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Decode and Forward Cooperative Diversity for Modified SV Model Based UWB Communication System

C N Deshmukh, V T Ingole

Abstract— Cooperative wireless networks have emerged as a major technology for future communication systems because cooperation in ad-hoc networks can save limited network resources. Cooperative techniques are the means to adopt the diversity, which is inherent in a wireless medium. While ultra-wideband (UWB) offers high information rates for wireless communication and sensor networks, the EIRP limits on UWB devices severely affects its coverage radius. This paper aims to investigate the possible improvement of a cooperative system, using decode and forward (DAF) protocol. The proposed DAF scheme along with Amplify-and-Forward (AAF) cooperative protocol for modified SV model based UWB channel is examined to determine the BER performance. Different combining methods are used and their performances for UWB system are analyzed. The result indicates that DAF provides satisfactory performance over direct link transmission. Also error detection mechanism at the realy can provide improved performance for both MRC and ERC, in case of DAF protocol.

Index Terms— AAF,;BER; DAF; ESNRC; ERC; FRC; MRC; modified SV Model; SNR; SNRC; UWB

1 Introduction

THE next generation wireless system are required to provide enhanced data rates and guarantee to the quality of service (QoS) desired by multimedia traffic. Different techniques are currently being used to achieve this goal. Among these techniques, diversity is of primary importance due to the very nature of wireless environment [4]. Ultra Wide Band (UWB) technology demonstrates a great promise for high speed short range wireless communication. UWB system faces major challenges in achieving the desired performance and coverage due to low power transmission [3].

Cooperative communication has emerged as an important concept to enhance the reliability and performance over fading wireless channel. Cooperative diversity is motivated by a need to mitigate wireless channel effects resulting from slow time varying, frequency non selective multipath fading, large-scale shadowing and path loss. Cooperative diversity is a relatively new class of spatial diversity technique that is enabled by relaying and cooperative communication [4]. The major motivation here is to improve the reliability of communication in terms of outage probability or symbol/ bit error rate (SER/BER). In both cases, cooperation allow for tradeoff between target performance and required transmitted power.

Cooperative network configuration relies on multiple nodes, each comprising a single-antenna system, to provide transmit diversity. The users relay messages to each other and propagate redundant signals over multiple paths in the network. This redundancy enables the receiver to average out the channel fluctuations due to fading, shadowing, and other interference.

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The separation between the spatially distributed user terminals helps create the signal independence required for diversity [11].

2 Literature Review

UWB technology is creating interest for several applications related to wireless communication. The coverage limitations can be overcome using relaying concept. In [3] 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 [15] DAF performance enhancement using interference cancellation is provided.Cooperative commication in context of TH-UWB is investigated in [16]. It provides average bit error probability of impulse radio UWB system with DAF protocol and is based on computing charecteristic function of dicision variable at the destination. In [17] a simple opportunistic relaying with DAF and AAF under aggregate power constraint is consider The findings reveal that cooperation provides diversity benefits even when cooperative relays do not transmit but choose to listen. An analytical framework for performance evaluation of relay assisted UWB communication is discussed in [18]. It accounts for single link characterization of UWB channels, network topology and power allocation techniques. In this paper a simple DAF is proposed for modified SV model based UWB system. The paper also compares the BER performances for AAF and DAF schemes. Performance improvement in case of error detection at relay is presented. Section 3 presents the system model. Section 4 provides SER/BER analysis for cooperative UWB system. In Section 5 simulation environment with result is discussed. Section 6 concludes the paper.

3 System Model

3.1 Channel Model

This model starts with physical realization that rays arrives in clusters. The cluster arrival times are modeled as Poisson arrival process with some fixed rate Λ, within each cluster subsequent rays also arrives according to Poisson process with another fixed rate λ. Each cluster consists of rays i.e. $\lambda << \Lambda$

Let arrival time of lth cluster be T_l, l= 0, 1, 2…

Let the arrival time of kth ray measured from beginning of the lth cluster be $\tau_{k,l}$, k = 0,1,2, ...

