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EPS-TRA: Energy efficient Peer Selection and Time switching Ratio Allocation for SWIPT-enabled D2D Communication

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***Abstract*—This paper considers device-to-device (D2D) network with Simultaneous Wireless Information and Power Transfer (SWIPT) enabled devices to ensure self-sustained communication in situations like disasters. Such direct link networks can ensure connectivity with devices having drained back-up, when trapped in collapsed infrastructure, through mutual sharing of energy on RF link. To guarantee successful execution of SWIPT session for an isolated device in wake of disasters, it is pertinent to select a reliable peer with ultimate aim to maximize link Energy Efficiency (EE). In practice, Energy Harvesting (EH) is not achievable after Information Decoding (ID), however, it has been made possible through splitting the signal in the time domain. Selection of D2D peer for self-sustained communication with an objective to maximize EE through optimum time based splitting of signal has not been extensively studied . In this paper to manifest the aforesaid goal, we worked out a joint problem of peer association and time switching ratio allocation with an objective to maximize the EE for a device contained under collapsed infrastructure. We propose an Energy efficient Peer Selection and Time switching Ratio Allocation (EPS-TRA) algorithm to solve the proposed mixed integer problem. Numerical results validate our proposed approach in acquiring better EE when compared with Uniform Allocation Scheme of time slots for EH & ID. Furthermore, results explain how EE of the link varies with the choice of constrained variables i.e. data rate and harvested energy.**

***Index Terms*—Device-to-Device Networks, Simultaneous Wireless Information and Power Transfer, Energy Harvesting**

I. INTRODUCTION

Cellular communication problems are pervasive in many disaster situations and natural force majeure conditions. Nearly all case studies of disasters occurring in the last 30 years have faced communication infrastructure failure. This indicates that despite massive technological development, issues of communication failure persist and are still inevitable. When public communication networks fail, the impact can be widely felt and can wipe out access to a standard mobile or land-line telecommunication including internet and emergency satellite-based communications. Whether communication infrastructure is partially or completely knocked-offline; it may prove to be a matter of life and death for the affectees. The main power grid is affected during initial stages of the natural calamity which results in no power supply in the region thus primarily affecting the mobile phones using batteries as power backup because they run out of energy more quickly. The situation becomes more devastating when someone is trapped under collapsed infrastructure with drained-up mobile phone battery and no cellular coverage. In such scenarios, instant connectivity with individuals is required to safeguard their lives. To address this issue of no or less power and still have ubiquitous connectivity with public safety organizations operating outside tumbled infrastructure, a self-sustained communication network is envisaged in which devices can simultaneously communicate and transfer energy with the trapped node on a direct link.

Device-to-Device (D2D) communication is one of the promising addition to the 5G technologies which can act as an alternate source of connectivity to dispense with Base Station (BS) involvement during disasters. Although D2D networks can be of immense importance in the wake of natural catastrophe yet they are associated with challenges of high power consumption and energy efficient peer selection. To ensure power efficient reliable communication, Simultaneous Wireless Information and Power Transfer (SWIPT) is a promising technique to prolong the battery life of smart devices along with

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meeting Quality of Service (QoS). Energy Harvesting (EH) along with Information Decoding (ID) has become possible through time switching, power splitting and antenna switching techniques. Practical constraints like variable sensitivities for signal strength necessitate dual receivers in a single cell phone for ID and EH.

Energy-efficient in the wireless network has been integrated with many other technologies such as IoT and fog and became a major concern for self-sustained D2D communication [1][2]. Energy scavenging (also widely known as EH) is the process of converting free RF present in the environment (in the form of ambient energy) into electrical energy to power up autonomous or wireless devices. EH from free RF has come forth as an emerging technique to power up wireless devices where back-up batteries are impractical or cannot last longer. Since batteries have inherent constraints of finite energy, disposal concerns and bulky size therefore concept of EH can be exploited to augment back-up hours of battery. In the wake of emergency situations like disasters, it is the primary concern of disaster management authorities to have energy efficient communication with affectees of the disaster in no power and network coverage region. In such a scenario, affectees can be traced and remain connected through instant direct link SWIPT enabled D2D communication. Recent research works investigated in D2D communications with SWIPT [3][4][5][6] where beam forming, wave shaping and power splitting techniques have been primary focused. To the best of our knowledge, the Time Switching (TSW) based SWIPT for energy efficient resource utilization between two devices in direct communication to enhance spectrum efficiency per joule of consumed energy has been overlooked, hence, requires immediate attention.

