Amplify and Forward Cooperative Diversity for TSV -Model Based 60 GHz WPAN System

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ABSTRACT

In recent years, considerable attention has been devoted to design and standardization of wireless system operating in the 60 GHz band. Further in the context of WLAN (Wireless Local Area Network) and WPAN (Wireless Personal Area Network) systems for High Data Rate (HDR) wireless communications, the unlicensed frequency band available in the millimeter wave region has become more and more attractive. However at 60 GHz the shadowing phenomenon is the main cause of strong signal impairments even for shorter distances of few meters. Cooperative communication networks have received significant interests from both academia 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. Thus cooperative diversity forms an attractive method to mitigate such shadowing effects by use of dedicated active or passive relay stations. The objective of this paper is to implement and analyze a low complexity amplify-and-forward (AAF) cooperative transmission technique. With the AAF method, 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 such as ERC, FRC, ESNRC and SNRC are evaluated. The results indicate satisfactory diversity benefits offered by AAF cooperative diversity protocol as compared to single link transmission. The FRC combining provides attractive benefits but requires channel quality information whereas ERC comparatively, provides better benefits, but requires no channel information. Also, positioning of the relay near to source and / or destination gives slight performance benefits.

Keywords: AAF, BER, BPSK, ESNRC, ERC, FRC, LOS, NLOS, QPSK, SNR, SNRC, TSV Model

I. 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]. In many emerging 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. A new diversity method has recently been proposed to overcome the above limitations. The basic idea of this 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. With AAF, relays receive noisy versions of the source’s data, amplify and re-transmit to the destination [12].

In [3, 4] the user cooperation strategy is described to achieve diversity gains via cooperation of mobile users. A cooperative communication for UWB system is proposed in [2] to enhance the performance and coverage of UWB by cooperation among UWB devices. It provides SER analysis and optimum power allocation strategy for UWB multiband OFDM system. A low complexity cooperative diversity is developed and analyzed in [5, 8] to combat fading induced by multipath propagation. It outlines fixed relaying strategies like amplify and forward (AAF) and decode and forward (DAF), selection relaying schemes and incremental relaying schemes. In [6] a distributed cooperative data relaying for diversity in impulse-based UWB ad-hoc networks is presented. The proposed schemes combine the mechanism of the medium access control and physical layers in a cooperative and distributed way to either select the best relay from multiple available ones for data forwarding or optimally combine the synchronized data forwarding of all participating relays, so as to improve the data transfer diversity. A double-differential modulation for an amplify-and-forward protocol based on cooperative communication is proposed in [13] over Nakagami-m fading channels. The proposed scheme is capable of achieving performance gain in the presence of random carrier offsets and without channel knowledge at relay or destination. The problem of network lifetime limitation in wireless relay communication system by developing optimal power allocation techniques is addressed in [14]. It uses multiple relay nodes operating with amplify and forward relaying protocol to improve the symbol error rate (SER) performance for MPSK signal using the concept of moment generating function. A performance analysis for cooperative diversity system with best relay selection over Rayleigh fading channels is presented in [15]**.** Closed form expressions for the average symbol error rate (SER), the outage probability and the average end-to-end SNR gain obtained from relay selection are derived and significant advantage of relay selection is presented. Most of the literature reflects that the AAF protocol is used to derive diversity benefits. However the performance evaluation is based on Rayleigh channels or Nakagami-m fading channels. Similarly the impact on performance due to positioning of relay with respect to the source and destination is not found in the above discussed literature. This paper proposes a simple AAF protocol and the performance benefits by using combining techniques like ERC, FRC, SNRC and ESNRC. In this paper the diversity benefits of using single relay based low complexity AAF protocol over indoor channels at 60 GHz for WPAN systems is put forth. Also, diversity benefits due to positioning of relay near to the source and / or destination and placement of relay with respect to source and destination is presented.

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

II. SYSTEM MODEL

A. Channel Model

The Complex impulse response is given as [1]

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

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

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

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

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

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

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 coefficient

$|\Gamma_0|\cong 1$: 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

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

$Gt(\theta, \phi)$: Antenna gain of Tx

$Gr(\theta, \iota)$: 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

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

$\overline{\gamma_b}$ 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. 2.1. 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.

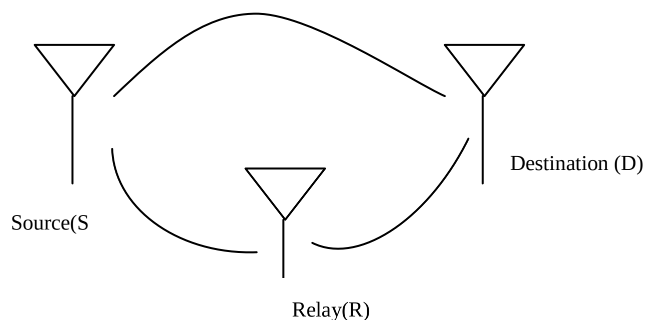

Fig. II.1: Direct data transmission and transmission through relay

E. Receiver Model

The receiver performs symbol by symbol detection of the received signal. A symbol/bit for a BPSK modulated signal is detected as follows:

$$\hat{y}_d[n] = \begin{cases} +1 \ (Re\{y_d[n]\} \geq 0) \\ -1 \ (Re\{y_d[n]\} < 0) \end{cases} \tag{11}$$

In case of QPSK modulated signal two bits per symbol are transmitted and can be detected as

$$\hat{y}_d[n] = \begin{cases} [+1,+1] \ (0^o \leq \angle y_d[n] < 90^o) \\ [-1,+1] \ (90^o \leq \angle y_d[n] < 180^o) \\ [+1,-1] \ (-90^o \leq \angle y_d[n] < 0^o) \\ [-1,-1] \ (-180^o \leq \angle y_d[n] < -90^o) \end{cases} \tag{12}$$

III. 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

$$\boldsymbol{E}[|\boldsymbol{y}_r^2|] = \boldsymbol{E}[|\boldsymbol{h}_{s,r}|^2]\boldsymbol{E}[|\boldsymbol{x}_s|^2] + \boldsymbol{E}[|\boldsymbol{z}_{s,r}|^2] = |\boldsymbol{h}_{s,r}|^2\boldsymbol{\xi} + \boldsymbol{2\sigma}_{s,r}^2 \quad (13)$$

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

$$\beta = \sqrt{\frac{\xi}{|\boldsymbol{h}_{s,r}|^2\xi + 2\boldsymbol{\sigma}_{s,r}^2}} \quad (14)$$

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

B. Combining Type

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

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.

$$y_d[n] = \sum_{i=1}^{k} y_{i,d}[n] \quad (15)$$

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

$$y_d[n] = y_{s,d}[n] + y_{r,d}[n] \quad (16)$$

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

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

$$y_d[n] = \sum_{i=1}^{k} w_{i,d} \cdot y_{i,d}[n], \tag{17}$$

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

$$y_d[n] = w_{s,d} \cdot y_{s,d}[n] + w_{s,r,d} \cdot y_{r,d}[n] \tag{18}$$

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

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

$$y_d[n] = \sum_{i=1}^{k} SNR_i \cdot y_{i,d}[n] \tag{19}$$

For one relay the equation can be simplified as

$$y_d[n] = SNR_{s,d} \cdot y_{s,d}[n] + SNR_{s,r,d} \cdot y_{r,d}[n] \tag{20}$$

where $\mathrm{SNR_{s,d}}$ and $\mathrm{SNR_{s,r,d}}$ 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

$$y_{r,d} = h_{r,d}x_r + z_{r,d} = h_{r,d}\beta(h_{s,r}x_s + z_{s,r}). \tag{21}$$

The received power will then be estimated as

$$E\left[\left|y_{r,d}\right|^2\right] = \beta^2\left|h_{r,d}\right|^2\left(\left|h_{s,r}\right|^2\xi + 2\sigma_{s,r}^2\right) + 2\sigma_{r,d}^2 \tag{22}$$

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

$$SNR = \frac{\beta^2\left|h_{s,r}\right|^2\left|h_{r,d}\right|^2\xi}{\beta^2\left|h_{r,d}\right|^2 2\sigma_{s,r}^2 + 2\sigma_{r,d}^2} \tag{23}$$

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.

