RF Energy Harvesting and Information Transmission in IoT Relay Systems based on Time Switching and NOMA

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***Abstract*—A huge expansion of billions of Internet of Things (IoT) sensor and devices is expected over the next few years which will consume more power. Therefore, energy efficiency is a major concern for the development of fifth generation (5G) wireless systems. In wireless communication systems, energy harvesting (EH) is an emerging paradigm that allows the sensor nodes to recharge themselves through radio frequency (RF) signals directed to them from the source node and then relaying or transmitting the information. Although a myriad of works have been carried out in the literature for EH, the absolute vast majority of those works only consider RF EH at relay node and transmission of source node data successfully to its destination node. Those approaches do not consider the data transmission of the relay node that may be an IoT node which needs to transmit its data along with the source node data to their respective destinations. Thus, such approaches are clearly ineffective for energy efficient IoT relay systems. In this paper, we rather focus on RF EH and information transmission based on time switching (TS) relaying and non-orthogonal multiple access (NOMA) for IoT relay systems. A source node information data is relayed through power constrained IoT relay node IoT_R that first harvests the energy from source node RF signal using TS protocol and then transmits source node information along with its information using NOMA protocol. We have mathematically derived analytical expressions for outage probability, throughput and sum-throughput for our proposed system. We have also formulated an algorithm to find out optimal TS factor that maximizes the sum-throughput for our proposed system. Our proposed system analytical results are validated by the simulation results.**

I. Introduction

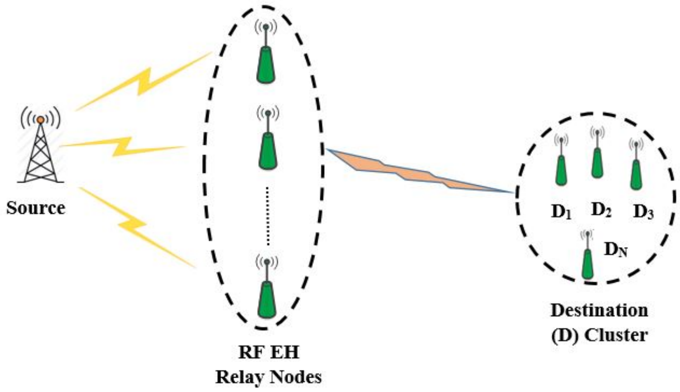
With the rapid expansion of Internet of Things (IoT) technology, it is expected that billions of small devices will be connected with each other over the next few years [1][2]. The technological development in IoT integrates various sensors, devices, smart objects to be fully operated as autonomous device-to-device (D2D), machine-to machine (M2M) without any human intervention [3][4]. As IoT can support massive smart object communications, it is considered as one of the most important part of fifth generation (5G) wireless systems [5][6]. Such massive communications of smart objects will consume a huge power. Therefore, energy efficient green communication within the context of 5G and IoT is a challenging problem to be solved [7].

These massive IoT sensor nodes and devices are usually battery operated and hence replacement of battery in such small objects is not a feasible option. Moreover, cooperative communication such as conventional relaying techniques requires the aiding relaying node to spend their energy that may prevent the battery operated IoT relay nodes and devices to take an active part in relaying.

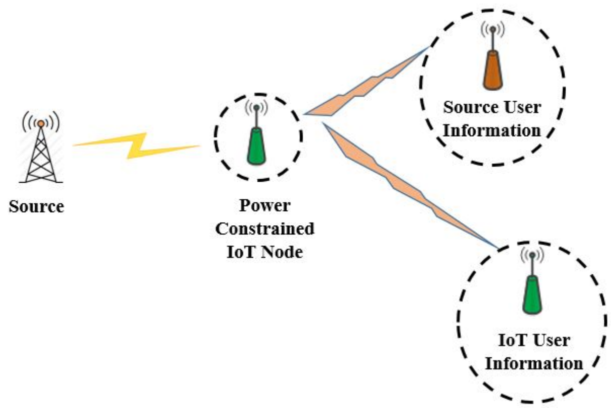
Energy harvesting (EH) from ambient radio frequency (RF) signals has become an energy efficient solutions to power massive IoT sensors and devices [8]. RF EH is thus considered as an appealing solution in extending the lifetime of these IoT sensors and devices from months to years and even decades, that ultimately enable their self-sustaining operations [9]. In wireless communication systems, simultaneous information and power transfer (SWIPT) is an emerging paradigm that allows the wireless IoT sensor nodes to recharge themselves through RF signals directed to them from the source node and then relaying or transmitting the information [10]. Meanwhile, accommodating multiple users that can be multiplexed in power domain, non-orthogonal multiple access (NOMA) has been proposed as another important candidate for future 5G technology for providing spectral efficiency and power gains [11][12].

