of the incoming signal is performed at the relay. Assuming that the channel characteristic can be estimated perfectly, the gain for the amplification can be calculated as follows. The power of the incoming signal is given by

$$E[|y_r^2|] = E[\left|h_{s,r}\right|^2]E[|x_s|^2] + E[\left|z_{s,r}\right|^2] = |h_{s,r}|^2\xi + 2\sigma_{s,r}^2 \quad (11)$$

where s denotes the sender and r the relay. To send the data with the same power the sender did, the relay has to use a gain of

$$\beta = \sqrt{\frac{\xi}{|h_{s,r}|^2\xi + 2\sigma_{s,r}^2}} \quad (12)$$

This term has to be calculated for every block and therefore the channel characteristic of every single block needs to be estimated.

B. Decode and Forward (AAF) Protocol

Recent generation wireless transmission is rarely analogue and the relay has enough computing power, hence DAF is most often the preferred method to process the data at the relay. With decode and forward protocol, the relay node decodes the received signal to get source information. Further this decoded information is re-encoded and retransmitted to the destination. Unlike the AAF protocol the noise is not amplified as it is excluded by the decoding process. There are two main implementations of such a system. The relay can decode the original message completely resulting in higher computing time, but has plentiful advantages. If the source message contains an error correcting code, received bit errors might be corrected at the relay station. If error coding is not implemented at the source one can use a simple check sum mechanism. Thus depending on the type of implementation an incorrect message might not be sent to the destination. But it is not always possible to fully decode the source message. The additional delay caused to fully decode and process the message is not acceptable, the relay might not have enough computing capacity or the source message could be coded to protect sensitive data. In such a case, the incoming signal is just decoded and re-encoded symbol by symbol. So neither an error correction can be performed nor a checksum calculated. Due to broadcast nature of the wireless medium, the relay and the destination will receive a noisy copy of the signal. Thus received signal at the destination from the relay can be given as

$$y_{r,d} = h_{r,d}\bar{x} + n_{r,d} \qquad (13)$$

Where, $\bar{x}$ is the symbol detected by the relay and n is noise.

Pseudo Error Detection: No error correcting code has been implemented in this paper. Thus correction of the signal received by the relay is not possible. However, to simulate this scenario, a pseudo error detection mechanism is used. The mechanism implemented at the relay station, checks every decoded symbol and allows this symbol to be re-encoded and sent if and only if it was correctly detected. The overall performance of a system supported by this mechanism is similar to one using error correction and thus an error correcting code can be simulated in this way.

C. Combining Type

All incoming signals the same burst of data are combined using different types of diversity combined techniques and their performance is compared.

C. 1 Equal Ratio Combining (ERC)

If computing time is a crucial point, or the channel quality could not be estimated, all the received signals can just be added up. This is the easiest way to combine the signals, but the performance will not be that good in return.

$$y_d[n] = \sum_{i=1}^{k} y_{i,d}[n] \qquad (14)$$

As only one relay station is used in simulation, the above equation is simplified to

$$y_d[n] = y_{s,d}[n] + y_{r,d}[n] \qquad (15)$$

where $y_{s,d}$ and $y_{r,d}$ denote the received signal from the sender and the relay respectively.

C. 2 Fixed Ratio Combining (FRC)

A much better performance can be achieved, when fixed ratio combining is used. Instead of just adding up the incoming signals, they are weighted with a constant ratio, which will not change a lot during the whole communication. The ratio should represent the average channel quality and therefore should not take account of temporary influences on the channel due to fading or other effects. But influences on the channel, which change the average channel quality, such as the distance between the different stations, should be considered. The ratio will change only gently and therefore needs only a little amount computing time. The FRC can be expressed as

$$y_d[n] = \sum_{i=1}^{k} w_{i,d} \cdot y_{i,d}[n], \tag{16}$$

where $w_{i,d}$ denotes weighting coefficient of the incoming signal $y_{i,d}$. Due to use of one relay station, the equation further simplifies to

$$y_d[n] = w_{s,d} \cdot y_{s,d}[n] + w_{s,r,d} \cdot y_{r,d}[n] \tag{17}$$

where $w_{s,d}$ and $w_{s,r,d}$ denotes the weight of the direct link and one of the multi-hop link respectively.

C. 3 Signal to Noise Ratio Combining (SNRC)

The quality of the link is determined by the SNR value. If this SNR is used to weight the received signal a much better performance can be achieved. The received signals can be expressed as

$$y_d[n] = \sum_{i=1}^{k} SNR_i \cdot y_{i,d}[n] \tag{18}$$

For one relay the equation can be simplified as

$$y_d[n] = SNR_{s,d} \cdot y_{s,d}[n] + SNR_{s,r,d} \cdot y_{r,d}[n] \tag{19}$$

where $SNR_{s,d}$ and $SNR_{s,r,d}$ denotes the weight of the direct link and complete multi-hop link respectively.The estimation of the SNR of a multi-hop link using AAF or a direct link can be performed by sending a known symbol sequence in every block.

C. 3.1 Estimation of SNR using AAF

The mechanism used for estimation of SNR using AAF is given below.