IV. SIMULATION ENVIRONMENT, RESULT AND DISCUSSION

The source produces a random bipolar bit sequence which is either modulated with Binary Phase Shift Keying (BPSK) or Quadrature Phase Shift Keying (QPSK). The data is divided into blocks of unit length without loss of generality. Signal structure is generated consisting of bits, symbols, modulation type, bit sequence, symbol sequence and received sequence. Generate the channel structure constituting of attenuation structure related to the channel fading, distance, path loss and noise. Channel defined by the TSV model at 60 GHz is used during simulation. All the channels have same path loss and average signal-to-noise ratio as it is assumed that channel between source and destination, channel between source and relay is similar to channel between relay and destination. The generated receiver structure comprises of combining type, weight in case of FRC, received signal after phase shift correction and signal to be analyzed. The relay structure constitutes of amplification factor, pseudo error detection and signal to be send. The SNR is varied from 0 dB to 60 dB in steps of 2.5 dB. The numbers of iterations are kept at 10^4. The Amplify and Forward (AAF) diversity arrangement sends the data twice and therefore requires twice the bandwidth of the single link transmission. To compensate for this effect, the single link channel is modulated using BPSK and the diversity arrangement uses QPSK. As QPSK has twice the bandwidth of BPSK, both this arrangements have the same overall bandwidth. The destination receives two samples of the same data i.e. from direct link and other from relay and these samples are combined. In Equal Ratio Combining (ERC) the different received signal are added whereas the Fixed Ratio Combining (FRC) is weighting the incoming signals with a fixed ratio. Other combining methods namely Signal-to-Noise Ratio Combining (SNRC) and Enhanced Signal-to-Noise Combining (ESNRC) are used and require precise/approximate information of the channel quality. The channel quality is determined by calculation of SNR in both these cases as given in equation 23 and 24 respectively. The average BER is calculated depending upon the type of modulation. For BPSK the BER is given as y = [1 – sqrt (SNR / (0.5 + SNR))] /2 whereas for QPSK the average BER is given as y = [1 – sqrt (SNR / (1 + SNR))] /2.

In order to understand the impact of positioning of the relay with respect to the source and destination, in the first part, it is assumed that the three stations (sender, relay and destination) have an equal distance from each other. The three stations are arranged at the edges of a triangle with a normalized length of one. Thus all the channels have same path loss and average signal-to-noise ratio. With this equidistant arrangement the different combining and amplifying types are compared to see their advantages and disadvantages. In the second part, the location of the relay station is varied to see the effect on the performance for different locations of the relay .In the first case the relay is kept equidistant from source and destination whereas in the second case relay is placed near to the source/ destination. The ESNRC combining is used in all the above cases.

Table 1: Channel Models depending on 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 2.1: Channel Parameters

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
$\sigma_{cluster}$	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
Ω(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 2.2: Channel Parameters

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
$\sigma_{cluster}$	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	-0.303*d	-109	-107.2	4.44*d	3.46*d	4.44*d	3.46*d

	-85.8	-90.3			-105.4	-98.4	-105.4	-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 (Table 1) described by TSV model (IEEE 802.15.4a) at 60 GHz using parameters given in table 2.1 and table 2.2are shown below.

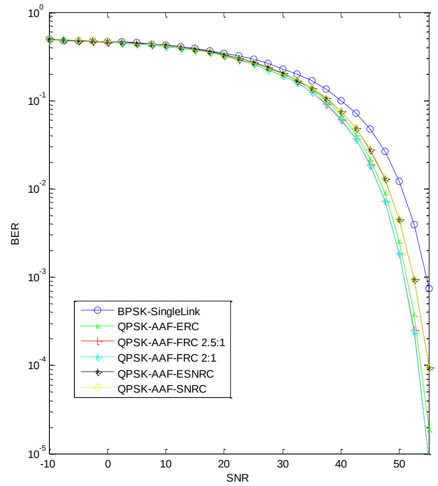

Fig. a.1: Different Combining types (CM11)

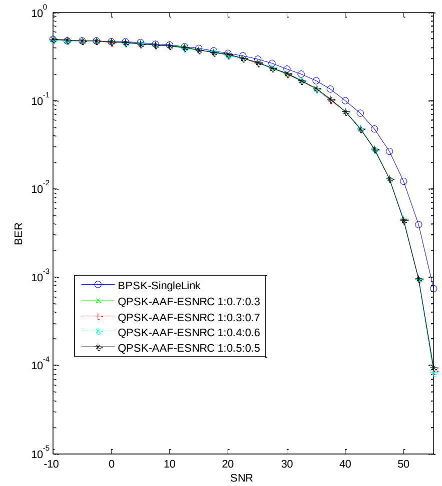

Fig. a.2: Benefits of Relay location (CM11)

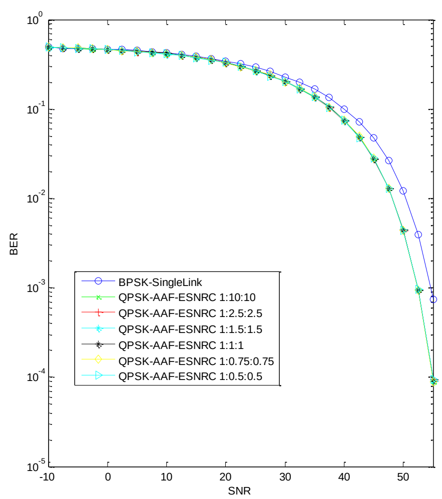

Fig. a.3: Effect of increasing distance (CM11)

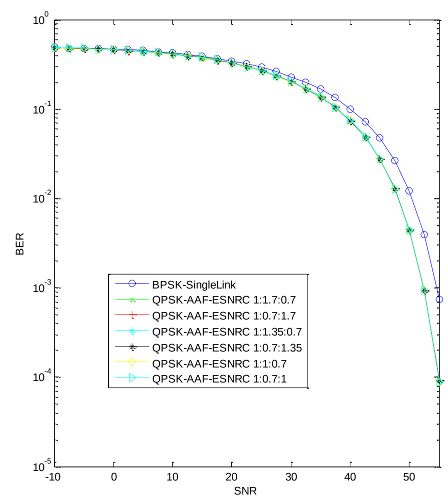

Fig. a.4: Relay close to Sender/Destination (CM11)

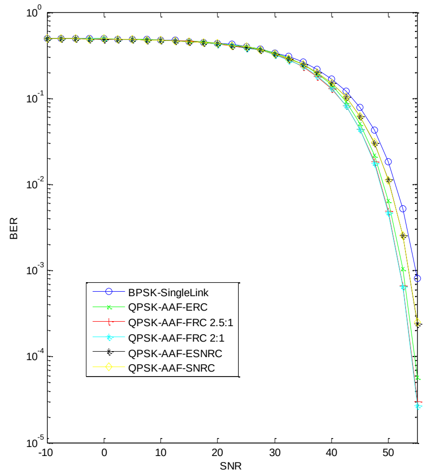

Fig. b.1: Different Combining types (CM12)

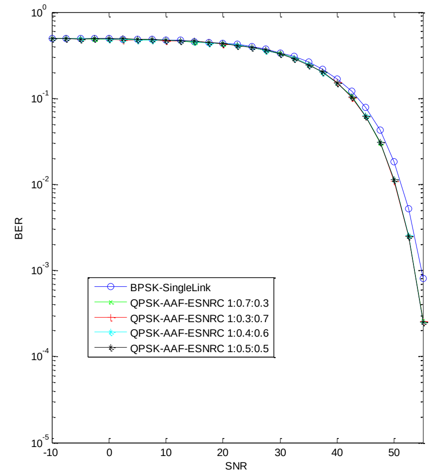

Fig. b.2: Benefits of Relay location (CM12)

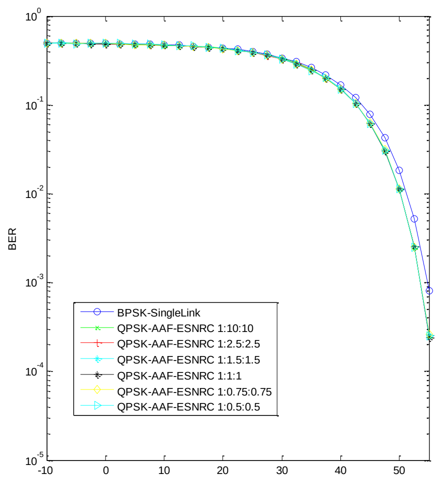

Fig.b.3: Effect of increasing distance (CM12)

