

Throughput Analysis Using Three-Step Two-Way Decode and Forward Multi-Relay Network for Wireless Energy Harvesting

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Abstract

This paper presents a novel scheme of “Radio Frequency Energy Harvesting” in Three-step Two-way “Decode-and-Forward (DF)” Multi Relay Network. Here, all the relay nodes receive signals from both the source nodes and then the best relay is selected on the basis of maximum overall SNR. Simulation results demonstrate that our proposed scheme outraces the contrast scheme with respect to throughput. Furthermore, it has also been shown how the throughput of the system varies with respect to power splitting factor and energy conversion factor for different values of source power and distance between the nodes.

Keywords:- DF relay, Energy conversion factor, Multi relay network, Power splitting factor, RF EH, Three-step Two-way, Throughput

INTRODUCTION

“Radio Frequency (RF) Energy Harvesting (EH)” in wireless networks has drawn considerable attention in recent past [1]. Here, a source transmits an RF signal that is received by a relay node which harvests energy and transmits the information to the destination node. RF EH is considered as an alternative technique to power the low power sensors or low power circuits [2]. This technique can easily be applied to wireless sensor networks such as relay [3]. There are various relaying schemes such as “Amplify and Forward (AF), Decode and Forward (DF), Joint Decode and Forward (JDF), and Denoise and Forward (DNF) network” [8].

DF relaying is better than AF because of its better capacity gain & SNR. Study is extended in [5] where AF networks is studied with Rayleigh fading channels which are independent but the distribution is not necessarily identical under the influence of a finite number of co-channel interferers. In [5], the “Probability Density Function (PDF)” of the equivalent instantaneous Signal to Interference plus Noise Ratio (SINR) is derived. This work is extended in [6] where the authors have considered “Power Splitting Relaying (PSR) and Time Switching Relaying (TSR)” protocol for DF-relay networks. In [6], the authors have derived the outage probability

expression with a given power splitting coefficient and subsequently maximum transmission rate power splitting coefficient is obtained. The authors in [7] have obtained throughput for DF relay system with three-terminal model. The expressions of ergodic capacity, outage capacity and throughputs are determined. Here, PSR protocol is preferred to TSR protocol because of low noise environment, small value of distance and small value of transmission rate [3]. In [4], the authors have compared the performance of “Two-Way Relaying (TWR)” with that of “One-Way Relaying (OWR)”. TWR can be performed in three time slots, where first two time slots are allotted for the signal to be transmitted from source to relay and the third time slot is used to transmit signal to the destination node by the relay node. Since during the first timeslot two sources transmit symbols to relay simultaneously in the same frequency band, TWR is more frequency efficient than OWR. This study is further extended to Three-step method where two nodes communicate with each other via an intermediate relay node [8]. Here, a three-step two-way DF relay network has been modeled for RF EH and its performance is compared with that of single relay network.

The above direction of research has motivated us to focus on Three-step Two-way DF relay network

for the purpose of RF EH. The pertinent contributions related to this work are listed below:

A novel scheme of RF EH has been developed in three-step two-way DF multi relay network where the best relay is selected to forward the information signal to the destination nodes.

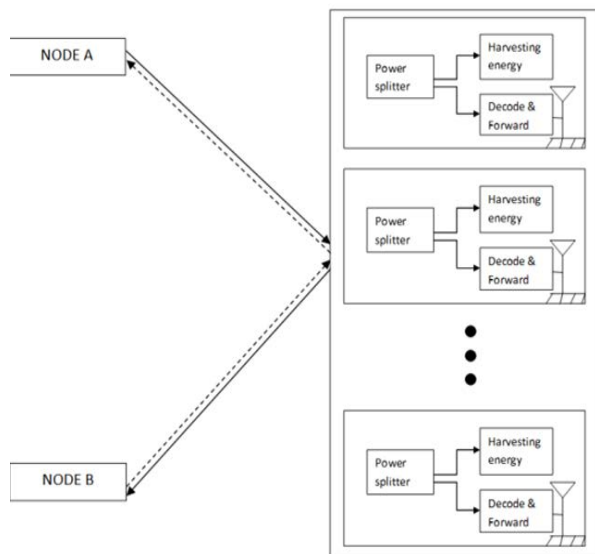
The performance of the proposed scheme has been assessed by studying its throughput performance with respect to power splitting factor as well as energy conversion factor for various values of source power and distance between the nodes.

