RF Energy Harvesting and Information Transmission based on Power Splitting and NOMA for IoT Relay Systems

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***Abstract*—Due to the proliferation of the Internet of Things (IoT), an unprecedented expansion of wireless devices and communication among these devices for data transmission is expected over the next few years. IoT devices are rather power constrained and are mostly battery operated devices. Therefore, energy efficiency of such IoT devices or systems is a major concern. In this paper, radio frequency (RF) energy harvesting and information transmission based on Non-orthogonal multiple access (NOMA) protocol is considered for wireless powered IoT relay systems. A source node needs the help of power constrained IoT relay node IoT_R to transmit its data. IoT_R node first harvests the energy from the RF signal of the source node and process the information in the first stage and then transmits the source node information data along with its data using NOMA protocol in the next stage. Unlike most of the previous works in this domain, this paper also considers the data transmission of the IoT_R node along with the source node to its intended destination nodes. Specifically, considering the energy constrained nature of IoT nodes and devices, we have used the combination of power splitting (PS) and NOMA protocol and have mathematically derived the outage probability and sum-throughput for the proposed system. We have also formulated an algorithm to find out the optimal power splitting factor that maximizes the sum-throughput of the proposed system. Our proposed system analytical results are validated by the simulation results.**

***Index Terms*—Radio frequency, energy harvesting, power splitting, internet of things, relaying, NOMA**

I. Introduction

With the proliferation of the Internet of things (IoT), device-to-device (D2D), machine-to-machine (M2M) communication is expected to connect billion of things in the next few years [1][2]. Amidst the advancement of these technologies, automation, D2D, M2M communications are fully possible without any human intervention [3]. IoT can support massive objects communication and thus it is considered as one of the important parts of the fifth generation (5G) networks [4]. Sensor nodes are the principal components which bring the idea of IoT into reality. These sensor nodes are rather power constrained and are battery operated devices. With unprecedented expansion and connection of billions of such

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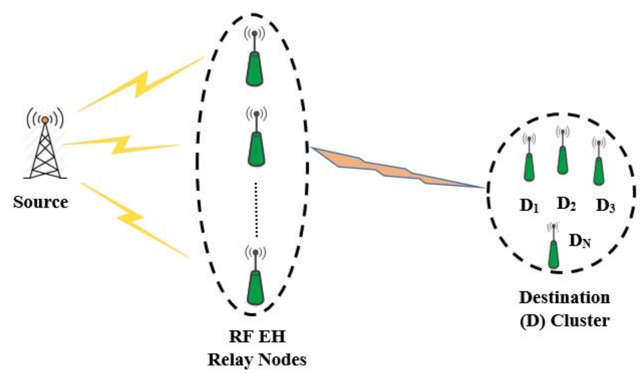

Fig. 1. Generic RF EH relay communication system

sensor nodes within the context of IoT and 5G is expected to consume more power. Thus, it is challenging to address the energy efficiency aspect of such IoT sensor nodes [5].

In order to mitigate the wireless impairments such as fading and other environmental factors, cooperative communication has been widely considered as an effective solution [6][7][8][9]. However, conventional cooperative relaying techniques requires the participating relaying nodes to spend extra energy for data transmission which may prevent the battery operated IoT nodes to take an active part in relaying. Therefore, wireless energy harvesting (EH) from ambient Radio Frequency (RF) signals is considered as a buoyant energy efficient solution to combat the issue of powering massive IoT sensor and devices [10][11][12].

An illustration of generic RF EH relay communication system is shown in Fig. 1, where one of the RF EH relaying node is selected by the source node to transmits its information to its intended destination. The harvested energy from source RF signals allows the relay node to power up themselves for simultaneous information processing and transmission [13]. According to previous study, it is also inferred that using more than one relay increases the complexity of the systems greatly [14]. Such cooperative RF EH relay communication systems as depicted by Fig. 1, only considers the transmission of source node data successfully. In this paper, we envisioned a ubiquitous IoT relay systems where an IoT node that can acts as a relay for transmitting source node information data to its intended destination and at the same time, it also has its own data to transmit to its destination node. Further, if EH is employed in such IoT relay systems, it has the potential to provide unlimited energy to sensor nodes and thus enabling self-sustainable green communications [15]. Meanwhile, non-orthogonal multiple access (NOMA) has been proposed as another important key candidate for future 5G technology by accommodating multiple users which can be multiplexed in power domain for providing spectral efficiency and capacity gains [16][17].

Nasir *et al.* [18] studied the ergodic capacity and throughput of EH-based decode and forward (DF) relaying network through power splitting (PS) and time switching (TS) method. The authors showed that, PS relaying outperforms the TS relaying scheme against a wide range of signal-to-noise ratio (SNR). Ramezani *et al.* [19] considered a fair enhancement algorithm in dual-hop communication networks. For ensuring throughput maximization, the authors proposed an algorithm to improve the time allocation factor for energy and information transfer. The authors in [20] proposed an EH-based PS method in which one node is served with information data while another node is served with energy transfer from the intermediate helping node which consecutively harvests the energy from the source node. Under this scenario, the authors developed an optimization problem to address the energy enhancement of the system.