In this paper, we investigate the joint problem of peer selection and time switching ratio for a SWIPT enabled D2D network. The goal is to maximize the EE of the link while satisfying the QoS and energy causality constraints in the network. The problem formulated is non-convex and is difficult to solve in polynomial time. To cope with this issue, we decompose the problem into two parts of peer selection and time switching ratio allocation problem; and solve it using a sequential iterative approach. We study SWIPT within D2D paired devices in the wake of situations when people are trapped in collapsed buildings or isolated disaster struck regions where a self-sustained direct communication is imperative to save lives. Our work primarily revolves around the selection of a reliable peer among competing nodes with an objective to maximize the energy efficiency of D2D link.

Our major contributions presented in this paper can be summarized as:

- We propose a time switching based D2D link energy efficiency maximization approach for devices enabled with SWIPT mode. SWIPT at D2D level has been proposed with practical assumptions of highly directive antennas and energy harvesting modules with better efficiencies. We have divided the time frame into three sub-slots for optimum trade-off between EH and ID.
- In our proposed approach we have formulated a Mixed Integer Linear Fractional Programming (MILFP) problem using Time Switching (TSW) ratio α as a continuous variable and peer association ζ as a binary integer variable. Formulated problem is Non-Deterministic Polynomial Time Hard (NP-Hard) problem therefore it cannot be solved either through linear fractional or integer optimization algorithms.
- We decompose the problem into two separate sub-problems as 1) time switching ratio optimization which has been solved using Linear Fractional Programming (LFP) and 2) integer peer association problem which has been solved through Branch and Bound Algorithm solver in Yalmip. We propose an Energy efficient Peer Selection and Time Switching Ratio Allocation (EPS-TRA) algorithm.
- Our proposed scheme elaborates the effects of various network parameters on EE and how they can be controlled based on the choice of constraints. Numerical results show that the achieved EE of D2D link through our proposed approach meets an increase of 300% over uniform allocation of time switching ratio between energy harvesting and information decoding.

The rest of this paper is structured as follows. Section 2 describes the the Related Work and in Section 3, we discuss System Model and formulate a mix integer optimization problem followed with the introduction of an iterative EPS-TRA algorithm in Section 4 for sequential solving of problem through Branch and Bound (BAB) and Linear Fractional Programming (LFP). In Section 5, we will carryout performance evaluation. Finally, we will conclude the paper and discuss some future research directions in Section 6.

II. RELATED WORK

Energy management in the mobile environment is a never-end problem that requires lots of attention to improve energy and power consumption. Many researchers these days coupling these concepts with technologies such as reinforcement and deep learning to autonomously manage the energy consumption in the cloud and edge environments [7][8]. The notion of SWIPT was proposed in [9] to study the trade-off between information decoding and energy harvesting from the same RF signal. Authors in [10] proposes a 3-layer

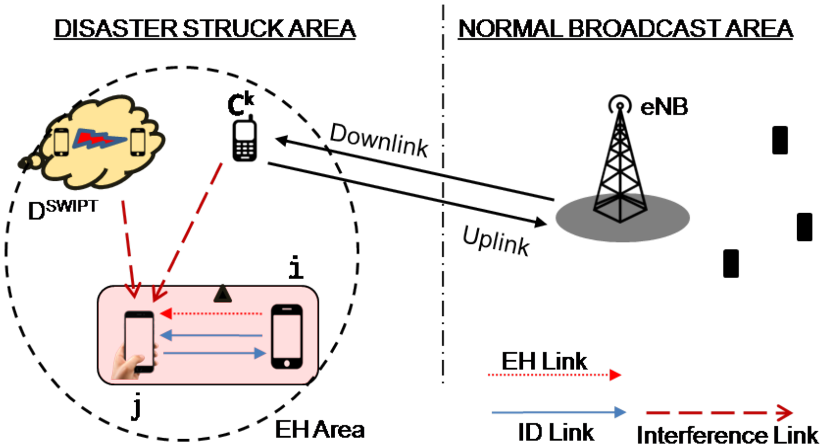


Fig. 1. Single cell scenario where device i has establish D2D link with device j for SWIPT. Three time slots are being used for information decoding and energy harvesting