The efficiency of the proposed scheme has been established by comparing its throughput performance with its suitable contrast scheme.

The rest of the paper is organized as follows: Section II and section III describes the proposed model and mathematical description respectively. Results are discussed in section IV. Finally, Section V concludes the paper.

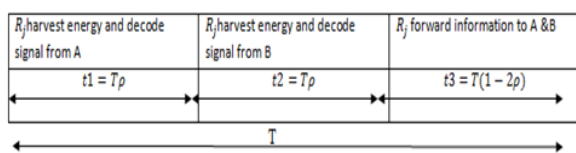
SYSTEM MODEL

The model of the proposed scheme is presented in Fig.1.



→ : Signal transmission from node A via relay to node B.
 - → : Signal transmission from node B via relay to node A

Fig. 1 Block diagram of three-step relay



For the mathematical analysis of the system model the following assumptions are taken [8]:

- Here two nodes A and B exchange information through a multi relay network where DF relays are considered.

- The distance between nodes A&B is high enough so that they need to communicate with the help of an intermediate relay network.
- Full communication is taking place for the time block “T” and since we are using three step two way method therefore the total time block “T” is partitioned into three slots with $t1=t2=T\rho$ and $t3=T(1-2\rho)$ where ρ is the time splitting factor as shown in Fig 2 [8].
- The frequency channels are considered to be constant and reciprocal over the transmission block ‘T’. It is also assumed that they are independent to each other and experience Rayleigh fading.

Total communication is taking place in the following steps:

1. In the first time slot $t1$, node A sends the signal which is received and divided into two parts with the help of a power splitter which is installed at j^{th} relay R_j . A portion of the signal received by relay is utilized for the purpose of energy harvesting and restportion is used for signal processing as evident from Fig.1.
2. The node B repeats the same process as done by the node A in the second time slot with $t2=T\rho$
3. Finally, in the third time slot $t3=T(1-2\rho)$, the j^{th} relay transmits the received signal to both the nodes A and B simultaneously.

The channel coefficient between node A to j^{th} relay at relay station and node B to j^{th} relay at relay station are considered as g_{Aj} and g_{Bj} respectively. Since multiple relays are used, best relay is selected on the basis of maximum SNR from node A to node B via relay station.

MATHEMATICAL MODELING

A. Energy harvesting and Information Processing

The Energy harvesting part:

During first two time slots $t1=t2=T\rho$ signal received at the relay is given as [8]

$$Y_{i \rightarrow R_j} = \sqrt{\frac{P_i}{d_{ij}^\alpha}} g_{ij} x_i + n_i(1)$$

where $Y_{i \rightarrow R_j}$ ($i=A,B$) is the signal sent from the source nodes to the relay R_j . P_i transmitted power which is received at j^{th} relay.

The distances from i^{th} source node to j^{th} relay are d_{ij} . The channel co-efficient from i^{th} source node to j^{th} relay are g_{ij} and the path loss is α . The signal from i^{th} node, x_i which is received with the additive

white Gaussian noise n_i , are of unit mean. The received signal is divided into two parts by power splitter: $\sqrt{\lambda}Y_{i \rightarrow R_j}$ for harvesting energy and $\sqrt{1 - \lambda}Y_{i \rightarrow R_j}$ for signal processing which depends on the value of the power splitting factor, λ_i corresponding with node $i=A, B$.

The harvested energy from i^{th} source node is given as [8]

$$E_i = \lambda_i \eta \frac{P_i}{d_{ij}^\alpha} |g_{ij}|^2 T \rho(2)$$

where η is the energy efficiency factor of the harvester.