Using AAF, the received signal from the relay is

$$y_{r,d} = h_{r,d} x_r + z_{r,d} = h_{r,d} \beta (h_{s,r} x_s + z_{s,r}). \tag{20}$$

The received power will then be estimated as

$$E\left[\left|y_{r,d}\right|^2\right] = \beta^2 \left|h_{r,d}\right|^2 \left(\left|h_{s,r}\right|^2 \xi + 2\sigma_{s,r}^2\right) + 2\sigma_{r,d}^2 \tag{21}$$

Hence the SNR of one relay multi-hop link can be estimated as

$$SNR = \frac{\beta^2 \left|h_{s,r}\right|^2 \left|h_{r,d}\right|^2 \xi}{\beta^2 \left|h_{r,d}\right|^2 2\sigma_{s,r}^2 + 2\sigma_{r,d}^2} \tag{22}$$

C. 3.2 Estimation of SNR using DAF

In order to calculate the SNR of a multi-hop link using DAF, the BER of the link is calculated first and then translated to an equivalent SNR. The BER over a one relay multi-hop link can then be calculated as

$$BER_{s,r,d} = BER_{s,r}\left(1 - BER_{r,d}\right) + (1 - BER_{s,r}) BER_{r,d} \tag{23}$$

Inverse functions are used to calculate the SNR from BER.

C. 4 Enhanced Signal to Noise Combining (ESNRC)

Another credible combining method is to ignore an incoming signal when the other incoming channels have a much better quality. If the channels have more or less the same channel quality the incoming signals are treated equally. The same can be expressed as

$$y_d[n] = \begin{cases} y_{s,d}[n] & (SNR_{s,d}/SNR_{s,r,d} > 10) \\ y_{s,d}[n] + y_{s,r,d}[n] & (0.1 \le SNR_{s,d}/SNR_{s,r,d} \le 10) \\ y_{s,r,d}[n] & (SNR_{s,d}/SNR_{s,r,d} < 0.1) \end{cases} \tag{24}$$

Exact knowledge of channel characteristic is not required while using this combining method. An approximate channel quality is sufficient combine the signals. Equal ratio combining is further beneficial as it requires very less computing power.

C. 5 Maximum Ratio Combining (MRC)

The Maximum Ratio Combiner achieves the best possible performance by multiplying each input signal with its corresponding conjugated channel gain. This assumption is based on the fact that the channels phase shift and attenuation is perfectly known by the receiver.

$$y_d[n] = \sum_{i=1}^{k} h_{i,d}^*[n].y_{i,d}[n] \qquad (25)$$

For one relay system the above equation can be simplified as

$$y_d[n] = h_{s,d}^*[n].y_{s,d}[n] + h_{r,d}^*[n].y_{r,d}[n] \qquad (26)$$

As seen from the above equation, the MRC considers only last hop and thus is a big disadvantage for multi-hop environment. Hence MRC is used only in combination with DAF and pseudo error correction mechanism.

SIMULATION ENVIRONMENT, RESULT WITH DISCUSSION

Table No.1: Channel Model and Environment

Channel Model	Environment
CM1	Residential LOS TSV & SV
CM2	Residential NLOS TSV & SV
CM3	Office LOS TSV
CM4	Office NLOS TSV
CM7	Desktop LOS TSV & SV
CM8	Desktop NLOS SV

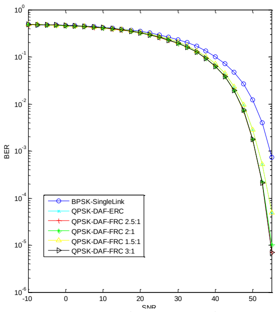
Table No.2: Channel Parameters (CM 1.x and CM 2.x)

Parameter	CM1.1	CM1.2	CM1.3	CM1.4	CM1.5	CM2.1	CM2.2	CM2.3	CM2.4
Λ [1/ns]	0.191	0.194	0.144	0.045	0.21	0.191	0.194	0.144	0.045
λ [1/ns]	1.22	0.90	1.17	0.93	0.77	1.22	0.90	1.17	0.93
Γ [ns]	4.46	8.98	21.5	12.6	4.19	4.46	8.98	21.5	12.6
γ [ns]	6.25	9.17	4.35	4.98	1.07	6.25	9.17	4.35	4.98
σ_{cluster}	6.28	6.63	3.71	7.34	1.54	6.28	6.63	3.71	7.34
σ_{ray}	13.0	9.83	7.31	6.11	1.26	13.0	9.83	7.31	6.11
σ_{φ}	49.8	119	46.2	107	8.32	49.8	119	46.2	107
$\Omega(d)$ [dB]	-88.7	-108	-111	-110.7	--	-88.7	-108	-111	-110.7
tx_hpbw	360	60	30	15	360	360	60	30	15
rx_hpbw	15	15	15	15	15	15	15	15	15

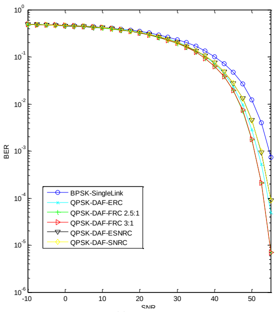
Table No.3: Channel Parameters (CM 3.x, CM 4.x, CM 7.x and CM 8.x)