There have also been other EH-based studies using NOMA protocol. Ha *et al.* [21] studied the outage realization of EH based DF relaying NOMA networks. They derived the closed form equation of the outage probability. However, it is to be noted that the destination nodes receives two copies of the same information through the source node direct link and EH-based relay. Kader *et al.* [22] studied TS and PS with EH and NOMA in a spectrum sharing environment. A pair of primary-secondary transmitter and receiver is considered in which secondary transmitter acts as an relay, harvests the power from the primary transmitter (PT) RF signal and then forwards the PT data along with its information using NOMA protocol. Jain *et al.* [23] also proposed an EH-based spectrum sharing protocol for wireless sensor networks. The authors assumed the sensor node as a secondary user that harvests the power and spectrum from PT and then transmits the superimposed signal, i.e., PT information along with its information signal to the respective destination nodes. However, EH considering the energy-efficient data transmission of source and IoT relay node together based on PS and NOMA, previous studies haven't considered the mathematical analysis for outage probability, throughput and sum-throughput suitable for IoT relay systems.

Motivated by these works in [21][22][23], we have considered an RF EH based on power splitting and NOMA for IoT relay systems. Here, the power constrained IoT node acts as a DF relay which in turn harvests the energy from source node RF signal and then transmits its information along with source node information data using NOMA protocol to its respective destination nodes.

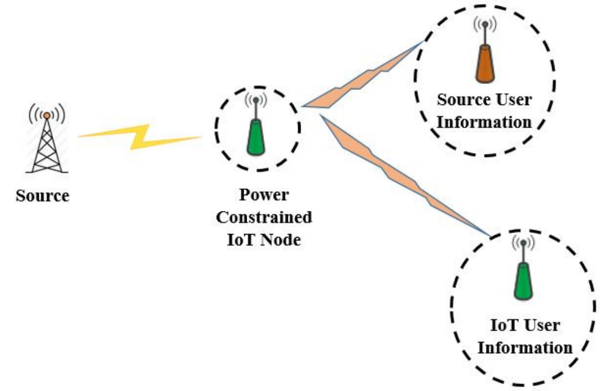

Fig. 2. Considered system model scenario

In summary, the major contribution of this paper can be outlined as:

- Realizing the energy constrained nature of IoT nodes, we have considered and investigated an RF EH-based on power splitting and NOMA for IoT relay systems. Unlike several of the previous works, where the participating relay node is used only to transmit source node data successfully, we have also considered to send the IoT relay node data along with source node data to its respective destination.
- We have mathematically derived the outage probability, throughput and sum-throughput for our considered scenario. The developed analysis is corroborated through Monte-Carlo simulations and some representative performance comparisons are presented.

The rest of the paper is organized as follows. In Section II, we present the system model for our considered scenario. Section III deals with the considered system model based on power splitting and NOMA protocol along with outage probability, throughput and sum-throughput derivations. In Section IV, we explain algorithm - Golden section search method to find out the optimal power splitting factor that maximizes the sum-throughput for our considered system. Numerical results and discussions are presented in Section V. Conclusion and future works are presented in Section VI.

II. SYSTEM MODEL

We have considered a cooperative relaying EH scenario as shown in Fig. 2, where a source node has to transmit its information data to the destination i.e, source user. As shown in Fig. 2, we have considered that the source node cannot transmit its information to its destination due to fading or weak link between a source-destination pair and it will seek the help of IoT node (IoT_R) for relaying its information data. Here, the source node may be an IoT node which has abundant

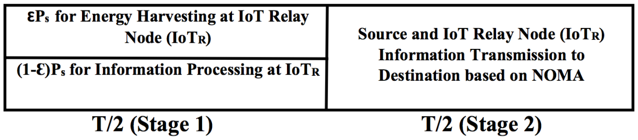

Fig. 3. System model based on power splitting and NOMA

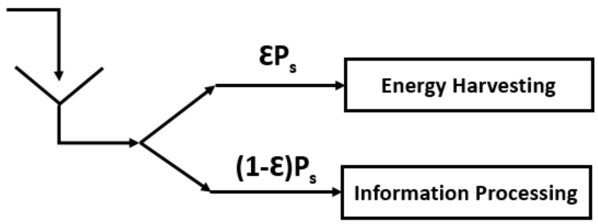

Fig. 4. Power splitting protocol for energy harvesting and information processing at the IoT_R

energy supply from other sources. Cooperative communication with single relay is a simple but effective communication scheme especially for energy constrained networks such as IoT networks [24]. Further, using more than one relay increases the complexity of the systems greatly [14]. Hence, we have considered a single IoT_R node for our system model. Nevertheless, it can be extended to multiple IoT_R node scenario as well.

IoT_R node is rather power constrained node that acts as a DF relay and it will first harvest RF energy from source signal using power splitting protocol in the first stage and then transmits the source information data along with its own data using NOMA protocol in next stage. Here, IoT_R serves the dual purpose of energy harvesting and forwarding the information. Unlike several of the previous works, here the information data forwarded by IoT_R node is the source node information data and its own data. Both source node and IoT_R node information data are transmitted at the same time using NOMA protocol which is explained in the next section. The destination pair for source and IoT_R node serves as the receiving end for data transmission.

III. System Model based on Power Splitting and NOMA

The considered system model scenario based on PS and NOMA protocol is shown in Fig. 3. A basic power-splitting protocol for energy harvesting and information processing at the IoT_R is shown in Fig. 4. As shown in Fig. 4, this scheme assumes that power constrained (IoT_R) node will first harvest energy from source node signal using εP_s where P_s is the power of the source transmit signal. IoT_R uses remaining power $(1-\varepsilon)P_s$ for information processing. We have assumed that, all nodes are considered to be operating in half duplex mode and an independent Rayleigh block fading with channel coefficient $h_i \sim CN(0, \lambda_i = d_i^{-v})$ with zero mean and variance λ_i is assumed between any two nodes where, d_i is the distance between the corresponding link and v is the path loss exponent.