We assume the $P = P_A = P_B$. The total energy harvested at R_j is therefore [8]:

$$E_{total} = \eta T \rho \left(\lambda_A \frac{|g_{Aj}|^2}{d_{Aj}^\alpha} + \lambda_B \frac{|g_{Bj}|^2}{d_{Bj}^\alpha} \right) (3)$$

B. The Information processing part:

A part of the received signals which is used for decoding and forwarding is given as [8]

$$Y_{R_j \text{ from } i} = \sqrt{1 - \lambda_i} \left(\sqrt{\frac{P_i}{d_{ij}^\alpha}} g_{ij} x_i + n_i \right) (4)$$

The signals \bar{x}_A and \bar{x}_B are the decoded signal from A and B, respectively during the first two time slots at j^{th} relay. During time slot t_3 , R_j sends the normalized signal x_R to the two destinations.

$$x_R = \frac{\bar{x}_A + \bar{x}_B}{\sqrt{2}} (5)$$

Furthermore, at node B [8]

$$Y_{R_j \rightarrow B} = \sqrt{\frac{P_{R_j}}{d_{Bj}^\alpha}} g_{Bj} x_R + n_B (6)$$

putting (5) into (6), at node B the signal x_A can easily be obtained from x_R by subtracting its known signal which is x_B . Here the one of the known parameters of the system is channel state information (CSI). We can estimate the signal received at B (from A via R_j) as [8]

$$\hat{x}_{A \rightarrow B} = \sqrt{\frac{P_{R_j}}{d_{Bj}^\alpha}} g_{Bj} \frac{\bar{x}_A}{\sqrt{2}} + \hat{n}_B (7)$$

where the noise at the node B has zero-mean and covariance σ_B^2 and defined as $\hat{n}_B = N(0, \sigma_B^2)$.

We assume that $\lambda_A = \lambda_B = \lambda$ because tunable or adaptive power splitter are very complicated hard to make and very expensive to implement here we have used one power splitter. So with a single power splitter with a fixed power splitting ratio λ , the power of R_j , P_R can be expressed as [8]

$$P_R = \frac{E_{total}}{T(1-2\rho)} = \eta \lambda p \left(\frac{|g_{Aj}|^2}{d_{Aj}^\alpha} + \frac{|g_{Bj}|^2}{d_{Bj}^\alpha} \right) \left(\frac{\rho}{1-2\rho} \right) (8)$$

The Outage probability and Throughput are calculated by considering the signal sent from node A to B through the relay R. The SNR of this signal at R_j , $\overline{\gamma_{R_j}}$, can be calculated from (4) as

$$\overline{\gamma_{R_j}} = \frac{P |g_{Aj}|^2 (1-\lambda)}{d_{Aj}^\alpha \sigma_A^2} (9)$$

In which σ_A^2 is variance of Gaussian noise at node A. The node B received the signal from R_j , the SNR $\overline{\gamma_B}$ is at node B is calculated [8]

$$\overline{\gamma_B} = \frac{P_{R_j} |g_{Bj}|^2}{d_{Bj}^\alpha 2 \sigma_B^2} = \frac{(|g_{Aj}|^2 d_{Bj}^\alpha + |g_{Bj}|^2 d_{Aj}^\alpha) |g_{Bj}|^2}{b} (10)$$

where, $b = \frac{d_{Bj}^\alpha d_{Aj}^\alpha 2 \sigma_B^2 (1-2\rho)}{n \lambda P \rho}$.

Note from (9) that $|g_{Aj}|^2$ has exponential distribution therefore $\overline{\gamma_{R_j}}$ also follows the exponential distribution.

$$\gamma = \min(\overline{\gamma_{R_j}}, \overline{\gamma_B}) (11)$$

where γ is the overall SNR from node A to node B.

Here we have considered L number of relays so

for $j=1, 2, 3, 4, \dots, L$

$$M = \max_i(\gamma_i) (12)$$

$$P_{out} = \Pr\{M \leq \gamma_{th}\} = \Pr\left\{ |g_{Aj}| \leq \frac{\gamma_{th} d_{Aj}^\alpha \sigma_A^2}{(1-\lambda)P} \right\} = 1 - e^{-\frac{\gamma_{th} d_{Aj}^\alpha \sigma_A^2}{(1-\lambda)P}} (13)$$

The overall throughput can be given as

$$T = (1 - P_{out}) U \rho (14)$$

where U is the source transmission rate of node A, B and R_j .

SIMULATION

The impact of various parameters on the throughput of the proposed model is analyzed in this section. A comparative performance analysis of the proposed model with the existing suitable scheme is also presented here. Simulation has been carried out using MATLAB R2015a.