Parameter	CM3.1	CM3.2	CM4.1	CM4.2	CM7.1	CM7.2	CM8.1	CM8.2
Λ [1/ns]	0.041	0.027	0.032	0.028	0.037	0.047	0.037	0.047
λ [1/ns]	0.971	0.293	3.45	0.76	0.641	0.373	0.641	0.373
Γ [ns]	49.8	38.8	109.2	134	21.1	22.3	21.1	22.3
γ [ns]	45.2	64.9	67.9	59.0	8.85	17.2	8.85	17.2
σ_{cluster}	6.60	8.04	3.24	4.37	3.01	7.27	3.01	7.27
σ_{ray}	11.3	7.95	5.54	6.66	7.69	4.42	7.69	4.42
σ_{φ}	102	66.4	60.2	22.2	34.6	38.1	34.6	38.1
Ω(d) [dB]	-3.27*d -85.8	-0.303*d -90.3	-109	-107.2	4.44*d -105.4	3.46*d -98.4	4.44*d -105.4	3.46*d -98.4
tx_hpbw	30	60	360	30	30	60	30	60
rx_hpbw	30	60	15	15	30	60	30	60

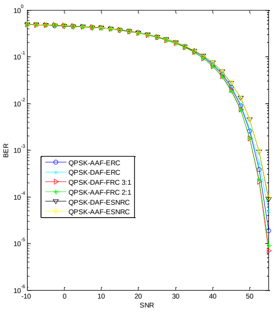
The simulation results for various channels described by TSV model (IEEE 802.15.4a) at 60 GHz, starting for CM1.1 are shown below.



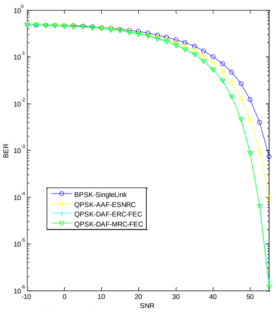
a.1: Estimation of best ratio for FRC



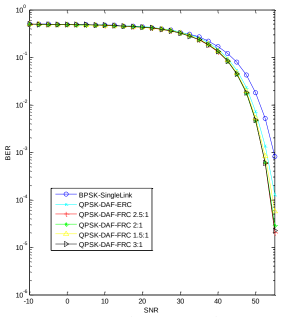
a.2: Comparison different combining types



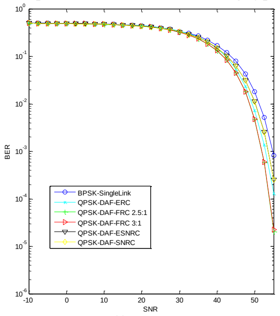
a.3: DAF versus AAF



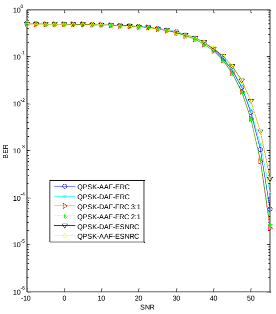
a.4: Effect of Pseudo error detection



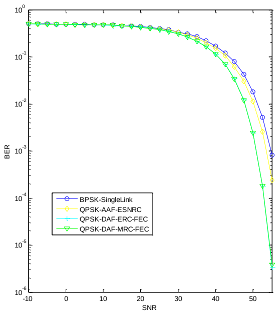
b.1: Estimation of best ratio for FRC



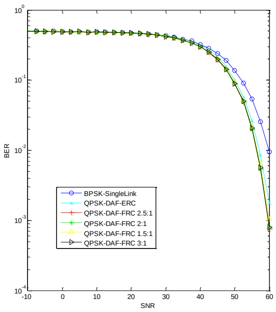
b.2: Comparison different combining types



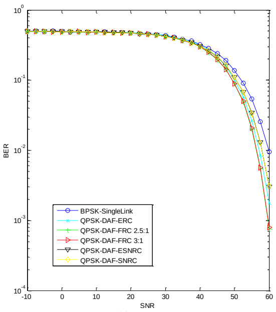
b.3: DAF versus AAF



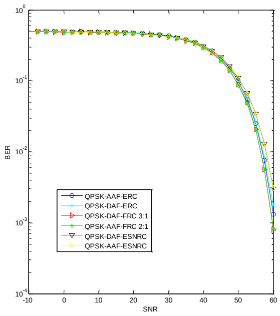
b.4: Effect of Pseudo error detection



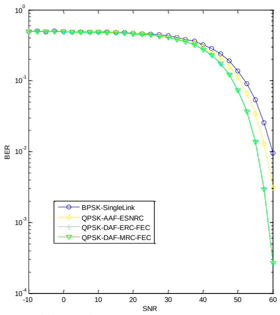
c.1: Estimation of best ratio for FRC



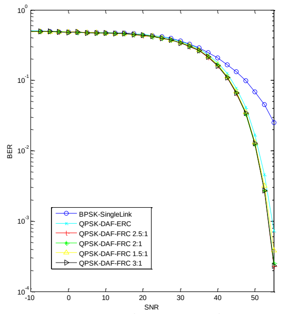
c.2: Comparison different combining types



