Abstract—Energy harvesting (EH) and simultaneous wireless information and power transfer (SWIPT) is promising solution for energy constrained network. In this paper, we propose multi-relay selection (MRS) algorithm and adopt relay ordering criterion based on maximum harvested power to improve the performance and life time of battery dependent nodes. We adopt amplify and forward (AF) based relaying strategy for optimum relay selection subset $N$ from available $M$ relays. Simulation and numerical results demonstrated that our proposed scheme is optimum in terms of energy efficiency and system outage probability.

I. INTRODUCTION

Energy harvesting (EH) has gained the substantial attention of researcher in academia and industry to provide solution for battery constrained wireless networks where battery replacement and recharging is infeasible in hazardous environment e.g.; nuclear plants, sensor implanted in human body [1], as well as promising technology to reduce emission of $CO_2$ and greenhouse impact on environment [2] which is 0.7% of telecommunication sector [3]. Simultaneous wireless information and power transfer (SWIPT) with EH enables harvesting ambient radio frequency (RF) signals from the environment to prolong the life time of energy constrained wireless network. Thus energy constrained nodes can scavenge energy and process information simultaneously [4]. The SWIPT-EH scheme for a single input single output (SISO) channel was studied in [5]. Motivated by the benefits of multi antenna techniques, SWIPT for multiple input multiple output (MIMO) and multiple input single output (MISO) broadcast channels was investigated in [6]. The SWIPT schemes for MIMO relay networks were studied in [7]. Performance of EH system with a simple relay selection scheme was analysed in [8], where the selection is based on the current available energy and CSI. In [9], author discussed practical schemes for SWIPT on time switching (TS) and power splitting (PS) under cognitive radio (CR) network consider point to point transmission with or with out CSI.

In the context of relaying strategies, transmission policies for enabling wireless EH and information processing at the energy constrained relay is developed in [9],[10]. Relaying strategy is extensively studied due to its ability to overcome mitigating, fading and path loss effect in wireless communication. Relay has capability to extend the coverage area and spatial diversity gain without enlarging transmit power.

Recently, bi-directional or two-way relaying strategy has gained much attention in wireless networks to overcome the path loss, fading and transmission limitation. Two-way relaying network improve the bandwidth efficiency by allowing users to transmit data simultaneously [11]. The most popular protocols for multi hop relay networks are amplify-and-forward (AF) and the decode-and-forward (DF). AF protocol has less computation complexity because its simply amplify the received signal and forward to destination without decoding. Single relay selection (SRS) considering signal to noise ratio (SNR) was proposed in [12], while power allocation for relay ordering was investigated in [13], multi relay selection scheme based on CSI provide better performance but as overhead in terms of cost and complexity, then author proposed a power allocation scheme for relays with out analysing the relay selection criterion. Single relay selection (SRS) and multi relay selection (MRS) schemes were proposed in [14], where trusted relay channel is selected based on CSI to minimize the system outage probability. In [15], DF based relaying scheme to minimize the average sum bit error rate (BER) was proposed where two relays were selected from available relays.

Much research efforts has been devoted in two way relay networks, while research on SRS in wireless networks is frequently available in the literature. Research on MRS in which more than one relay can be selected for energy constrained network require more attention. By our best knowledge, the research in EH with MRS scheme is very limited, so this motivated us to exploit the multi relay selection by joining the benefits of energy harvesting. This offers solid foundation for our research to combine EH and multi-relay selection inspired by [15], where authors have proposed the spectrum sharing protocol in cognitive two-way relay networks with out considering relay ordering and energy storage. We consider AF relay networks and propose MRS schemes that is different from [16], which is for DF relaying. By comparing the results in [15],[16], our proposed scheme is better in terms of energy efficiency for the energy constrained nodes.

In this paper, we investigate energy harvesting and information transfer in multi-relay based network to increase the life time of battery dependent nodes. The proposed scheme enables an energy harvesting and information transfer under multi-relay $M$ selection from sub set of available $N$ relays. We propose the efficient relay selection algorithm to minimize the computation complexity by adopting relay ordering that enhance the system performance. We consider all nodes equipped with single antenna and can not receive and transmit
at the same time. We present analytical expressions for the outage probability of the system. The derived outage probability provides a useful insight that enables the proposed scheme to achieve a better outage performance compared with the direct transmission. Finally, numerical results provide valuable insights for the impact of various system parameters.

II. SYSTEM MODEL DESCRIPTION

We begin by describing the architecture of the wireless network with energy harvesting and multi relay selection.

A. System Model

We consider a single-hop wireless network where a user $S$ attempts to deliver information to the user $D$. Let suppose the following scenario that $D$ is not within the transmission range of $S$ and thus requires intermediate relay nodes to facilitate communication. We consider that there exists total $M$ number of relays which are willing to act as the relay node to help the transmission. Furthermore, all nodes are the half-duplex constrained and equipped with single antenna and can not receive and transmit at the same time [17]. The whole process can be divided in in two phases [18].