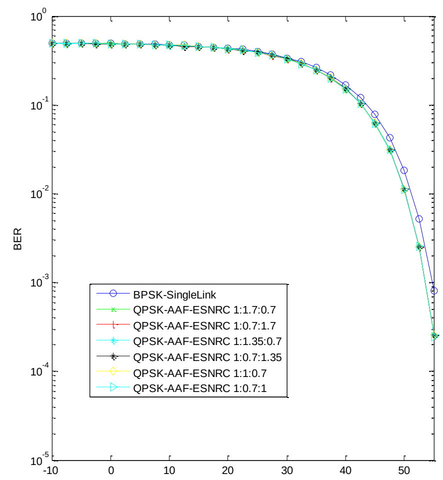

Fig. b.4: Relay close to Sender/Destination (CM12)

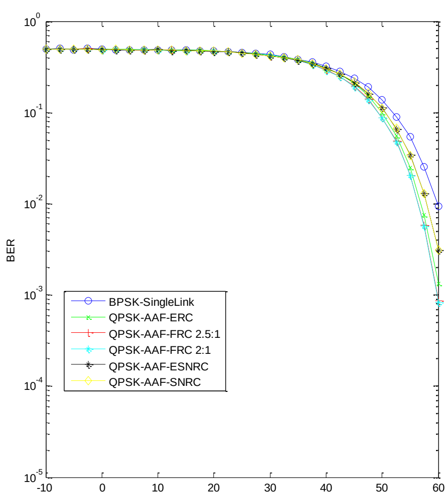

Fig. c.1: Different Combining types (CM13)

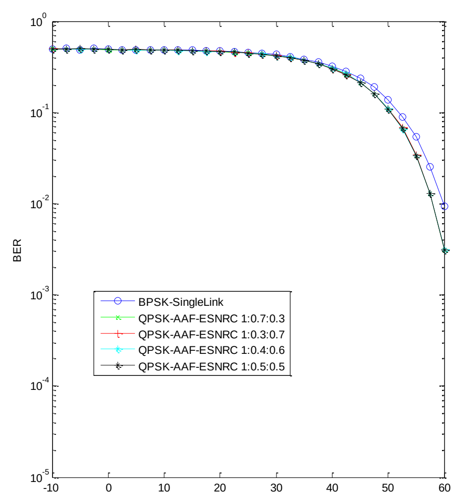

Fig. c.2: Benefits of Relay location (CM13)

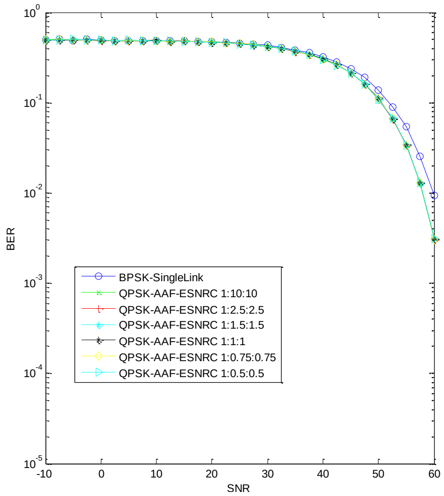

Fig. c.3: Effect of increasing distance (CM13)

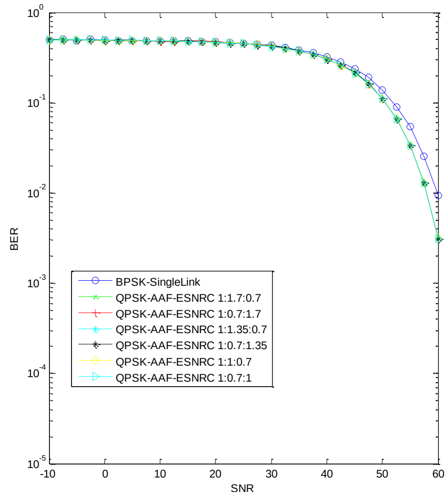

Fig. c.4: Relay close to Sender/Destination (CM13)

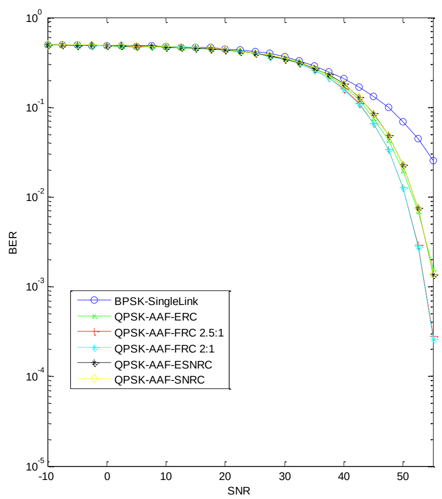

Fig. d.1: Different Combining types (CM14)

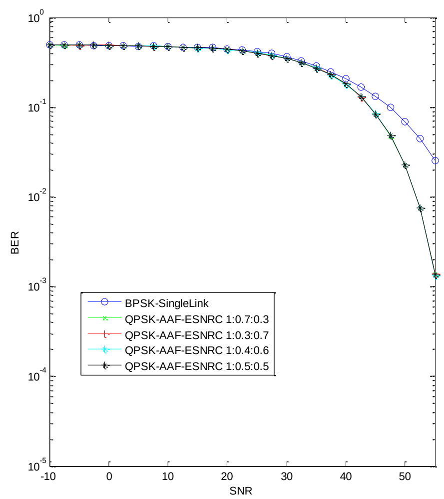

Fig. d.2: Benefits of Relay location (CM14)

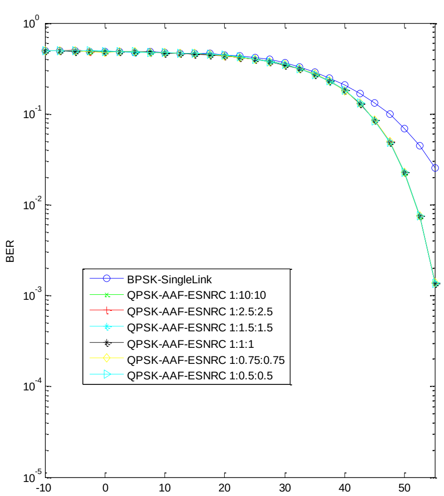

Fig. d.3: Effect of increasing distance (CM14)

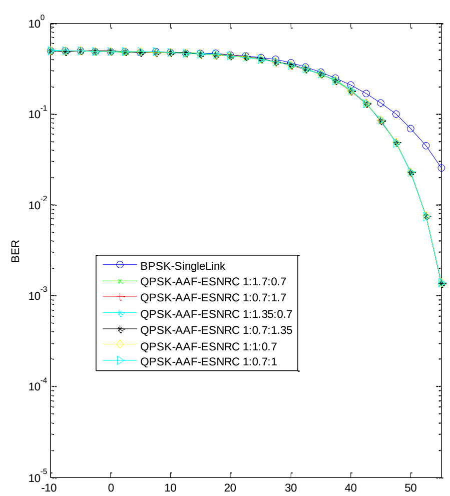

Fig. d.4: Relay close to Sender/Destination (CM14)

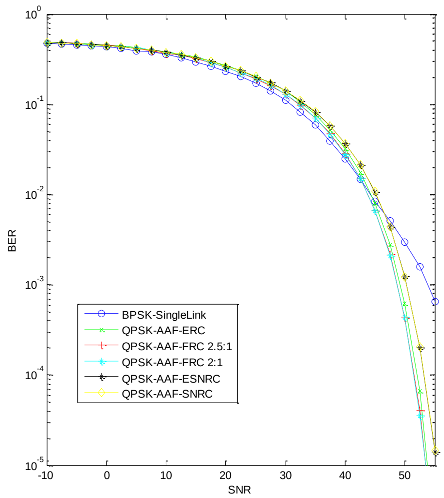

Fig. e.1: Different Combining types (CM15)

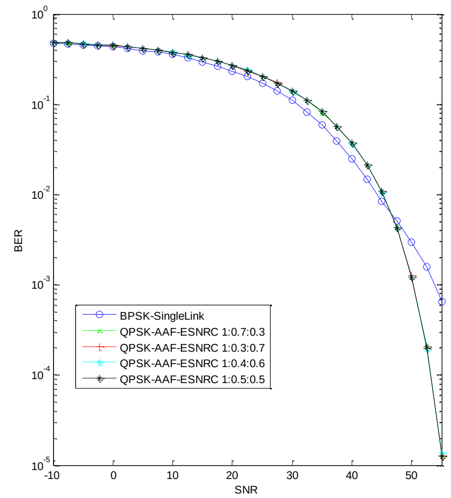

Fig. e.2: Benefits of Relay location (CM15)

