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



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

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## ABSTRACT

Cooperative diversity has emerged as a major technique of providing gains from spatial diversity to devices/terminals. 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. In this paper, a low complexity cooperative diversity scheme for UWB channel is proposed. The scheme uses Amplify-and-Forward (AAF) cooperative protocol to ascertain the BER performance. Different combining methods are used and their performances for UWB system are analyzed. Performance analysis based on positioning of the relay has been carried out. The result indicates that AAF provides satisfactory performance over direct link transmission.

***Keywords** - AAF, modified SV Model, UWB, SNR, BER, ERC, FRC, SNRC, ESNRC*

## 1. INTRODUCTION

The In order to meet the demand of multi-rate multimedia communications, the next generation wireless system must employ advanced algorithms and techniques so as to enhance the data rates and guarantee to the quality of service (QoS) desired by various classes of 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 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. The separation between the spatially distributed user terminals helps create the signal independence required for diversity [11].

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

## 2. SYSTEM MODEL

### *2.1 **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 $\Lambda$, within each cluster subsequent rays also arrives according to Poisson process with another fixed rate $\lambda$. Each cluster consists of rays i.e. $\lambda << \Lambda$
Let arrival time of $l^{th}$ cluster be $T_l$, $l= 0, 1, 2, \ldots$ ..
Let the arrival time of $k^{th}$ ray measured from beginning of the $l^{th}$ cluster be $\tau_{k,l}$ , $k = 0,1,2, \ldots$
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.

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

$$p(\tau_{k,l}|\tau_{(k-l),1}) = \lambda \exp[-\lambda(\tau_{k,l} - \tau_{(k-l),1})], \quad k>0, l>0$$

The amplitudes of $k^{th}$ path within the $l^{th}$ 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, $T_l$;
- $\Gamma$= cluster arrival rate;
- $\lambda$=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 $l^{th}$ cluster,
- $\{\tau_{k,l}^i\}$ is the delay of the $k^{th}$ multipath component relative to the $l^{th}$ 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.

$$20\log 10(\xi_l \beta_{k,l}) \propto \text{Normal}(\mu_{k,l}, \sigma_1^2 + \sigma_2^2).$$

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, $\xi_l$ 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

### *2.2 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.

### *2.3 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 $\overline{\gamma_b} = \frac{\xi}{2\sigma^2}\mathrm{E}(a^2)$ , where $\mathrm{E}(a^2)=a^2$

### *2.4 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 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.

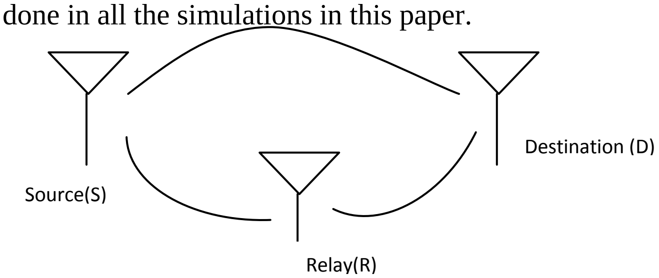



Fig. II.1: Direct data transmission and transmission through relay

## *3. SER/BER ANALYSIS FOR COOPERATIVE UWB SYSTEM*

### *3.1 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

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

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

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

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

### *3.2 Combining Type*

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

3.2.1 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.

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

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

3.2.2 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.

3.2.3 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. 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

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

3.2.4 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

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

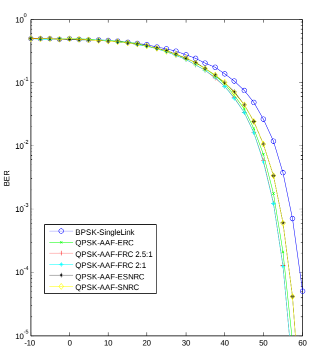
Exact knowledge of channel characteristic is not required while using this combining method. An approximate channel quality is sufficient combine the signals. Equal ratio combining is further beneficial as it requires very less computing power.