The output waveforms for throughput versus power splitting factor of Two Step Three Way Relaying with single relay and multi relay are compared. For fair comparison, related parameters are set according to Table 1 [8]. The simulation results are based on equations (10), (11), (12) and (13).

Table 1 Default values

Transmission rate bits/sec/Hz	\bar{U}	3
Threshold SNR dB	$\gamma^{th}=2^{\bar{U}} - 1$	7
Energy coefficient	η	1
Path loss coefficient	α	2.7
Noise variance	$\hat{n}_i = N(0, \sigma_i^2)$	0.01
Time splitting factor	ρ	1/3
The distance between source and relay station	d_{Aj}	1

The variation of throughput relative to power splitting factor (λ) for different values of distance between relay station to destination node i.e. d_{Bj} is shown in plot 1. We have kept d_{Aj} constant and varied d_{Bj} .

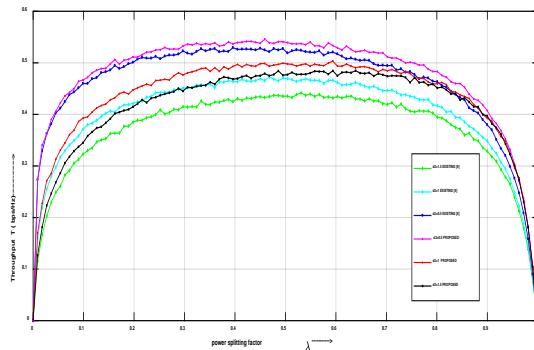


Fig.3 Throughput versus power splitting factor for various values of d_{Bj} .

In the above plot throughput is plotted against λ for different $\frac{d_{Aj}}{d_{Bj}}$ ratios and compared the proposed work with the existing work. For $\frac{d_{Aj}}{d_{Bj}} = 2$, $\frac{d_{Aj}}{d_{Bj}} = 1$ and $\frac{d_{Aj}}{d_{Bj}} = 2/3$ we have calculated the throughputs for $\lambda = 0.5$. We have got an improvement of throughput by 0.0204, 0.0287 and 0.0416 respectively for the above values of $\frac{d_{Aj}}{d_{Bj}}$.

As seen from the plots, as we increase the distance between the nodes, throughput decreases. For simulation purpose, we have kept the distance from A to R_j fixed i.e. $\frac{d_{Aj}}{d_{Bj}} = 1$. Moreover, the distance d_{Bj} is varied from 0.5 to 1.5. We have got a significant decrease in throughput as we increase the overall distance between the nodes but it is still better than the existing scheme as seen from Fig 3. It can be seen from the equation (3) that as we move the node B far from relay station, the energy harvested and the received signal strength at relay ‘ R_j ’ in the relay station decreases due to higher path loss. In the second phase i.e. information exchange phase, ‘ R_j ’ sends the received signals to both the nodes. Since during the second phase the transmitted power of R_j depends only on the amount of harvested energy during the first phase,

the strength of the received signal at B becomes weak as a result of which ‘‘Throughput’’ decreases. The percentage improvements in throughput for different values of overall distance between the nodes are shown in Table 2. The variation of throughput with respect to power splitting factor for various values of power transmitted from node A is shown in Fig. 4.

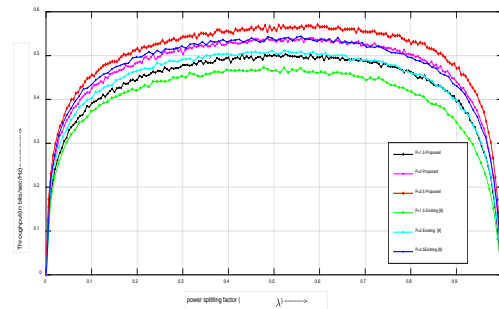


Fig.4 Throughput versus power splitting for various values of source power

In the above plot throughput is plotted against λ for different values of power transmitted from node A. It is observed that the proposed method of energy harvesting in two-way multi relay network shows a better throughput when compared with the existing scheme. As seen from the plot, throughput increases with the increase of transmitted power P up to a certain point after which throughput begins to decrease. This is because of the fact that as we increase the value of transmitted power P, the energy harvested at relay station also increases because the energy harvested is directly proportional to P as shown in equation (3). Further, the throughput also depends on the energy harvested at the relay so it will increase by increasing the value of P.