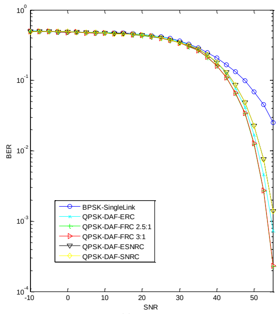
c.3: DAF versus AAF



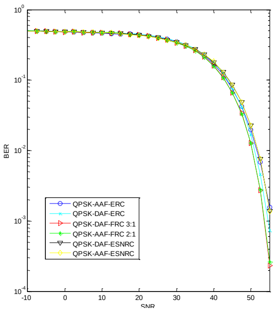
c.4: Effect of Pseudo error detection



d.1: Estimation of best ratio for FRC



d.2: Comparison different combining types



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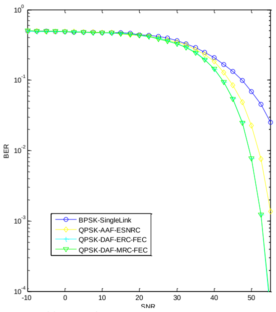

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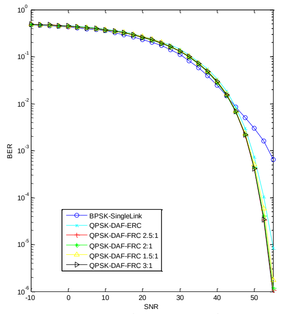

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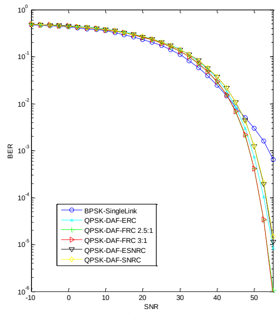

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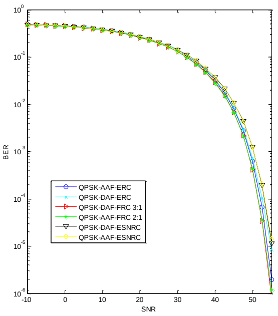

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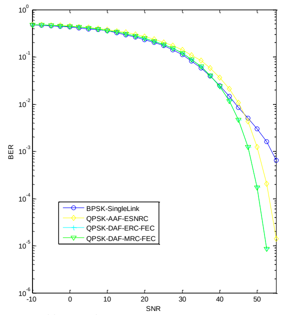

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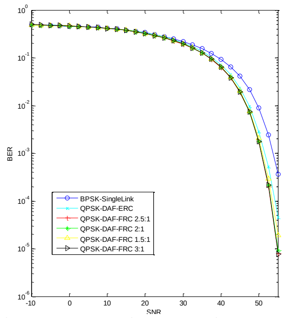

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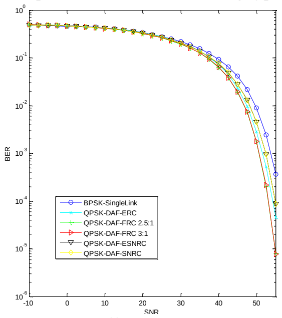

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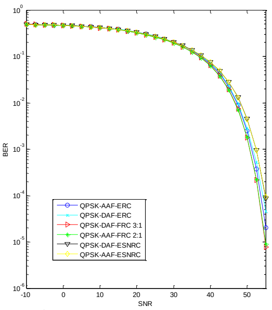
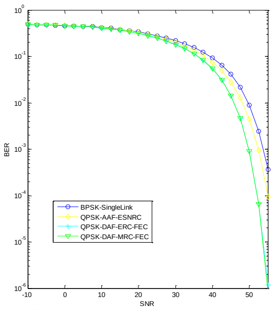


f.3: DAF versus AAF



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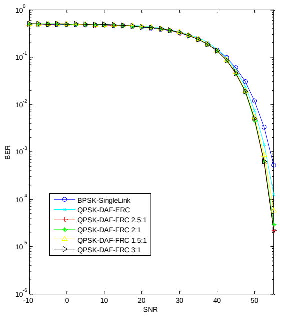

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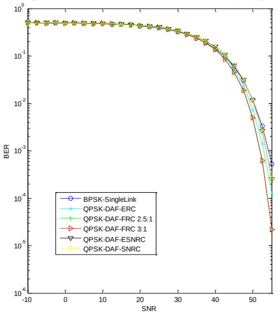
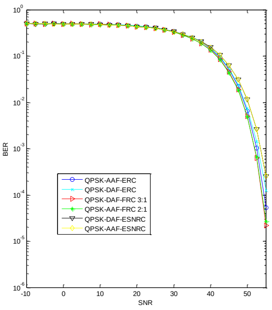
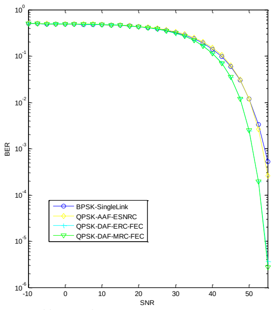