In the first phase, the source node $S$ broadcasts its information to all relay nodes $M$. We assume that user $S$ has a fixed power supply, i.e., $P_S$, where there is no fixed energy supply for the relay nodes and thus needs to harvest energy from the received signals.

In the second phase, efficient relay selection algorithm helps to select $N$ relays based on the harvested power and transfer the information to the destination node $D$. We assume that the direct link between $S$ and $D$ in is deep fading so at $D$, we ignore the signal which directly comes from $S$.

All channels undergo the quasi-static Rayleigh fading channel [19]. Let $g_i$ and $h_j$ be the channel coefficients between $S$ and $R_i$, $R_i$ and $D$, respectively. We thus have $g_i \sim \mathcal{CN}(0, \Omega_i)$ and $h_j \sim \mathcal{CN}(0, \Omega_j)$ for $i = 1, 2 \cdots M$ and for $j = 1, 2 \cdots N$. They are modeled as zero-mean complex gaussian random variables with variances $\Omega_i$ and $\Omega_j$ respectively.

B. Energy Harvesting and Information Transfer

As shown in Fig. 1, the energy harvesting and information transfer process includes two phases. In phase 1, the user $S$ transmits its signal to the relay nodes $R_i$. Thus, the received signals at $R_i$ can be expressed as

$$y_{R_i} = \sqrt{P_s} g_i x + n_i \tag{1}$$

Here, $x$ is the unit-power signal intended for $D$. $n_1 \sim \mathcal{CN}(0, \sigma_i^2)$ denotes the narrow-band Gaussian noise introduced by the antenna at $R_i$ and $i = 1, 2, \cdots, M$. According to power splitting method [20], the received information at relay nodes can be divided into two parts, one for energy harvesting while the other one for information transfer. The given expression below presents energy harvesting at relay nodes during the first phase

$$\sqrt{\lambda} y_{R_i} = \sqrt{\lambda P_{s,R_i}} g_i x + \sqrt{\lambda} n_i \tag{2}$$

Here, $0 < \lambda < 1$ represents the portion of information split for energy harvesting at $R_i$. It is worth noting that $R_i$ exploits all the harvested energy to forward the received signal to $D$, resulting $\lambda \neq 0$ or $\lambda \neq 1$. Now, we calculate the transmitted power received on the relay node $R_i$ as

$$P_{R_i} = \eta \lambda P_s |g|^2 \tag{3}$$

The stored energy at $R_i$ is computed as

$$E_h = \frac{1}{2} \eta \lambda P_s |g|^2. \tag{4}$$

Here, $0 \leq \eta \leq 1$ represents the energy conversion efficiency. The coefficient $1/2$ is following the fact that the time duration of each phase is normalized to $1/2$. During the phase 2, the relay nodes $R_i$ needs to forward the information based on the AF and superposition coding scheme. Relay nodes can split its harvested power into two parts: $P_{R_i} = \alpha P_{R_i} + (1-\alpha) P_{R_i}$. $\alpha P_{R_i}$ is used to forward the remaining primary information $\sqrt{1-\lambda} y_{R_i}$ transmitted from $S$ to the user $D$, whereas $(1-\alpha) P_{R_i}$ is used to store at relays for future use. The transmitting information at the relay nodes $R_i$ is given by

$$x_{R_i} = \beta \sqrt{\lambda P_{R_i}} (\sqrt{1-\lambda} y_{R_i})$$

represents the white Gaussian noise introduced by the signal conversion from passband to baseband at $R_i$. The power normalization factor $\beta$ of $R_i$ is given by

$$\beta = \frac{1}{\sqrt{(1-\lambda)(\sigma_i^2 + \sigma_j^2)} + \frac{\sigma_i^2}{\sigma_j^2}} \approx \frac{1}{\sqrt{(1-\lambda) P_s |g|^2}}. \tag{6}$$

where the approximation is tight at high SNR. The power vector $p = [P_1, P_2, P_3 \cdots P_M]$ represents the harvested power of each node while, each relay node may have different level of power but the total power $P \leq P_{max}$. We consider the Maximal ratio combiner (MRC) [21] to combine the signals received from the $N$ relay nodes involved in the transmission process. In order to simplify the analysis, we assume that $\sigma_1 = \sigma_2 = \sigma_0$. Signal received at $D$ can be presented as

$$y_{D,i} = \sqrt{P_{R_i}(1-\lambda)} y_{R_i} h_i + n_i \tag{7}$$
where $a$ is a weight of MRC which is dependent on $\eta$

where, $\eta_i = \sqrt{P_s P_j g_j^* h_j^*}/[(P_s \beta^2_i |g_i|^2 + 1)\sigma_0], \forall \ i = 1, 2, \cdots, M \ and \ j = 1, 2 \cdots N$ and $(\cdot)^*$ represents the conjugate function. The total SNR at the destination $D$ can be represented as

$$\gamma = \sum_{i=1}^{N} \frac{P_s \sigma_0 |g|^2 P_j |h|^2}{\sigma_0^2 |g|^2 + P_s \sigma_0 |h|^2 + 1}$$  \hspace{1cm} (9)$$