A. Stage 1

During this stage, a source node signal x_s with P_s power is transmitted to the IoT_R node for half of the block time T i.e., $T/2$ period of time. Here, IoT_R is considered to work as power splitting based DF relay node as shown in Fig. 4. The IoT_R node divide the received power P_s in the ratio εP_s:(1- ε)P_s. Accordingly here, εP_s is for energy harvesting and (1- ε)P_s is for information processing by IoT_R respectively, $0 \leq \varepsilon \leq 1$. The information signal received at IoT_R during this stage is given as:

$$y_{IoT_R} = \sqrt{P_s} h_{IoT_R} x_s + n_{IoT_R}, \tag{1}$$

where $n_{IoT_R} \sim CN(0, \sigma^2_{IoT_R})$ is the additive white Gaussian noise at IoT_R with mean zero and variance $\sigma^2_{IoT_R}$ and $h_{IoT_R} \sim CN(0, \lambda_h)$ is the channel coefficient between source node and IoT_R node with zero mean and variance λ_h. The energy harvested at IoT_R in $T/2$ period of time is given as:

$$E_{h_{IoT_R}} = \frac{\eta \varepsilon P_s |h_{IoT_R}|^2 T}{2}, \tag{2}$$

where $0 \leq \eta \leq 1$ is the energy conversion efficiency. Here, we assume that the pre-processing power for the energy harvesting is negligible in contrast to the transmission power P_s which is in line with the previous works [21][22][23]. The signal received at the information receiver of the IoT_R is given as:

$$\sqrt{(1-\varepsilon)} y_{IoT_R} = \sqrt{(1-\varepsilon) P_s} h_{IoT_R} x_s + n_{IoT_R}, \tag{3}$$

In Eq. (3), we also assumed that the noise factor is not affected by power sharing.

The transmit power of IoT_R i.e., P_{IoT_R} in $T/2$ block of time is given as:

$$P_{IoT_R} = \frac{E_{h_{IoT_R}}}{T/2} = \eta \varepsilon P_s |h_{IoT_R}|^2, \tag{4}$$

B. Stage 2

During this stage, the IoT_R node transmits a superimposed composite signal $Z_{I_{C1}}$ which consists of source information x_s and IoT_R information x_{IoT_R} to the respective destination node i.e., source user and IoT user using NOMA protocol. The superimposed composite signal $Z_{I_{C1}}$ following NOMA protocol is given as:

$$Z_{I_{C1}} = \sqrt{\phi_1 P_{IoT_R}} x_s + \sqrt{\phi_2 P_{IoT_R}} x_{IoT_R} \tag{5}$$

where $\phi_1 + \phi_2 = 1$ and $\phi_2 = 1 - \phi_1$.

Now, the received signals at the respective source user and IoT user can be given as:

$$y_{s_{rec}} = \sqrt{P_{IoT_R}} h_{s_{rec}} Z_{I_{C1}} + n_{s_{rec}}, \tag{6}$$

$$y_{IoT_{rec}} = \sqrt{P_{IoT_R}} h_{IoT_{rec}} Z_{I_{C1}} + n_{IoT_{rec}}, \tag{7}$$

where $n_{s_{rec}}$ and $n_{IoT_{rec}}$ is the additive white Gaussian noise at the receiver of source and IoT user node respectively with mean zero and variance $\sigma^2_{s_{rec}}$ and $\sigma^2_{IoT_{rec}}$. Also, $h_{s_{rec}} \sim CN(0, \lambda_g)$ is the channel coefficient between IoT_R node and receiving source user with zero mean and variance λ_g and $h_{IoT_{rec}} \sim CN(0,\lambda_z)$ is the channel coefficient between IoT_R node and receiving IoT user with zero mean and variance λ_z. We have also assumed that $h_{s_{rec}} > h_{IoT_{rec}}$. Therefore, $\lambda_g > \lambda_z$ and $\phi_1 < \phi_2$.

Here, by following the NOMA protocol, source user information receiver first decodes information x_{IoT_R} by considering x_s as noise. Then it cancels x_{IoT_R} by successive interference cancellation to decode its own information signal x_s. However, IoT user receiver decodes the information x_{IoT_R} by presuming x_s as a noise.

C. Outage Probability, Throughput and Sum-throughput

Subsequently from Eq. (1), the received signal to noise ratio (SNR) at IoT_R node is given by:

$$\gamma_{IoT_R} = \frac{(1-\varepsilon)P_s|h_{IoT_R}|^2}{\sigma^2_{IoT_R}} = (1-\varepsilon)\delta|h_{IoT_R}|^2 \tag{8}$$

where $\delta \triangleq \frac{P_s}{\sigma^2_{IoT_R}}$ represents the transmit signal-to-noise ratio (SNR) from the source.

Similarly from Eq. (5), the received SNR with x_{IoT_R} and x_s at the receiving source user is given by:

$$\gamma^{x_{IoT_R}\to x_s}_{s_{rec}} = \frac{\phi_2 P_{IoT_R}|h_{s_{rec}}|^2}{\phi_1 P_{IoT_R}|h_{s_{rec}}|^2 + \sigma^2_{s_{rec}}} \tag{9}$$

$$\gamma_{s_{rec}} = \frac{\phi_1 P_{IoT_R}|h_{s_{rec}}|^2}{\sigma^2_{s_{rec}}} \tag{10}$$

where $\gamma^{x_{IoT_R}\to x_s}_{s_{rec}}$ is the SNR required at the receiving source user to decode and cancel IoT_R information i.e., x_{IoT_R}.