For energy harvesting and decoding the information separately, power splitting (PS) relaying and time splitting (TS) relaying are very popular SWIPT schemes. In PS relaying scheme, the receiver uses a portion of received power for energy harvesting purpose and uses the remaining power for information decoding. However, in TS relaying scheme, the receiver switches between energy harvesting and information decoding over time.

Nasir *et al.* studied amplify-and-forward (AF) relaying network based on TS and PS relaying schemes [13]. Analytical expressions for the outage probability and the ergodic capacity for delay-limited and delay tolerant transmission modes were studied and derived in thier study. Du *et al.* theoretically analyze the system outage probability based on TS and PS relaying protocols by investigating the outage analysis of multi-user cooperative transmission network with TS and PS relay receiver architectures [14]. A cooperative



(a) Generic RF EH relay communication system



(b) Proposed system model based on NOMA

Fig. 1: RF EH in IoT relay systems

SWIPT NOMA protocol has been studied in [15]. Here, near NOMA users that are close to source node acts as EH based relay to help far NOMA users. They derived the closed-form expressions for the outage probability and system throughput by considering the user selection schemes. Ha *et al.* [16] studied the outage performance of EH based decode-and-forward (DF) relaying NOMA networks by deriving the closed form equation of the outage probability. Kader *et al.* [17] studied TS and PS with EH and NOMA in a spectrum sharing environment. The secondary transmitter acts as an EH based relay and then transmits the primary transmitter data along with its data using NOMA protocol. Jain *et al.* [18] also proposed an EH-based spectrum sharing protocol for wireless sensor networks. However, although a myriad of such EH works have been carried out in the literature, EH considering the energy-efficient data transmission of source and IoT relay node together based on TS and NOMA suitable for IoT relay systems has not been considered. This motivated us to propose RF EH and information transmission based on TS and NOMA for IoT relay systems and analyze their performance by deriving the analytical expressions for outage probability, throughput and sum-throughput. In summary, the principal contribution of this paper can be outlined as:

- We have proposed an RF EH-based on TS and NOMA suitable for IoT relay systems.
- Previous work and approach in this domain, do not consider the data transmission of the relay node that may be an IoT node which needs to transmit its data along with the source node data to their respective destinations. In this paper, we rather focus on RF EH and information transmission based on TS relaying and NOMA for IoT relay systems.
- We have mathematically derived the outage probability, throughput and sum-throughput for our proposed system. We have also formulated an iterative algorithm-Golden Section Search Method to find the optimal time switching and power splitting factor for sum-throughput maximization.
- Our proposed system analytical results are validated by the simulation results.

The rest of the paper is organized as follows. In Section II, we present our system model for the considered scenario. Section III deals with the proposed system model based on time switching 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 time switching that maximizes the sum-throughput for our proposed system. Numerical results and discussions are presented in Section V. Conclusion and future works are drawn in Section VI.

II. System Model

In order for small IoT device to communicate and transmit data, M2M relaying has been proposed as a suitable heterogeneous architecture for 802.16p IoT, Third Generation Partnership Project (3GPP) machine type communications (MTC) and European Telecommunications Standards Institute (ETSI) M2M[19]. An illustration of generic RF EH relay communication system is shown in Fig. 1(a), where a source node selects one of the RF EH relaying node to transmits its information to its intended destination. Such cooperative RF EH relay communication systems as depicted by Fig. 1(a), 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 transmits its own data to transmit to its destination node.

It is also understood that using more than one relay increases the complexity of the systems greatly [20]. Therefore, we have considered a single relay IoT_R node for our system model. But, it can be extended to multiple relay IoT_R node scenario as well. We have considered a scenario as shown in Fig. 1 (b), where a source has to transmit its information data to the destination i.e, source user. Due to fading or weak link between a source-destination pair, the source node seek the help of IoT relay node (IoT_R) for relaying its information data. IoT_R is rather power constrained node that acts as a DF relay. It first harvests the RF energy from source signal using TS protocol in the first stage and then transmits source information data along with its own data using NOMA protocol in next subsequent stage. The dual purpose of energy harvesting and forwarding the information data is thus served by IoT_R. The receiving end for source and IoT_R node serves as the destination for data transmission.