We further consider that the link between source and destination is in deep fading or negligible due to poor transmission, the upper bound of system outage probability can be given by [21],[22]

$$P_{out}(P, R) = \frac{\sigma_0^N}{N!} \prod_{i=1}^{N} \frac{P_s \Omega_2^2 + P_R \Omega_3^2}{P_s \Omega_2^2 P_R \Omega_3^2} (2(2N+1)R - 1)^N$$ \hspace{1cm} (10)$$

### III. Multi Relay Selection Scheme

In this section, we propose Multi relay selection scheme based on outage probability upper bound under maximum harvested power. For a relaying network where $M$ relay nodes are available, $N$ number of relays will be selected for transmission. If maximum power first used in optimal relay selection search, then we need to find out the power of each relay node then add the power of $N$ relays to fulfill the power requirement for transmission to destination node $D$. The computation complexity increases exponentially with $M$ and it is obviously undesirable. In order to decrease computation complexity, we introduce the idea of relay ordering on the basis of maximum power first criteria. The original selected relay set is expressed as $R_i = R_1, R_2, R_3, \cdots R_M$ and the number of selected relays will always equal to or less than the total number of available relays. So the computation complexity after applying relay ordering is decreased. From Eq. (9) we can see that, for a certain relay node $R_i$, its contribution factor in the outage upper bound can be described by the following expression

$$\phi_i = \frac{P_s \Omega_2^2 + P_i \Omega_3^2}{P_s \Omega_2^2 P_i \Omega_3^2}$$ \hspace{1cm} (11)$$

We observe smaller value of $\phi_i$ when channel condition is better because contribution factor depends on $P_s$ or $P_i$ that leads to optimal power allocation under such circumstances. We use this ordering result in the following $N$ relay selection scheme all the time. We observe that when the proposed ordering criterion is selected the computation complexity gets smaller. Simulation results verify that it performs close to the optimal exhaustive search scheme. Relay selection scheme consists of two steps, first finding the power of each relay and then selection of $N$ relays where the total power of $N$ relays is sufficient to transmit the remaining information to the destination node. In the relay selection procedure, we need to find the total power of $N$ relays by using the given algorithm, then we calculate the outage probability upper bound according to Eq. (9).

We consider source node $S$ broadcast signals to all relay nodes $M$ in first phase. The power at each relay is different due to path loss and fading factors. In step 2, Power calculation is performed at $R_i$ to transmit data to destination $D$. We consider the relay which has maximum power to transfer data, rest of relays energy is stored for next phase. In step 4, If power at $R_i$ is less than the required power then find another relay $N$ which has maximum power, select and combine those relay power to transfer data. Calculate the outage probability to measure the performance.

### IV. Simulations

Fig.2, shows the EE comparison with different SNR, numerical and simulation results demonstrate peak point where EE attain highest value. Before reaching this point, EE increases as SNR(dB) increases, here EE and SNR behaviour is directly proportional. After peak point, we observe the the EE and SNR relation are opposite and EE alter sharply. The most desirable value of SNR for achieving EE is 15 dB. The position
validate the accuracy of our results and provide a valuable insight to our proposed scheme. In this model, we consider the distance between user $S$ and $D$ is normalized. Let $d_1$ and $d_2$ represents the distance between $S$ and $R_i$, $R_j$ and $D$, respectively, thus we have $d_1=1-d_2$. We further consider large scale path loss and we have $\Omega_i = 1/d_1^2$ and $\Omega_j = 1/d_3^2$ for $g_i$ and $h_j$ receptively.

In Fig. 4, we verify the analytical results for outage probability through simulation under different SNR. We find from the figure that analytical results show a good agreement with the simulation results. Moreover, we observe that the lower bound and upper bound is quite appropriate as these bounds are tight. As shown in this figure, the simulation results of user $S$ and $D$ are coincident on account of the fact the at parameters of these two users are uniform.

V. Conclusion

In this paper, we present an efficient energy harvesting and power transfer scheme based on amplify and forward (AF) relaying strategy. We develop an algorithm that efficiently selects the $N$ relay out of $M$ on the basis of Maximum harvested power. We suggest relay ordering to minimize the relay selection complexity. Hence numerical and simulation results demonstrated that our proposed scheme is optimum in term of energy efficiency and achieve better results as compared to direct transmission. In future research work, we will consider the energy harvesting with efficient MRS selection for secure communication.

REFERENCES


