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Relaying Protocols in Wireless Passive Sensor Networks

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ABSTRACT

Node cooperation is considered in the existence of two relaying protocols i.e. “Amplify and Forward (AF)” also called “Store and Forward (SF)” and the second relaying protocol is “Decode and Forward”. The two stated protocols are different from each other and perform different operations on received data before retransmitting to next hop. Also the selection of each protocol is varying in accordance to the distance of a sensor node from the destination node (RF source). This work is achieved by first modelling an empirical system consists of single relay, source and destination. And the two relaying protocols (SF and DF) were modelled and implemented. This approach is then extended for three relay nodes and the two sets of relaying nodes were implemented again on every single node.
Keywords: Relaying Protocols, AF, DF, WPSN, RF, BER.

I. INTRODUCTION

In wireless sensor networks, signal is severely degraded by the multipath signals which can be compensated with the use of diversity. Taking the advantageous of diversity, the destination node accumulates or combines all the received signals received via independent links and makes the final decision upon the transmitted bits. This characteristic of sensor networks is called the cooperative attempt and is always there when they are active. Sensor nodes, with this property enhance their quality of service and offer good BER compare to the conventional mode of communication. The senor nodes make use of their processing capabilities to locally carry out simple calculations and send out only interested data [5]. This approach or capability of WPSN can offer spatial diversity against fading in a wireless channel4 [22]-[23]. If there is no direct line of sight or having difficulty in communication, then one sensor node help another, called relay node in order to accomplish transmission from source to the desired destination [23]. This cooperative behaviour is adopted by each sensor node in the network along with the normal communication responsibility. Node Cooperation results in various trades off in terms of resources e.g. data rate and transmit power. Because in cooperative mode if there are “N” number of sensor nodes, then the total power would be divided into “N” number of portions and with that individual part of the total power, the data would be transmitted to each node. Hence, total power available at the single node divided and thus it is reduced for all users because of diversity [24]. The scenario that this work will consider would assume that all nodes work in the same band and therefore the source node will behave in broadcast manner, while the destination node is in multiple channel access mode as depicted in the following figure 10. Channel between each pair of node is independent and have random effect on data.

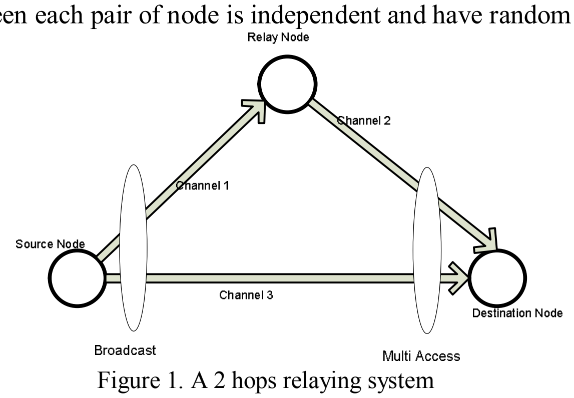

Figure 1. A 2 hops relaying system

II. Relaying Protocols

The two approaches are employed by the relaying nodes named as Amplify-and-Forward (AF) or Repeater and Decode-and-Forward (DF) in order to accomplish their job in the case when channel is severely fading. The need of two approaches arises when signal is very week and is unable to reach the destination node. The factors that weaken the signal are path loss (Large Scale Fading (LSF)) e.g. Reflection, Diffraction, Scattering etc. and Small Scale Fading (SSF) e.g. Rayleigh, Ricean, Nakagami, Doppler Spectrum, Autoregressive Model etc. [25]-[26] that could be resolved through the use of space, time and multiple antenna diversities. In a very simple case shown below is the 4 nodes system. In which two terminals T1 and T2 transmit to the destination terminals T3 and T4 respectively. But due to

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broadcast nature of wireless communication system, they also share resources with other nodes coming in the range of WPSN field [25] such as shown in Fig 3.2 and jointly communicate the data.

