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Opportunistic-Harvesting: RF Wireless Power Transfer Scheme for Multiple Access Relays System

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ABSTRACT Wireless communications have become one of the main stake holders on which our contemporary world relies for carrying out many daily activities. In this era, the number of connected devices is increasing rapidly, contemplating not only smart phone, but also growing connectivity of machines, sensors, and so on. Therefore, it is important to investigate the alternative energy sources for powering these connected small devices. In this paper, we design an RF wireless power transfer scheme for multiple access relay system model with different signal transmission schemes. Here, it is assumed that the sources and relay are self-powered devices and fitted in with rechargeable batteries. Therefore, each node is powered by an RF wireless power transfer that relies on a dedicated energy beam sent from the destination (serves as a power beacon) and other RF transmission links and such approach is referred as *opportunistic-harvesting* (OH) scheme. An idea of message combining resorting to network coding (NC) and physical layer NC is presented. Performance is demonstrated in terms of error rate and outage probability analyses by using OH. The schemes presented in this paper contribute substantially to sustaining the energy in the proposed scheme.

INDEX TERMS Wireless power transfer, energy harvesting, cooperative communication, relay networks, network coding.

I. INTRODUCTION

Development of wireless communication networks, connected devices, and improvement of Internet of Things (IoT) have deeply impacted in every aspect of human life. The growing demand for energy in the world set for front challenges in the future research. Hence, a natural spin from the traditional and limited energy sources to alternative energy sources is a natural step to supply the exponential growth of energy demand of the mankind. RF energy harvesting has received tremendous attention in the recent years as it lengthens the life of energy limited wireless devices. Therefore, simultaneous RF wireless power transfer (WPT) [1], [2] has become promising advances to enable new ways of information and power delivery. In this paper, we present a cooperative communication network with a WPT assisted nodes as an RF wireless power transfer cooperative network. In fact, the design and performance analysis of RF wireless power transfer have attracted substantial attention recently (see, e.g., [3], [4]).

In general, the traditional wireless networks are powered by a fixed power supply. However, frequent replacing and recharging may be cumbersome due to several reasons including a large number of connected devices, labor involvement, and the location of the wireless device (remote areas and forests etc. where access is limited or infeasible). Network links are entirely energised by ambient radio signals, such as the TV and radio broadcasting, wireless transmission and power transfer across a noisy coupled-inductor circuit as in [5]. A network structure that uses RF power transfer over cellular networks with power beacons is studied using stochastic geometry in [6]. Wireless power transfer via RF signals is considered for cognitive radio wireless networks in [7]. Here, secondary transmitters harvest energy from ambient RF signal of nearby active primary transmitters. RF-based wireless power transfer for relay schemes and its technical fundamentals together with advanced schemes like simultaneous information and power transfer is explained in [8]. This also provides a handful description about interference exploitation as a useful source as RF energy harvesting. A comprehensive review and recent development on RF energy harvesting schemes are given in [9]–[13].

As the current set-up of RF wireless power transfer enabled communication system harvests relatively a little energy in each operation cycle, it is important to link the node with a rechargeable battery or a suitable storage device, otherwise, it will lead to performance degradation. The energy accumulation process of cooperative wireless networks with a self-powered relay depends on a single wireless power transfer as modeled in [14]–[16]. These works assumed no direct link between the source to destination, however, this is disadvantageous as in certain attempts, and harvested energy may be smaller than the required energy storage to maintain a reliable communication. In such a situation, the destination can rely on the direct link. In our previous work, we have considered the *store-then-cooperate* fashion with a direct link [17], [18].

The fundamental idea of physical layer network coding (PLNC) is to exploit the combination of signals that arises naturally when electromagnetic (EM) waves are superimposed on each other. In particular, at a receiver, the transmissions at the same time by wireless nodes result in the reception of a weighted sum of the signals [19]. Cooperative relay based wireless system is an ideal technique in combating the fading effects [20]–[26]. The relay nodes, in general, energised by a limited power supply, this adversely affects their lifetime. Wireless power transfer is considered for cognitive radio networks in [7]. Then, the same set up from a practical point of view is analyzed in [27] by assuming hardware impairment and their impact on the system performance. A classic multi-user radio frequency wireless power transfer (RF-WPT) rate analysis and trade-off are first analyzed in [28]. Following this, a scheme for RF-WPT using *harvest-then-transmit* protocol is given in [30] using TDMA fashion, however, there is no direction presented for saving excessive energy in the battery.

The motivation of this work is to investigate the system that uses PLNC and network coding (NC) schemes and present a flexible RF wireless power transfer scheme to sustain the energy needs of the system along with the improvement in symbol error rate and the outage probability of the system. In this work, we propose two main systems using NC and PLNC over multiple access relay system (with multiple relays) in order to boost the overall energy sustainability of the system. The proposed strategy appears to be simple, but it is an efficient system in improving the system level operation. This architecture can be employed within wireless sensor networks or injunction with other indoor applications.

Our three-fold contributions of this paper are summarized below:

- We investigate two signal transmissions and RF-WPT assisted scheme in a multiple access multi-relay systems using PLNC and NC. We outline the direct power supply scheme as our baseline scheme.
- We propose a new energy harvesting scheme called *Opportunistic-Harvesting* (OH), which is an improved scheme based on two energy harvest schemes, namely, *energy-harvest* (EH) and *store-then-cooperate* (STC) in [17] and [18]. OH maintains the ratio of energy harvested by the source and the relay in the system to be at the desired level. However, as in [17], [18], the system requires both the EH and STC schemes, which are applied in a dynamic switch algorithm (Algorithm 1 in [17] and [18]) to maintain the ratio of energy harvested from the source and the relay in the system.
- Both OH and DPS schemes use the equal amount of energy. The symbol error rate performance of OH scheme is improved as compared to the system using DPS scheme, which is proved with the simulation results. Also, the outage probability analysis of the system model with network coding signal transmission scheme shows that the performance of OH scheme is better as compared to the EH scheme given in [17] and [18].

Our objective is to sustain or improve the system performance through RF energy harvesting. We design a flexible energy harvesting scheme called *opportunistic harvesting* scheme.

In order to understand the impact of the energy harvesting scheme on the quality of the signal (QoS), we set equal time and energy resource for all the energy source methods that are discussed in the paper, i.e., DPS and OH. QoS is studied using system performance parameters like symbol error rate (SER) and outage probability (OP).

The structure of the paper and main objectives are explained below.

1. Section II explains a multiple access relay system (with multiple parallel relays).
   The purpose of choosing this system model is to exploit different signal transmission scheme and power transmission scheme. Also the multiple relays with limited resource (all nodes will share a fixed amount of energy and time duration) used in system will help to understand the impact of diversity order of the signal.
2. In Section II, we choose NC and PLNC as message combining transmission schemes. Thereby, to design OH according to different message combining schemes and compare its performance between the message combining schemes and also to the system with DPS.
3. In Section III-A and Section III-B, we explain the baseline DPS and energy harvesting scheme OH, respectively. In DPS scheme, we derive a value for the energy to be used in all the system models. E_{DPS} is the total energy used by all the system, irrespective of

the number of relays and the signal transmission scheme used in the system. E_{DPS} value is found by using the power supply and time duration consumed by the system as in (16).

The OH scheme is designed for both the NC-mR and PLNC-mR systems. OH scheme is a flexible scheme as it allows the user to decide the energy harvesting ratio, $\delta_{I/R}$ between the amount of energy harvested in relay node and source node. $\delta_{I/R}$ is set with the help of adjusting the time duration of initial energy harvesting phase i.e., T_{EH}.

Also, the total time allocated is equal for all the system models. This helps to study the symbol error rate and the outage probability of the system under equal energy and time resources. Thereby, we demonstrate the practical possible application of RF energy harvesting without sacrificing other radio resources.

4 In Section IV, the outage probability for the presented system models is derived, namely, NC using DPS, PLNC using DPS, NC using OH and PLNC using OH, respectively.

Simulations results are presented in Section V, and, finally, the paper concluded in Section VI.

II. SYSTEM MODEL

A multiple access relay system (MARS) is considered, which consists of two information sources A and B, m relays R_i, $i = 1, 2, \ldots, m$ and a destination D. R_i receives signals from each source and then re-transmits to the destination after *Zero-forcing detection (ZFD)*. The destination serves as a hybrid access point (HAP). This employs two separate antennas for information receiving and energy harvesting as explained in [29]. It is assumed that the nodes does not experience signal interference during simultaneous information transmission and energy transfer due to different frequencies of RF signals used for information transmission and energy transfer. High frequency RF signals are used for energy transfer and relatively low frequency RF signals are used for information transmission. Quadrature Phase Shift Keying (QPSK) modulation is used and it is assumed that all the channels experience AWGN noise with variance of N_0.

The system model is investigated with the different signal transmission schemes. The two signal transmission schemes are physical layer network coding (PLNC) and network coding (NC) operation at the relay and the destination. The two power supply schemes are fixed power supply scheme and wireless power transfer scheme.

All the notations used in this paper are described as below.