architecture (physical layer, social layer and physical-social layer) where energy harvesting has been linked with social awareness among devices. The authors in [11] use MIMO diversity technique for SWIPT and three configurations of two types of receivers have been proposed. User Provided Networks (UPN) or opportunistic communication originate from the concept of self-sustained networks in isolated areas. Mendes et. al in [12] highlights the configuration of UPN where the end-user is at the same time a consumer and provider of network services. The idea of On-Demand Connectivity (ODC) similar to opportunistic communication can be used to harvest energy from nearby nodes and share information simultaneously as explored in [13].

Energy can be harvested either from free RF in the environment; power beacons to be installed for this purpose or from nearby nodes over D2D link. In [14] SWIPT enabled D2D communication was analyzed using ambient RF transmitters distributed through Ginibre α-Determinantal Point Process (DPP) and Poisson Point Process (PPP). Concepts of Dynamic Power Splitting (DPS) in SWIPT was proposed in [15] where three schemes of DPS; Time Switching (TS), Static Power Splitting (SPS) and On-off Power Splitting (OPS) are investigated. Simultaneous wireless information and energy transfer in a two-user MIMO interference channel has been discussed in [16], in which each receiver either decodes information or harvests energy using four different modes as – (ID1, ID2), (EH1, EH2), (EH1, ID2), and (ID1, EH2).

EH is accomplished at the cost of rate requirement of the channel, therefore, a compromise has to be drawn. The trade-off between the amount of energy used for relaying and the energy used for ID of cellular data at the relaying node has been elaborated in [17]. Maximization of network rate through beam forming design has been studied in [18] with co-existing cellular and D2D users. Energy harvesting from the nearest RF transmitter can be used to power up or charge devices operating autonomously. A large scale cognitive network can be used to transfer power wirelessly to places with no or partially crashed power grid. Three different scenarios have been compared in [19] for wireless power reception (i.e., nearest beacon, cooperative power beacon and best power beacon).

Energy efficient stable matching between cellular user and D2D pair based on mutual preference has been explored in [20]. Resource allocation has been done among multiple D2D pairs in [21] through simultaneous harvesting of energy from power beacon and using same spectrum for information dissemination [22][23]. EH at the relay with SWIPT to prolong the lifetime of energy-constrained network has been studied in [24] where energy harvested at one node can be relayed to other devices in the affected area through multi-hop. It has been considered in [25] that D2D pair can harvest energy from up-link transmission of the cellular user if it exceeds a predefined threshold. In [26], the authors describe that D2D transmitters that have no transmission opportunity can harvest energy from primary transmitters and use the same energy for relaying the data. Harvest then transmits protocol has been defined in [27] where D2D users can first harvest energy from the RF transmission of other cellular users and use same for information transmission while cooperating with each other to maximize the network throughput.

III. System Model and Problem Formulation

A. System Model

We consider a D2D network with SWIPT mode enabled devices present in it. We denote D2D User Equipment (DUE), Cellular User Equipment (CUE) and DUE with SWIPT mode by the set $\mathbb{D} = \{1.... \mid M \mid\}$, $\mathbb{C} = \{1.... \mid C \mid\}$ and $\mathbb{D}^S = \{1.... \mid N \mid\}$ respectively. Both DUEs and CUEs are sharing same orthogonal frequency division multiplexing (OFDM) resource block set in the up-link denoted by $\mathbb{R}x = \{1.... \mid K \mid\}$. We assume that DUEs equipped with SWIPT mode can harvest energy from transmitted signal of directly paired DUE$\in \mathbb{D}^S$ and from interference in the form of free RF. Highly directive antennas are considered for transmission and energy harvesting along Line of Sight (LOS) within maximum distance of D2D transmission. Table.1 summarizes the variables used throughout the paper.