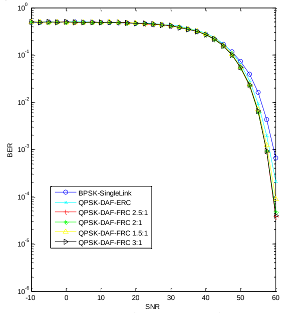
g.2: Comparison different combining types



g.3: DAF versus AAF



g.4: Effect of Pseudo error detection



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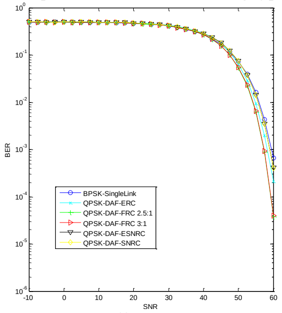
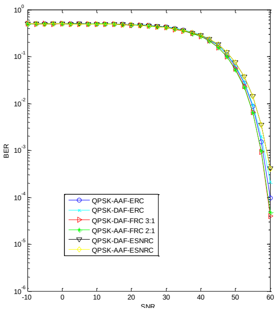
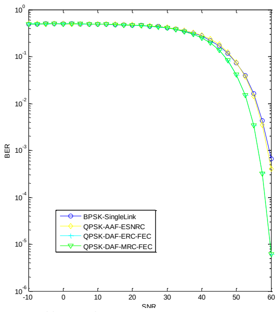


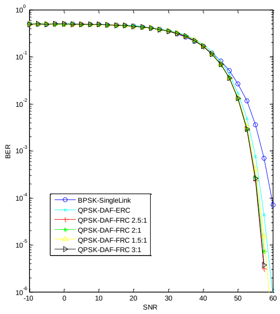
h.2: Comparison different combining types



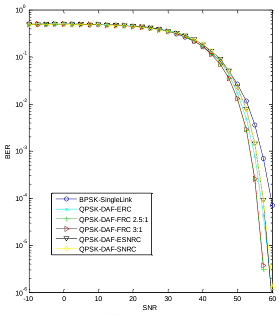
h.3: DAF versus AAF



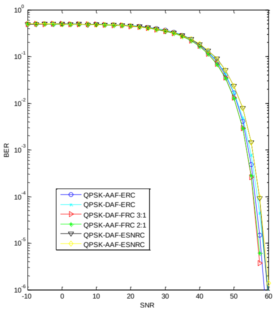
h.4: Effect of Pseudo error detection



i.1: Estimation of best ratio for FRC



i.2: Comparison different combining types



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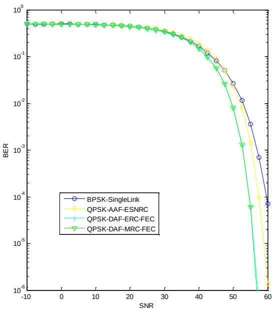

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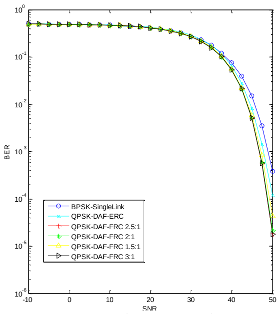
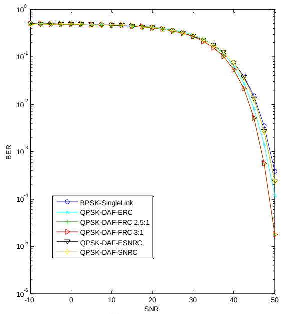
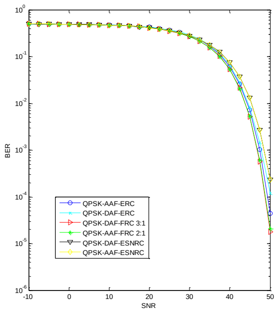


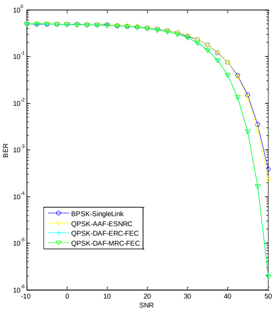
j.1: Estimation of best ratio for FRC



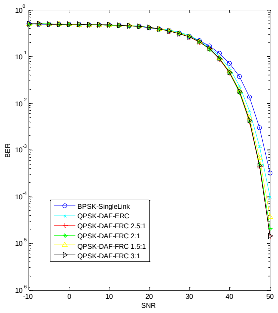
j.2: Comparison different combining types



j.3: DAF versus AAF



j.4: Effect of Pseudo error detection



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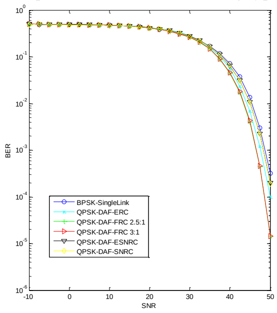