III. System Model based on Time Switching and NOMA

The considered system model based on TS and NOMA is shown in Fig. 2. We have also assumed that all nodes are considered to be operating in half duplex mode. 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. In this TS relaying scheme, power constrained IoT_R node first harvests the energy from the source node RF signal for αT duration and uses time $\frac{(1-\alpha)T}{2}$ for information processing and $\frac{(1-\alpha)T}{2}$ for information transmission to source and IoT user using NOMA protocol. The detailed step of our proposed system model based on TS and NOMA is given below.

A. Stage 1

In this stage, the source transmits signal x_s with power P_s to the IoT_R for half of the block time T i.e., $T/2$ period of time. Here, IoT_R node works as an TS based relay. The IoT_R node divide the time block in the ratio αT:$\frac{(1-\alpha)T}{2}$:$\frac{(1-\alpha)T}{2}$. Here αT is for energy harvesting by IoT_R and $\frac{(1-\alpha)T}{2}$ is for information processing by IoT_R respectively, $0 \le \alpha \le 1$. The information signal received at IoT_R during this stage is given as:

$$\hat{y}_{IoT_R} = \sqrt{P_s} h_{IoT_R} x_s + n_{IoT_R}, \tag{1}$$

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 $\sigma^2_{IoT_R}$. $h_{IoT_R} \sim CN(0, \lambda_h)$ 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 αT duration of time is given as:

$$\hat{E}_{h_{IoT_R}} = \eta P_s |h_{IoT_R}|^2 \alpha T, \tag{2}$$

where $0 \le \eta \le 1$ is the energy conversion efficiency. The pre-processing power for the energy harvesting is assumed to be negligible in contrast to the transmission power P_s.

The transmit power of IoT_R i.e., $\hat{P}_{IoT_R}$ in $\frac{(1-\alpha)T}{2}$ block of time can be given as:

$$\hat{P}_{IoT_R} = \frac{\hat{E}_{h_{IoT_R}}}{(1-\alpha)T/2} = \frac{2\eta P_s |h_{IoT_R}|^2 \alpha}{(1-\alpha)}, \tag{3}$$

B. Stage 2

In this stage, the IoT_R node transmits a superimposed composite signal $\hat{Z}_{I_{C1}}$ which consists of source information x_s and IoT_R information x_{IoT_R} to the respective destination of source and IoT relay node using NOMA protocol [12].

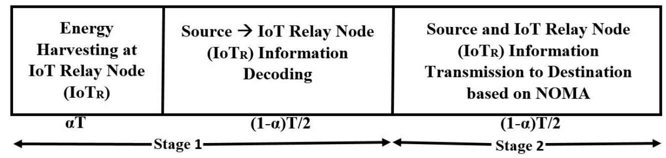


Fig. 2: Proposed system model based on time switching (TS) and NOMA

The superimposed composite signal $\hat{Z}_{I_{C1}}$ following NOMA protocol can be given as:

$$\hat{Z}_{I_{C1}} = \sqrt{\phi_1 \hat{P}_{IoT_R}} x_s + \sqrt{\phi_2 \hat{P}_{IoT_R}} x_{IoT_R} \tag{4}$$

where $\phi_1 + \phi_2 = 1$ and $\phi_2 = 1 - \phi_1$.
Now, the received signals at the receiver of Source user and IoT user can be respectively given as:

$$\hat{y}_{s_{rec}} = \sqrt{\hat{P}_{IoT_R}} h_{s_{rec}} \hat{Z}_{I_{C1}} + n_{s_{rec}}, \tag{5}$$

$$\hat{y}_{IoT_{rec}} = \sqrt{\hat{P}_{IoT_R}} h_{IoT_{rec}} \hat{Z}_{I_{C1}} + n_{IoT_{rec}}, \tag{6}$$

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 $\phi_1 < \phi_2$.

C. Outage Probability, Throughput and Sum-throughput

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

$$\hat{\gamma}_{IoT_R} = \frac{P_s |h_{IoT_R}|^2}{\sigma^2_{IoT_R}} = \hat{\delta} |h_{IoT_R}|^2 \tag{7}$$

where $\hat{\delta} \triangleq \frac{P_s}{\sigma^2_{IoT_R}}$.

According to Eq. 4, the received SNR with x_{IoT_R} and x_s at the receiving source user is given by:

$$\hat{\gamma}_{s_{rec}}^{x_{IoT_R} \to x_s} = \frac{\phi_2 \hat{P}_{IoT_R} |h_{s_{rec}}|^2}{\phi_1 \hat{P}_{IoT_R} |h_{s_{rec}}|^2 + \sigma^2_{s_{rec}}} \tag{8}$$

$$\hat{\gamma}_{s_{rec}} = \frac{\phi_1 \hat{P}_{IoT_R} |h_{s_{rec}}|^2}{\sigma^2_{s_{rec}}} \tag{9}$$

where $\hat{\gamma}_{s_{rec}}^{x_{IoT_R} \to x_s}$ is the SNR required at x_s to decode and cancel x_{IoT_R}.