For the first cluster T_0= 0 and for the first ray within l^{th} cluster $\tau_{k,l} = 0$.

Hence $\tau_{k,l}$ and T_l are independent inter-arrival exponential probability density function.

$$p\,(T_l|T_{l-1}) = \Lambda \exp[-\Lambda\,(T_l - T_{l-1})], \qquad l > 0$$

$$p\,(\tau_{k,l}|\tau_{(k-l),l}) = \lambda \exp[-\lambda\,(\tau_{k,l} - \tau_{(k-l),l})], \qquad k > 0, l > 0$$

The amplitudes of k^{th} path within the lth cluster obey Rayleigh distribution. Whereas the clustering of the multipath arrivals, S-V model uses two Poisson process to describe multipath channel. The first Poisson process describes the arrival of the cluster, and second process describes the arrival of rays within that cluster [1].

- T_l = the arrival time of the first path of the l-th cluster;
- $\tau_{k,l}$ = the delay of the k-the path within the l-th cluster relative to the first path arrival time, T_l ;
- Γ= cluster arrival rate;
- λ=ray arrival rate, i.e., the arrival rate of path within each cluster.

Therefore, $\tau_{0,l} = T_l$ The distribution of cluster arrival time and ray arrival time are given by

Let the gain of k^{th} ray of l^{th} cluster be denoted by $\beta_{k,l}$ and its phase $\theta_{k,l}$. Hence impulse response given will become

$$h(t) = \sum_{l=0}^{\infty}\sum_{k=0}^{\infty} \beta_{k,l}\ e^{j\theta_{k,l}}\ \delta(t - T_l - \tau_{k,l})$$

$\theta_{k,l}$ is statistically independent uniform random variable and $\beta_{k,l}$ is statistically independent positive random variable. The IEEE group made some modification on S-V channel using log-normal distribution to express multipath amplitudes and using another log-normal stochastic variable to express general multipath fluctuations.

Mathematically, the impulse response is described as

$$h_i(t) = X_i \sum_{l=0}^{L}\sum_{k=0}^{K} \propto_{k,l}^{i}\ \delta(t - T_l^i - \tau_{k,l}^i)$$

where

- $\{\propto_{k,l}^{i}\}$ are the multipath gain coefficients,
- $\{T_l^i\}$ is the delay of the lth cluster,
- $\{\tau_{k,l}^i\}$ is the delay of the k^{th} multipath component relative to the lth cluster arrival time (T_l^i),
- $\{X_i\}$ represents the log-normal shadowing, and i refers to the i^{th} realization.

The channel coefficients are defined as a product of small-scale and large-scale fading coefficients, i.e.

$\alpha_{k,l} = p_{k,l}\ \xi_l\ \beta_{k,l}$,

The amplitude statistics of the measurements were found to best fit the log-normal distribution rather than the Rayleigh that was used in the original S-V model. In addition, the large-scale fading is also log-normally distributed.

$$20\log10(\xi_l\,\beta_{k,l}) \propto \text{Normal}(\mu_{k,l}, \sigma_1^2 + \sigma_2^2).$$

$$\text{Or } |\xi_l\,\beta_{k,l}| = 10^{\frac{(\mu_{k,l}+n_1+n_2)}{20}}$$

where $n_1 \propto \text{Normal}(0,\ \sigma_1^2)$. and $n_2 \propto \text{Normal}(0,\ \sigma_2^2)$.

Are independent and correspond to the fading on each cluster and ray, respectively. The behavior of the power delay profile is

$$E[|\xi_l\,\beta_{k,l}|^2] = \Omega_0\, e^{-T_l/\Gamma}\ e^{-X_{k,l}/\gamma}$$

which reflects the exponential decay of each cluster, as well as the decay of the total cluster power with delay.

In the above equations, ξ_l reflects the fading associated with the l^{th} cluster, and $\beta_{k,l}$ corresponds to the fading associated with the k^{th} ray of the l^{th} cluster.

3.2 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.