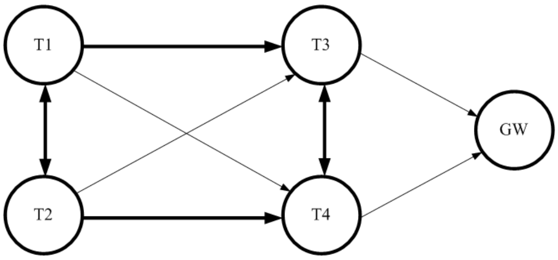

Figure 2. Relaying Nodes in Wireless Sensor Network

Each transmitting terminal focuses to send the data to their respective destination e.g. in a direct transmission between T1 and T3, the node T1 acts as source and T2 acts as relay node. So that in the case when fading is severe between T1 and T3 and transmission is not successful, then information is sent through the relay node (T2).

Relay transmission also happens when received information is severely corrupted that is called *physically degraded relay channel* e.g. the destination node receives data which is very different than the one received by relay node, and then the automatic retransmission occurs through the neighbour node. It is therefore, relay channel must be coping with the following three approaches [25],[27],[28].

- Facilitation
  - Relay should keep the interference smaller as much possible between the active communicating nodes to let them to transfer data more reliably.
  - Relay must not help the source directly.
- Cooperation
  - Since resources are shared with T2 as well, therefore it fully decodes the source message and re-transmits the source message in case T1 fails to deliver data successfully to destination node. Also in certain scenario, the received signal is not necessarily decoded, but simply reshape that signal to a higher amplitude and transmit towards the destination
- Observation
  - Relay encodes the quantized version of received signal and keeps record of every transmission that has been sent towards the destination.

In node cooperation, various protocols are employed to perform various operations. In fixed relaying, the received signal is either Amplify-and-Forward or Decode-and-Forward, depends upon the power availability.

Amplify and Forward: It is stated earlier that in Amplify and Forward method, relay receives the noisy signal and siply amplify and retransmits. AF is also called Non Regenerative mode due to the reason that the information bits are not extracted from the received signal. This mode of processing is also called less power consuming mode between the two, because it puts less processing burden on relay compare to DF. Therefore relay mostly employs AF when complexity increases or other parameters like received SNR is low. This copy of signal when reaches at the destination, the destination node then combines all the received copies from different channels and apply the MRC (Maximal Ratio Combining) technique to make the final decision [29],[30]. If there are $"N"$ number of relays in a system, by the time it reaches to the final destination, the signal would have been passed through $"N+1"$ number of independent channels and effect of each channel would remain in the final combined signal.

Referring to Fig 3.2.1, source broadcasts the signal. This is received at the destination and relay node respectively as [31]

$$y_{s,d}[n]=a_{s,d}x_s[n]+z_{s,d}[n] \;\;\&\;\; y_{s,r}[n]=a_{s,r}x_s[n]+z_{s,r}[n] \qquad (3.2.1.1)$$

Where $a_{s,d}$ and $a_{r,d}$ represents that up to what extent the signal is faded when travelled from source to destination and source to relay respectively. The noise and interferences received from other systems are represented by $z_d[n]$ and $z_r[n]$. "n" is the time slot in which transmission occurs. In cooperative behaviour, the relay node will also transmit the same signal

$$y_{r,d}[n]=a_{r,d}y_{s,r}[n]+z_{r,d}[n] \qquad (3.2.2.2)$$

The relay transmitted message would be received at the destination. The combined signal at the destination would be generally in the following form [32],[33].

$$y_d[n]=y_{s,d}[n]+y_{r,d}[n] \qquad (3.2.2.3)$$

This makes the three nodes system as shown in figure 12.