The received SNR at the receiving IoT user node associated with symbol x_{IoT_R} is given by:

$$\gamma_{IoT_{rec}} = \frac{\phi_2 P_{IoT_R}|h_{IoT_{rec}}|^2}{\phi_1 P_{IoT_R}|h_{IoT_{rec}}|^2 + \sigma^2_{IoT_{rec}}} \tag{11}$$

As we can see from Fig 2., the data transmission is break down into two separate hops which are independent of each other. Hence, the outage occurs only if source to IoT_R path and IoT_R to corresponding destination path fails to satisfy the SNR constraint. Therefore, the outage probability of the source node can be given as:

$$P_{Out_S} = Pr(min(\gamma_{IoT_R},\gamma_{s_{rec}}) \le \psi) \tag{12}$$

where $\psi = 2^R - 1$ is the lower threshold for SNR i.e., outage probability, R being the target data rate.
Similarly, the outage probability of the IoT_R node can be given as:

$$P_{Out_{IoT_R}} = Pr(min(\gamma^{x_{IoT_R}\to x_s}_{s_{rec}},\gamma_{IoT_{rec}}) \le \psi) \tag{13}$$

The throughput of the source node can be given as:

$$Thr_S = \frac{(1-P_{Out_S})R}{2} \tag{14}$$

where R is measured in bits per second per hertz.
The throughput of the IoT relay node can be given as:

$$Thr_{IoT_R} = \frac{(1-P_{Out_{IoT_R}})R}{2} \tag{15}$$

The factor 1/2 in Eq. 14 and Eq. 15 is originated by the predicament that the two transmission phases are involved in the system.

Therefore, the sum-throughput of the whole system can be given as:

$$Thr = Thr_S + Thr_{IoT_R} = (1-P_{Out_S})\frac{R}{2} + (1-P_{Out_{IoT_R}})\frac{R}{2} \tag{16}$$

Theorem 1: The outage probability and throughput of the source node can be expressed as:

$$\begin{aligned} P_{Out_S} = 1 - 2\sqrt{\frac{\lambda_h\lambda_g(1-\varepsilon)x_0}{a}}K_1\left(2\sqrt{\frac{\lambda_h\lambda_g(1-\varepsilon)x_0}{a}}\right) \\ + \sum_{n=0}^{\infty}\frac{(-1)^n}{n!}(\lambda_h x_0)^{n+1}E_{n+2}\Big(\frac{(1-\varepsilon)\lambda_g}{a}\Big) \end{aligned} \tag{17}$$

$$\begin{aligned} Thr_S = \frac{R}{2}\left(2\sqrt{\frac{\lambda_h\lambda_g(1-\varepsilon)x_0}{a}}K_1\left(2\sqrt{\frac{\lambda_h\lambda_g(1-\varepsilon)x_0}{a}}\right)\right. \\ \left. - \sum_{n=0}^{\infty}\frac{(-1)^n}{n!}(\lambda_h x_0)^{n+1}E_{n+2}\Big(\frac{(1-\varepsilon)\lambda_g}{a}\Big)\right) \end{aligned} \tag{18}$$

where $x_0 = \frac{\psi}{(1-\varepsilon)\delta}$, $a = \varepsilon\eta\phi_1$, $K_1(.)$ is a first-order modified Bessel function of the second kind, and $E_n(a) = \int_{y=1}^{\infty} y^{-n}e^{-ay}dy$ is the exponential integral of order n.
Proof:

From Eq. 8, we have,
$\gamma_{IoT_R} = (1-\varepsilon)\delta X$ where $|h_{IoT_R}|^2 = X$
Also, from Eq. 10, we have,

$$\gamma_{s_{rec}} = \frac{\phi_1 P_{IoT_R}|h_{s_{rec}}|^2}{\sigma^2_{s_{rec}}} \triangleq \delta XYa$$

where $Y = |h_{s_{rec}}|^2, \sigma^2_{s_{rec}} = 1, a = \eta\varepsilon\phi_1$
From Eq. 12, the outage probability of the source is:

$$\begin{aligned} P_{Out_S} &= Pr(min(\gamma_{IoT_R},\gamma_{s_{rec}}) < \psi) \\ &= 1 - Pr(min(\gamma_{IoT_R},\gamma_{s_{rec}}) \ge \psi) \\ &= 1 - Pr((1-\varepsilon)\delta X \ge \psi, \delta aXY \ge \psi) \\ &= 1 - Pr\big(X \ge \frac{\psi}{(1-\varepsilon)\delta}, Y \ge \frac{\psi}{\delta aX}\big) \end{aligned}$$

Let $x_0 = \dfrac{\psi}{(1-\varepsilon)\delta}$

$$\begin{aligned} &= 1 - Pr\big(X \ge x_0, Y \ge \frac{(1-\varepsilon)x_0}{aX}\big) \\ &= 1 - \int_{x_0}^{\infty} f_X(x)\Big(\int_{\frac{(1-\varepsilon)x_0}{ax}}^{\infty} f_Y(y)dy\Big)dx \\ &= 1 - \int_{x_0}^{\infty} \lambda_h e^{-\lambda_h x}\Big(\int_{\frac{(1-\varepsilon)x_0}{ax}}^{\infty} \lambda_g e^{-\lambda_g y}dy\Big)dx \\ &= 1 - \int_{x_0}^{\infty} \lambda_h e^{-\lambda_h x}\big(e^{-\lambda_g\frac{(1-\varepsilon)x_0}{ax}}\big)dx \\ &= 1 - \int_{x_0}^{\infty} \lambda_h\big(e^{-\lambda_h x - \lambda_g\frac{(1-\varepsilon)x_0}{ax}}\big)dx \\ &= 1 - \Bigg(\underbrace{\lambda_h\int_{x=0}^{\infty}\big(e^{-4\lambda_g\frac{(1-\varepsilon)x_0}{a4x} - \lambda_h x}\big)dx}_{I_1} \end{aligned}$$

$$-\underbrace{\lambda_h\int_{x=0}^{x_0}\left(e^{-\lambda_g\frac{(1-\varepsilon)x_0}{ax}-\lambda_h x}\right)dx}_{I_2}\Bigg)$$