3.3 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

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

$\overline{\gamma_b}$ denotes the average signal-to-noise ratio, defined as

$(\boldsymbol{\gamma\_b})^{\bar{}} = \boldsymbol{\xi} /$ 〖$\boldsymbol{2\sigma}$〗 ^$\boldsymbol{2}$ E($\boldsymbol{a}^2$) , where E($\boldsymbol{a}^2$)=a^2

3.4 Cooperative Model

All 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 UWB model of such a system is illustrated in Fig. II.1. Consider a two-user cooperation over UWB 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.

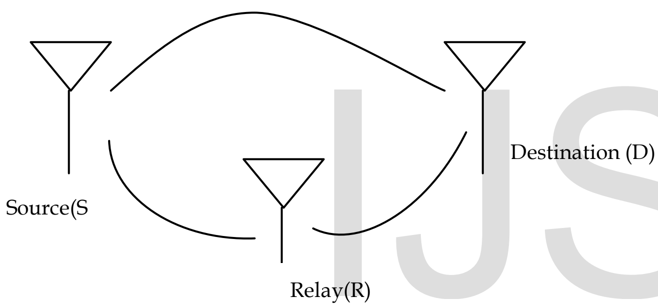

Fig. 3.1: Direct data transmission and transmission through relaytables

4 SER/BER Analysis for Cooperative UWB System Form

4.1 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

$$\boldsymbol{E}[|\boldsymbol{y}_r^2|] = \boldsymbol{E}[|\boldsymbol{h}_{s,r}|^2]\boldsymbol{E}[|\boldsymbol{x}_s|^2] + \boldsymbol{E}[|\boldsymbol{z}_{s,r}|^2] = |\boldsymbol{h}_{s,r}|^2\boldsymbol{\xi} + \boldsymbol{2\sigma}_{s,r}^2$$

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

$$\beta = \sqrt{\frac{\xi}{|\boldsymbol{h}_{s,r}|^2\boldsymbol{\xi} + \boldsymbol{2\sigma}_{s,r}^2}}$$

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

4.2 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

$$y_{r,d} = h_{r,d}\bar{x} + n_{r,d}$$

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.

4.3 Combining Type

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

4.3.1 Equal Ratio Combining (ERC)

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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.

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

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

$$y_d[n] = y_{s,d}[n] + y_{r,d}[n]$$

where ys,d and yr,d denote the received signal from the sender and the relay respectively.

4.3.2 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

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

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

$$y_d[n] = w_{s,d} . y_{s,d}[n] + w_{s,r,d} . y_{r,d}[n]$$

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

4.3.3 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

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

For one relay the equation can be simplified as

$$y_d[n] = SNR_{s,d} . y_{s,d}[n] + SNR_{s,r,d} . y_{r,d}[n]$$

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.

4.3.3.1 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
$y_{r,d} = h_{r,d} x_r + z_{r,d} = h_{r,d} \beta (h_{s,r} x_s + z_{s,r})$.

The received power will then be estimated as

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

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

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

4.3.3.2 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

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

Inverse functions are used to calculate the SNR from BER.

4.3.4 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

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

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.

4.3.5 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.

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

For one relay system the above equation can be simplified as

$$y_d[n] = h_{s,d}^*[n] . y_{s,d}[n] + h_{r,d}^*[n] . y_{r,d}[n]$$

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.

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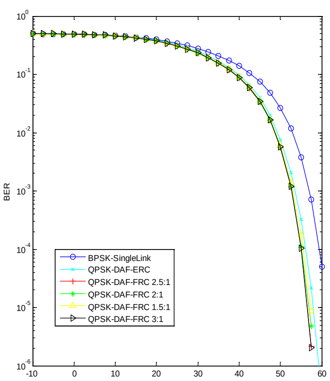
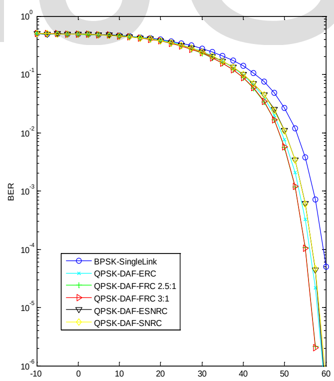
5 Simulation Environment, Result with Discussion

Following UWB channels parameters were considered for performance analysis.