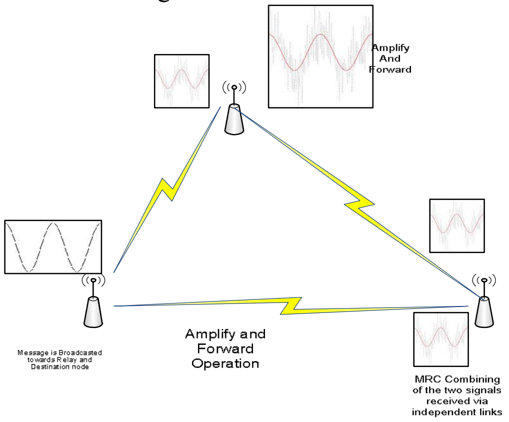

Figure 3. Source, Relay and Destination Communication via Repeater or AF mode

Relay does not perform any operation on the received data and retransmits with amplification factor β that could be set according to the available power. The appropriate gain is approximated as [21]

$$\beta \leq \sqrt{\frac{P}{\left|a_{s,r}\right|^2 P + N_0}} \qquad (3.2.2.4)$$

That is made dependent on the fading coefficient and is measured to high accuracy by the relay node.

Decode and Forward: Information is successfully extracted when source and relay data are received by the destination node. If suppose there is an error in relay's transmission and data is not extracted, then the required data is recovered from the combined signal. It is therefore the combined probability is important to be considered.

$$P_{S,DF} \cong \Pr[\mu_{s,d} > \mu_d, \mu_r > \mu_d] \qquad (3.2.2.1)$$

Using conditional law of probability to write the right side of the overall probability equation as

$$\Pr[\mu_{s,d} > \mu d, \mu_r > \mu_d]$$
$$= \Pr[\mu_s > \mu_d]\Pr[\mu_d > \mu_d \mid \mu_s > \mu_d]$$
$$= e^{-\sigma^2 r_s{}^{\eta} \mu_d} \Pr[\mu_d > \mu_d \mid \mu_s > \mu_d]$$

μ is the SNR level of the received signal which must be satisfying above conditions. However if source and relay transmission is unsuccessful towards the destination, the source re transmits the original data, which is called Adaptive Decode-and-Forward and can be written as [17],[26].

$$P_{s,ADF} = \Pr[\mu_{s,d} > \mu_d, \mu_r > \mu_d] + \Pr[\mu_{s,s} > \mu_d, \mu_r \leq \mu_d] \qquad (3.2.2.2)$$

$\mu_{s,s}$ denotes that source to destination transmission was unsuccessful initially and therefore retransmitted on request.

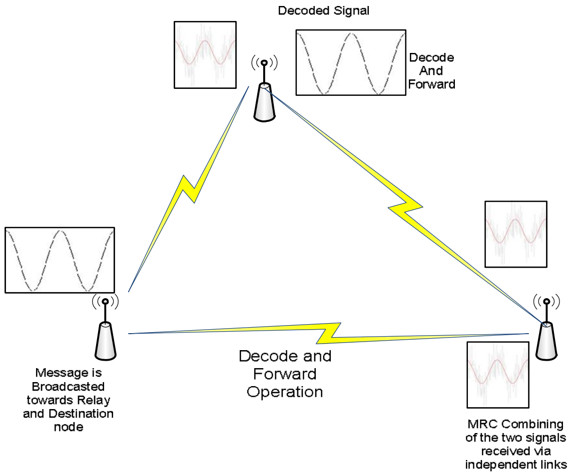

Figure 4. Source, Relay and Destination Communication via Decode-and-Forward or DF mode

III. System Model, Approach and Achieved Results with Discussion

When signal is transmitted over a long communication path, the received signal is observed in a different form than the original. The envelope amplitude of this signal when observed would seem to be fluctuating as the time passes by. This effect is caused by "fading". This effect puts some limitations on the system design. However, if different signals are received, then fading over one path is different than another [34],[35]. Therefore if copy of the same signal is received via different links, then it is rarely happen that all channels are severely faded but it is good for reducing fading effect. This technique is called "diversity" which improves the combined signal to noise ratio and process of combining these signals at the receiver is called "Maximal Ratio Diversity" or Maximum Ration Combining (MRC) [36],[37].

a. System Design

Data passed through each relay node would be passed through the process shown by the following block diagram but only if the serving relay is choosing DF mode for retransmission of the received signal.