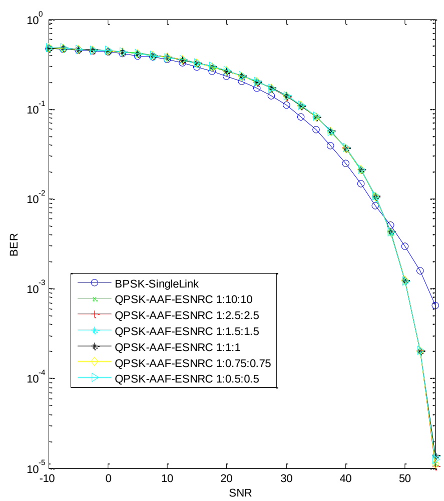

Fig. e.3: Effect of increasing distance (CM15)

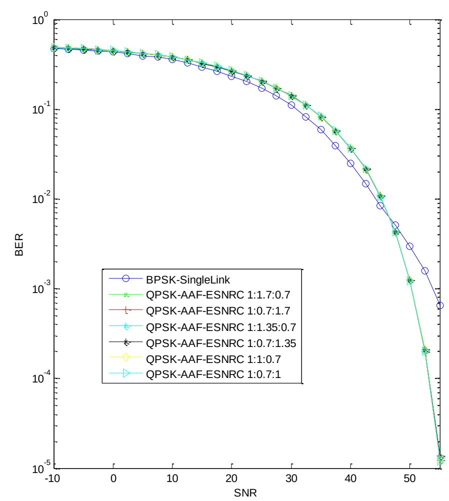

Fig. e.4: Relay close to Sender/Destination (CM15)

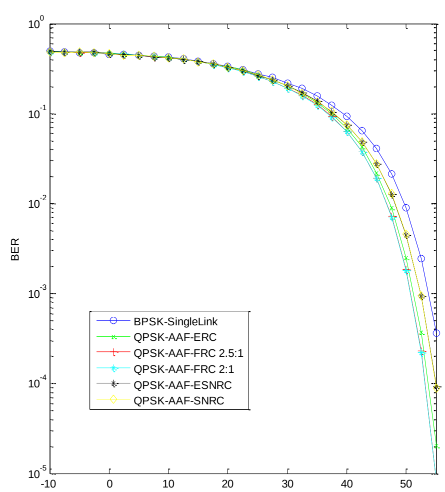

Fig. f.1: Different Combining types (CM21)

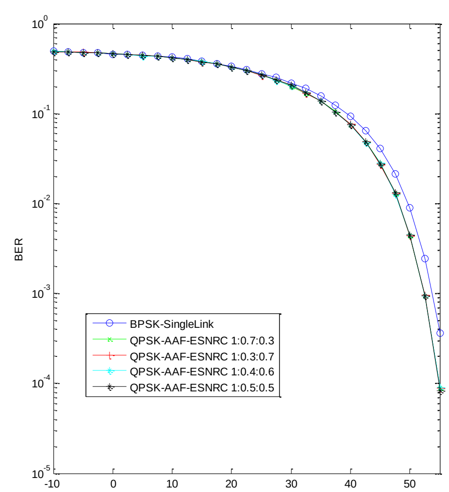

Fig. f.2: Benefits of Relay location (CM21)

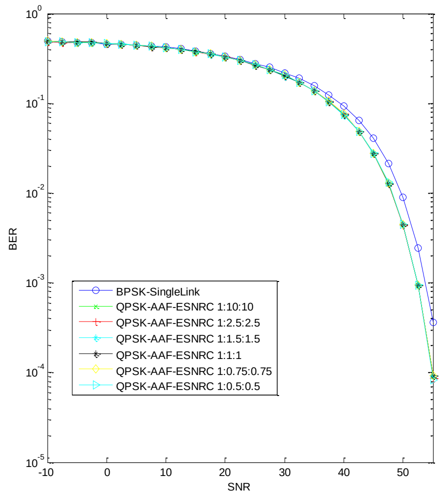

Fig. f.3: Effect of increasing distance (CM21)

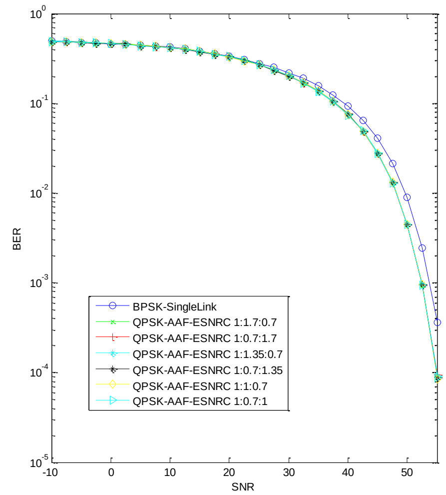

Fig. f.4: Relay close to Sender/Destination (CM21)

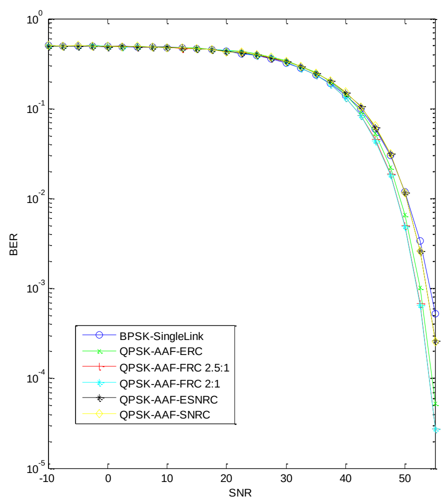

Fig. g.1: Different Combining types (CM22)

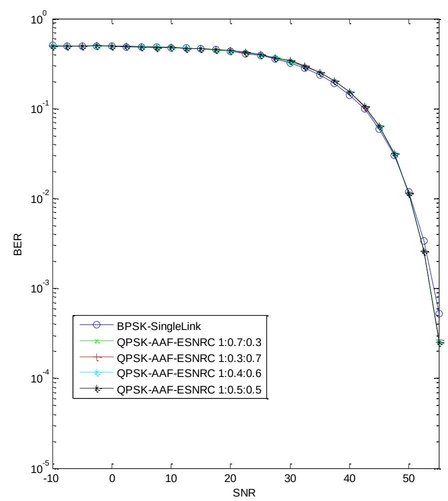

Fig. g.2: Benefits of Relay location (CM22)

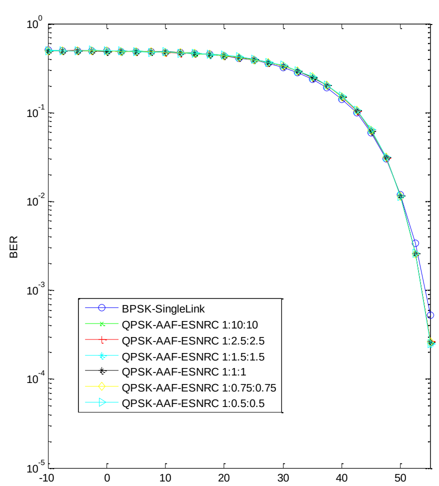

Fig. g.3: Effect of increasing distance (CM22)

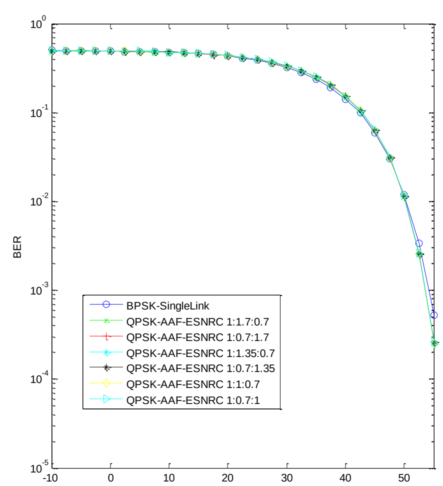

Fig. g.4: Relay close to Sender/Destination (CM22)

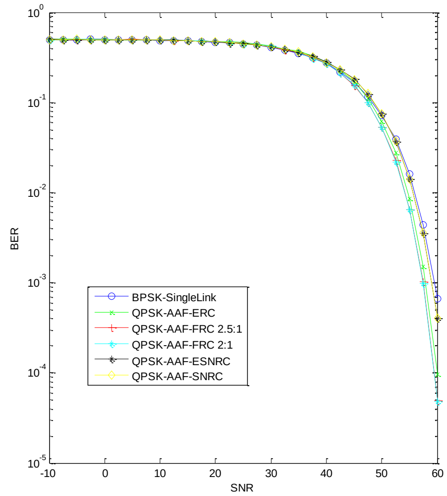

Fig. h.1: Different Combining types (CM23)