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

$$\hat{\gamma}_{IoT_{rec}} = \frac{\phi_2 \hat{P}_{IoT_R} |h_{IoT_{rec}}|^2}{\phi_1 \hat{P}_{IoT_R} |h_{IoT_{rec}}|^2 + \sigma^2_{IoT_{rec}}} \tag{10}$$

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 can be given as:

$$\hat{P}_{Out_S} = Pr(min(\hat{\gamma}_{IoT_R}, \hat{\gamma}_{s_{rec}}) \leq \hat{\psi}) \tag{11}$$

where $\hat{\psi} = 2^R - 1$ is the lower threshold for SNR i.e., outage probability.
Similarly, the outage probability of the IoT relay node IoT_R can be given as:

$$\hat{P}_{Out_{IoT_R}} = Pr(min(\hat{\gamma}_{s_{rec}}^{x_{IoT_R} \to x_s}, \hat{\gamma}_{IoT_{rec}}) \leq \hat{\psi}) \tag{12}$$

The throughput of the source node can be given as:

$$T\hat{h}r_S = \frac{(1-\hat{P}_{out_S})(1-\alpha)R}{2} \tag{13}$$

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

$$T\hat{h}r_{IoT_R} = \frac{(1-\hat{P}_{Out_{IoT_R}})(1-\alpha)R}{2} \tag{14}$$

Therefore, the sum-throughput of the whole system using TS and NOMA can be given as:

$$\begin{aligned} T\hat{h}r &= T\hat{h}r_S + T\hat{h}r_{IoT_R} \\ &= \frac{(1-\hat{P}_{Out_S})(1-\alpha)R}{2} + \frac{(1-\hat{P}_{Out_{IoT_R}})(1-\alpha)R}{2} \end{aligned} \tag{15}$$

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

$$\begin{aligned} \hat{P}_{Out_S} = 1 - 2\sqrt{\frac{\lambda_h\lambda_g x_0}{k}} K_1\Big(2\sqrt{\frac{\lambda_h\lambda_g x_0}{k}}\Big) \\ + \sum_{n=0}^{\infty}\frac{(-1)^n}{n!}(\lambda_h x_0)^{n+1}E_{n+2}\Big(\frac{\lambda_g}{k}\Big) \end{aligned} \tag{16}$$

$$\begin{aligned} T\hat{h}r_S = \frac{(1-\alpha)R}{2}\Bigg(2\sqrt{\frac{\lambda_h\lambda_g x_0}{k}} K_1\Big(2\sqrt{\frac{\lambda_h\lambda_g x_0}{k}}\Big) \\ - \sum_{n=0}^{\infty}\frac{(-1)^n}{n!}(\lambda_h x_0)^{n+1}E_{n+2}\Big(\frac{\lambda_g}{k}\Big)\Bigg) \end{aligned} \tag{17}$$

where, $x_0 = \frac{\hat{\psi}}{\hat{\delta}}$, $k = \frac{2\alpha\eta\phi_1}{(1-\alpha)}$, $K_1(.)$ 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. 7 we have,

$\hat{\gamma}_{IoT_R} = \hat{\delta}X$ where, $|h_{IoT_R}|^2 = X$

Also, from Eq. 9, we have,

$$\hat{\gamma}_{s_{rec}} = \frac{\phi_1\hat{P}_{IoT_R}|h_{s_{rec}}|^2}{\sigma^2_{s_{rec}}} \triangleq \delta XYk$$

where $Y = |h_{s_{rec}}|^2, \sigma^2_{s_{rec}} = 1, k = \dfrac{2\alpha\eta\phi_1}{(1-\alpha)}$

From Eq. 11, the outage probability of the source is:

$$\begin{aligned} \hat{P}_{Out_S} &= Pr(min(\hat{\gamma}_{IoT_R}, \hat{\gamma}_{s_{rec}}) < \hat{\psi}) \\ &= 1 - Pr(min(\hat{\gamma}_{IoT_R}, \hat{\gamma}_{s_{rec}}) \geq \hat{\psi}) \\ &= 1 - Pr(\hat{\delta}X \geq \hat{\psi}, \hat{\delta}kXY \geq \hat{\psi}) \\ &= 1 - Pr\big(X \geq \frac{\hat{\psi}}{\hat{\delta}}, Y \geq \frac{\hat{\psi}}{\delta kX}\big) \end{aligned}$$