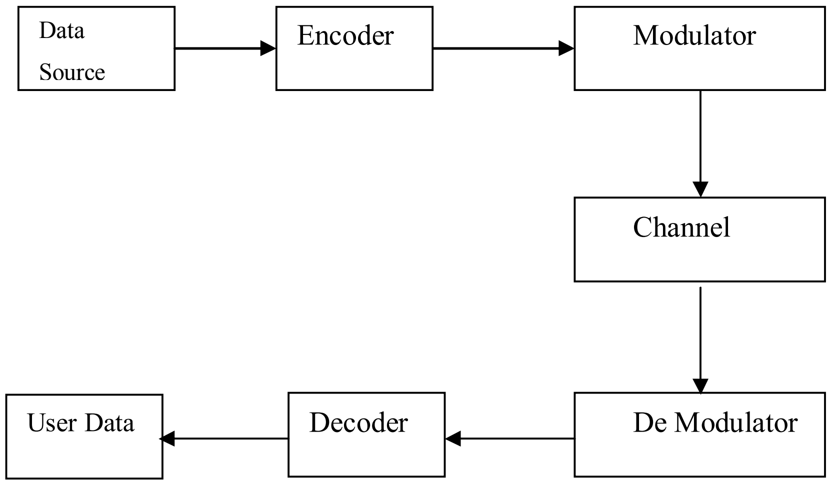

Figure 5. Block diagram of a Digital Communication Process System

Block diagram shows that initially, the data source randomly generates bit stream of 0s and 1s. Data stream is passed through encoder. Half convolutional encoder would be used in system design, which will introduce redundant bits equal to the information bits i.e. each information bit would have one redundant bit. The encoded bits would be modulated using different modulation schemes e.g. BPSK, QPSK etc. The modulator would generate a set of finite time duration waveforms and will provide mapping between the encoder output and the generated set of waveforms. The modulated signal is passed through flat fade channel and channel state information is known at the receiver. Channel introduces multiplicative noise but at the receiver, the received signal is also distorted by the AWGN noise. At the receiver, the same modulation scheme is used to de-map the signal and user data is decoded from the de-mapped signal.

The above block diagram would be integrated in each relay which could be more generally seen in the form of following flow chart.

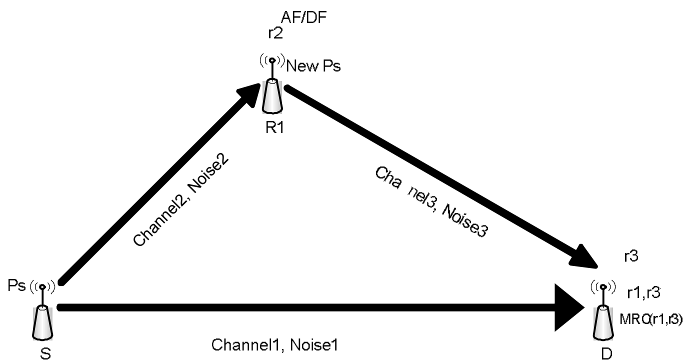

Figure 6. One Relaying node using either AF or DF

Results-1: One Relay Coded system using BPSK, QPSK and 8PSK schemes

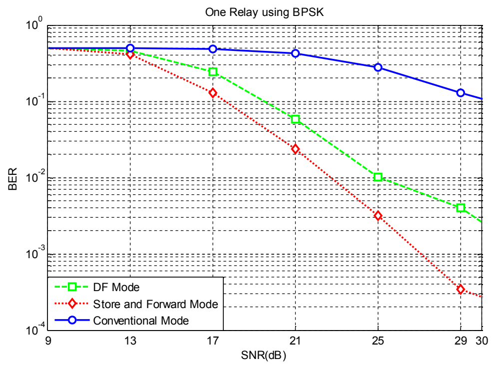

Figure 7. One Relay outputs using BPSK

One Relay output using BPSK. The unity power is shared between relay and the destination node i.e. source transmits data towards relay and destination with half power.