- Sources A and B are denoted as I where $I \in \{A, B\}$. The number of relays in PLNC-mR and NC-mR is R_i, where the relays are indexed by $i \in \{1, 2, \ldots, m\}$.
- P_I and P_R is specified as average signal transmission power at the nodes I and R, respectively. X_I and X_R are QPSK symbols of I and R, respectively. The real and imaginary parts of signal X are denoted as $\Re(X)$ and $\Im(X)$, respectively.
- In Figure 1a, 2a, 3a and 4a, the channel link from the node I to destination D is denoted as link ID. Similarly, all the channel links are denoted as $\{ID, IR, RD\}$ and the corresponding distances between pairs of nodes are given as $\{d_{ID}, d_{IR}, d_{RD}\}$, respectively.
- The Gaussian channel links $\{ID, IR, RD\}$ are represented as $\{H_{ID}, H_{IR}, H_{RD}\}$, respectively. $H_{ID} = 10\Psi\log(d_{ID})$, $H_{IR} = 10\Psi\log(d_{IR})$ and $H_{RD} = 10\Psi\log(d_{RD})$, where Ψ is the path loss factor.
- The modulo addition operation is denoted as $\oplus$. The extrinsic information symbol and estimation of the information of a QPSK symbol a is referred as $\widehat{a}$ and $\tilde{a}$, respectively.
- The log-likelihood ratio (LLR) of channel links ID and RD are designated as L_{ID} and L_{RD}, respectively.
- The time duration for each time cycle is denoted as T.
- RF energy harvested in I and R using the power transmitted from the D, P_D are given as E_I and E_R, respectively. The ratio between the energy harvested in I and R is given as $\delta_{I/R}$.
- RF energy harvesting efficiency is denoted as η_{EH} where $0 < \eta_{EH} < 1$.
- Power attenuation is given as ζ_{DI} and ζ_{DR} for channel links DI and DR, respectively.
- The percentage of time allocated for energy harvesting phase is denoted as T_{EH}.
- The total number of signal transmissions in each system model is given as n_{tx}. The power used in each transmission and the total power used in all the transmissions is denoted as P_{tx} and P_t, respectively.
- The threshold energy E_{EH} is the energy required for each node to transmit the signal.

In following subsections, NC and PLNC schemes for MARS with the single relay are discussed and the system model is further extended to multiple relay system. The single relay and multiple relay system of MARS with NC operation are named as NC-1R and NC-mR, respectively. The single relay and multiple relay system of MARS with PLNC operation are named as PLNC-1R and PLNC-mR, respectively.

A. NETWORK CODING ON A SINGLE RELAY SYSTEM (NC-1R)

This system consists of two sources, a relay and destination as shown in Figure 1a. The relay receives signals from each source and uses the ZFD. Then, the relay undergo network coding operation on the received signals. Then, the relay retransmits network coded symbols to the destination [31]. The destination extracts the extrinsic information received (this is performed by using minimum mean square error (MMSE) estimation i.e. the forms to be in the tanh domain) from the relay R. This adds to the respective sources' LLRs in order to jointly estimate the sources' signal at D [21].

The sources A and B have direct channel links to D. The system has three equal time slots in an operation cycle, the time duration for each time slot is equally divided such that $\frac{T}{3}$ as it is shown in Figure 1b.

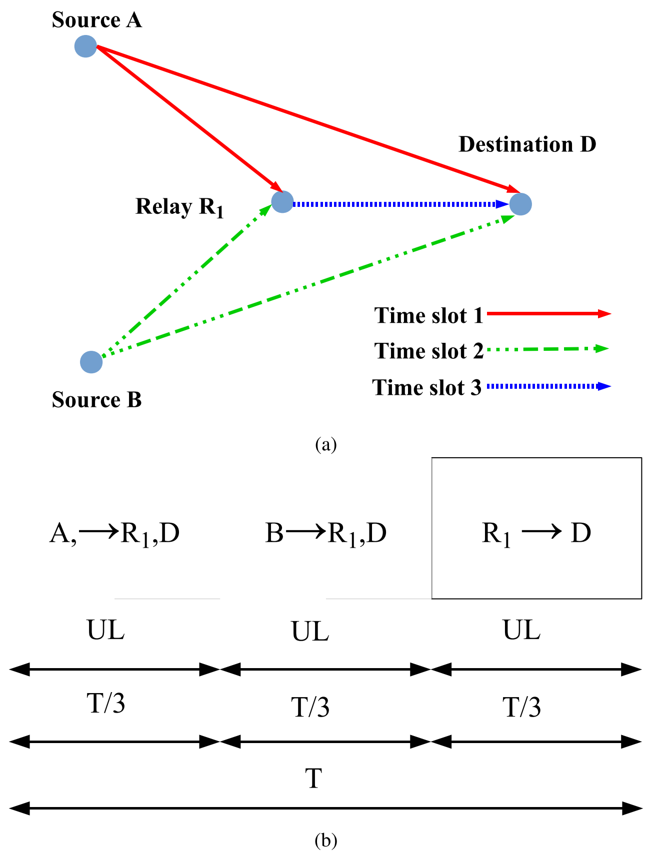

FIGURE 1. System model and its time slot diagram of NC-1R with DPS scheme. (a) NC-1R model with DPS scheme. (b) Time slot diagram of NC-1R model with DPS scheme.

The received signals at the destination from I and R in the first and second times slots, respectively, can be expressed by

$$Y_{ID} = \sqrt{P_I} H_{ID} X_I + N_{ID},$$
$$Y_{IR} = \sqrt{P_I} H_{IR} X_I + N_{IR}. \quad (1)$$

The real and imaginary parts of $\widehat{X}_A$ and $\widehat{X}_B$ are detected from the received signals Y_{AR} and Y_{BR} respectively, by using ZFD. As in Figure 1a, the detected signals Y_{AR} and Y_{BR} are combined using the network coding operation in the third time slot. Then, the network coded signal X_R can be computed as $\Re(\widehat{X}_R)+j\Im(\widehat{X}_R) = X_R$, where $\Re(\widehat{X}_R) = \Re(\widehat{X}_A) \oplus \Re(\widehat{X}_B)$, $\Im(\widehat{X}_R) = \Im(\widehat{X}_A) \oplus \Im(\widehat{X}_B)$, and $j = \sqrt{-1}$. The received signal at D from R is given by

$$Y_{RD} = \sqrt{P_R} H_{RD} X_R + N_{RD}. \quad (2)$$

The LLR estimations for the real part of QPSK signals Y_{ID} and Y_{RD} are given as[1]

$$L_{ID,Real} = \frac{2\sqrt{P_I}|H_{ID}|^2}{\sigma_{ID}^2} \cdot \Re\left(\frac{Y_{ID}}{H_{ID}}\right),$$
$$L_{RD,Real} = \frac{2\sqrt{P_R}|H_{RD}|^2}{\sigma_{RD}^2} \cdot \Re\left(\frac{Y_{RD}}{H_{RD}}\right). \quad (3)$$

[1]Similarly, we obtain the LLR estimation for imaginary part of the received symbols of Y_{ID} and Y_{RD}.

The QPSK symbol X_{ID} at D is estimated by using these LLRs in (3). The extrinsic information $\widehat{L}_{ID}$ is estimated by resorting to the diversity of the received signals at D. The real and imaginary parts of extrinsic LLR of the link ID are estimated by using network decoding operation with LLR of the link[2] $\bar{I}D$ and RD as given below in *tanh* domain

$$\tilde{L}_{ID,Real} = 2\tanh^{-1}\left\{\left(\tanh\left[\frac{\Re(L_{\bar{I}D})}{2}\right]\right) \times \left(\tanh\left[\frac{\Re(L_{RD})}{2}\right]\right)\right\}. \quad (4)$$

In [21], the authors use (4) for binary phase shift keying (BPSK) signal and here we modified it for QPSK signal by treating QPSK symbol as two BPSK bearings. The extrinsic LLRs of X_I received from R, $\tilde{L}_{ID,Real}$, is added to bit LLRs of $\tilde{L}_I$ in order to obtain estimated LLR $\widehat{L}_I$ at D. We compute the real part of $\tilde{L}_I$ as $\tilde{L}_{I,Real} = \tilde{L}_{ID,Real} + \Re(L_{ID})$ and we similarly obtain imaginary part. Then, we form the final LLR by combining the real and imaginary parts of L_I as

$$\tilde{L}_I = \tilde{L}_{I,Real} + j\tilde{L}_{I,Imag}. \quad (5)$$

B. NETWORK CODING IN MULTIPLE RELAY SYSTEM (NC-mR)

The multiple relay system model NC-mR is the extension of single relay system NC-1R. The system operates with two sources A and B, the m number of relays and the destination D as shown in Figure 2a. The number of relays in NC-mR is $\boldsymbol{R}_i = R_1, \ldots, R_m$. The system model NC-mR is similar to NC-1R but it has multiple relays $\boldsymbol{R}_i$ instead of single relay R_1. The information phase of NC-mR possesses $(2+m)$ number of time slots and $\frac{T}{(2+m)}$ is the time duration for each time slot as shown in Figure 2b. In the first time slot, A broadcasts signal to $\boldsymbol{R}_i$ and D and in the second time slot, B broadcasts signal to $\boldsymbol{R}_i$ and D. The relays $\boldsymbol{R}_i$ perform network coding operation as similar to the previous case (i.e., R_1 in NC-1R). The relays $\boldsymbol{R}_i$ re-transmit the network coded signal in the 3^{rd}, .., $(2+m)^{th}$ time slots, respectively.

The system model equations and LLR estimates of the NC-mR are same as the NC-1R. The relay R represents relay R_i of Figure 2a in (1), (2) and (3) while $i = 1$.

The diversity order will increase with an increase in the number of relays in addition to the direct signal from the source. In the case of NC-mR, the maximum diversity is achieved by combining the extrinsic LLRs of all the available relays. Thus, the LLRs can be expressed as

$$\tilde{L}_{ID,Real} = \sum_{i=1}^{m} 2\tanh^{-1}\left\{\left(\tanh\left[\frac{\Re(L_{\bar{I}D})}{2}\right]\right) \times \left(\tanh\left[\frac{\Re(L_{RiD})}{2}\right]\right)\right\}, \quad (6)$$

where $\Re(L_{RiD})$ is the LLR estimation for the real part of the QPSK symbols received at the destination from the relays R_i.

[2]The subscript $\bar{I}$ refers to the opposite source when source I is considered.