Let $x_0 = \dfrac{\hat{\psi}}{\hat{\delta}}$,

$$\begin{aligned} &= 1 - Pr\big(X \geq x_0, Y \geq \frac{x_0}{kX}\big) \\ &= 1 - \int_{x_0}^{\infty} f_X(x)\Big(\int_{\frac{x_0}{kx}}^{\infty} f_Y(y)dy\Big)dx \\ &= 1 - \int_{x_0}^{\infty} \lambda_h e^{-\lambda_h x}\Big(\int_{\frac{x_0}{kx}}^{\infty} \lambda_g e^{-\lambda_g y}dy\Big)dx \\ &= 1 - \int_{x_0}^{\infty} \lambda_h e^{-\lambda_h x}\big(e^{-\lambda_g\frac{x_0}{kx}}\big)dx \\ &= 1 - \int_{x_0}^{\infty} \lambda_h\big(e^{-\lambda_h x - \lambda_g\frac{x_0}{kx}}\big)dx \\ &= 1 - \Bigg(\underbrace{\lambda_h\int_{x=0}^{\infty}\big(e^{-4\lambda_g\frac{x_0}{k4x} - \lambda_h x}\big)dx}_{I_1} \\ &\quad \underbrace{- \lambda_h\int_{x=0}^{x_0}\big(e^{-\lambda_g\frac{x_0}{kx} - \lambda_h x}\big)dx}_{I_2}\Bigg) \end{aligned}$$

Let us first evaluate the integral I_1

Now, using the formula,

$$\int_0^{\infty} e^{-\frac{\beta}{4x} - \gamma x}dx = \sqrt{\frac{\beta}{\gamma}}K_1\sqrt{\beta\gamma} \quad [21], Eq. 3.324.1$$

$$I_1 = \lambda_h\sqrt{\frac{4\lambda_g x_0}{k\lambda_h}}K_1\Bigg(\sqrt{\frac{4\lambda_g x_0\lambda_h}{k}}\Bigg)$$

$$I_1 = 2\sqrt{\frac{\lambda_h\lambda_g x_0}{k}}K_1\Bigg(2\sqrt{\frac{\lambda_h\lambda_g x_0}{k}}\Bigg)$$

Now, let us evaluate the integral I_2

$$I_2 = \lambda_h\int_{x=0}^{x_0}\big(e^{-\lambda_h x - \frac{\lambda_g x_0}{kx}}\big)dx$$

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

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

Substituting $y = \dfrac{1}{x} \to dx = -\dfrac{1}{y^2}dy$

$$= \sum_{n=0}^{\infty}\frac{(-1)}{n!}(\lambda_h)^{n+1}\int_{y=\frac{1}{x_0}}^{\infty} y^{-n-2}e^{-\frac{\lambda_g x_0 y}{k}}dy$$

Now, substituting further $t = x_0 y \to dt = x_0 dy$

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

Now, by definition of exponential integral of order n

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

$$I_2 = \sum_{n=0}^{\infty}\frac{(-1)}{n!}(\lambda_h x_0)^{n+1}E_{n+2}\Big(\frac{\lambda_g}{k}\Big)$$

Therefore,

$\hat{P}_{Out_S} = 1 - I_1 + I_2$

$\hat{P}_{Out_S} = 1 - 2\sqrt{\frac{\lambda_h \lambda_g x_0}{k}} K_1\Big(2\sqrt{\frac{\lambda_h \lambda_g x_0}{k}}\Big)$

$+ \sum_{n=0}^{\infty} \frac{(-1)^n}{n!} (\lambda_h x_0)^{n+1} E_{n+2}\Big(\frac{\lambda_g}{k}\Big)$

Putting the value of $\hat{P}_{Out_S}$ in Eq. 13, we get,

$$T\hat{h}r_S = \frac{(1-\alpha)R}{2}\Bigg(2\sqrt{\frac{\lambda_h \lambda_g x_0}{k}} K_1\Big(2\sqrt{\frac{\lambda_h \lambda_g x_0}{k}}\Big) - \sum_{n=0}^{\infty} \frac{(-1)^n}{n!} (\lambda_h x_0)^{n+1} E_{n+2}\Big(\frac{\lambda_g}{k}\Big)\Bigg)$$

This ends the proof of Theorem 1.