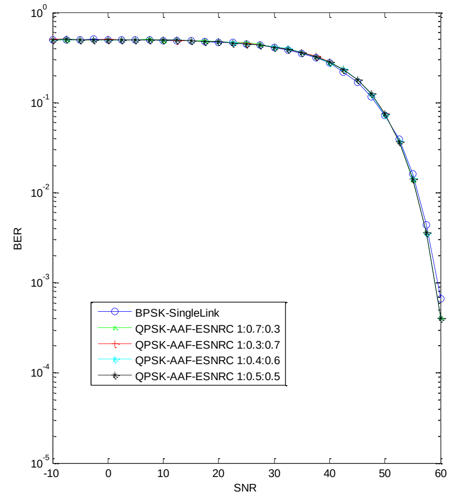

Fig. h.2: Benefits of Relay location (CM23)

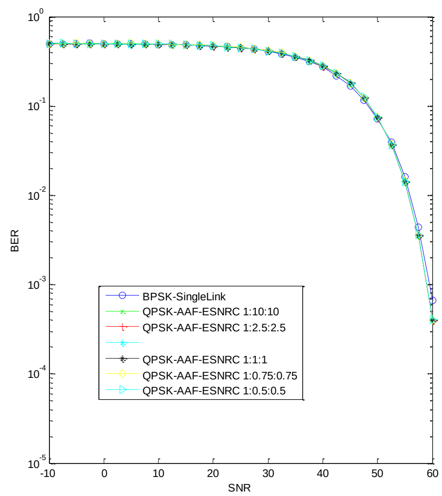

Fig. h.3: Effect of increasing distance (CM23)

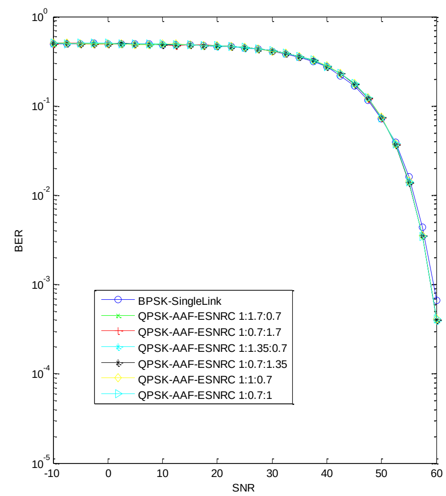

Fig. h.4: Relay close to Sender/Destination (CM23)

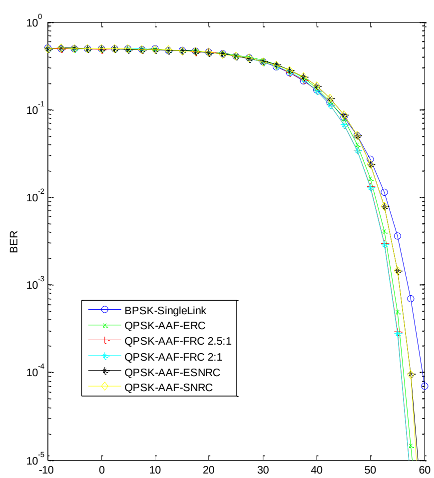

Fig. i.1: Different Combining types (CM24)

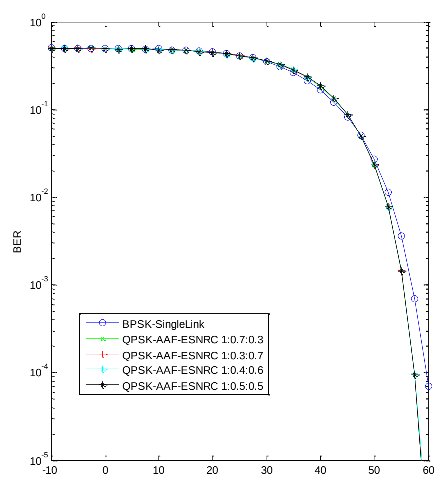

Fig. i.2: Benefits of Relay location (CM24)

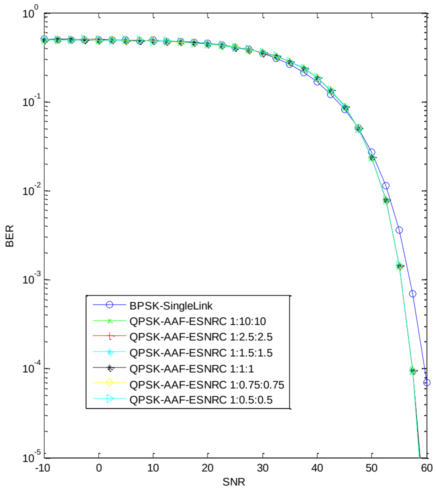

Fig. i.3: Effect of increasing distance (CM24)

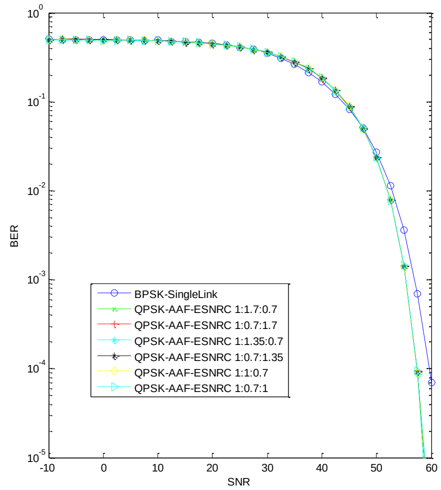

Fig. i.4: Relay close to Sender/Destination (CM24)

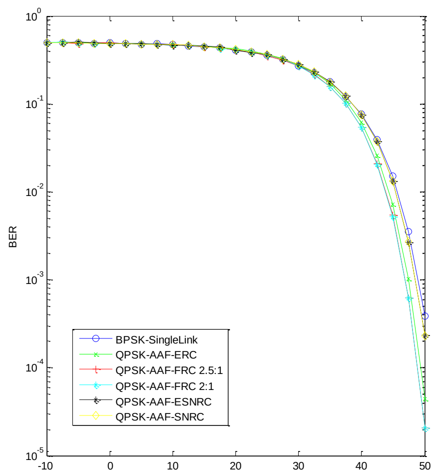

Fig. j.1: Different Combining types (CM31)

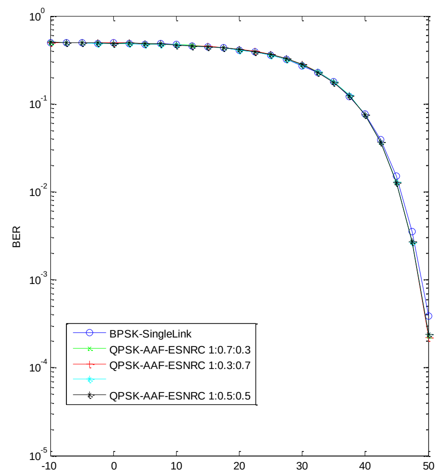

Fig. j.2: Benefits of Relay location (CM31)

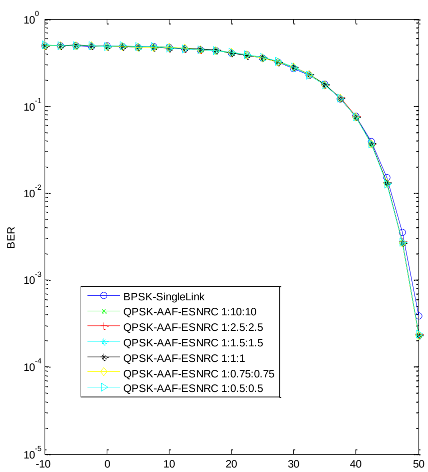

Fig. j.3: Effect of increasing distance (CM31)

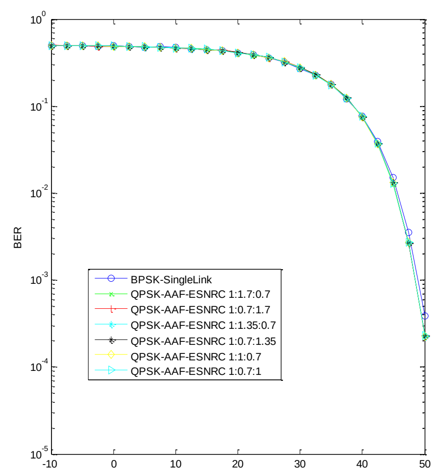

Fig. j.4: Relay close to Sender/Destination (CM31)