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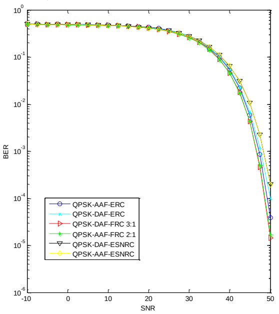
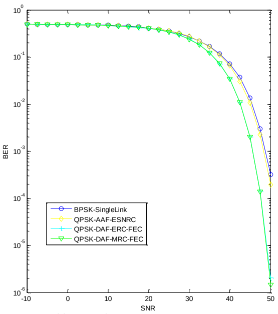


k.3: DAF versus AAF



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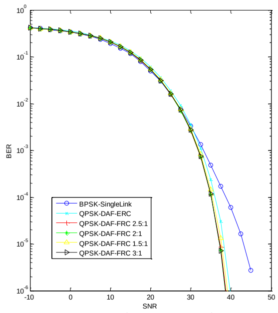
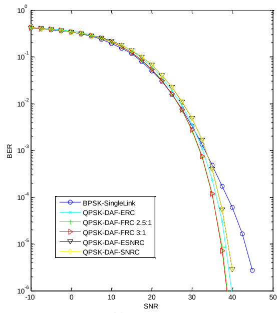
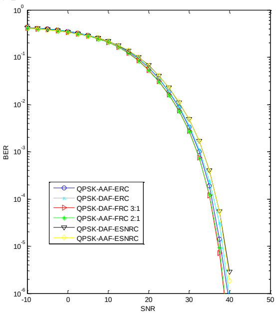


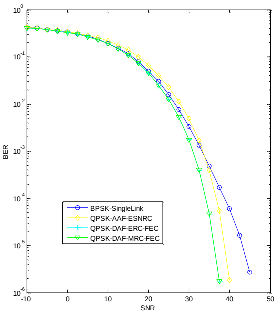
l.1: Estimation of best ratio for FRC



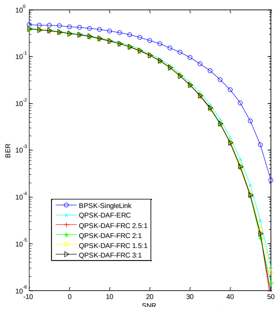
l.2: Comparison different combining types



l.3: DAF versus AAF



l.4: Effect of Pseudo error detection



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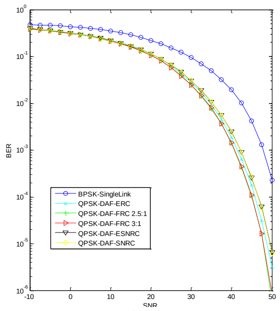

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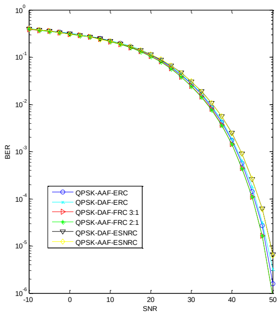
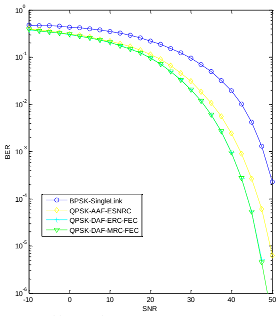


m.3: DAF versus AAF



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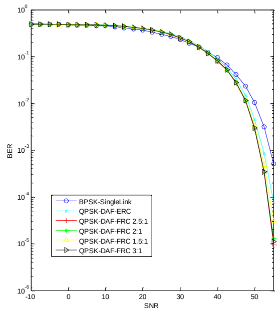

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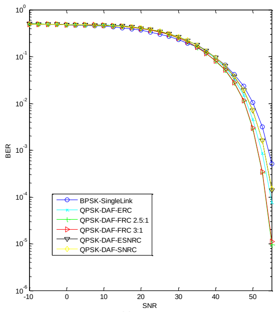
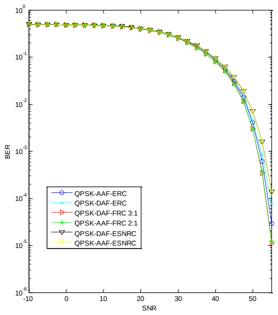
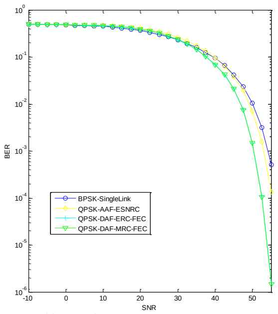


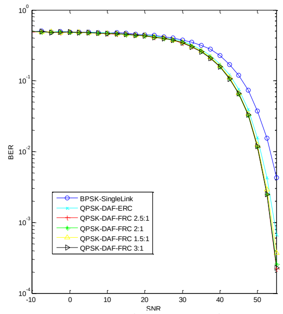
n.2: Comparison different combining types