## 4 SIMULATION ENVIRONMENT, RESULT AND DISCUSSION

Following UWB channels parameters were consider for performance analysis.

| Channel Type | Cluster arrival rate (Lam) | Mean No of Cluster (Lmean) | Cluster decay factor (Gam) |
|---|---|---|---|
| CM1 (Residential LOS) | 0.047 | 3.0 | 22.61 |
| CM2 (Residential NLOS) | 0.12 | 3.5 | 26.27 |
| CM3 (Office LOS) | 0.016 | 5.4 | 14.6 |
| CM4 (Office NLOS) | 0.16 | 3.1 | 19.8 |
| CM5 (Outdoor LOS) | 0.0448 | 13.6 | 31.7 |
| CM6 (Outdoor NLOS) | 0.0243 | 10.5 | 104.7 |
| CM7 (Industrial LOS) | 0.0709 | 4.75 | 13.47 |
| CM8 (Industrial NLOS) | 0.089 | 1.0 | 5.83 |

| Channel Type | Ray decay factor (gamma0) | Mean Nakagami m-factor (m0) | SD of entire impulse response (std_shd) | Freq. dependency factor (Kappa) |
|---|---|---|---|---|
| CM1 (Residential LOS) | 12.53 | 0.67 | 2.22 | 1.12 |
| CM2 (Residential NLOS) | 17.5 | 0.69 | 3.51 | 1.53 |
| CM3 (Office LOS) | 6.4 | 0.42 | 0 | 0.03 |
| CM4 (Office NLOS) | 11.2 | 0.5 | 3.9 | 0.71 |
| CM5 (Outdoor LOS) | 3.7 | 0.77 | 0.83 | 0.12 |
| CM6 (Outdoor NLOS) | 9.3 | 0.56 | 2.0 | 0.13 |
| CM7 (Industrial LOS) | 0.615 | 0.36 | 6.0 | -1.103 |
| CM8 (Industrial NLOS) | 0.3 | 0.3 | 6.0 | -1.427 |



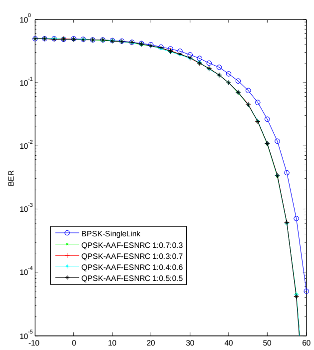
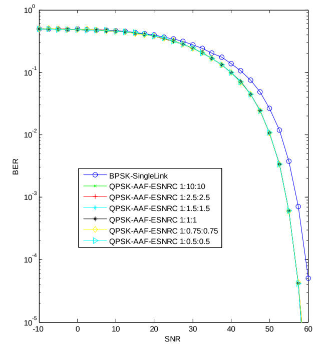




Fig. a.1: Different Combining types Fig. a.2: Benefits of Relay location



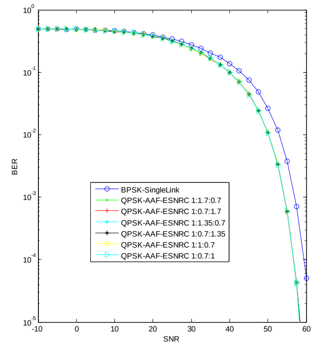
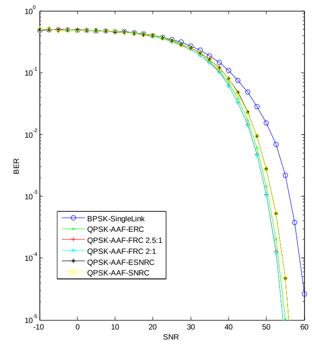




Fig. a.3: Effect of increasing distance Fig. a.4: Relay close to Sender/Destination



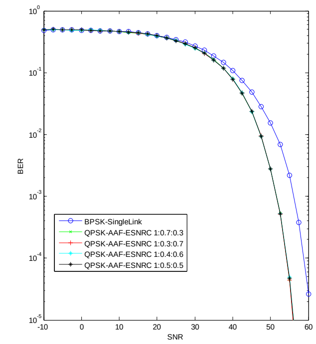
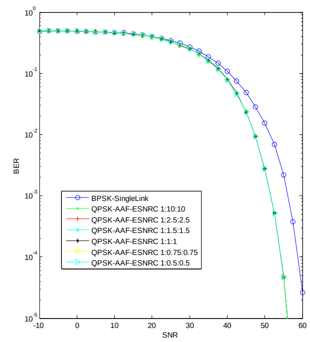