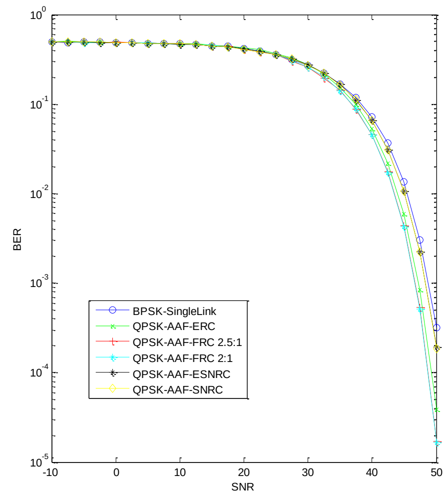

Fig. k.1: Different Combining types (CM32)

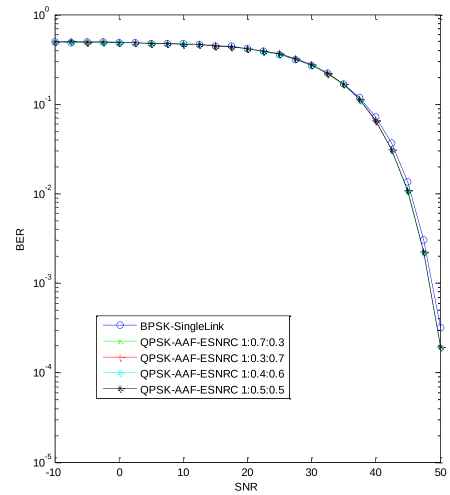

Fig. k.2: Benefits of Relay location (CM32)

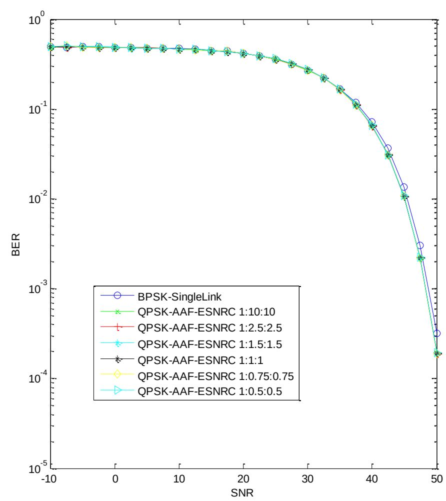

Fig. k.3: Effect of increasing distance (CM32)

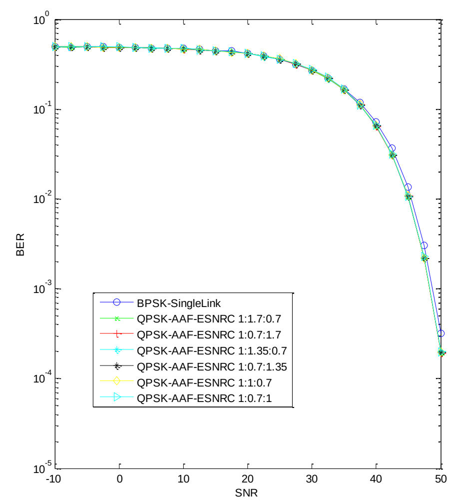

Fig. k.4: Relay close to Sender/Destination (CM32)

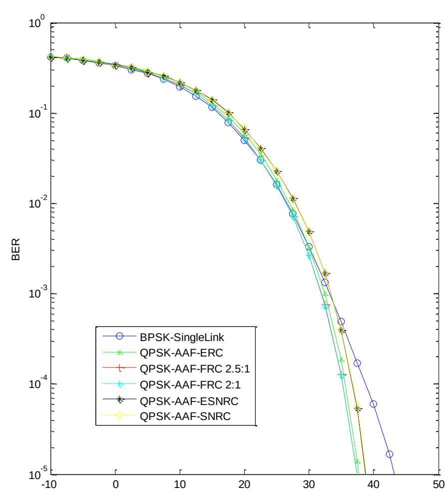

Fig. l.1: Different Combining types (CM41)

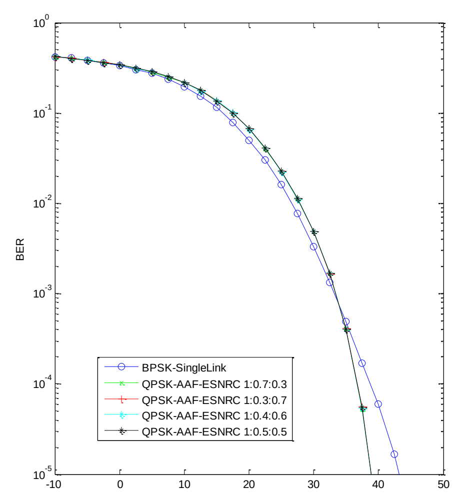

Fig. l.2: Benefits of Relay location (CM41)

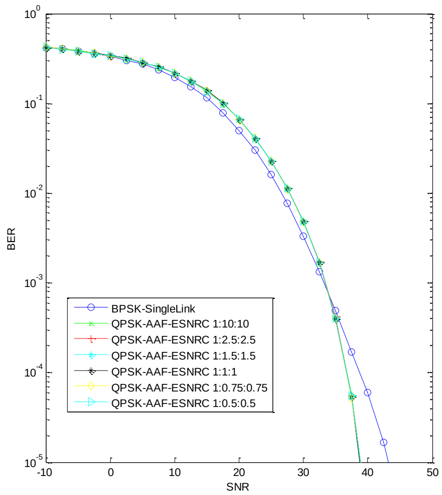

Fig. l.3: Effect of increasing distance (CM41)

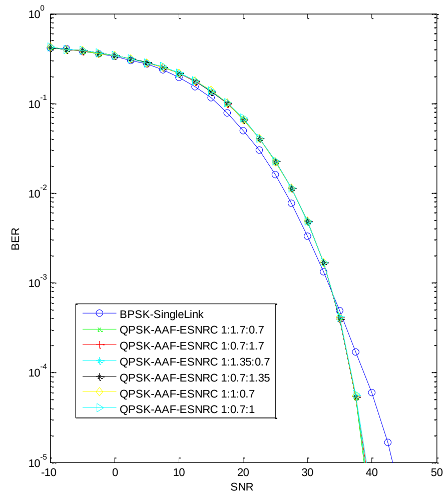

Fig. l.4: Relay close to Sender/Destination (CM41)

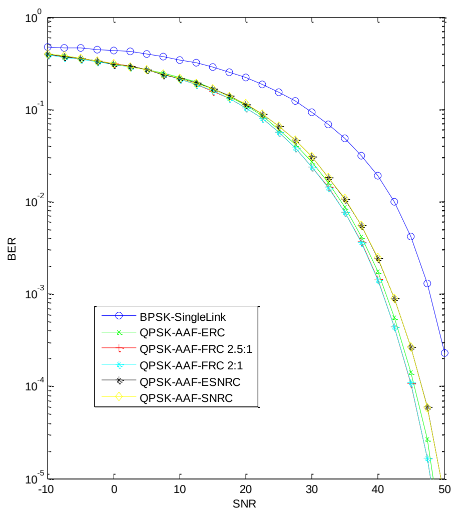

Fig. m.1: Different Combining types (CM42)

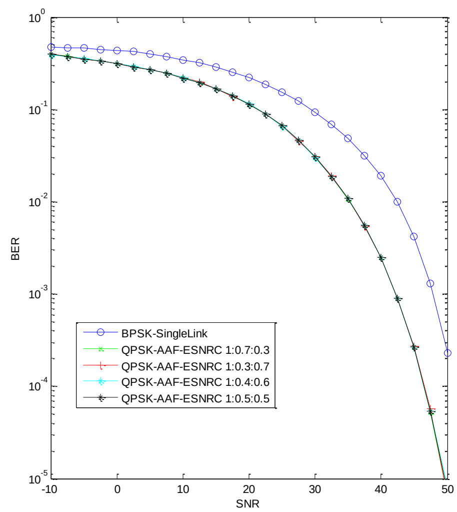

Fig. m.2: Benefits of Relay location (CM42)

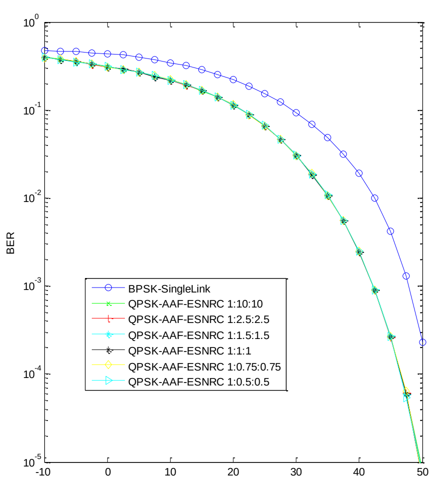

Fig. m.3: Effect of increasing distance (CM42)