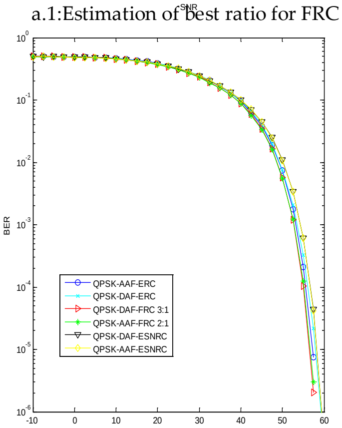
Channel Type	Cluster arival rate (Lam)	Mean No of Cluster (Lmean)	Cluster decay factor (Gam)	Ray decay factor (gamma0)
CM1 (Residential LOS)	0.047	3.0	22.61	12.53
CM2 (Residential NLOS)	0.12	3.5	26.27	17.5
CM3 (Office LOS)	0.016	5.4	14.6	6.4
CM4 (Office NLOS)	0.16	3.1	19.8	11.2
CM5 (Outdoor LOS)	0.0448	13.6	31.7	3.7
CM6 (Outdoor NLOS)	0.0243	10.5	104.7	9.3
CM7 (Industrial LOS)	0.0709	4.75	13.47	0.615
CM8 (Industrial NLOS)	0.089	1.0	5.83	0.3



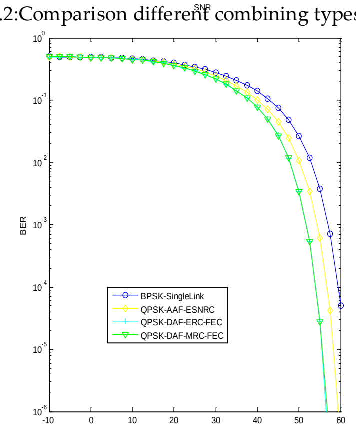
a.1:Estimation of best ratio for FRC



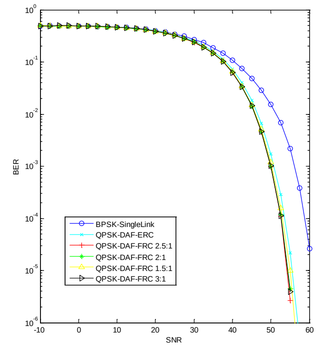
a.2:Comparison different combining types



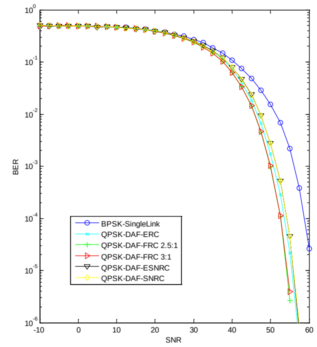
a.3: DAF versus AAF



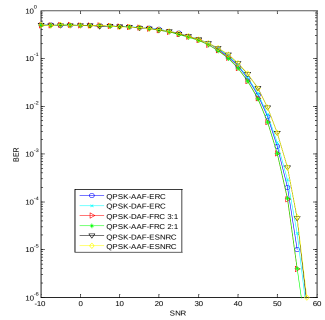
a.4: Effect of Pseudo error detection



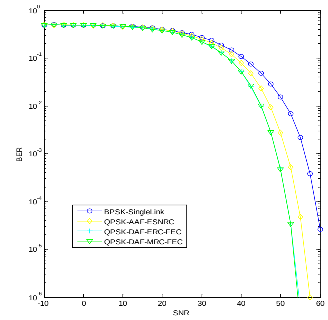
b.1:Estimation of best ratio for FRC



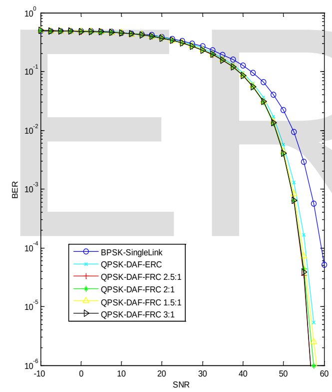
b.2: Comparison different combining types