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

$$\hat{P}_{Out_{IoT_R}} = 1 - 2\sqrt{d\lambda_h(\lambda_g + \lambda_z)} K_1\Big(2\sqrt{d\lambda_h(\lambda_g + \lambda_z)}\Big) \quad (18)$$

$$T\hat{h}r_{IoT_R} = \frac{(1-\alpha)R}{2}\Bigg(2\sqrt{d\lambda_h(\lambda_g + \lambda_z)} K_1\Big(2\sqrt{d\lambda_h(\lambda_g + \lambda_z)}\Big)\Bigg) \quad (19)$$

where, $d = \frac{\hat{\psi}}{(\phi_2 - \phi_1 \hat{\psi})l}$, $l = \frac{2\alpha\eta P_s}{(1-\alpha)}$

Proof:

From Eq. 12, the outage probability of IoT relay node is:

$\hat{P}_{Out_{IoT_R}} = Pr(min(\hat{\gamma}_{s_{rec}}^{x_{IoT_R} \to x_s}, \hat{\gamma}_{IoT_{rec}}) < \hat{\psi})$

$\hat{P}_{Out_{IoT_R}} = 1 - Pr\big(\frac{\phi_2 lXY}{\phi_1 lXY + 1} \geq \hat{\psi}, \frac{\phi_2 lXZ}{\phi_1 lXZ + 1} \geq \hat{\psi}\big)$

where $\hat{P}_{IoT_R} = \frac{2\alpha\eta P_s |h_{IoT_R}|^2}{(1-\alpha)} \triangleq \frac{2\alpha\eta\hat{\delta}X}{(1-\alpha)}, l = \frac{2\alpha\eta P_s}{(1-\alpha)}$

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

$= 1 - Pr\big(Y \geq \frac{\hat{\psi}}{(\phi_2 - \phi_1\hat{\psi})lX}, Z \geq \frac{\hat{\psi}}{(\phi_2 - \phi_1\hat{\psi})lX}\big)$

Conditioning on X, we have,

$= 1 - \int_0^{\infty} Pr\big(Y \geq \frac{\hat{\psi}}{(\phi_2 - \phi_1\hat{\psi})lx}\big) \times$

$Pr\big(Z \geq \frac{\hat{\psi}}{(\phi_2 - \phi_1\hat{\psi})lx}\big) f_X(x)dx$

put $\frac{\hat{\psi}}{(\phi_2 - \phi_1\hat{\psi})lx} = T$

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

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

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

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

substituting the value of T above

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

TABLE I: Simulation Parameters

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

let d $= \frac{\hat{\psi}}{(\phi_2 - \phi_1\hat{\psi})l}$

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

Now, using the formula

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

$= 1 - \lambda_h \sqrt{\frac{4(\lambda_g + \lambda_z)d}{\lambda_h}} K_1\Big(\sqrt{4(\lambda_g + \lambda_z)d\lambda_h}\Big)$

$\hat{P}_{Out_{IoT_R}} = 1 - 2\sqrt{d\lambda_h(\lambda_g + \lambda_z)} K_1\Big(2\sqrt{d\lambda_h(\lambda_g + \lambda_z)}\Big)$

Putting the value of $\hat{P}_{Out_{IoT_R}}$ in Eq. 14, we get,

$$T\hat{h}r_{IoT_R} = \frac{(1-\alpha)R}{2}\Bigg(2\sqrt{d\lambda_h(\lambda_g + \lambda_z)} K_1\Big(2\sqrt{d\lambda_h(\lambda_g + \lambda_z)}\Big)\Bigg)$$

This ends the proof of Theorem 2.

Combining Eq. 17 and Eq. 19, we finally get the analytical equation for the sum-throughput of the proposed system using TS and NOMA.

IV. Optimal Time Switching α^* for Sum-Throughput Maximization

In order to find out optimal time switching factor α that gives the best performance for sum-throughput maximization for our proposed system using TS and NOMA, we evaluate $\big(\frac{dT\hat{h}r(\alpha)}{d\alpha}\big)_{TS} = 0$ where $T\hat{h}r(\alpha)$ is the sum-throughput function with respect to time switching factor α. By analyzing the throughput function for source and IoT node versus α as shown in Fig. 6, we determine that these are concave functions which have a unique maxima α^*, on the interval $[0, 1]$. Therefore, we resort to Golden Section Search Method [22] which is simple yet compelling iterative process to find out the optimal α^* that maximizes the sum-throughput for the proposed system. With Golden Section Search Method, optimal α^* can be computed offline before the data transmission.