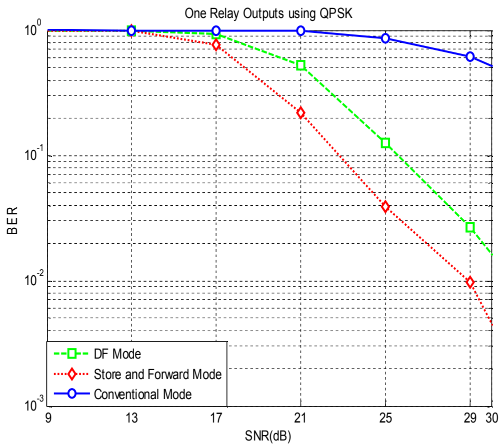

Figure 8. One Relay outputs using QPSK

One Relay output using QPSK. The unity power is shared between relay and the destination node i.e. source transmits data towards relay and destination with half power.

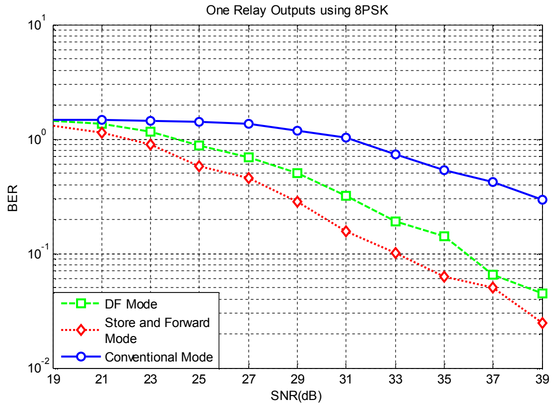

Figure 9. One Relay outputs using 8PSK

One Relay output using 8PSK. The unity power is shared between relay and the destination node i.e. source transmits data towards relay and destination with half power.

Discussion of Results-1: Figure 17-19, show the bit error probability of three types of transmission mode over a range of SNR. These are the outputs of a coded system using ½ rate convolutional code. The performance is observed over three types of different modulation schemes and throughout it is found that AF takes full advantage in terms of providing less transmission error compare to other two. But there is obvious change in error probability when the number of sensor nodes increased. The reason is that, each sensor node has now more choices to achieve path diversity and to transfer the desired data over various paths. This offers more capability to combat fading and achieve. When number of relay nodes increase, the serving node will equally distribute the total available power among all relay nodes and with that fraction of power, the data would be sent to each relaying node including destination node. Power consumption should be at minimum if there are more relays available to help the serving node. This statement will also be proved at the end of this section. Moreover for comprehensive results, it is important to extend the model for multiple relaying nodes. The above model is for single relay, while in practical scenarios, a network consists of many relay nodes. Therefore, model is extended for multiple relays as depicted by the following diagram.

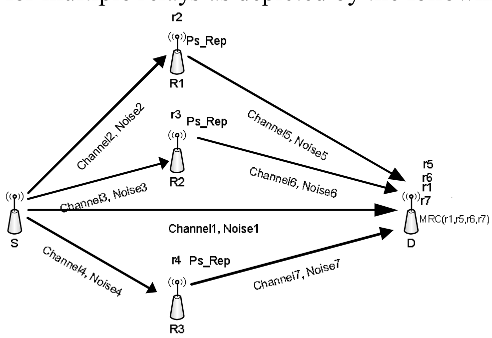

Figure 10. Diversity in Multiple nodes using Repeater Mode

In Figure 20, it is only one transmit antenna and 4 receive antennas. Each receive antenna has a distinct and independent experience of channel effect. The received data (r2, r3 and r4) at relay R1, R2 and R3 is amplified by the corresponding power factors which are introduced by each relay node distinctly.

At the destination, these are combined to evaluate the resultant SNR. Since each relay simply amplifies what they receive, therefore at the destination node, each received data is having the channel effect through which the received data had passed. Therefore, received data is equalized at the destination and then the user data is extracted after decoding. Mathematical analysis for the repeater mode is as follow.