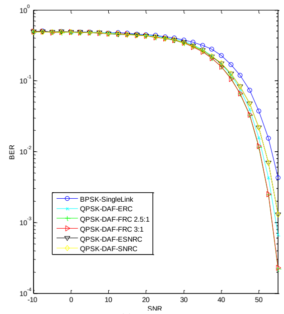
n.3: DAF versus AAF



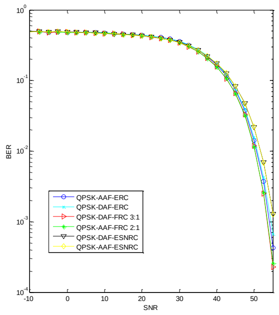
n.4: Effect of Pseudo error detection



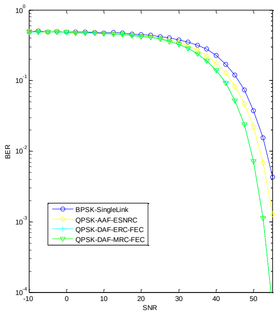
o.1: Estimation of best ratio for FRC



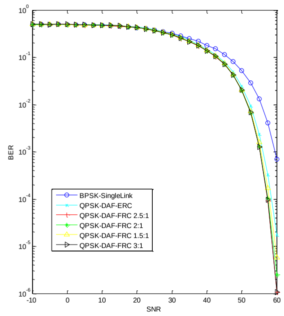
o.2: Comparison different combining types



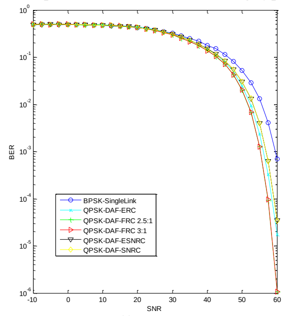
o.3: DAF versus AAF



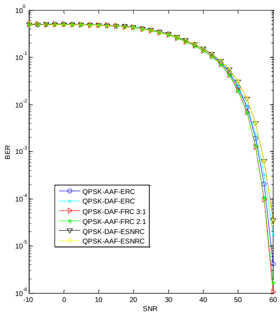
o.4: Effect of Pseudo error detection



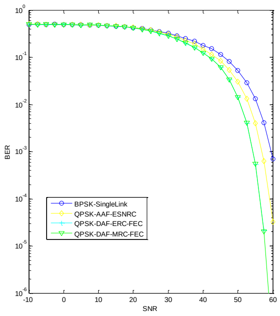
p.1: Estimation of best ratio for FRC



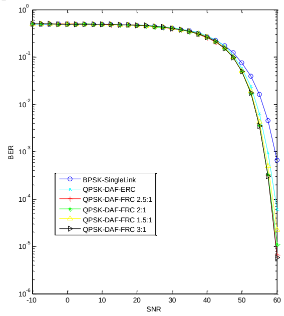
p.2: Comparison different combining types



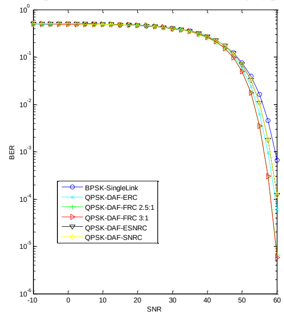
p.3: DAF versus AAF



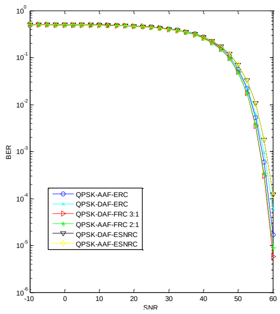
p.4: Effect of Pseudo error detection



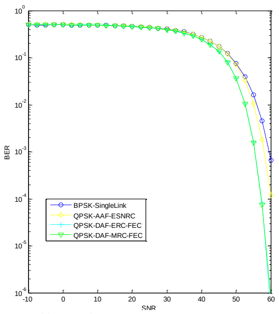
q.1: Estimation of best ratio for FRC



q.2: Comparison different combining types



q.3: DAF versus AAF



q.4: Effect of Pseudo error detection

The figures a.1 to q.1 and a.2 to q.2 show the performance for various FRC and ERC for DAF and comparison between different combining techniques for channels defined by TSV model at 60 GHz. Similarly, figures a.3 to q.3 indicates the performance comparison between AAF and DAF. Figures a.4 to q.4 shows the impact of using error detection at the relay in case of DAF protocol. The performance for channel CM4.1 is best amongst all the channels.

In order to compare the benefits of different combining techniques, the best ratio for the FRC is evaluated and it is found that the best performance is obtained when the ratio is 3:1. The performance of ERC is inferior to that of FRC but better than single link transmission for higher SNR values. To achieve a BER of 10^{-3} the SNR value for FRC (3:1) is approximately 7 dB to 8 dB below the SNR value for single link transmission, which is a remarkable advantage. The SNRC and ESNRC display nearly similar performances. ESNRC require approximate channel quality while combining where as SNRC requires precise channel quality information. Looking at the benefits of using SNRC in comparison to ESNRC, it is not worth to get exact channel information, as it involves higher computing power and bandwidth.

Comparison of ERC results for AAF and DAF protocol shows that AAF provides better performance than DAF. The possible reason for degraded performance in case of ERC in DAF is due to the fact that wrongly detected symbol at relay station is really difficult to be corrected at the destination, where these two signals are combined. The fixed ratio combining (FRC) shows good performance in case of AAF and DAF both as compared to single transmission. This results because of the fact that the direct-link on an average provides better quality than multi-hop link and will provide benefit if the direct link is weighted more as the multi-hop link is more prone to errors. It can also be observed that the weight associated with direct link for DAF is more in comparison to that of weight associated with direct link for AAF, to get similar BER performance. The ESNRC shows approximately similar performance in case of AAF and DAF. ESNRC can be disadvantageous if the number of wrongly detected symbols at the relay increases.