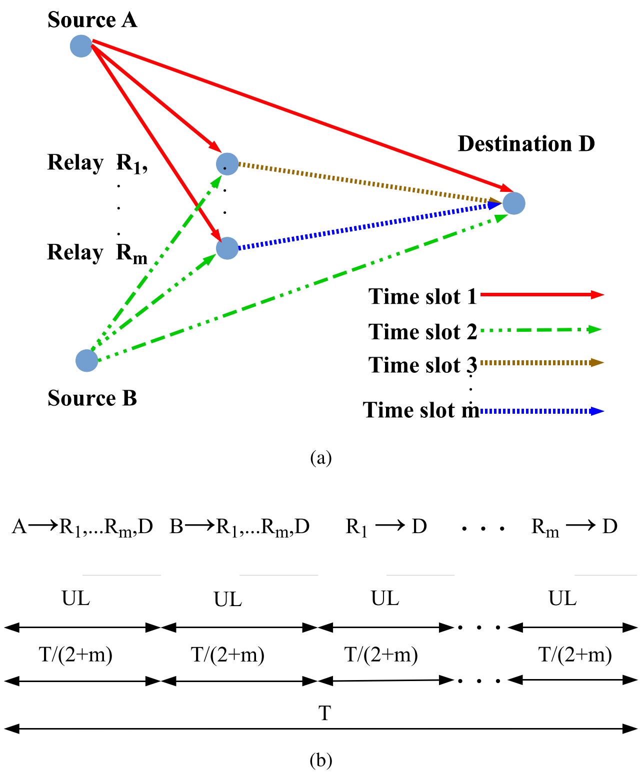

FIGURE 2. System model and its time slot diagram of NC-mR with DPS scheme. (a) NC-mR model with DPS scheme. (b) Time slot diagram of NC-mR model with DPS scheme.

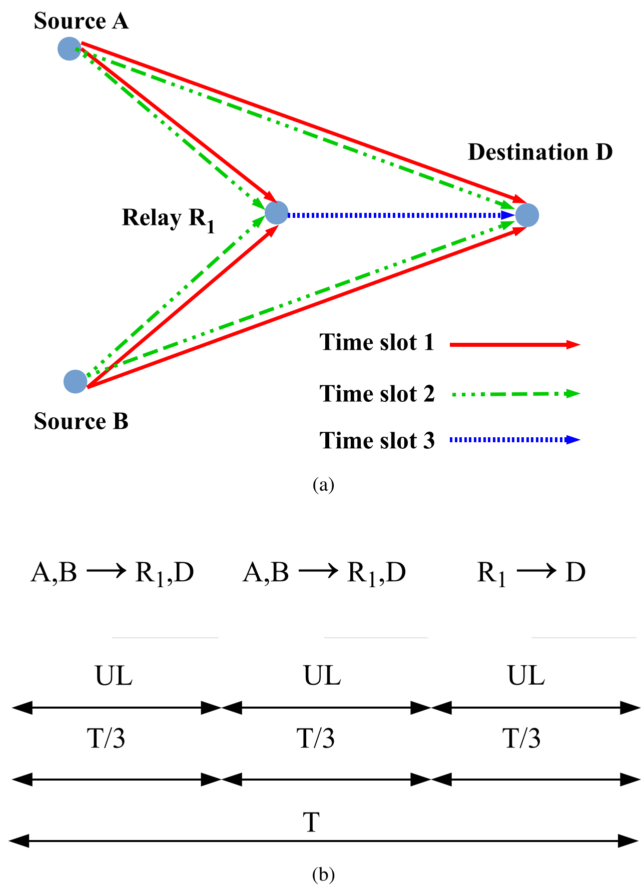

FIGURE 3. System model and its time slot diagram of PLNC-1R with DPS scheme. (a) PLNC-1R model with DPS scheme. (b) Time slot diagram of PLNC-1R model with DPS scheme.

Similarly, the imaginary part of extrinsic LLR L_I can be obtained. Then, final LLR can be computed by combining the real and imaginary parts of L_I as

$$\tilde{L}_I = \tilde{L}_{I,Real} + j\tilde{L}_{I,Imag}\ . \tag{7}$$

C. PHYSICAL LAYER NETWORK CODING IN SINGLE RELAY SYSTEM (PLNC-1R)

The system model PLNC-1R is a MARS with the sources A and B, the relay R and the destination D as shown in Figure 3a. The information phase of PLNC-1R has three time slots and $\frac{T}{3}$ is the time duration for each time slot as shown in Figure 3b. In the first time slot, A and B broadcast signals X_A and X_B, respectively, as a PLNC symbol to D and R. In the second time slot, A and B broadcast signals X_A and $-X_B$ respectively, as a PLNC signal to D and R. Any one of the symbols should be inversed in any one of the time slots. X_B is selected as the inverted symbol in the second time slot.

In the third time slot, R decodes the signal using the ZFD method and then retransmits the decoded signal to D. PLNC-1R uses the physical layer network coding cancellation method in both the relay and destination as they receive the same PLNC signal twice from both the sources in the first- and second-time slots [31]. In the second time slot, source B transmits the inverse version of the same signal (X_B as $-X_B$) which is transmitted in the first time slot. The information from B can be canceled by combining the PLNC signals from the first- and second-time slot. Thus, R and D have two versions of the signal from A and B. Then, both R and D decodes the signal X_A and X_B by using the ZFD method and then the relay retransmits either X_A or X_B based on signal to noise ratio (SNR) of the detected signal to the destination. Here, we assume X_A has higher SNR than X_B. D decodes the received signal from R using ZFD method. D combines all the decoded versions of X_A. Then, D can use two different methods to detect X_A and X_B.

The received signals at D and R from A and B in the first time slot can be written as

$$\begin{aligned} Y_{D\_T1} &= \sqrt{P_A}H_{AD}X_A + \sqrt{P_B}H_{BD}X_B + N_{D\_T1}, \\ Y_{R\_T1} &= \sqrt{P_A}H_{AR}X_A + \sqrt{P_B}H_{BR}X_B + N_{R\_T1}. \end{aligned} \tag{8}$$

The received signals at D and R from A and B in the second time slot can be written as

$$\begin{aligned} Y_{D\_T2} &= \sqrt{P_A}H_{AD}X_A - \sqrt{P_B}H_{BD}X_B + N_{D\_T2}, \\ Y_{R\_T2} &= \sqrt{P_A}H_{AR}X_A - \sqrt{P_B}H_{BR}X_B + N_{R\_T2}, \end{aligned} \tag{9}$$

where signal from source B in the second time slot is the inverse of the same signal sent. The relay performs the

PLNC cancellation via $\widehat{X}_A = f_{ad}(Y_{R\_T1}, Y_{R\_T2})$ and $\widehat{X}_B = f_{ad}(Y_{R\_T1}, -Y_{R\_T2})$, where f_{ad} is the detection function using modular addition of the received signals. Then, the relay retransmits X_R to the destination, where X_R is either $\widehat{X}_A$ or $\widehat{X}_B$. Here, X_R is related to the highest SNR link given by $\Gamma_R = \max\{\Gamma_A, \Gamma_B\}$, will be forwarded to the destination in order to assist the destinations' joint detection, where Γ_A is the received SNR at R corresponding to A and Γ_B is the received SNR at R corresponding to B.

In the third time slot, the received signal at D from R can expressed by

$$Y_{D\_T3} = \sqrt{P_R} H_{RD} X_R + N_{D\_T3}. \tag{10}$$

Based on Γ_R, X_R is either $\widehat{X}_A$ or $\widehat{X}_B$. Thus the formula for estimating $\widehat{X}_A$ and $\widehat{X}_B$ at destination is generalized as follows

$$\widehat{X}_A = \begin{cases} f_{ad}(Y_{D\_T1}, Y_{D\_T2}, Y_{D\_T3}), & \text{if } \Gamma_A > \Gamma_B \\ f_{ad}(Y_{D\_T1}, Y_{D\_T2}), & \text{otherwise} \end{cases}$$
$$\widehat{X}_B = \begin{cases} f_{ad}(Y_{D\_T1}, -Y_{D\_T2}), & \text{if } \Gamma_A > \Gamma_B \\ f_{ad}(Y_{D\_T1}, -Y_{D\_T2}, Y_{D\_T3}). & \text{otherwise} \end{cases} \tag{11}$$

Here, we assume X_A has higher SNR than X_B. Thus, $X_R = \widehat{X}_A$. Then the information $\widehat{X}_A$ is estimated by using (11) and the function is written as

$$\widehat{X}_A = f_{ad}(Y_{D\_T1}, Y_{D\_T2}, Y_{D\_T3}), \tag{12}$$

where $\widehat{X}_A$ is the extrinsic information of X_A and $\tilde{X}_A$ is the estimated symbol.

The information $\widehat{X}_B$ is estimated by using (11) and the function is written as

$$\widehat{X}_B = f_{ad}(Y_{D\_T1}, -Y_{D\_T2}), \tag{13}$$

where $\widehat{X}_B$ is the extrinsic information of X_B and $\tilde{X}_B$ is the estimated symbol.

D. PHYSICAL LAYER NETWORK CODING ON A MULTIPLE RELAY SYSTEM (PLNC-mR)

The multiple relay system model PLNC-mR is an extension of a single relay system PLNC-1R in MARS using PLNC signal transmission scheme. The system has two sources A and B, the m number of relays and the destination D as shown in Figure 4a. The information phase of PLNC-mR possesses three-time slots and $\frac{T}{3}$ is the time duration for each time slot as shown in Figure 4b. In first time slot, A and B broadcasts signals X_A and X_B respectively, as a PLNC signal to D and R. Similarly in the second time slot, A and B broadcasts signals X_A and $-X_B$ respectively, as a PLNC signal to D and R. In the third time slot, all the relays in PLNC-mR decode signal using ZFD method as similar to R_1 in PLNC-1R. Then all the relays retransmit signals at same time slot as a PLNC signal to D.