Let us first evaluate the integral I_1

Now, using the formula,

$$\int_0^\infty e^{-\frac{\beta}{4x}-\gamma x}dx=\sqrt{\frac{\beta}{\gamma}}K_1\left(\sqrt{\beta\gamma}\right)\text{[25], Eq. 3.324.1}$$

$$I_1=2\sqrt{\frac{\lambda_h\lambda_g(1-\varepsilon)x_0}{a}}K_1\left(2\sqrt{\frac{\lambda_h\lambda_g(1-\varepsilon)x_0}{a}}\right)$$

Now, let us evaluate the integral I_2

$$I_2=\lambda_h\int_{x=0}^{x_0}\left(e^{-\lambda_h x-\frac{(1-\varepsilon)\lambda_g x_0}{ax}}\right)dx$$

Expanding the term $e^{-\lambda_h x}$ in Taylor series

$$=\lambda_h\sum_{n=0}^{\infty}\frac{(-1)}{n!}(\lambda_h)^n\int_{x=0}^{x_0}x^n e^{-\frac{(1-\varepsilon)\lambda_g x_0}{ax}}dx$$

Substituting $y=\frac{1}{x}$, and further $t=x_0y$, we get,

$$=\sum_{n=0}^{\infty}\frac{(-1)}{n!}(\lambda_h x_0)^{n+1}\int_{t=1}^{\infty}t^{-n-2}e^{-\frac{(1-\varepsilon)\lambda_g t}{a}}dt$$

Now, by definition of exponential integral of order n

We have, $E_n(a)=\int_{y=1}^{\infty}y^{-n}e^{-ay}dy$

$$I_2=\sum_{n=0}^{\infty}\frac{(-1)}{n!}(\lambda_h x_0)^{n+1}E_{n+2}\left(\frac{(1-\varepsilon)\lambda_g}{a}\right)$$

Therefore,

$$P_{Out_S}=1-2\sqrt{\frac{\lambda_h\lambda_g(1-\varepsilon)x_0}{a}}K_1\left(2\sqrt{\frac{\lambda_h\lambda_g(1-\varepsilon)x_0}{a}}\right)+\sum_{n=0}^{\infty}\frac{(-1)^n}{n!}(\lambda_h x_0)^{n+1}E_{n+2}\left(\frac{(1-\varepsilon)\lambda_g}{a}\right)$$

Putting the value of P_{Out_S} in Eq. 14, we get,

$$Thr_S=\frac{R}{2}\left(2\sqrt{\frac{\lambda_h\lambda_g(1-\varepsilon)x_0}{a}}K_1\left(2\sqrt{\frac{\lambda_h\lambda_g(1-\varepsilon)x_0}{a}}\right)-\sum_{n=0}^{\infty}\frac{(-1)^n}{n!}(\lambda_h x_0)^{n+1}E_{n+2}\left(\frac{(1-\varepsilon)\lambda_g}{a}\right)\right)$$

This ends the proof of Theorem 1.

Theorem 2: The outage probability and throughput of the IoT node can be expressed as:

$$P_{Out_{IoT_R}}=1-2\sqrt{c\lambda_h(\lambda_g+\lambda_z)}K_1\left(2\sqrt{c\lambda_h(\lambda_g+\lambda_z)}\right)\tag{19}$$

$$Thr_{IoT_R}=\frac{R}{2}\left(2\sqrt{c\lambda_h(\lambda_g+\lambda_z)}K_1\left(2\sqrt{c\lambda_h(\lambda_g+\lambda_z)}\right)\right)\tag{20}$$

where $c=\frac{\psi}{(\phi_2-\phi_1\psi)b}$, $b=\eta\delta\varepsilon$

Proof:

From Eq. 13, the outage probability of IoT relay node is:

$$P_{Out_{IoT_R}}=Pr(min(\gamma_{s_{rec}}^{x_{IoT_R}\to x_s},\gamma_{IoT_{rec}})<\psi)$$

$$P_{Out_{IoT_R}}=1-Pr\left(\frac{\phi_2 bXY}{\phi_1 bXY+1}\geq\psi,\frac{\phi_2 bXZ}{\phi_1 bXZ+1}\geq\psi\right)$$

where $P_{IoT_R}=\eta\varepsilon P_s|h_{IoT_R}|^2\triangleq\eta\varepsilon\delta X, b=\eta\delta\varepsilon$

$X=|h_{IoT_R}|^2, Y=|h_{s_{rec}}|^2, Z=|h_{IoT_{rec}}|^2, \sigma^2_{IoT_{rec}}=1, \sigma^2_{s_{rec}}=1$

$$=1-Pr\left(Y\geq\frac{\psi}{(\phi_2-\phi_1\psi)bX},Z\geq\frac{\psi}{(\phi_2-\phi_1\psi)bX}\right)$$