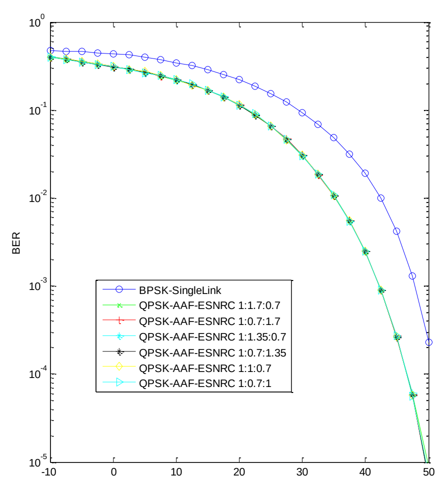

Fig. m.4: Relay close to Sender/Destination (CM42)

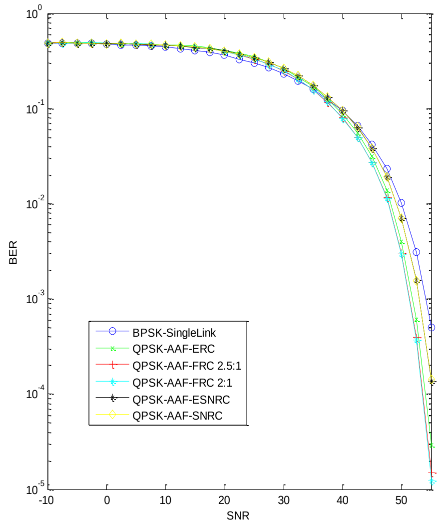

Fig. n.1: Different Combining types (CM71)

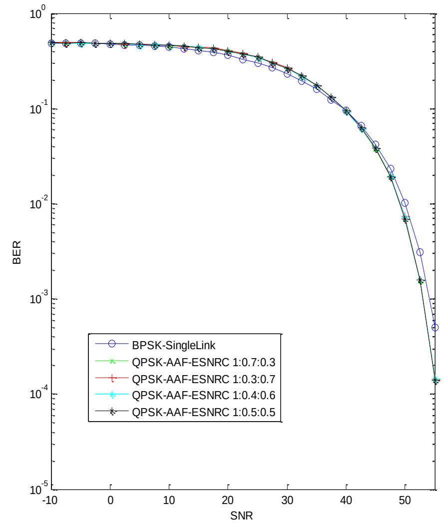

Fig. n.2: Benefits of Relay location (CM71)

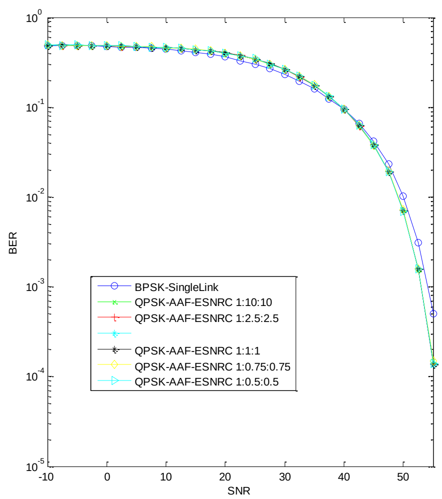

Fig. n.3: Effect of increasing distance (CM71)

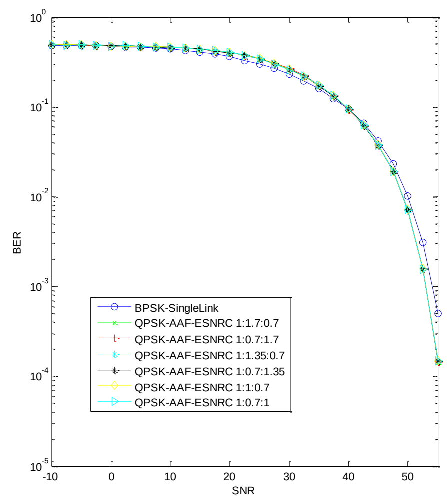

Fig. n.4: Relay close to Sender/Destination (CM71)

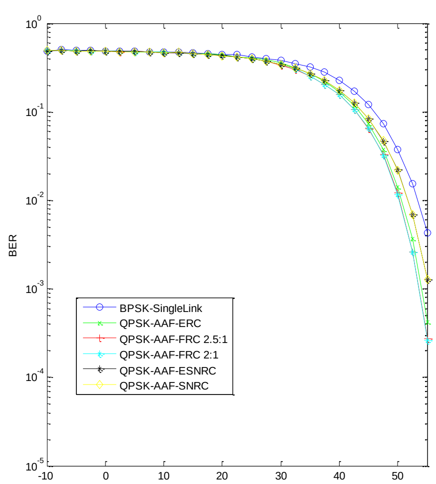

Fig. o.1: Different Combining types (CM72)

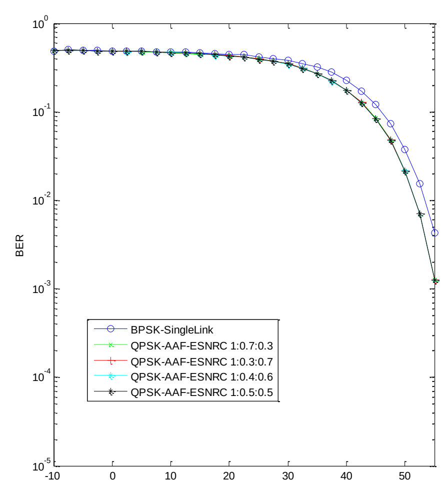

Fig. o.2: Benefits of Relay location (CM72)

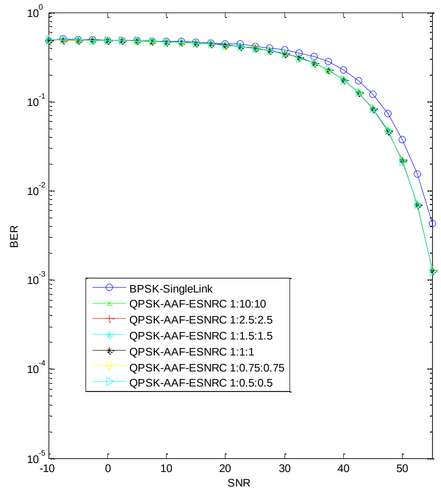

Fig. o.3: Effect of increasing distance (CM72)

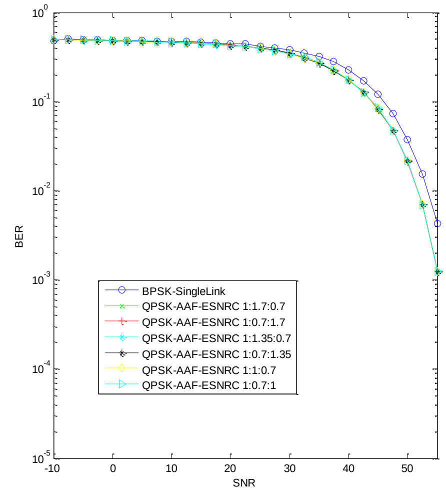

Fig. o.4: Relay close to Sender/Destination (CM72)

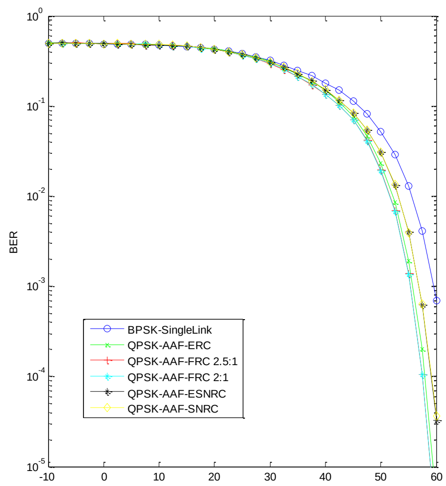

Fig. p.1: Different Combining types (CM81)