We assume that there is a perfect synchronization when the sources transmit their signals during the first- and second-time slots. Under the same assumption, all the relays can also generate and transmit PLNC symbols during the third time slot.

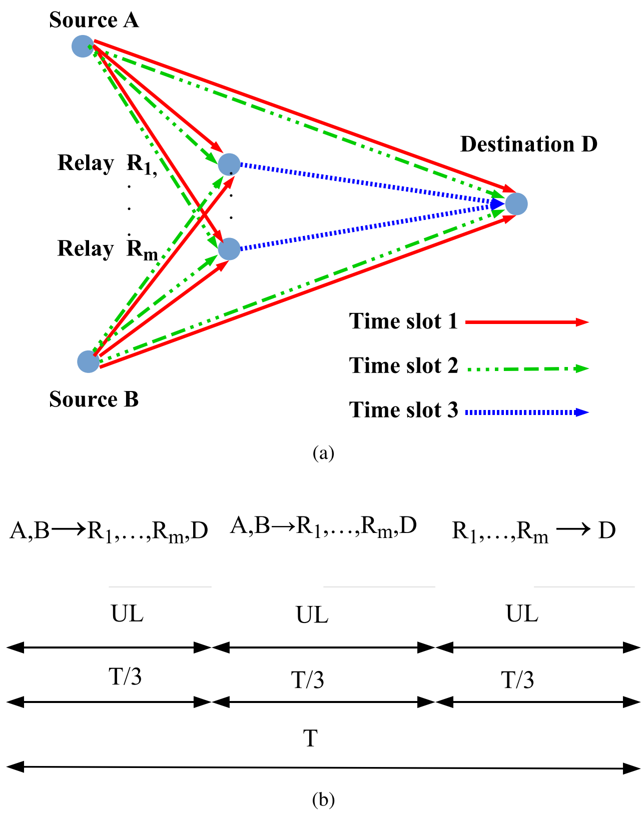

FIGURE 4. System model and its time slot diagram of PLNC-mR with DPS scheme. (a) PLNC-mR model with DPS scheme. (b) Time slot diagram of PLNC-mR model with DPS scheme.

The PLNC-mR has a similar transmission and estimation process as PLNC-1R. R represents relays R_i, where $i \in \{1, 2, \ldots, m\}$ of Figure 4a in (8), (9), (12) and (13). The equation of the first and second time slots of PLNC-mR are given in (8) and (9), respectively.

In the third time slot, all the relays retransmit the X_{R_i} to the destination. Here, symbols related to highest SNR link $\Gamma_{R_i} = \max\{\Gamma_{A_i}, \Gamma_{B_i}\}$ will be forwarded to the destination in order to improve the destinations' error rate performance, where Γ_{R_i} is the highest achieved SNR when compared between Γ_{A_i} and Γ_{B_i}. Here Γ_{A_i} is the average of all the received SNR at R_i corresponding to A_i and Γ_{B_i} is the average of all the received SNR at R_i corresponding to B. We assume Γ_{A_i} is higher than Γ_{B_i}. Thus, $X_{R_i} = \widehat{X}_{A_i}$. Then, the signals are transmitted from all the relays to the destination that can be written as

$$Y_{D\_T3} = \sum_{i=1}^{m} \sqrt{P_{Ri}} H_{RiD} X_{Ri} + N_{D\_T3}, \tag{14}$$

where Y_{D_T3} is PLNC signal received at the destination from the m number of relays.

The equations to find the extrinsic information $\widehat{X}_A$ and $\widehat{X}_B$, can be derived from equation as given in (12) and (13), respectively. By using ZFD on extrinsic informations $\widehat{X}_A$ and $\widehat{X}_B$, the signal estimates $\tilde{X}_A$ and $\tilde{X}_B$ are estimated.

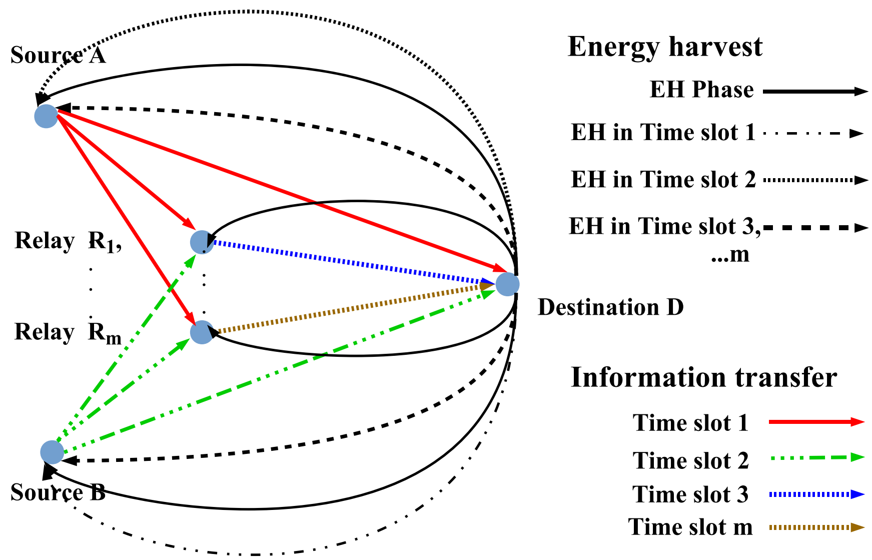

FIGURE 5. NC-mR model with OH scheme.

III. RF ENERGY HARVESTING SCHEME

In this section, we present the proposed RF WPT scheme. Also, traditional DPS scheme is presented as a baseline using the PLNC-mR and NC-mR system models.

A. BASELINE SCHEME

In DPS scheme, the signal transmit power is kept equal in all the scenarios discussed in this section. The power of the signal for each transmission is denoted as P_{tx}. The total number of signal transmissions in each system model is given as n_{tx}. In NC-mR, the n_{tx} is given as $(2+m)$, where 2 is sum of a single signal transmissions from the sources A and B to both R and D, and m is the number of signal transmission from relay R to the D. In PLNC-mR, the $n_{tx} = (4+m)$, where sum of two signal transmissions from the sources A and B to both R and D, and m is the number of signal transmission from relay R to the D, i.e., 4. The P_{tx} is given as

$$P_{tx} = P_t/n_{tx}, \tag{15}$$

where P_t is the total power supplied to the system. Thus, the total energy E_{DPS} requirement is given as

$$E_{DPS} = P_t T, \tag{16}$$

where T is the total time allocated for all the signal transmission in the system, E_{DPS} is the amount required of energy for the system to maintain a sustainable transmission.

B. RF WIRELESS POWER TRANSFER SCHEME

The proposed *Opportunistic-Harvesting* (OH) scheme is an improved scheme based on two energy harvest schemes, namely, *store-then-cooperate* (STC) and *energy-harvest* (EH) in our previous work [17], [18]. In the proposed scheme, the harvested amount of energy meets the minimum power requirements of source and relay. Rajaram *et al.* [17] [18] introduced an STC and EH schemes with a dynamic switch algorithm to overcome the difference in energy harvested among the nodes in the system over a fixed period of time. However, there is a shortcoming of this dynamic switch model - the difference in outage probability performance between STC and EH schemes. In order to overcome this, in the case of OH scheme, the system can manage the energy harvesting ratio between source and relay without using EH and STC schemes in a dynamic switch and maintains the outage probability performance of the system without any variation. Further, the SER performance of the system using OH scheme is better than the system using STC and EH schemes.

In the proposed OH scheme, radio frequency (RF) signals of HAP are used as the only viable source for the energy harvesting. OH scheme is used on system models for PLNC-mR and NC-mR instead of direct power supply scheme. The PLNC-mR and NC-mR are completely dependent on wireless power transfer (WPT) to signal transmission. Here, the destination D serves as a HAP. The energy harvested in each node is stored in a battery. The purpose of the rechargeable battery is to maintain a constant power supply at each node and also stores the excess energy. The OH scheme on the PLNC-mR and NC-mR can be implemented on the PLNC-1R and NC-1R, respectively, by presenting the number relays in system model as one.

The OH scheme for NC-mR and PLNC-mR is designed based on the $\delta_{I/R}$ of their respective system model.

1) OPPORTUNISTIC-HARVESTING SCHEME ON NC-mR

In the opportunistic harvesting scheme for NC-mR, there are two phases, the first phase is energy harvesting phase and the second phase is information transfer phase as shown in Figure 5. The entire time duration of both the phases is

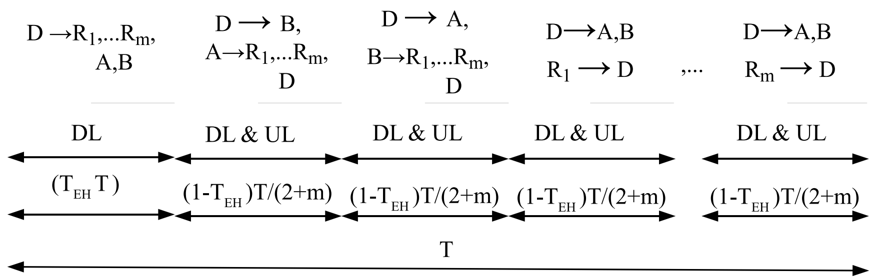

FIGURE 6. Time slot diagram of NC-mR model with OH scheme.

denoted as T. In the energy harvesting phase, all the nodes in the system model harvest energy using wireless power transfer from the destination for a specified time is denoted as $T_{EH}T$. The rest of the time is allocated for the information transfer phase, which is denoted as $(1 - T_{EH})T$. Further, this phase is divided into $(2 + m)$ equal time slots with the time duration $\frac{(1-T_{EH})T}{2+m}$ as shown in Figure 6, where m is number of relays. In the OH scheme, the nodes are opportunistic in nature to harvest energy using WPT whenever the nodes are not transmitting or receiving the signal. In the first and second time slots, B and A harvest energy from D using WPT, respectively. Again, both A and B harvest energy using WPT from D at $(2 + m)$ time slots and in the same time slots the relay R retransmits of the signal to D. The total number of transmission, n_{tx} in NC-mR is $(2 + m)$.