Conditioning on X, we have,

$$=1-\int_0^\infty Pr\left(Y\geq\frac{\psi}{(\phi_2-\phi_1\psi)bx}\right)\times Pr\left(Z\geq\frac{\psi}{(\phi_2-\phi_1\psi)bx}\right)f_X(x)dx$$

putting, $\frac{\psi}{(\phi_2-\phi_1\psi)bx}=U$

$$=1-\int_0^\infty Pr(Y\geq U)Pr(Z\geq U)f_X(x)dx$$

$$=1-\int_0^\infty\left(\int_U^\infty\lambda_g e^{-\lambda_g y}dy\right)\left(\int_U^\infty\lambda_z e^{-\lambda_z z}dz\right)\lambda_h e^{-\lambda_h x}dx$$

$$=1-\int_0^\infty e^{-\lambda_g U}e^{-\lambda_z U}\lambda_h e^{-\lambda_h x}dx$$

substituting the value of U above

$$=1-\int_0^\infty e^{-\lambda_g\frac{\psi}{(\phi_2-\phi_1\psi)bx}}e^{-\lambda_z\frac{\psi}{(\phi_2-\phi_1\psi)bx}}\lambda_h e^{-\lambda_h x}dx$$

let $c=\frac{\psi}{(\phi_2-\phi_1\psi)b}$

$$=1-\int_0^\infty e^{-\lambda_g\frac{c}{x}}e^{-\lambda_z\frac{c}{x}}\lambda_h e^{-\lambda_h x}dx$$

$$=1-\lambda_h\int_0^\infty e^{-4(\lambda_g+\lambda_z)\frac{c}{4x}-\lambda_h x}dx$$

Now, using the formula,

$$\int_0^\infty e^{-\frac{\beta}{4x}-\gamma x}dx=\sqrt{\frac{\beta}{\gamma}}K_1\left(\sqrt{\beta\gamma}\right)$$

$$=1-\lambda_h\sqrt{\frac{4(\lambda_g+\lambda_z)c}{\lambda_h}}K_1\left(\sqrt{4(\lambda_g+\lambda_z)c\lambda_h}\right)$$

$$P_{Out_{IoT_R}}=1-2\sqrt{c\lambda_h(\lambda_g+\lambda_z)}K_1\left(2\sqrt{c\lambda_h(\lambda_g+\lambda_z)}\right)$$

Putting the value of $P_{Out_{IoT_R}}$ in Eq. 15, we get,

$$Thr_{IoT_R}=\frac{R}{2}\left(2\sqrt{c\lambda_h(\lambda_g+\lambda_z)}K_1\left(2\sqrt{c\lambda_h(\lambda_g+\lambda_z)}\right)\right)$$

This ends the proof of Theorem 2.

Combining Eq. 18 and Eq. 20, we finally get the analytical equation for the sum-throughput of the proposed system.

IV. Optimal Power Splitting Factor ε for Sum-throughput Maximization

In order to find out the optimal power splitting factor ε that gives finest performance for the sum-throughput maximization for our proposed system, we evaluate $\frac{dThr(\varepsilon)}{d\varepsilon}=0$, where $Thr(\varepsilon)$ is the sum-throughput function with respect to power splitting factor ε. By analyzing the combined sum-throughput function for source and IoT node versus ε as in Fig. 10 and Fig. 11, we determine that these are concave functions which

TABLE I
SIMULATION PARAMETERS

Parameter	Symbol	Values
Source and IoT Node Rate	R	1bps/Hz
Source Node Transmit SNR	δ	0-20 dB
Energy Harvesting Efficiency	η	1
Mean of $\lvert h_{IoT_R}\rvert^2 \rightarrow X$	λ_h	1
Mean of $\lvert h_{s_{rec}}\rvert^2 \rightarrow Y$	λ_g	1
Mean of $\lvert h_{IoT_{rec}}\rvert^2 \rightarrow Z$	λ_z	0.5
Noise Variance	$\sigma^2_{IoT_{rec}}, \sigma^2_{s_{rec}}$	1
Power Factor for NOMA	ϕ_1	0.2
Power Factor for NOMA	ϕ_2	0.8

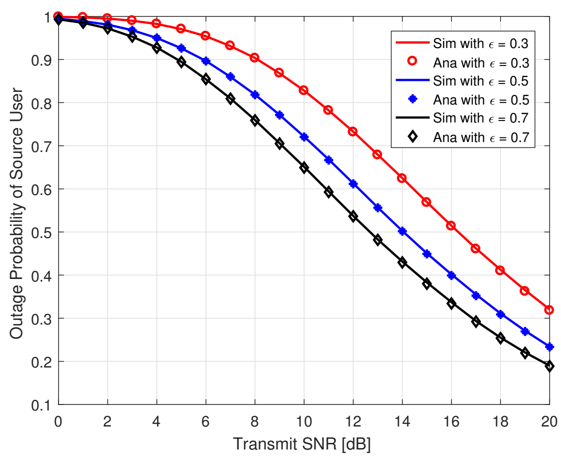

Fig. 5. Outage probability of source user

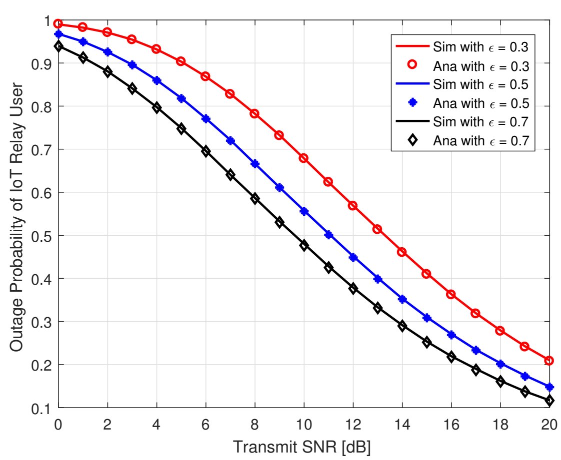

Fig. 6. Outage probability of IoT relay user

have a unique maxima ε^* on the interval $[0,1]$. Therefore, we resort to Golden section search method [26] which is simple yet compelling iterative process to find out the optimal ε^* that maximizes the sum-throughput of the proposed system.