The DAF protocol with pseudo error detection mechanism provides much better performance than AAF and single link transmission in case of MRC as well as ERC. The performance of maximum ratio combining is slightly better than equal ratio combining in presence of pseudo error detection mechanism. This indicates that the performance in presence of pseudo error detection mechanism is independent of the type of combining method used at the destination.

CONCLUSION

This paper presents the performance benefit of using Decode and Forward protocol for WPAN communication systems at 60 GHz. The results clearly establish that the different combining methods used along with DAF provide better performance as compared to single link transmission. The benefits due to ERC may be limited if number of wrongly detected symbols at the relay increase. The SNRC and ESNRC combining techniques provide nearly comparable performance. The benefits obtained from SNRC are very modest when compared with the computing power and bandwidth required to get exact channel information. AAF with ERC has a better performance than DAF with ERC, as wrongly detected symbols at the relay can hamper the performance in case of DAF. In order to provide similar BER performance, the weight associated with direct link in AAF with FRC (FRC 2:1) is lesser than that of DAF with FRC (FRC 3:1). Further the DAF protocol can provide highly improved performance, if error detection mechanism is used at the relay. Thus DAF protocol provides performance benefits in terms of BER improvement over that of single link transmission.

REFERENCES

[1] H. Harada, R. Punada, H. Sawada, C H Choi and Y Shoji, "*IEEE 802.15.4a* channel model",2006.

[2] W. Pam Siriwongpairat, Weifeng Su, Zhu Han, and K. J. Ray Liu, "Employing Cooperative Diversity for Performance Enhancement in UWB Communication Systems", *IEEE WCNC, pp 1854- pp 1859 2006.*

[3] A. Sendonaris, E. Erkip, and B. Aazhang, "User cooperation diversity Part I: System description," *IEEE Trans. Commun., vol. 51, no. 11,* Nov.2003.

[4] A. Sendonaris, E. Erkip, and B. Aazhang, "User cooperation diversity - Part II: Implementation aspects and performance analysis, "*IEEE Trans. Commun., vol. 51, no. 11,* Nov. 2003.

[5] J. N. Laneman, D. N. Tse, and G. W. Wornell, "Cooperative diversity in wireless networks: efficient protocols and outage behavior," *IEEE Trans. Inform. Theory, vol. 50, no. 12,* Dec. 2004.

[6] Shouhong Zhu, Kin K. Leung, and Anthony G. Constantinides, "Distributed Cooperative Data Relaying for Diversity in Impulse-Based UWB Ad-Hoc Networks", *IEEE Transactions On Wireless Communications, Vol. 8, No. 8,* August 2009.

[7] Heba Shaban and Mohamad Abou El-Nasr, "Amplify-and-Forward Cooperative Diversity for Green UWB-Based WBSNs", *Hindawi Publishing Corporation, The Scientific World Journal* Volume 2013

[8] J. Nicholas Laneman and Gregory W. Wornell, "Cooperative Diversity in Wireless Networks: Algorithms and Architectures", September 2002.

[9] Andreas Meier and John Thompson, "Cooperative Diversity in Wireless Network", *Erasmus Project,* 2004.

[10] L. Lily Yang, "60GHz: Opportunity for Gigabit WPAN and WLAN Convergence", *Intel Corporation, ACM SIGCOMM Computer Communication Review,* Volume 39, Number 1, January 2009.

[11] Nan Guo, Robert C. Qiu, Shaomin S.Mo and Kazuaki Takahashi, "60-GHzMillimeter-Wave Radio: Principle, Technology, and New Results", *Hindawi Publishing Corporation, EURASIP Journal on Wireless Communications and Networking,* Volume 2007.

[12] Ha X. Nguyen, "Cooperative Transmission Techniques in Wireless Communication Networks", Ph D thesis Department of Electrical and Computer Engineering, University of Saskatchewan, Canada, August, 2011.

[13] A. Nosratinia, T. Hunter, and A. Hedayat, "Cooperative Communication in Wireless Networks," IEEE Communications Magazine, vol. 42, 2004, pp. 74-80.

[14] Michael R. Souryal, Branimir R. Vojcic, "Performance Of Amplify-And-Forward And Decode-And-Forward Relaying In Rayleigh Fading With Turbo Codes", IEEE ICASSP, 2006.

[15] Zimmermann, P. Herhold andG. Fettweis, "On the Performance of Cooperative Diversity Protocols in Practical Wireless Systems", *58th IEEE Vehicular Technology Conference,* October 2003.

[16] Siddeeq Y. Ameen, Mohammed K. Yousif, "Decode and Forward Cooperative Protocol Enhancement Using Interference Cancellation", *International Journal of Electrical, Computer, Electronics and Communication Engineering,* Vol: 8 No: 2, 2014.

[17] Charles S.C.Leong, Beng Sin Lee, Andy R. Nix and Paul Strauch, "A Robust 60GHz Wireless Networks with Parallel Relaying", *International Conference on communications,*Vol.6, 2004 pp3528-pp3532