E_I and E_R are computed as

$$\begin{aligned} E_I &= \eta_{EH} P_D \zeta_{DI} \left(T_{EH}T + \frac{(1+m)(1-T_{EH})T}{2+m} \right), \\ E_R &= \eta_{EH} P_D \zeta_{DR} T_{EH} T. \end{aligned} \tag{17}$$

The energy harvesting ratio is denoted as $\delta_{I/R}$ – this ratio between the energy harvested at source and relay. $\delta_{I/R}$ is adjustable by setting the values of T_{EH} and T. Alternatively, if $\delta_{I/R}$ and T are set, then the value of T_{EH} can be calculated. $\delta_{I/R}$ is written as

$$\delta_{I/R} = \frac{E_I}{E_R} = \frac{\eta_{EH} P_D \zeta_{DI} \left(T_{EH}T + \frac{(1+m)(1-T_{EH})T}{2+m} \right)}{\eta_{EH} P_D \zeta_{DR} \cdot T_{EH} T}, \tag{18}$$

where the value of η_{EH} and P_D is equal for both E_I and E_R. The values of m, ζ_{DI} and ζ_{DR} are predefined values. The ratio between energy harvested in source and relay based on node's requirement is written as

$$\delta_{I/R} = \frac{\zeta_{DI} \left(T_{EH}T + T + mT \right)}{\zeta_{DR} (2+m) \left(T_{EH} T \right)}. \tag{19}$$

The value of T_{EH} is calculated by setting $\delta_{I/R}$ in (19) to 1. It is assumed that the calculated value of T_{EH} is at the acceptable level for energy harvesting phase to allow all the relay nodes to harvest threshold energy for the signal transmission. The relay nodes are completely dependent on energy harvesting phase to harvest energy for the signal transmission.

As the energy harvested in all the nodes is variable in nature, the amount of power drawn from these nodes may not be at desired level. The transmit signal power from node I and R in OH is set to be P_{EH}, $P_I = P_R = P_{EH}$, respectively. The energy E_{DPS} is the same amount of energy used in DPS scheme and OH scheme. The P_{EH} is computed using E_{DPS} and is given as

$$P_{EH} = \frac{E_{DPS}}{(1 - T_{EH})T(2+m)}. \tag{20}$$

The threshold energy E_{EH} is the energy required for each node to transmit the signal which is computed using E_{DPS} and is given as

$$E_{EH} = \frac{E_{DPS}}{(2+m)}. \tag{21}$$

The excess energy available in nodes at I and R in each time cycle is given as

$$E_{ex} = (E_R - E_{EH}) = (E_I - E_{EH}). \tag{22}$$

In our system, a Lithium-ion battery is fitted in every EH node to stores the excess energy. The energy stored in batteries Bt_I and Bt_R is denoted as $E_{I,S}$ and $E_{R,S}$, respectively, and written as

$$\begin{aligned} E_{R,S}^{+} &= E_{R,S} + (E_R - E_{EH})\eta_{Bt}, \\ E_{I,S}^{+} &= E_{I,S} + (E_I - E_{EH})\eta_{Bt}, \end{aligned} \tag{23}$$

where the current energy level and the previous energy level of the battery Bt_R is denoted as $E_{R,S}^{+}$ and $E_{R,S}$, respectively. Similarly, the current energy level and the previous energy level in the battery Bt_I is denoted as $E_{I,S}^{+}$ and $E_{I,S}$, respectively. The efficiency of battery is represented as η_{Bt} [32]. The impact of distance on power attenuation is elucidated as the distance d with path loss exponent Ψ is inversely proportional to harvested energy E, namely,

$$d^{\Psi} \propto \frac{1}{E}. \tag{24}$$

This effect is offset by adjusting T_{EH} in 19. $\delta_{I/R}$ is set as 1 to allow both Bt_R and Bt_I to charge at equal pace.

Thus, OH for NC-mR is designed based on the energy requirement of the source and relay.

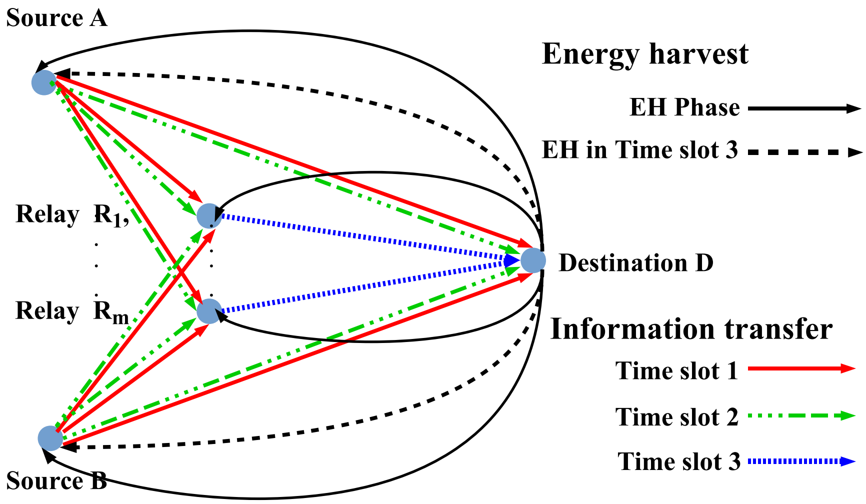

FIGURE 7. PLNC-mR model with OH scheme.

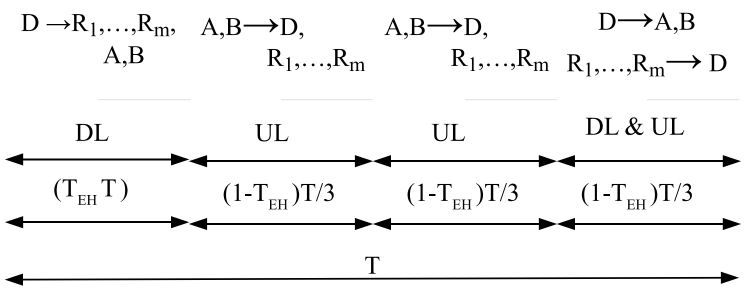

FIGURE 8. Time slot diagram of PLNC-mR model with OH scheme.

2) OPPORTUNISTIC-HARVESTING SCHEME ON PLNC-mR

In the opportunistic harvesting scheme for PLNC-mR, there are two phases; the first phase is energy harvesting phase and the second phase information transfer phase as shown in Figure 7. The entire time duration of both the phases is denoted as T. In the energy harvesting phase, all the nodes in the system model, harvest energy using wireless power transfer from the destination for a specified time is denoted as $T_{EH}T$. The rest of the time is allocated for information transfer phase and denoted as $(1-T_{EH})T$. Further, this phase is divided into three equal time slots with the time duration $\frac{(1-T_{EH})T}{3}$ as shown in Figure 8. In the OH scheme, the nodes are opportunistic in nature to harvest energy using WPT whenever the nodes are not transmitting or receiving signal and in the third time slot, the sources A and B harvest energy using WPT from D. The total number of transmission n_{tx} in NC-mR is $(4+m)$.

E_I and E_R are computed as

$$E_I = \Big(T_{EH}T + \frac{(1-T_{EH})T}{3}\Big)\big(\eta_{EH}P_D\zeta_{DI}\big),$$
$$E_R = \big(T_{EH}T\big)\big(\eta_{EH}P_D\zeta_{DR}\big). \tag{25}$$

The energy harvesting ratio is denoted as $\delta_{I/R}$, which is the ratio between the energy harvested at source and relay. $\delta_{I/R}$ is adjustable by setting the values of T_{EH} and T. Alternatively, if $\delta_{I/R}$ and T are set, then the value of T_{EH} can be calculated. $\delta_{I/R}$ is written as

$$\delta_{I/R} = \frac{E_I}{E_R} = \frac{\Big(T_{EH}T + \frac{(1-T_{EH})T}{3}\Big)\big(\eta_{EH}P_D\zeta_{DI}\big)}{\big(T_{EH}T\big)\big(\eta_{EH}P_D\zeta_{DR}\big)}, \tag{26}$$

where the value of η_{EH} and P_D is equal for both E_I and E_R. The values of ζ_{DI} and ζ_{DR} are predefined values. The equation to define the ratio between energy harvested in source and relay based on node's requirement is written as

$$\delta_{I/R} = \frac{\big(2T_{EH}T + T\big)\zeta_{DI}}{\big(3T_{EH}T\big)\zeta_{DR}}. \tag{27}$$

In both the OH and DPS schemes, the energy of the signal in all the signal transmission is equal. The power available to each source is equal to half of power available to the each relay. This is effected by the fact that the sources encounter two consecutive transmissions as compared to the single transmission that takes place at each R_i

Then, the value of T_{EH} is calculated by setting $\delta_{I/R} = 2$ in (27). It is assumed that the calculated value of T_{EH} is at the acceptable level for energy harvesting phase to allow all the relay nodes to harvest threshold energy for the signal transmission. The energy supply of the relay nodes is completely dependent on RF WPT. However, the source nodes are not completely dependent on energy harvesting phase – they harvest energy in both the energy harvesting phase and information transfer phase