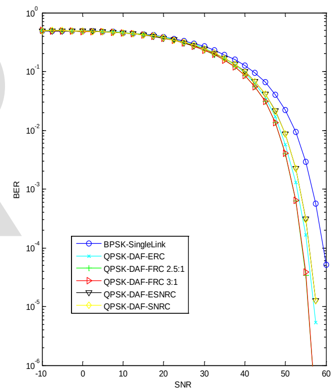
b.3: DAF versus AAF



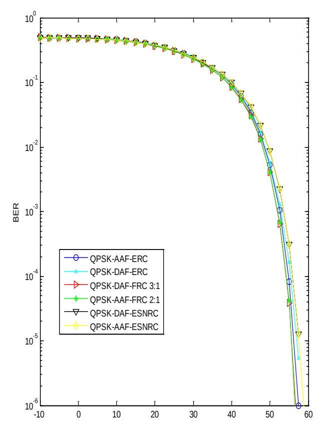
b.4: Effect of Pseudo error detection



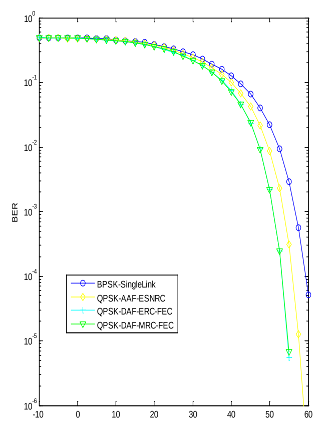
c.1: Estimation of best ratio for FRC



.2: Comparison different combining types



c.3: DAF versus AAF



c.4: Effect of Pseudo error detection

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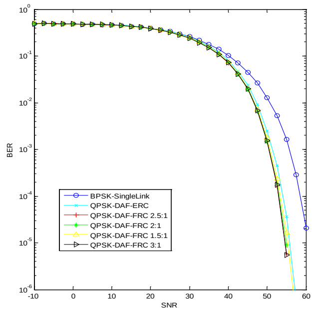
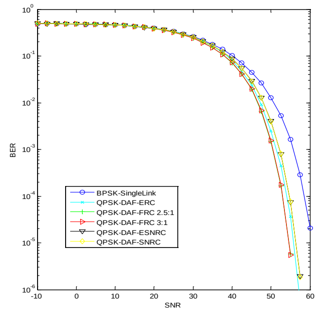
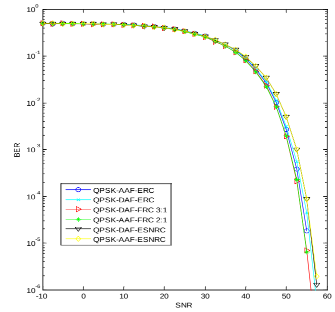


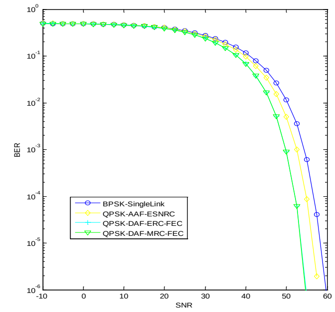
d.1:Estimation of best ratio for FRC



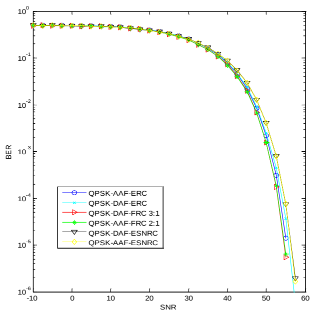
d.2: Comparison different combining types