Suppose, Signals received by destination node and R1 as

$$y_{S,D} = \sqrt{P_S}\, h_{S,D} S + \vartheta_{S,D}$$
$$y_{S,R1} = \sqrt{P_S}\, h_{S,R1} S + \vartheta_{S,R1} \qquad (4.2.1)$$

$y_{S,D}$ *and* $y_{S,R1}$ correspond to r1 and r2 in above figure. Each received signal has flat fad channel effect denoted by $h_{S,D}$ *and* $h_{S,R1}$ and is different from each other. Each transmitted data is multiplied with a randomly varying complex number $h_{S,D}$ *and* $h_{S,R1}$. Since the channel considered in this model is Rayleigh channel, therefore real and imaginary parts are Gaussian distributed with "mean = 0" and "variance = ½". Also the noises are distinct on each link and are uncorrelated with respect to the noise received by each antenna.

Destination nodes receives signal via relay as

$$y_{R1,D} = \sqrt{P_{R1}}\,(y_{S,R1}) h_{R1,D} + \vartheta_{R1,D}$$
$$OR \qquad (4.2.2)$$
$$r5 = \sqrt{P_{R1}}\,(\sqrt{P_S}\, h_{S,R1} S + \vartheta_{S,R1}) h_{R1,D} + \vartheta_{R1,D}$$

Since the channel is known at the receive antenna, therefore the destination node equalizes the two received signals and combine them as

$$MRC = \frac{y_{S,R1}}{h_{S,R1}} + \frac{y_{R1,D}}{h_{S,R1} * h_{R1,D}} \qquad (4.2.3)$$

Substituting the values in equation 4.2.3

$$= \sqrt{P_S}\, S + \frac{\vartheta_{S,R1}}{h_{S,R1}} + \frac{\sqrt{P_{R1}}\,(\sqrt{P_S}\, h_{S,R1} S + \vartheta_{S,R1})}{h_{S,R1}} + \frac{\vartheta_{R1,D}}{h_{S,R1} * h_{R1,D}}$$

$$= \sqrt{P_S}\, S + \frac{\vartheta_{S,R1}}{h_{S,R1}} + \frac{\sqrt{P_{R1}}\,(\sqrt{P_S}\, h_{S,R1} S)}{h_{S,R1}} + \frac{\sqrt{P_{R1}}\,\vartheta_{S,R1}}{h_{S,R1}} + \frac{\vartheta_{R1,D}}{h_{S,R1} * h_{R1,D}}$$

$$(4.2.4) \qquad = \sqrt{P_S}\, S + \frac{\vartheta_{S,R1}}{h_{S,R1}} + \sqrt{P_{R1} P_S}\, S + \frac{\sqrt{P_{R1}}\,\vartheta_{S,R1} h_{R1,D} + \vartheta_{R1,D}}{h_{S,R1} * h_{R1,D}}$$

Rearranging the signal and noise part of the equation 4.2.4

$$MRC\ (r1, r5) = \frac{\sqrt{P_S}\, h_{S,R1} S + \vartheta_{S,R1}}{h_{S,R1}} + \frac{\sqrt{P_{R1}}\,(\sqrt{P_S}\, h_{S,R1} S + \vartheta_{S,R1}) h_{R1,D} + \vartheta_{R1,D}}{h_{S,R1} * h_{R1,D}}$$

$$= \underbrace{\sqrt{P_S}\, S + \sqrt{P_{R1} P_S}\, S + \frac{\vartheta_{S,R1}}{h_{S,R1}}}_{\text{Signal Power}} + \underbrace{\frac{\sqrt{P_{R1}}\,\vartheta_{S,R1} h_{R1,D} + \vartheta_{R1,D}}{h_{S,R1} * h_{R1,D}}}_{\text{Noise Power}} \qquad (4.2.5)$$

This is the combined signal of $r1$ and $r5$. However each signal passed through each relay path could be worked out in the same fashion.