The power of the signal for each transmission in RF WPT is denoted as P_{EH}. Thus, we have

$$P_{EH} = \frac{E_{DPS}}{(1 - T_{EH})T(4 + m)}, \tag{28}$$

where $P_I = P_R = P_{EH}$. Since I transmits the signal at the first and second time slots, I requires $2P_I$ and R requires P_R. The threshold energy E_{EH} is the energy required for each node to transmit the signal that is computed as

$$E_{EH} = \frac{E_{DPS}}{(4 + m)}. \tag{29}$$

The excess energy available in nodes at I and R in each time cycle is given as

$$E_{ex} = (E_R - E_{EH}) = (E_I - 2E_{EH}). \tag{30}$$

The excess energy will be used to charge the rechargeable Lithium-ion battery fitted to the node. The energy stored in batteries Bt_I and Bt_R is denoted as $E_{I,S}$ and $E_{R,S}$, respectively, and written as

$$\begin{aligned} E^{+}_{R,S} &= E_{R,S} + (E_R - E_{EH})\eta_{Bt}, \\ E^{+}_{I,S} &= E_{I,S} + (E_I - 2E_{EH})\eta_{Bt} \end{aligned} \tag{31}$$

where the current energy level and the previous energy level of the battery Bt_R is denoted as $E^{+}_{R,S}$ and $E_{R,S}$, respectively. Similarly, the current energy level and the previous energy level in the battery Bt_I is denoted as $E^{+}_{I,S}$ and $E_{I,S}$, respectively. The efficiency of battery is denoted as η_{Bt} [32]. The amount of energy harvested and energy used in the nodes at I will be twice as compared to nodes at R due to OH scheme design in PLNC-mR. Hence, $\delta_{I/R}$ is set as 2 to allow both Bt_R and Bt_I to charge at equal pace. Thus, OH scheme for PLNC-mR is designed based on the energy requirement of the source and relay.

There is a limitation to design $\delta_{I/R}$ for each system model. This limitation is based on the availability of the resource. For example, if $\delta_{I/R}$ is 8, then the relay node harvests energy that is 8 times lesser than that of the source node. This means relay may not have sufficient energy to transmit signal.

IV. OUTAGE PROBABILITY ANALYSIS

In this section, the outage probability of the DPS and OH scheme are studied for the multiple relay system models, NC-mR and PLNC-mR. The number of relays in PLNC-mR and NC-mR is R_i, where the relays are indexed by $i \in \{1, 2, \ldots, m\}$. This study can be implemented for the single relay system models of NC-1R and PLNC-1R. The outage probability for this systems is considered under the following criteria – the successful delivery of both the signals X_A and X_B to D. The failure to satisfy this criterion will lead to information outage at the destination.

In this paper, the probability of the event U is represented as $\Pr(U)$. The complementary event of U is denoted as $\bar{U}$ and the probability of $\bar{U}$ is denoted as $\Pr(\bar{U})$. The outage probability criteria for the NC-mR and PLNC-mR are analyzed by studying the signal transmission events. There are two events based on the path of I to D signal transmission; direct I to D path and the I to D through R link are denoted as ID and $IR - RD$, respectively. In multiple relay system models, $IR - RD$ can have multiple sub-events that depend on each relay. Then the probability of the sub-events of $IR - RD$ is given as $\Pr(IRi - RiD)$, where the relays are indexed by $i \in \{1, 2, \ldots, m\}$.

In NC-mR and PLNC-mR, the event ID is consider as the main event because it can successfully transmit signal with the support of event $IR - RD$, but event $IR - RD$ is considered due to the increase in diversity. This increases the success probability of the NC-mR if the event $IR - RD$ is a success. As a special case in PLNC-mR, $IR - RD$ increases the diversity of any one of the signals from source as the relay transmits either X_A or X_B to the destination.

The outage probability analysis for outage event of the nodes at I, R and D in system model are not considered.

A. OUTAGE PROBABILITY ANALYSIS OF NC-mR

The success and failure probability of the channel link ID is represented as $\Pr(ID)$ and $\Pr(\overline{ID})$, respectively. $\Pr(ID)$ and $\Pr(\overline{ID})$ is estimated as follows.

$$\begin{aligned} \Pr(ID) &= \Pr\left(\Gamma_{ID} > 2^{\left(\frac{(2+m)k}{2T}\right)} - 1\right) \\ &= \mathrm{EXP}\left(-\frac{2^{\left(\frac{(2+m)k}{2T}\right)} - 1}{\Gamma_{ID}}\right), \\ \Pr(\overline{ID}) &= \Pr\left(\Gamma_{ID} < 2^{\left(\frac{(2+m)k}{2T}\right)} - 1\right) \\ &= 1 - \mathrm{EXP}\left(-\frac{2^{\left(\frac{(2+m)k}{2T}\right)} - 1}{\Gamma_{ID}}\right), \end{aligned} \tag{32}$$

where the SNR of link ID is given as

$$\Gamma_{ID} = \frac{P_I |H_{ID}|^2}{N_0}. \tag{33}$$

Similarly, the outage probability for all the individual channel links $\{ID, RD\}$ can be defined as in (32). The success probability of the channel link $IR - RD$ is represented as $\Pr(IR - RD)$. $IR - RD$ is considered as a success if the signal transmission is a success through any one of the subchannel links (i.e. $IRi - RiD$). The success probability of $IRi - RiD$ is given as $\Pr(IRi - RiD)$. We have,

$$\Pr(IRi - RiD) = \Pr(ARi)\Pr(BRi)\Pr(RiD), \quad i \in \{1, 2, \ldots, m\}. \tag{34}$$

The failure probability of the link $IRi - RiD$ is represented as $\Pr(\overline{IRi - RiD})$. We have,

$$\Pr(\overline{IRi - RiD}) = 1 - \Pr(IRi - RiD), \quad i \in \{1, 2, \ldots, m\}. \tag{35}$$

The failure probability of the channel link $IR - RD$ is represented as $\Pr(\overline{IR - RD})$. We have,

$$\Pr(\overline{IR - RD}) = \prod_{i=1}^{m} \Pr(\overline{IRi - RiD}). \tag{36}$$

The success probability of the signal transmission through the channel link $IR - RD$ is represented as $\Pr(IR - RD)$. We have,

$$\Pr(IR - RD) = 1 - \Pr(\overline{IR - RD}). \tag{37}$$

The failure probability of the signal transmission through the channel links ID and $IR - RD$ of the system NC-MR with DPS scheme is denoted as $\Pr(\overline{\text{NC-mR}^{DPS}})$, and it is given by

$$\begin{aligned}\Pr(\overline{\text{NC-mR}^{DPS}}) &= \Pr(\overline{IR - RD}) \\ &\quad + \Pr(IR - RD)\Pr(\overline{AD})\Pr(\overline{BD}).\end{aligned} \tag{38}$$

Next, we consider the outage probability of the system with OH scheme. Here, it is assumed that both source and relay to have reliable power supply and therefore only information outage is considered.

The time duration of the information transfer in the OH and DPS schemes is given as $(1 - T_{EH})T$ as shown in Figure 6 and T as shown in Figure 2b, respectively. The target rate of OH and DPS is directly dependent on the time duration of the information transfer to send the data ($\frac{(2+m)k}{2}$) from source to destination. The target rate of OH and DPS schemes is expressed as $\frac{(2+m)k}{2}(\frac{1}{(1-T_{EH})})$ and $\frac{(2+m)k}{2T}$, respectively. Based on the target rate expression, it is explained that the system needs to send more data per time unit in OH as compared to DPS. Thereby, increasing the probability of outage in the information transmission of the system using OH as compared to DPS.

$$\begin{aligned}\Pr(\overline{ID}) &= \Pr\left(\Gamma_{ID} < 2^{\frac{(2+m)k}{2(1-T_{EH})}} - 1\right) \\ &= 1 - \mathrm{EXP}\left(-\frac{2^{\frac{(2+m)k}{2(1-T_{EH})}} - 1}{\Gamma_{ID}}\right).\end{aligned} \tag{39}$$

We get the outage probability of the signal transmission with the maximum achievable diversity for the system using OH by substituting (39) in (38). It is represented as $\Pr(\overline{\text{NC-mR}^{OH}})$.

The difference in outage probability between the OH and DPS is due to the transmit signal power and the time duration of signal transmission. This is explained by analyzing the equation (32) and (39). Though the amount of energy utilized by both the OH and DPS is same, the transmit signal power is higher in OH as compared to DPS. This is due to the lesser time duration in OH compared to DPS to utilize the same amount of energy as in (20). Thereby the SNR of OH is better as compared to DPS, resulting in the improvement of the outage performance of OH. However, this outage performance improvement of OH is offset by the shorter time duration used for the information transfer by OH compared to DPS.

B. OUTAGE PROBABILITY ANALYSIS OF PLNC-mR

In PLNC-mR, both R and D should receive the signals from the source in the first and second time slots without fail, only then the events ID and $IR - RD$ is termed as success. The channel links representing the signal transmission from I to both $\{R, D\}$ in the first and second time slots are denoted as $\{IR_{T1}, ID_{T1}\}$ and $\{IR_{T2}, ID_{T2}\}$, respectively.

In PLNC-mR, $IR - RD$ increases the diversity of the signal from source as the relay transmits the signal to the destination, the signal is detected using the events ID and $IR - RD$ as in (12).