V. NUMERICAL RESULTS AND DISCUSSIONS

We present Monte-Carlo simulation results to corroborate our derived analysis for the proposed system in this section.

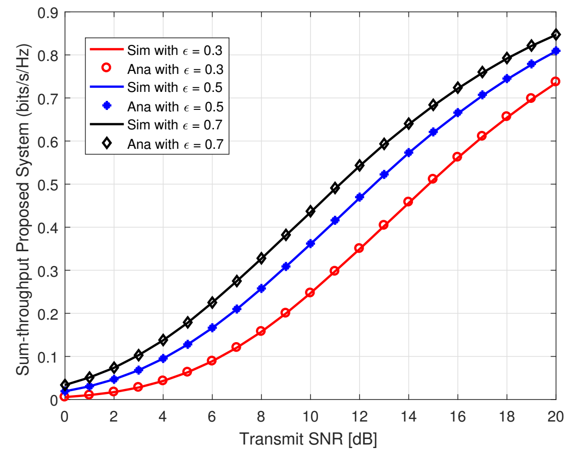

Fig. 7. Sum-throughput of proposed system

The simulation parameters are listed in Table 1. We have used MATLAB as a simulation tool to run the Monte-Carlo simulation by averaging over 10^5 random realizations of Rayleigh block fading channels h_{IoT_R}, $h_{s_{rec}}$, $h_{IoT_{rec}}$ to get the simulation results. The analytical results are computed using the derived Eq. 17, Eq. 18, Eq. 19 and Eq. 20 as given in Theorem 1 and Theorem 2. In Fig. 5 and 6, the outage probability of the source user and IoT relay user are plotted against the transmit SNR at different power splitting factor $\varepsilon = 0.3, 0.5, \& 0.7$. It can be seen that the outage probability is a decreasing function with respect to increase in δ and ε. Furthermore, our analysis exactly matched with the simulation results as depicted in Fig. 5 and Fig. 6. As the data transmission of source and IoT_R user depends on the energy harvested at the IoT_R user, we can see that as ε increases from 0.3 to 0.7, the outage probability for both source and IoT_R user decreases. As ε increases, the IoT_R user harvests more energy from the source user RF signal for data transmission that decreases the outage probability for both source and IoT_R user.

Considering, source user and IoT relay user as two user in the system for our proposed system, in Fig. 7, we plotted the sum-throughput against the transmit SNR at different power splitting factor $\varepsilon = 0.3, 0.5, \& 0.7$. It can be observed that sum-throughput is an increasing function with respect to increase in δ and ε. As ε increases, the IoT_R user harvests more energy and it uses the harvested energy to transmits the both source and IoT_R user data to their respective destinations which in turn increases the overall sum-throughput of the proposed system.

Similarly, in Fig. 8 and Fig. 9, we plotted the outage probability of the source and IoT_R user against the power splitting factor ε at different transmit SNR $\delta = 5, 10, \& 15$. In Fig. 8, we can see that the outage probability of the source user decreases with the increase in transmit SNR δ and ε, reaches to the minimum and then increases again. But, in Fig. 9, we can see a normal trend for IoT_R user i.e., the outage probability of the IoT_R user decreases with the increase the