Fig. b.1: Different Combining types Fig. b.2: Benefits of Relay location



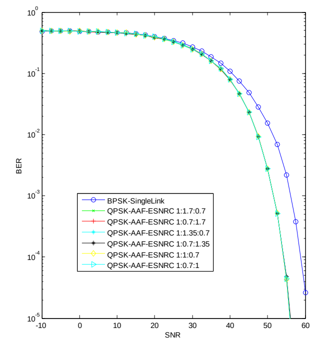
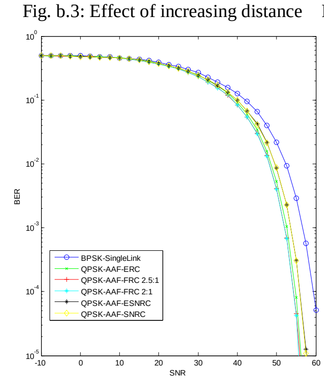




Fig. b.3: Effect of increasing distance Fig. b.4: Relay close to Sender/Destination



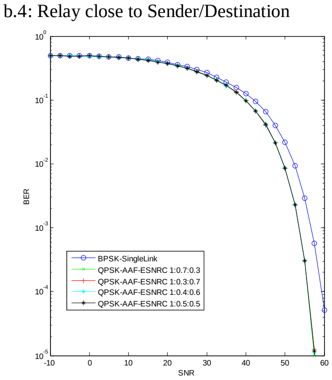




Fig. c.1: Different Combining types Fig.c.2: Benefits of Relay location

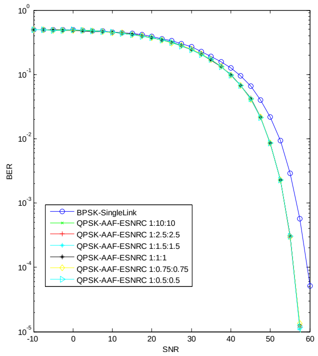


Fig.c.3: Effect of increasing distance

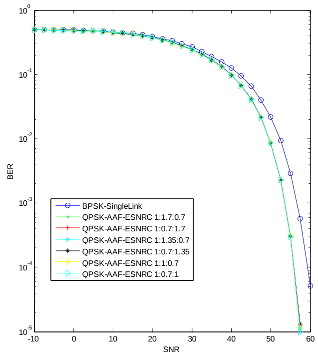


Fig.c.4: Relay close to Sender/Destination

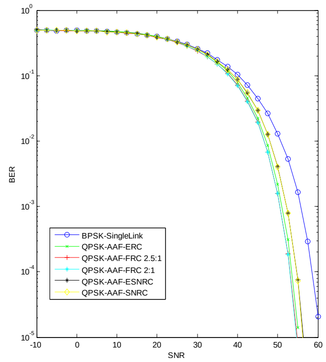


Fig. d.1: Different Combining types

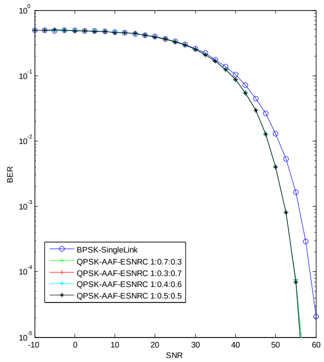


Fig. d.2: Benefits of Relay location

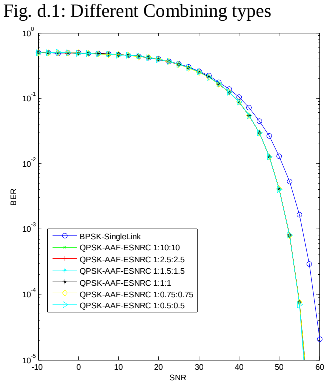


Fig.d.3: Effect of increasing distance

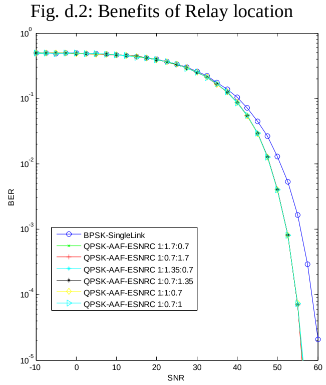


Fig. d.4: Relay close to Sender/Destination

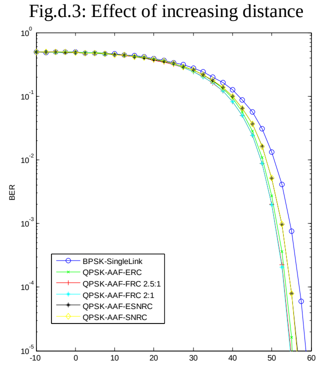


Fig. e.1: Different Combining types

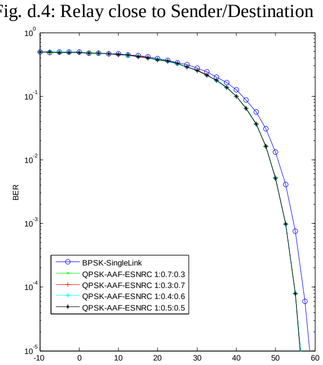


Fig. e.2: Benefits of Relay location

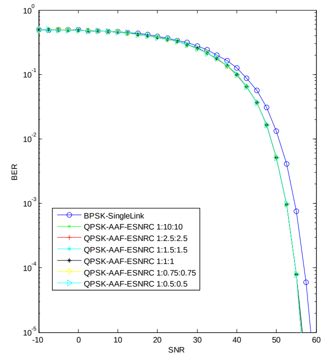


Fig.e.3: Effect of increasing distance

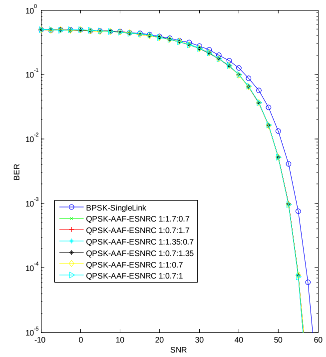


Fig. e.4: Relay close to Sender/Destination

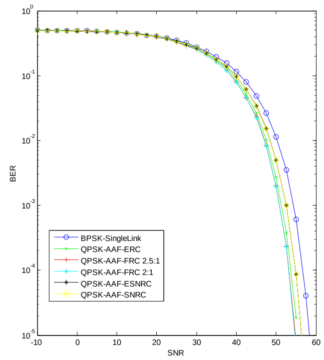


Fig. f.1: Different Combining types

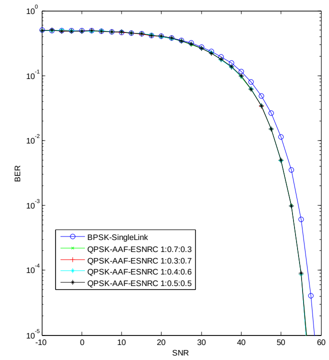


Fig. f.2: Benefits of Relay location

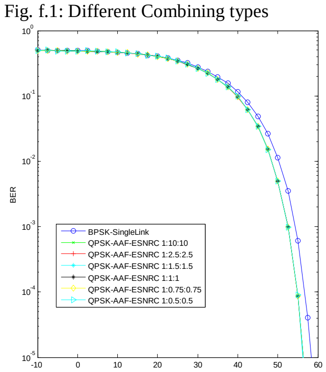


Fig.f.3: Effect of increasing distance