At the destination node, the received signal has the signal and noise power as shown in equation 4.2.5. The ratio of the expectation of signal power to the expectation of noise power gives SNR and could be written as.

$$SNR = \frac{\zeta\left\{\sqrt{P_S}\, S + \sqrt{P_{R1} P_S}\, S\right\}^2}{\zeta\left\{\dfrac{\vartheta_{S,R1}}{h_{S,R1}} + \dfrac{\vartheta_{S,R1} + \vartheta_{R1,D}}{h_{S,R1} * h_{R1,D}}\right\}} \qquad (4.2.6)$$

$$SNR = \frac{P_s\delta^2 + P_{R1}P_S\delta^2}{N_0} \tag{4.2.7}$$

In our system model since various SNR would be applied to see the error performance; the performance of which could be seen from equation 4.2.7. As the SNR increases, the noise factor is dominated by the signal factor and thus error probability is expected to be decreased constantly.

Each relay also has the choice to select the DF mode for retransmitting the received message as it could be seen in the following diagram.

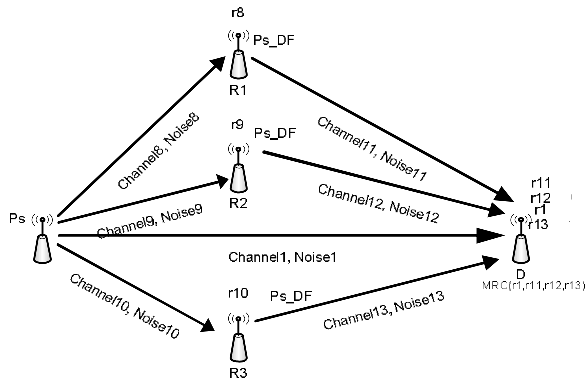

Figure 11. DF Mode Diversity in Multiple nodes

Each relay in above diagram first decodes the signal. The decoded bits are retransmitted via the distinct channel to the final destination. At the destination node, four uncorrelated signals are received and equalized individually. The equalized signals are combined using MRC to evaluate the resultant SNR. Mathematical analysis for the DF mode is as follow.

In a most simple case, suppose the destination node in figure 21 receives two uncorrelated signals $r1$ and $r11$ e.g.

$$\begin{aligned} r1 &= y_{S,D} = \sqrt{P_S}\, h_{S,D} S + \vartheta_{S,D} \\ r11 &= y_{R1,D} = \sqrt{P_{Ps\_DF}}\, h_{R1,D} \hat{S} + \vartheta_{R1,D} \end{aligned} \tag{4.2.8}$$

Where $\hat{S}$ are the information bits decoded by the relay node in advance. The relay node retransmits these bits with a new power factor represented by "Ps_DF". The equalized signals are combined at the destination node such as.

$$\begin{aligned} MRC\ (r1, r11) &= \frac{y_{S,D}}{h_{S,D}} + \frac{y_{R1,D}}{h_{R1,D}} \\ &= \frac{\sqrt{P_S}\, h_{S,D} S + \vartheta_{S,D}}{h_{S,D}} + \frac{\sqrt{P_{Ps\_DF}}\, h_{R1,D} \hat{S} + \vartheta_{R1,D}}{h_{R1,D}} \\ &= \sqrt{P_S} S + \frac{\vartheta_{S,D}}{h_{S,D}} + \sqrt{P_{Ps\_DF}} \hat{S} + \frac{\vartheta_{R1,D}}{h_{R1,D}} \end{aligned} \tag{4.2.9}$$

Re-arranging the signal and noise part of the equation 4.2.9

$$MRC(r1, r11) = \underbrace{\sqrt{P_S} S + \sqrt{P_{Ps\_DF}} \hat{S}}_{\text{Signal Power}} + \underbrace{\frac{\vartheta_{S,D}}{h_{S,D}} + \frac{\vartheta_{R1,D}}{h_{R1,D}}}_{\text{Noise Power}} \tag{4.2.10}$$

$$SNR = \frac{\zeta\left\{\sqrt{P_S} S + \sqrt{P_{R1}} S\right\}^2}{\zeta\left\{\frac{\vartheta_{S,D}}{h_{S,D}} + \frac{\vartheta_{R1,D}}{h_{R1,D}}\right\}} \tag{4.2.11}$$