The success and failure probability of the channel link ID_{T1} is represented as $\Pr(ID_{T1})$ and $\Pr(\overline{ID_{T1}})$, respectively. Then, $\Pr(ID_{T1})$ and $\Pr(\overline{ID_{T1}})$ is estimated as follows.

$$\begin{aligned}\Pr(ID_{T1}) &= \Pr\left(\Gamma_{ID_{T1}} > 2^{(\frac{3k}{2T})} - 1\right) \\ &= \mathrm{EXP}\left(-\frac{2^{(\frac{3k}{2T})} - 1}{\Gamma_{ID_{T1}}}\right), \\ \Pr(\overline{ID_{T1}}) &= \Pr\left(\Gamma_{ID_{T1}} < 2^{(\frac{3k}{2T})} - 1\right) \\ &= 1 - \mathrm{EXP}\left(-\frac{2^{(\frac{3k}{2T})} - 1}{\Gamma_{ID_{T1}}}\right),\end{aligned} \tag{40}$$

where the SNR of ID_{T1} and ID_{T2} is same and given as

$$\Gamma_{ID} = \frac{P_A|H_{AD}|^2 + P_B|H_{BD}|^2}{N_0}, \tag{41}$$

and the SNR of IR_{T1} and IR_{T2} is same and given as

$$\Gamma_{IR} = \frac{P_A|H_{AR}|^2 + P_B|H_{BR}|^2}{N_0}. \tag{42}$$

Note that the SNR of link ID and IR in the first and second-time slots are same because the signal power and the noise power are same for their respective link. Thus, the equation (40) can be used for the first and second-time slots of ID and IR.

The SNR of link RD is given as

$$\Gamma_{RD} = \frac{\sum_{i=1}^{m}\left(P_A|H_{RiD}|^2 + P_B|H_{RiD}|^2\right)}{N_0}. \tag{43}$$

Similarly, the outage probability for the channel link RD can be defined as in (40).

The success probability for the signal transmission through the channel link $IR - RD$ is represented as $\Pr(IR - RD)$. $IR - RD$ is considered as a success if the signal transmission is a success through any one of the subchannel links (i.e. $IRi - RiD$). The success probability of $IRi - RiD$ is given as $\Pr(IRi - RiD)$. We have,

$$\Pr(IRi - RiD) = \Pr(IRi_{T1})\Pr(IRi_{T2})\Pr(RiD), \quad i \in \{1, 2, \ldots, m\}. \tag{44}$$

The failure probability of the transmission through the channel link $IRi - RiD$ is represented as $\Pr(\overline{IRi - RiD})$. Thus, we have,

$$\Pr(\overline{IRi - RiD}) = 1 - \Pr(IRi - RiD), \quad i \in \{1, 2, \ldots, m\}. \tag{45}$$

The failure probability for the signal transmission through the channel link $IR - RD$ is represented as $\Pr(\overline{IR - RD})$. We have,

$$\Pr(\overline{IR - RD}) = \prod_{i=1}^{m} \Pr(\overline{IRi - RiD}). \tag{46}$$

The success probability of the transmission through the channel link $IR - RD$ is represented as $\Pr(IR - RD)$. We have,

$$\Pr(IR - RD) = 1 - \Pr(\overline{IR - RD}). \tag{47}$$

The failure probability of the channel links ID and $IR - RD$ of PLNC-mR using DPS to estimate signal by the method as in (12), is denoted as $\Pr(\overline{\text{PLNC-mR}^{DPS}_{(ID,IR-RD)}})$, and it is given by

$$\begin{aligned}\Pr(\overline{\text{PLNC-mR}^{DPS}_{(ID,IR-RD)}}) \\ = \Pr(\overline{IR - RD}) + \Pr(IR - RD)\Pr(\overline{ID_{T1}})\Pr(\overline{ID_{T2}}).\end{aligned} \tag{48}$$

The failure probability of PLNC-mR assisted DPS scheme to estimate the signal by using method as in (13) is denoted as $\Pr(\overline{\text{PLNC-mR}^{DPS}_{(ID)}})$, and it is given by

$$\Pr(\overline{\text{PLNC-mR}^{DPS}_{(ID)}}) = \Pr(\overline{ID}). \tag{49}$$

Next, we consider the outage probability of the system with OH scheme. This scheme is assumed that both source and relay to have reliable power supply. Therefore, only information outage is considered.

The time duration of the information transfer in the OH and DPS schemes is given as $(1 - T_{EH})T$ as shown in Figure 8 and T as shown in Figure 4b, respectively. The target rate of OH and DPS is directly dependent on the time duration of the information transfer to send the data ($\frac{3k}{2}$) from the source to destination. The target rate of OH and DPS schemes is expressed as $\frac{3k}{2}\left(\frac{1}{(1-T_{EH})}\right)$ and $\frac{3k}{2T}$, respectively. Based on the target rate expression, it is explained that the system needs to send more data per time unit in OH as compared to DPS. Thereby, increasing the probability of outage in the information transmission of the system using OH as compared to DPS. We have,

$$\begin{aligned}\Pr(\overline{ID_{T1}}) &= \Pr\left(\Gamma_{ID_{T1}} < 2^{\left(\frac{3k}{2(1-T_{EH})}\right)} - 1\right) \\ &= 1 - \text{EXP}\left(-\frac{2^{\left(\frac{3k}{2(1-T_{EH})}\right)} - 1}{\Gamma_{ID_{T1}}}\right).\end{aligned} \tag{50}$$

By substituting (50) in (48), we obtain the outage probability of OH for PLNC-mR to estimate signal by using method as in (12) and is given as $\Pr(\overline{\text{PLNC-mR}^{OH}_{(ID,IR-RD)}})$. Similarly by substituting (50) in (49), we obtain the outage probability of OH for PLNC-mR to estimate signal by using method as in (13) and is given as $\Pr(\overline{\text{PLNC-mR}^{OH}_{(ID)}})$.

The difference in outage probability between the OH and DPS is due to the transmit signal power and the time duration of signal transmission. This is explained by analyzing the equation (40) and (50). Though the amount of energy utilized by both the OH and DPS is same, the transmit signal power is higher in OH as compared to DPS. This is due to the lesser time duration in OH compared to DPS to utilize the same amount of energy as in (20). Thereby the SNR of OH is better as compared to DPS, results in improving outage performance of OH. But this outage performance improvement of OH is offset by the lesser time duration used for the information transfer by OH compared to DPS.

V. NUMERICAL RESULTS

In this section, we discuss the simulation setup and demonstrate the performance of MARS with NC and PLNC signal transmission schemes in both the direct power supply and the energy harvesting scheme. The performance of the direct power supply and the energy harvesting are studied based on the outage probability (OP) and symbol error rate (SER) performance of the signals received at the destination.

To compare the performance of NC and PLNC signal transmission scheme, the symbol error rate performance of NC scheme for the single relay (NC-1R) and two relays (NC-2R) systems are studied. The symbol error rate performance of PLNC scheme for the single relay (PLNC-1R) and two relays (PLNC-2R) systems are studied. The outage probability performance of NC scheme for the single relay (NC-1R), two relays (NC-2R) and three relays (NC-3R) systems are studied. The outage probability performance of PLNC scheme for the single relay (NC-1R), two relays (NC-2R) and three relays (NC-3R) systems are studied

The pairwise distances between the nodes are assumed to be $d_{AD} = d_{BD} = 30m$, $d_{AR_i} = d_{BR_i} = d_{R_iD} = 18m$, with the path loss exponent for free space $\Psi = 3.52$ [33], and the signal power attenuation of 30 dB per meter [4].

The channel gains g_{IR} and g_{RD} for the shorter channels IR and RD compared to the channel ID, respectively, are given as

$$\begin{aligned}g_{IR} &= 10\Psi \log\left(\frac{d_{ID}}{d_{IR}}\right), \\ g_{RD} &= 10\Psi \log\left(\frac{d_{ID}}{d_{Rd}}\right).\end{aligned} \tag{51}$$

In DPS scheme, the total power supplied for all the signal transmission in the system is $P_t = 30\ dBm$. The power transmitted from the destination is $P_d = 86\ dBm$ in OH scheme. We set data rate $k = 0.5$, $\eta_{EH} = 0.5$ [9] and $T = 1\ Sec$. The efficiency of Lithium-ion battery for charging and discharging is taken as $\eta_{Bt} = 0.9$ [32].

The power of the signal for each transmission of the direct signal transmission (point to point communication), NC-1R, NC-2R, NC-3R, direct PLNC signal as in (13), PLNC-1R, PLNC-2R and PLNC-3R of the DPS scheme is calculated

TABLE 1. Values of parameters used in OH scheme.

System model	$\delta_{I/R}$	T_{EH} (Sec)	T_{if} (Sec)	E_I (mJ)	E_R (mJ)	P_{EH} (mW)	E_{EH} (mJ)	E_{ex} (mJ)
NC-1R	1	0.273	0.727	167.55	167.54	45.67	33.33	134.20
NC-2R	1	0.297	0.703	182.28	182.28	35.55	25	157.28
NC-3R	1	0.310	0.690	192.64	192.66	28.99	20	170.64
PLNC-1R	2	0.068	0.932	88.77	41.89	35.77	33.33	8.55
PLNC-2R	2	0.068	0.932	88.77	41.89	26.83	25	16.89
PLNC-3R	2	0.068	0.932	88.77	41.89	21.46	20	21.89

using the (15) as 50 mW, 33.33 mW, 25 mW, 20 mW, 25 mW, 20 mW, 16.667 mW, 14.286 mW, respectively. The NC-2R and NC-3R use two and three relays, respectively, in the NC-mR system model. The PLNC-2R and PLNC-3R use two and three relays, respectively, in the PLNC-mR system model. The information transfer time of MARS using the OH is T_{if}, where $T_{if} = T - T_{EH}$. Table 1 shows the energy harvesting fraction between the source and relay, time allocation for energy harvesting phase, T_{if}, energy harvested in nodes I and R, P_{EH} at each node in OH scheme, E_{EH} (energy required) to be used as P_{EH} and E_{ex} at each node in a time cycle, for NC-1R, NC-3R, NC-3R, PLNC-1R, PLNC-3R and PLNC-3R system models using OH, respectively.