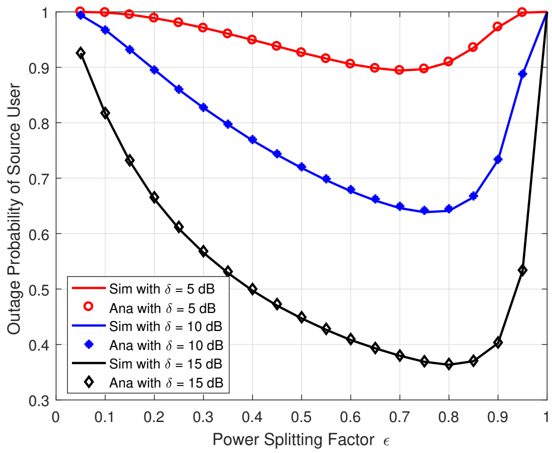

Fig. 8. Outage probability of source user v/s ε with different δ

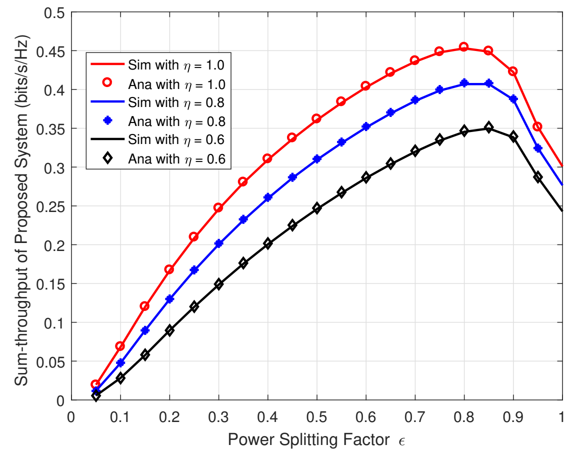

Fig. 11. Sum-throughput of proposed system v/s ε with different η

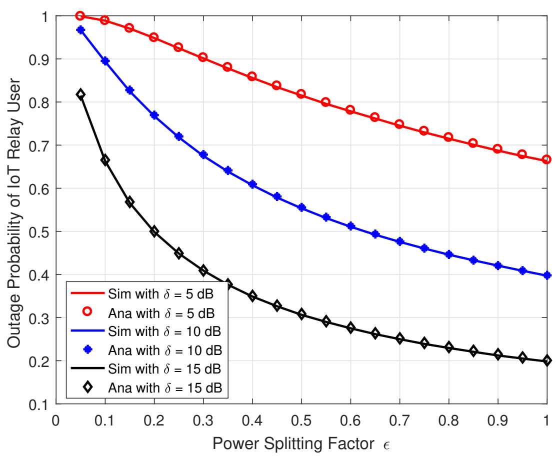

Fig. 9. Outage probability of IoT relay user v/s ε with different δ

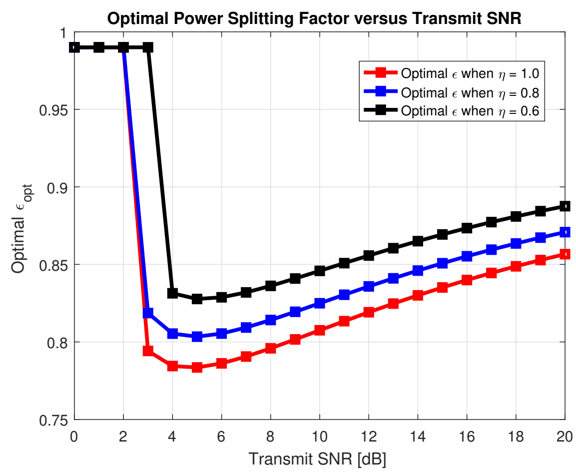

Fig. 12. Optimal ε for sum-throughput maximization

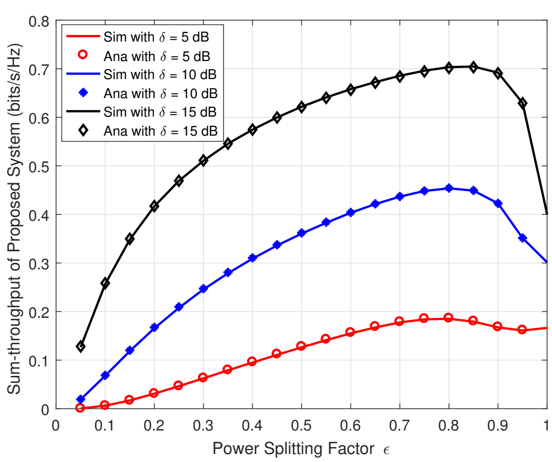

Fig. 10. Sum-throughput of proposed system v/s ε with different δ

transmit SNR δ and ε. The reason behind this is that, following the NOMA protocol, we have allocated more power to the data transmission of the IoT_R user than the source user.

Alongside, we wanted to further verify our analysis for the proposed system sum-throughput against the power splitting factor ε. So, we plotted sum-throughput against the ε varying from 0 to 1 and $\delta = 5, 10, \&15$. In Fig. 10, we can observe the trend that, the sum-throughput first increases with the increase in ε, and δ, reaches to the maximum and then decreases. Similarly, in Fig. 11, we plotted the sum-throughput for our proposed system with $\delta = 10$ at varying energy harvesting efficiency factor $\eta = 0.6, 0.8, \&1.0$. We can observe a similar trend as in Fig. 10. The sum-throughput first increases with the increase in ε, and η, reaches to the maximum and then decreases. This confirms that the sum-throughput is maximum at some optimal ε. Further it should be noted from Fig. 10 and Fig. 11 that, higher the value of ε, higher is the sum-throughput. In reality, we cannot have high ε as there will be less power allocated for information processing. Hence, there will be an outage in the system as no communication data will be transferred to the respective destinations. Therefore, we need to find optimal ε^* that maximizes the sum-throughput for the proposed system. In Fig. 12, we found out optimal ε^* that maximizes the sum-throughput of the proposed system through Golden section search method and plotted it against the transmit SNR. We can observe that the optimal ε^* first decreases and then slightly tends to increase with the increase in transmit SNR.

VI. Conclusion and Future Works

In this paper, we presented our system model on RF energy harvesting and information transmission where a power constrained IoT relay node first harvests the energy from the source node RF signal to power up itself using power splitting protocol and then transmits the source node information along with its information data using NOMA protocol. As opposed to conventional EH based relaying techniques, where a EH-based relay node only helps the source user to transmits its data successfully, our model also considers the data of the IoT relay user to be transmitted along with the source node data using NOMA protocol. We have mathematically derived the outage probability, throughput and sum-throughput for our proposed system where we corroborate our theoretical analysis with the simulation results. Through Golden section search method, we also found out the optimal power splitting factor that maximizes the sum-throughput of our proposed model. It is evident that our proposed system model is feasible for ubiquitous IoT relay systems for self-sustainable energy-efficient communication and data transmission.

For future work, we would like to investigate the ergodic capacity of the proposed system and derive the exact-forms of the sum-throughput for the proposed model. It would also be interesting to use IoT relay node as a bi-directional relay where it can be used to power up itself and different nodes by EH and at the same time transmits the information of the different nodes to the wireless access points or hybrid access points. We would also like to investigate the performance of our proposed model by introducing interference from other nodes and harvesting the energy from interfering signal as an additional source of energy.

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