f.3: DAF versus AAF



f.4: Effect of Pseudo error detection



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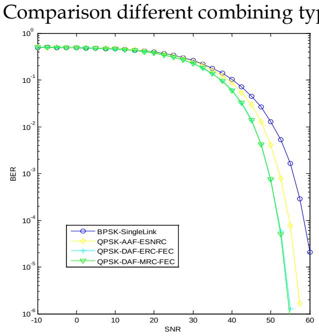
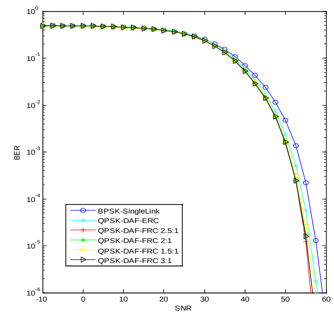
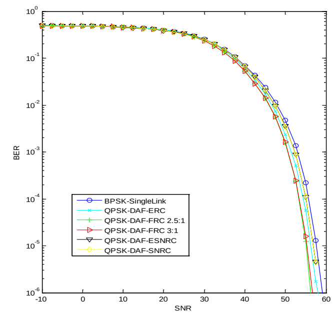


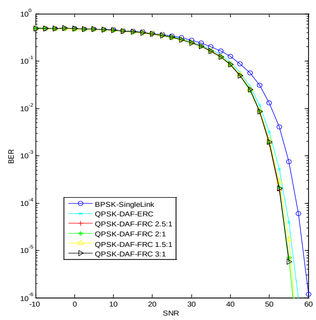
d.4: Effect of Pseudo error detection



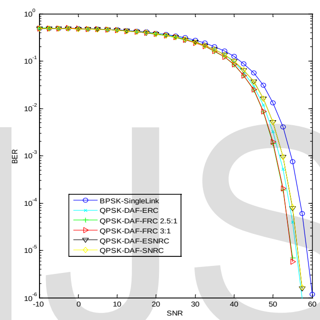
g.1:Estimation of best ratio for FRC



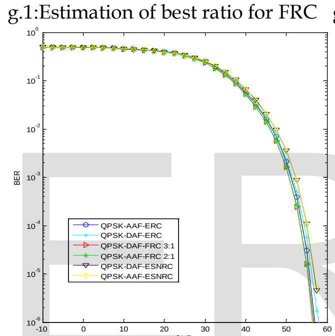
g.2:Comparison different combining types



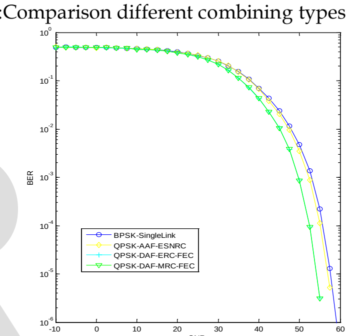
e.1: Estimation of best ratio for FRC



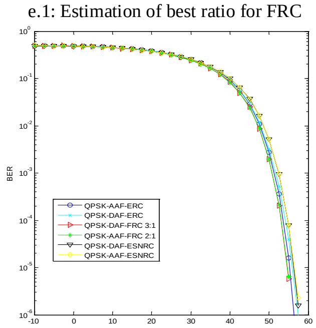
e.2: Comparison different combining types