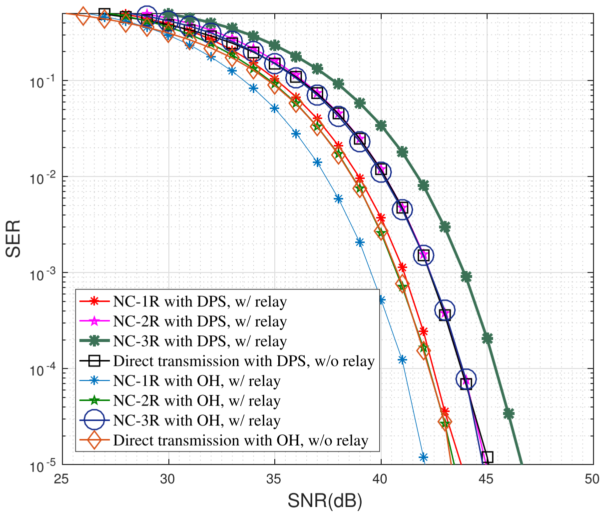

FIGURE 9. Comparison of SER of NC-mR with DPS and OH schemes using AWGN channels.

Figure 9 demonstrates the SER performance of NC-1R, NC-2R and NC-3R using DPS and OH schemes. The comparison of power supply scheme shows the improvement of the SER performance of the NC-mR using OH over the NC-mR using DPS scheme due to the excess power supply in OH with the same amount energy used in DPS. The comparison of NC-1R and direct signal transmission (point to point) show that the SER of NC-1R is better than direct signal transmission due to the diversity of received signals through *RD* and *ID* links at *D* of NC-1R. The comparison SER of NC-1R and NC-2R shows that the NC-1R has better performance as compared to NC-2R even though diversity order is higher than the received signals at *D* in NC-2R. This is due to negation effect of diversity factor by the inefficient decoding function at relays and reduced power of the signal due to increase in the number of nodes. similarly, the SER performance of NC-2R is better than NC-3R.

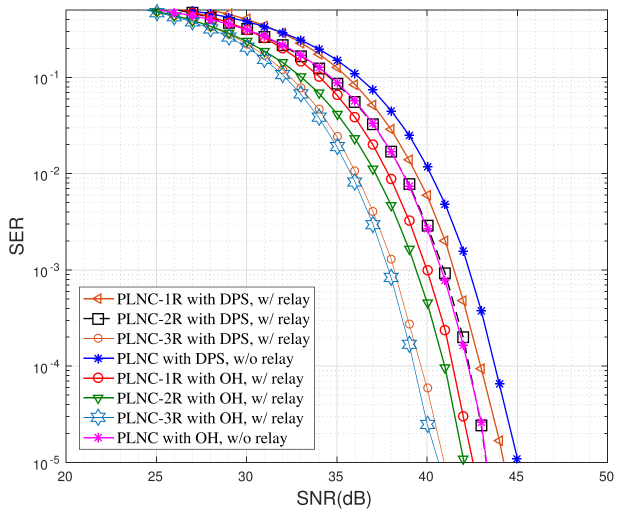

FIGURE 10. Comparison of SER of PLNC-mR with DPS and OH schemes using AWGN channels.

Figure 10 demonstrates the SER performance of the PLNC-1R, PLNC-2R and PLNC-3R using DPS and OH schemes. The comparison of power supply scheme shows the improvement of the SER performance of the PLNC-mR using OH over the PLNC-mR using DPS scheme due to the excess power supply in OH with the same amount energy used in DPS. The comparison of PLNC-1R and direct PLNC signal shows that the SER of PLNC-1R is better than the direct PLNC signal due to the diversity of received signals through *RD* and *ID* links at *D* of PLNC-1R. The Comparison of PLNC-2R and PLNC-1R shows that the PLNC-2R has better performance as compared to PLNC-1R due to the diversity order of received signals at *D* in PLNC-2R compared to PLNC-1R. The comparison of PLNC-2R and PLNC-3R shows the improved SER performance of PLNC-3R over PLNC-2R. SNR *dB* gain in SER performance of PLNC-3R from PLNC-2R is higher compared to SNR *dB* gain in SER performance of PLNC-2R from PLNC-1R, this shows drastic improvement in SER performance with increase in diversity order.

Figure 11 demonstrates OP performance of the NC-1R, NC-2R, and NC-3R using DPS and OH schemes. Comparison of the NC-mR using OH and DPS schemes shows that the OP performance of the NC-mR using DPS is better than that of the NC-mR using OH due to the time duration of the information transfer.

Though OH scheme uses less time allocation for information transfer as compared to DPS scheme, the power of signal at each node in the OH is higher than that of the DPS,

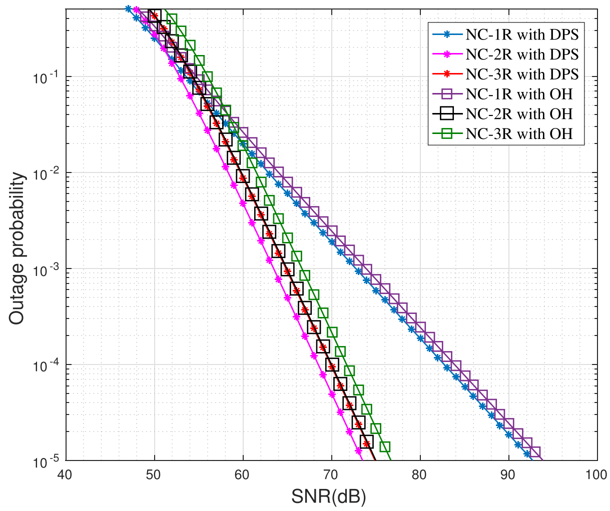

FIGURE 11. Comparison of outage probability of NC-mR with DPS and OH schemes with AWGN channels.

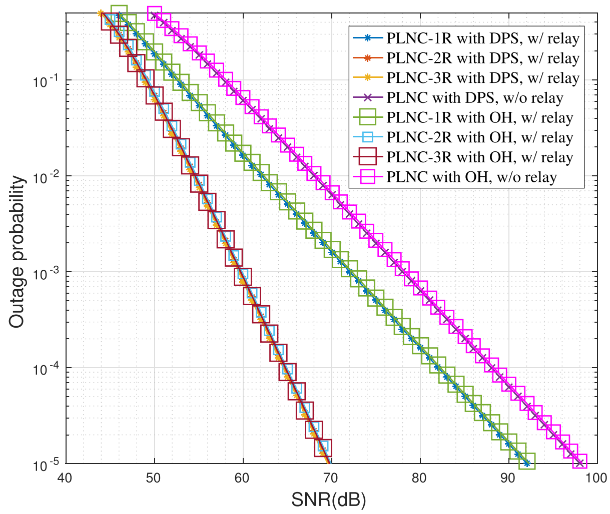

FIGURE 12. Comparison of outage probability of PLNC-mR with DPS and OH schemes with AWGN channels.

as shown in Table 1. This results in improving the outage performance of the OH in NC-mR.

Comparison between the NC-1R, NC-2R, and NC-3R in (38) demonstrates the effect of conditional probability on these system models. The increase in the number of relays increases the number of sub-events in $E_{IRi-RiD}$ of the NC-mR models, thus, increases the chance of success rate of a $E_{IRi-RiD}$ as in (34). The diversity order of the received signals at the destination is dependent on $E_{IRi-RiD}$ to increase the success rate of the system model.

Figure 12 demonstrates OP performance of the PLNC-1R, PLNC-2R and PLNC-3R using DPS and OH schemes. Comparison of the PLNC-mR using OH and DPS schemes shows that the OP performance of PLNC-mR using DPS is slightly better than the PLNC-mR using OH with the difference of less than 0.2 *dB* SNR. Though the time allocation for the information transfer of signal transmission in PLNC-mR models using OH is less as compared to the PLNC-mR models using DPS, the power of the signal in the PLNC-mR using OH is higher than the PLNC-mR using DPS. This results in improving outage performance of the PLNC-mR using OH.

Comparison between direct signal transmission as in (49), PLNC-1R, PLNC-2R and PLNC-3R as in (48) demonstrates the effect of conditional OP on these system models. The diversity order of received signals at destination increases the chance of success rate of the system model as in (44). Comparing PLNC-2R and PLNC-3R demonstrates that the increase in success rate due to the increase in a relay does not affect the OP of the MARS due to the decrease in signal power in each transmission as shown in Table 1.

Figure 11 and Figure 12 demonstrate the impact of time allocation for information transfer on the OP performance of OH. The information transfer time of the NC-mR and PLNC-mR models are given in Table 1. The PLNC-mR has more time to transfer information compared to the NC-mR thus performance the PLNC-mR using OH is better than the NC-mR using OH. The OP of the PLNC-mR using OH is almost equal to the PLNC-mR using DPS.

VI. CONCLUSION

An RF energy harvesting scheme for a multiple user and relay system with two different signal transmission schemes are investigated in this paper. The proposed RF WPT scheme is based on opportunistic harvesting (OH) and is adaptable to the system models with the PLNC and the NC. This allows the system model to use its resources efficiently based on the energy needs within its limits. The symbol error rate and outage performance metrics for multiple relay MARS with PLNC and NC signal transmission scheme using OH and DPS are studied together to see the impact of the OH scheme in various system models. The symbol error rate achieved by the system models using the OH is better than that of the system using the DPS.

The OH scheme increases the energy efficiency of the system by setting an energy harvesting ratio between the sources and the relay, and adjusts the time allocation for energy harvesting phase accordingly. The system is designed to use the minimum time for energy harvesting phase without compromising the energy needs of the nodes. The outage probability performance is improved with the increase in the amount of energy harvested by the each node and the maximum possible information transfer rate while using only a sufficient time for energy harvesting phase. The OH scheme can be used in the presence of high power WiFi routers or a WiFi router can be treated as the destination.

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