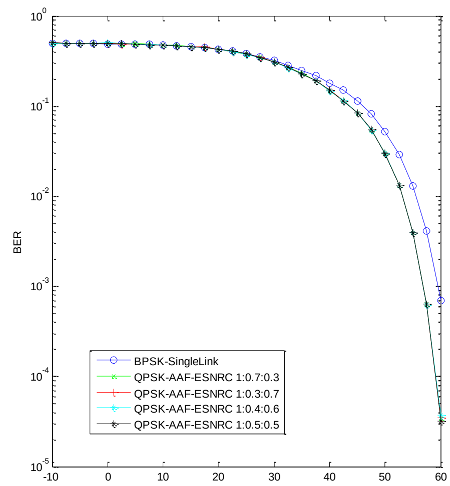

Fig. p.2: Benefits of Relay location (CM81)

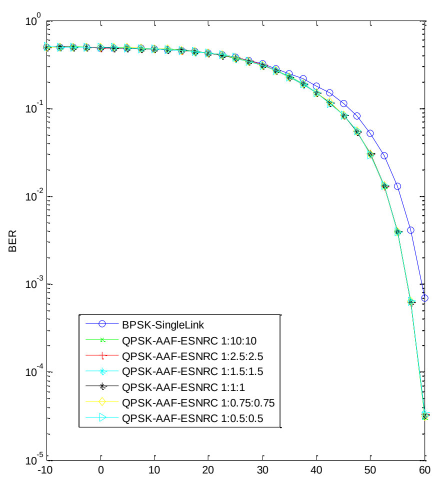

Fig. p.3: Effect of increasing distance (CM81)

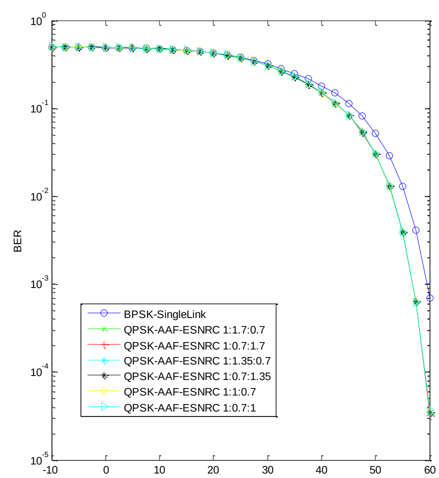

Fig. p.4: Relay close to Sender/Destination (CM81)

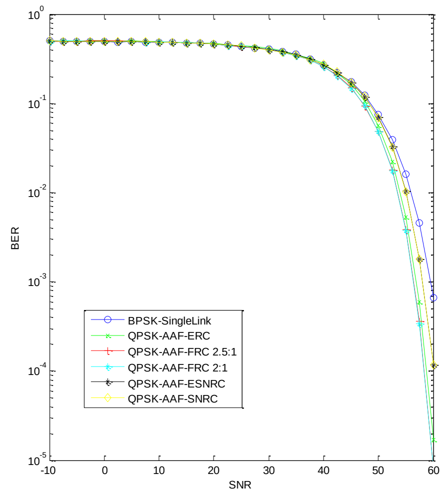

Fig. q.1: Different Combining types (CM82)

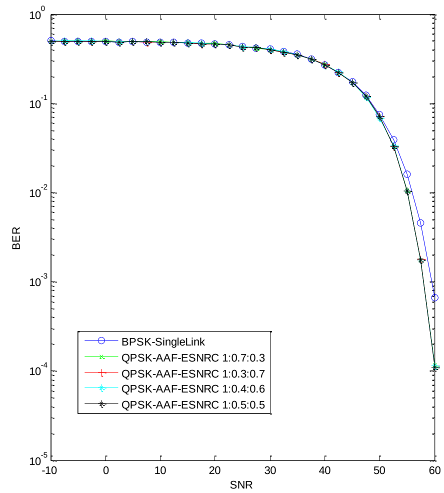

Fig. q.2: Benefits of Relay location (CM82)

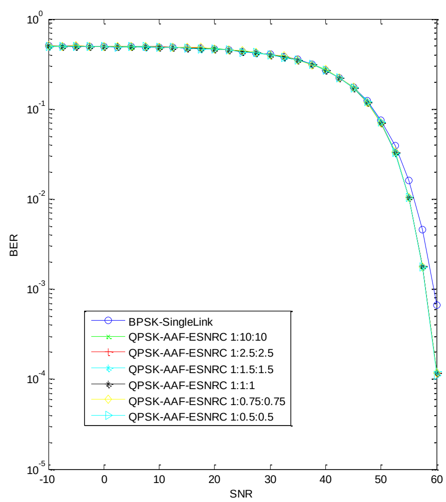

Fig. q.3: Effect of increasing distance (CM82)

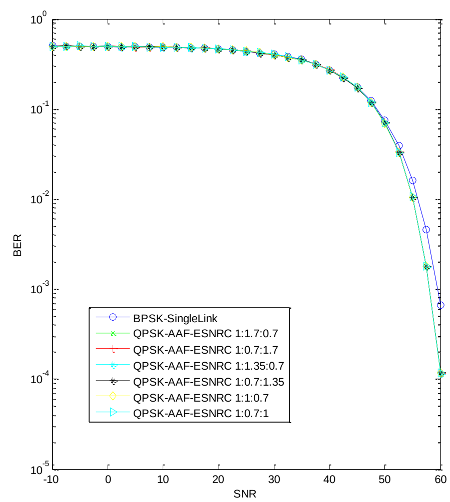

Fig. q.4: Relay close to Sender/Destination (CM82)

Figure a.1, figure b.1 up to figure q.1 show comparison between different combining techniques for all channels (CM11 to CM82). Figure a.2, figure b.2 up to figure q.2 depicts the benefits of relay location. Figure a.3, figure b.3 up to figure q.3 and figure a.4, figure b.4 up to q.4 shows the effect of positioning (placement) of relay with respect to the source and the destination. All the results indicate improved performance of different combining technique over that of single link transmission. The performance for CM11, CM12 and CM15 is better as compared to CM13. Similarly CM14 also shows slightly better performance as compared to CM13. The BER performance for ERC in all the cases is satisfactory though it does not require any channel knowledge except for phase shift. The FRC combining method provides best results for weight factor of 2. The performance for FRC is better than ERC is based on the assumption that the direct link has in general better quality than the multi-hub link. The ESNRC and SNRC show roughly the same performance but lags behind FRC/ERC. Though ESNRC depends on rough estimation of channel quality for every block, its performance is similar to that of SNRC which requires exact information of channel quality. With AAF protocol it is possible to derive benefits of diversity even when channel quality cannot be estimated by using ERC. The performance of CM24 is improved as compared CM21, CM22 and CM23. Channel CM41 and CM42 provides the best performance as compared to others. 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. When the relay positioned in between source and destination one can observe very slight improvement in performance when the relay is nearer to the source/destination as compared to central positioning of the relay.

To illustrate the results further let's discuss the performance in case of CM41 channel in terms of figures I.1, I.2, I.3 and I.4 respectively. From figure I.1 one can observe that the FRC (2:1) provides the best performance compared to FRC (2.5:1) and ERC combining. However it is noteworthy to see that the performance with ERC combining is only marginally lower than that of the FRC (2:1) and FRC (2.5:1) as ERC does not require any channel quality information. Though SNRC and ESNRC require precise/ approximate channel quality information, their BER performance is lagging behind ERC and FRC. Figure I.2 shows that when the relay is at mid position between source and destination (1:0.5:0.5) it provides the best result, however the performances associated with other positions is not lagging far behind the best performance. Figure I.3 does not indicate any specific pattern related to positioning of relay. Positioning of the relay nearer to the source and / or destination can provide slight improved performance as seen in figure I.4. Thus AAF protocol along with the combining techniques provides diversity gain, by providing improved performance over the single link transmission.

V. CONCLUSION

The Amplify and Forward (AAF) protocol for cooperative communication at 60 GHz is presented in this paper. The paper considers non cooperative model in terms of single link transmission and cooperative model using single relay and amplify and forward protocol. The system uses BPSK modulation for single link transmission and QPSK for cooperative transmission. The BER performance for different combining techniques like ERC, FRC, SNRC and ESNRC under varying SNR is presented. The effect of positioning of the relay with respect to the source and destination has been examined. The results indicate that diversity benefits can be obtained using AAF protocol over that of direct link transmission. The AAF protocol is often used when relay has only limited computing time/power available or when the time delay is required to be minimized. The FRC combining provides the best performance however it requires information related to average channel quality. On other hand ERC gives promising performance as compared to FRC and has an advantage that it requires no channel quality information. The performances in case of SNRC and ESNRC combining are more or less similar and lagging behind ERC and FRC, though they require precise / approximate channel quality information. When the relay is placed mid-way between the source and destination slightly improved performance is obtained. The placement of relay near to source or destination can also provide slight improvement in performance.

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