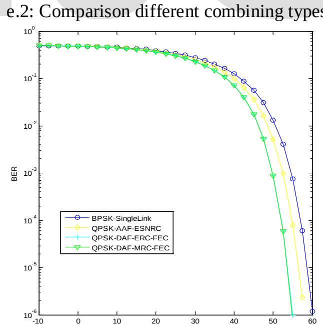
g.3: DAF versus AAF



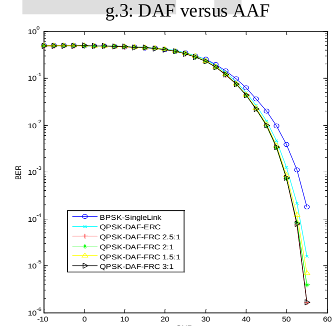
g.4: Effect of Pseudo error detection



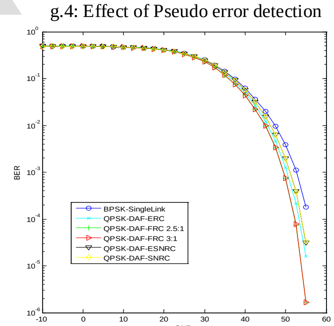
e.3: DAF versus AAF



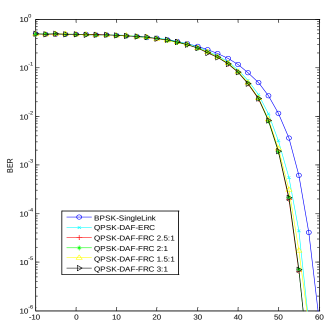
e.4: Effect of Pseudo error detection



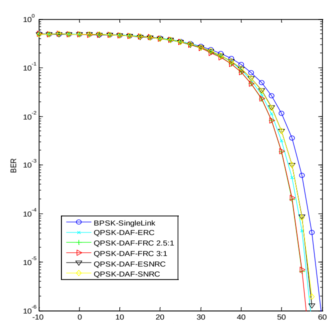
h.1:Estimation of best ratio for FRC



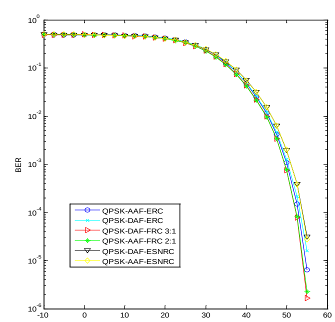
h.2:Comparison different combining types



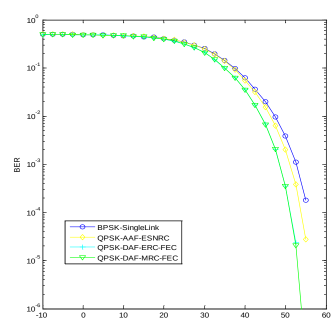
f.1:Estimation of best ratio for FRC



f.2:Comparison different combining types



h.3: DAF versus AAF



h.4: Effect of Pseudo error detection

The results depicted in fig a.1 to h.1 and fig a.2 to h.2 reflect the comparison between different combining methods namely FRC, ERC, ESNRC, SNRC for DAF protocol and BPSK direct link transmission. As seen from the results, FRC with weight of 3 provides best performance as compared to ERC and FRC with other weights. FRC exhibits highly improved performance as compared to single link transmission. To achieve a BER of 10^{-3} the required SNR for FRC is about 5dB-6dB below the one for single link, which is a remarkable benefit. Though ERC shows better performance, the performance will degrade if there is increase in number of wrongly detected symbols at the relay for lower value of SNR. The ESNRC and SNRC performances are similar. Though they have precise information about each single block, they do not show significant performance as compared to FRC.

The ERC combining shows better performance for AAF as compared to DAF. The simplest reason for this is that wrongly detected symbol at the relay becomes difficult to correct at the destination, where the two incoming signals are combined. It is also noticed that the weight associated with DAF-FRC (FRC 3:1) is greater than the weight associated with AAF-FRC (FRC 2:1) for similar performance. The ESNRC shows more or less similar performance in AAF or DAF system.

The MRC combining technique used along with DAF and pseudo error detection mechanism provides slightly better performance over ERC technique used along with DAF and pseudo error detection mechanism, suggesting the performance independence from the type of combining technique used. However the performance is highly improved as compared to the single link transmission and ESNRC.

6 Conclusion

This paper demonstrates the diversity benefits accrued by application of DAF cooperative diversity to modified SV model based UWB communication system. The results clearly indicate the improvement in performance due to DAF technique over that of single link transmission. Similarly, the BER performances over different diversity combining technique for DAF and AAF have been evaluated. The performance in term of BER for all the combining techniques is better as compared to single link transmission. For similar BER performance the weight associated with DAF-FRC is greater than that associated with AAF-FRC. In case of pseudo error detection, MRC shows slightly better performance than ERC, indicating performance independence with respect to the type of combining method used. If error correction mechanism is available at the relay, higher benefits can be reaped in term of improved BER performance.

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