V. Numerical Results and Discussion

In this section, we present the simulation results to verify our analysis for the proposed system as explained in the previous section. The simulation parameters are given in Table 1. We use MATLAB to run the Monte-Carlo simulation by averaging over 10^5 random realizations of Rayleigh block

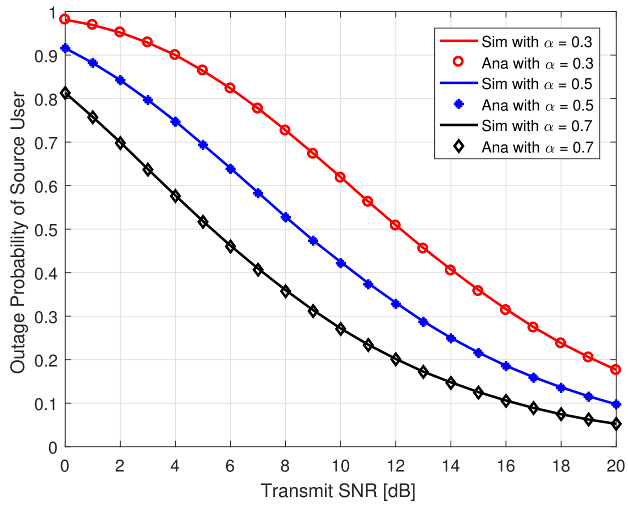


Fig. 3: Outage Probability of Source User

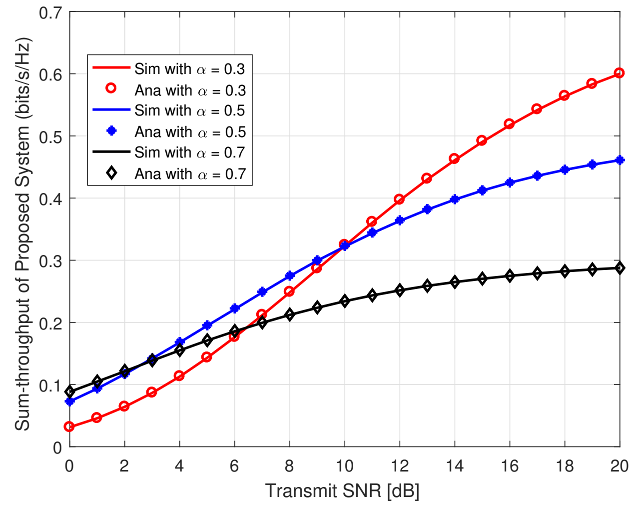


Fig. 5: Sum-throughput of proposed system

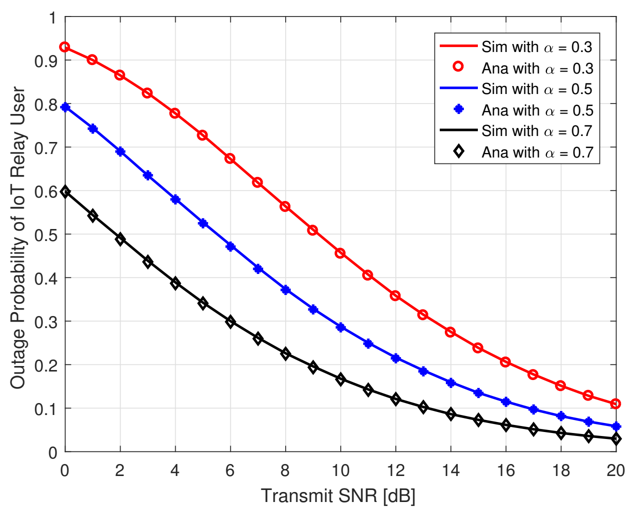


Fig. 4: Outage Probability of IoT Relay User

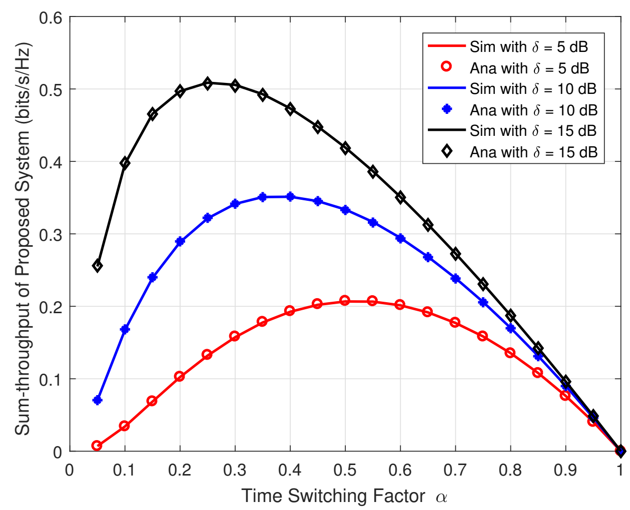


Fig. 6: Sum-throughput of proposed system v/s α with different δ

fading channels h_{IoT_R}, $h_{s_{rec}}$, $h_{IoT_{rec}}$ and get the simulation results. In Fig. 3 and Fig. 4, the outage probability of the source user and IoT relay user are plotted against the transmit SNR at different time switching $\alpha = 0.3, 0.5, \& 0.7$. It can be observed that outage probability is a decreasing function with respect to increase in transmit SNR and α. Furthermore, our analysis exactly matched with the simulation results as depicted in Fig. 3 and 4.

Considering, source user and IoT relay user as two user in the system for our proposed system, in Fig. 5, we plotted the sum-throughput against the transmit SNR at time switching $\alpha = 0.3, 0.5, \& 0.7$. It can be observed that sum-throughput is an increasing function with respect to increase in transmit SNR and α. It is interesting to note that at transmit SNR greater than 10 dB, the sum-throughput is higher at time switching $\alpha = 0.3$ than at $\alpha = 0.5$ and $\alpha = 0.7$, although the respective outage probability for both source and IoT user at $\alpha = 0.3$ is higher than $\alpha = 0.5$ and $\alpha = 0.7$ against all transmit SNR $0-20$ dB. This indicates that the time switching factor α plays an important factor for EH and information decoding.

Next, we intended to validate our analysis for the proposed system at different time switching factor α. We plotted the sum-throughput against the α varying from 0 to 1 and $\delta = 5, 10, \& 15$. In Fig. 6, we can observe the trend that, the sum-throughput first increases with the increase in α and transmit SNR, reaches to the maximum and then decreases. This confirms that the sum-throughput is maximum at some optimal time switching factor α^*.