It is also observed that for $\lambda = 0.5$ there are improvements of throughput by 7.41%, 5.64% and 4.29% for $P=1.5$, $P=2$, and for $P=2.5$ respectively when compared with the existing scheme. The percentage improvements in throughput for different values of source power are shown in Table 3.

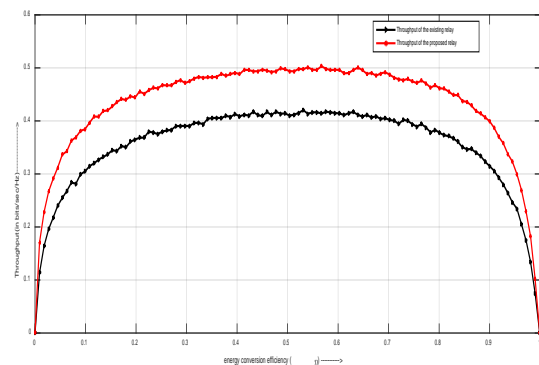


Fig.5 Throughput versus energy conversion efficiency (η)

In the above plot, throughput is plotted against η and the performance of the proposed work has been compared with the existing work. As we see that initially throughput increases with η but later it becomes almost independent of the value of η over a range. Afterwards, throughput decreases with increasing value of η . This can be explained as: For lower value of η , the amount of energy harvested will be less so throughput will also be less. As we increase η up to a certain value, more energy is harvested hence throughput also increases up to this point beyond throughput becomes almost independent of the value of η . Again, for higher value of η less amount of power is available for data transmission, hence overall throughput will be less.

The critical analysis of the above results has been presented in Table 2 and Table 3.

Table 2: Percentage Improvement of throughput for different values of λ by varying d_{Bj}

$d_{Bj}=1$ and $P=1.5$			
Power Splitting Factor (λ)	Throughput		Percentage Improvement (%)
	Existing ($d_{Bj}=1.5$)	Proposed ($d_{Bj}=1.5$)	
0.8010	0.3946	0.4512	14.3436
0.7020	0.4193	0.4740	13.0455
0.5040	0.4355	0.4771	09.5522
Power Splitting Factor (λ)	Throughput		Percentage Improvement (%)
	Existing ($d_{Bj}=1$)	Proposed ($d_{Bj}=1$)	
0.8010	0.4169	0.4597	10.2662
0.7020	0.4463	0.4847	08.6040
0.5040	0.4692	0.4979	06.1167
Power Splitting Factor (λ)	Throughput		Percentage Improvement (%)
	Existing ($d_{Bj}=0.5$)	Proposed ($d_{Bj}=0.5$)	
0.7020	0.4943	0.5114	03.4594
0.5040	0.5190	0.5394	03.9306
0.3060	0.5186	0.5364	03.4323

Table 3: Percentage Improvement of throughput for different values of λ by varying the P value

$P=1.5$			
Power Splitting Factor (λ)	Throughput		Percentage Improvement (%)
	Existing	Proposed	
0.306	0.4487	0.4784	06.6191
0.504	0.465	0.4995	07.4193
0.801	0.4164	0.4626	11.0951
For $P=2$			
Power Splitting Factor (λ)	Throughput		Percentage Improvement (%)
	Existing	Proposed	
0.306	0.4907	0.5154	05.0336
0.504	0.5027	0.5311	05.6494
0.801	0.4583	0.5016	09.4479
For $P=2.5$			
Power Splitting Factor (λ)	Throughput		Percentage Improvement (%)
	Existing	Proposed	
0.306	0.5154	0.5418	05.1222
0.504	0.5331	0.556	04.2956
0.801	0.4942	0.5264	06.5155

CONCLUSION

A novel three-step two-way DF multi relay network is proposed for RF EH. The variation of throughput is studied with respect to power splitting factor and energy conversion factor for different values of source power and distance between the nodes. The comparison of the throughput performance of the proposed scheme with the contrast scheme clearly establishes the supremacy of the developed model over the existing one. Present work can be extended to untrusted scenarios. Studying of secrecy performance incorporating a cluster of interferers can be another future area of research.

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