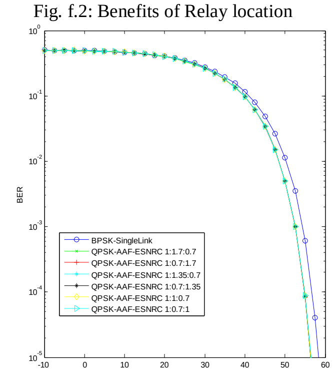


Fig. f.4: Relay close to Sender/Destination

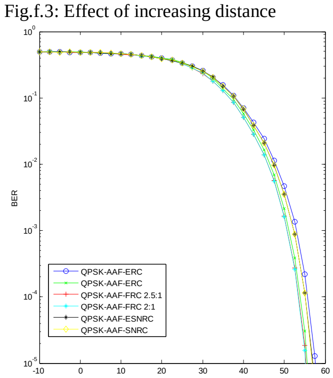


Fig. g.1: Different Combining types

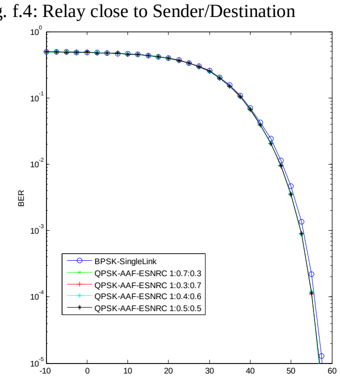


Fig. g.2: Benefits of Relay location

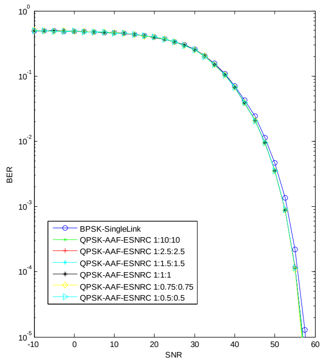



Fig.g.3: Effect of increasing distance

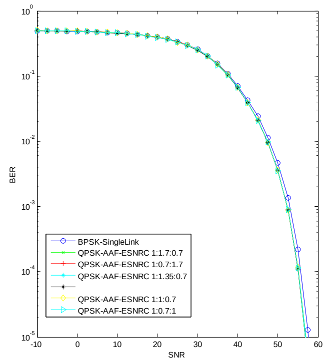



Fig. g.4: Relay close to Sender/Destination

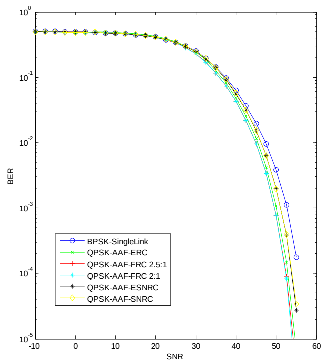



Fig. h.1: Different Combining types

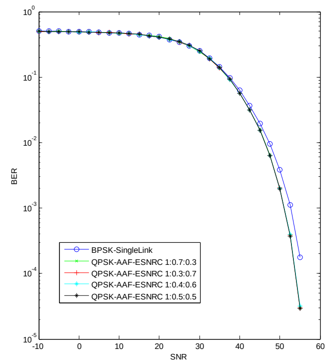



Fig. h.2: Benefits of Relay location

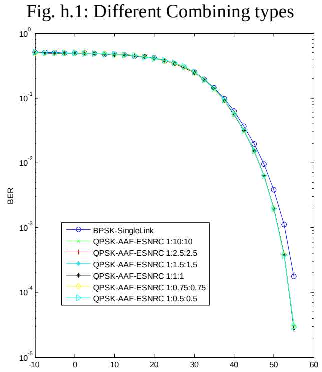



Fig.h.3: Effect of increasing distance

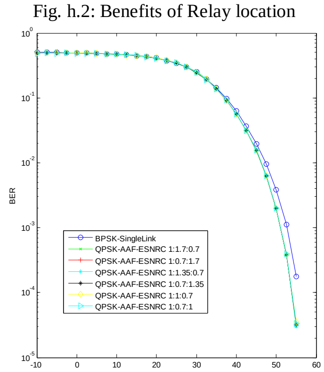



Fig. h.4: Relay close to Sender/Destination

The results above show the comparison between different combining methods namely FRC, ERC, ESNRC, SNRC and direct link transmission. As seen from the results, FRC with weight of 2 provides best performance as compare to ERC and FRC with other weight. Similarly ERC presents highly improved performance as compared to direct link. This result is remarkable as ERC does not need any channel information apart from phase shift for combining. Thus AAF protocol provides fine benefits as compared to single link transmission. 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 effect of placement of relay with respect to sender and destination has been investigated. The positioning of the relay does not reflect any significant change in performance as seen in the results; however it indicates improved performance as compared to BPSK single link transmission. The best performance is seen when the relay is equidistant (1:0.5:0.5) from the source and the destination. Some diversity benefit can be derived when the relay is either closer to the source or the destination. When the relay is located at a longer distance than the distance of direct link, the diversity benefits are reduced.

## 5 CONCLUSION

This paper demonstrates the diversity benefits accrued by application of AAF cooperative diversity to UWB communication system. Two methods for transmitting the data i.e. direct link and through relay are simulated.
The results clearly indicate the improvement in performance due to AAF technique over that of single link. The paper shows the performance of different diversity combining techniques. It can be clearly established that the ERC combining which does not require knowledge of channel provides as good as performance in comparison to FRC. FRC provides better performance but requires knowledge of channel quality. The placement of relay near to source or destination can provide slight improvement in performance. Similarly, placement of relay in between source and destination at equal distance provides certain performance advantage.

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