Therefore, we need to find optimal α^* that maximizes the sum-throughput for the proposed system. In Fig. 7, we found out optimal α^* that maximizes the sum-throughput of the

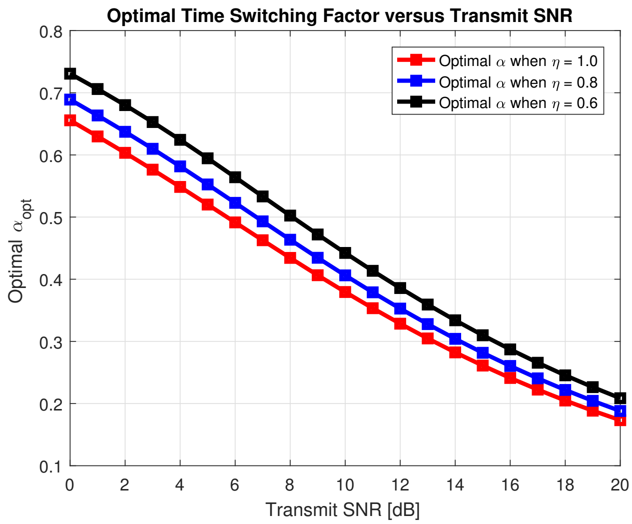


Fig. 7: Optimal α for sum-throughput maximization

proposed system through Golden section search method as explained in Section IV and plotted it against transmit SNR. In Fig. 7, we can observe that optimal α^* linearly decreases with increase in transmit SNR. Finding optimal α^* is important to avoid an outage in the proposed system and maximizing the sum-throughput.

VI. Conclusion and Future Works

Energy efficient green communication within the context of 5G and IoT is a challenging problem to be solved. Therefore, in this paper, we presented our model on RF energy harvesting and information transmission in IoT relay systems based on time switching and NOMA. Considering the energy constrained nature of the IoT, here a power constrained IoT relay node first harvests the energy from the source node RF signal to power up themselves. The IoT relay node can harvests the energy using time switching relaying protocol. Then in the next subsequent stage, IoT relay node transmits the source node information along with its information data to respective destinations using NOMA protocol. We have mathematically derived the expressions for outage probability, throughput and sum-throughput for our proposed system based on TS and NOMA. Further, we verified our derived analysis with the simulation results. We showed that our analytical results exactly matched with the simulation results. We also found out the optimal time switching factor α^* that maximizes the sum-throughput of the proposed system through the Golden Section Search Method.

For future work, we would also like to study the performance of our proposed system by introducing interference from other nodes and harvesting the energy from interfering signal.

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