$$SNR = \frac{P_s \delta_S^{\ 2} + P_{R1} \delta_{R1}^{\ 2}}{N_0} \tag{4.2.12}$$

Results-2: 3 Relays Un-coded system with BPSK, QPSK and 8PSK

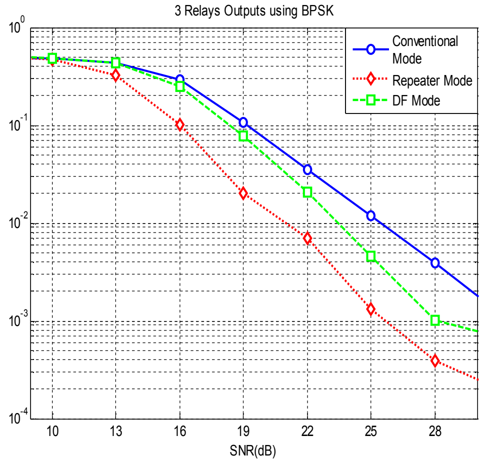

Figure 12. Three Relays outputs using BPSK

Three Relays outputs using BPSK. The unity power is shared among three relays and the destination node i.e. source transmits data towards relays and destination with one fourth power.

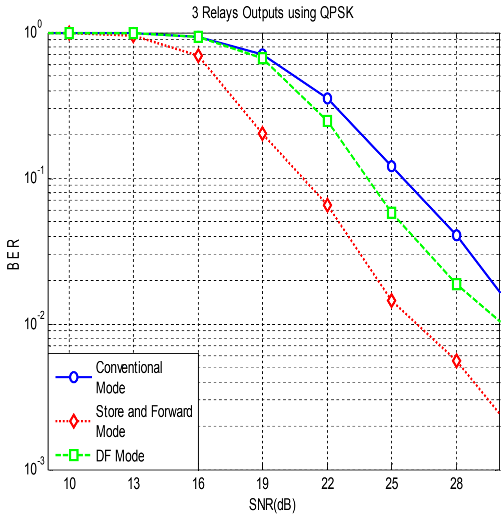

Figure 13. Three Relays outputs using QPSK

Three Relays outputs using QPSK. The unity power is shared among three relays and the destination node i.e. source transmits data towards relays and destination with one fourth power.

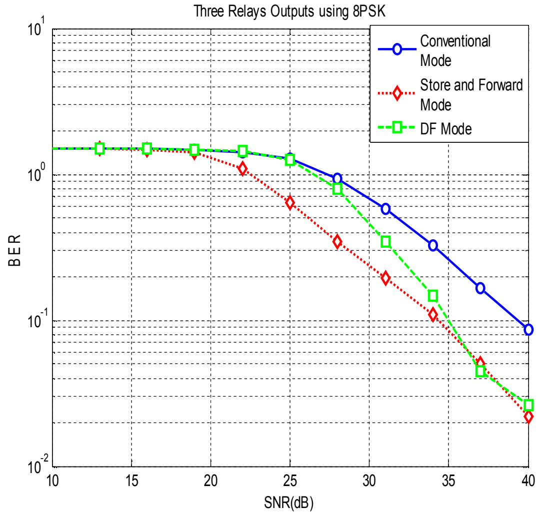

Figure 14. Three Relays outputs using 8PSK

Three Relays outputs using 8PSK. The unity power is shared among three relays and the destination node i.e. source transmits data towards relays and destination with one fourth power.

Discussion of Results-2: Results showing very obvious changes when number of relays are increased i.e. the error probability decreases when relaying nodes are changed from one relay to three. For example in BPSK the BER in One relay is slightly above from 10^{-3} at 28dB, while the same bit error rate is achieved at nearly 25dBs in the case of three relays.

IV. CONCLUSION

The cooperative system performance was investigated for two types of communication e.g. Cooperative communication with two relaying protocols and direct communication between source and destination. First of all, it has been proved from all graphs, the cooperative communication is always winning in multiple relays, no matter it is compared to AF or DF i.e. it provides low BER compare to un-cooperative communication, which provided that cooperative transmission offers spatial diversity against fading.

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