It is assumed that distance between nodes sharing RF energy can be up to 50m considering corridor propagation path loss in rician fading environment with directive antennas. Both nodes also share information simultaneously along with wireless power transfer.

Fig. 1 shows the scenario considering a node $i \in \mathbb{D}^S$ trapped in a disaster struck region and is falling low in power. To remain connected, it needs to be charged through another device in the vicinity $j \in \mathbb{D}^S$ using resource block k with simultaneous sharing of information. CUE on cell edge using resource block k can connect with nearby eNB, however, devices within disaster area need to connect directly for information dissemination. It is assumed that D2D devices enabled with SWIPT mode in disaster area form clusters based on proximity. Same resource block can be used between inter-cluster nodes and cellular users on edge. Cellular up-link resource block k is reused to enhance the spectrum efficiency. Interference in cellular link from D2D pair (using same resource block k) is managed by eNB whereas interference from other D2D or cellular links operating in same frequency k will be used for harvesting free RF at i receiver. Next, we will discuss the transmission model and the time switching model for the D2D transmission and energy harvesting.

1) Transmission Model: We consider $J \subset \mathbb{D}^S$ devices in vicinity of device $i \in \mathbb{D}^S$. The set J is created based on mutual reliability of all devices with $i \in \mathbb{D}^S$. Mutual reliability $\phi_{i,j}$ is defined as the a measure of reliability of a device i with device j based on frequency of interaction over a time span, duration of interaction and interval between subsequent interactions between them [28]. A device is considered part of set J, if they have a mutual reliability greater than certain threshold φ(i.e., $\phi_{i,j} \geq \varphi$). The received power at D2D receiver i when communicating in SWIPT mode is represented as

$$P^{D2D}_{r,i} = P^{D2D}_{t,j} d^{-n}_{i,j} \mid h^2_{i,j} \mid, \tag{1}$$

where $P^{D2D}_{t,j}$ is the transmit power of device j, $d^{-n}_{i,j}$ is the distance between device i and j , n is the path-loss exponent with $\mid h^2_{i,j} \mid$ as Rician channel coefficients which follow complex Gaussian distribution $\mathcal{CN}(0,1)$. When D2D receiver reuses resource block $k \in \mathbb{R}$, it will receive interference from other D2D transmitters and cellular users in the vicinity using same resource block. The Signal-to-Interference plus Noise Ratio (SINR) between D2D transmitter j and receiver i is expressed as

$$\gamma_{i,j} = \frac{P^{D2D}_{t,j} d^{-n}_{i,j} \mid h^2_{i,j} \mid}{\sum\limits_{m \neq j} P^{D2D}_{t,m} d^{-n}_{i,m} \mid h^2_{i,m} \mid + \sum\limits_{l \epsilon \mathbb{C}^R} P^{C}_{t,l} d^{-n}_{i,l} \mid h^2_{i,l} \mid + \sigma^2_n}, \tag{2}$$

where $P^{D2D}_{t,j} d^{-n}_{i,j} \mid h^2_{i,j} \mid$ is the signal power on D2D link received at device i when j is transmitting, $\sum\limits_{m \neq j} P^{D2D}_{t,m} d^{-n}_{i,m} \mid h^2_{i,m} \mid$ is the interference received from all other D2D transmitters, $\sum\limits_{l \epsilon \mathbb{C}^R} P^{C}_{t,l} d^{-n}_{i,l} \mid h^2_{i,l} \mid$ is the interference from all cellular users and σ^2_n is the AWGN noise which includes antenna noise and signal processing noise at receiver. Thus, the achievable data rate of link j to i is expressed as

$$R_{i,j} = log_2(1 + \frac{P^{D2D}_{t,j} d^{-n}_{i,j} h^2_{i,j}}{\sum\limits_{m \neq j} P^{D2D}_{t,m} d^{-n}_{i,m} h^2_{i,m} + \sum\limits_{l} P^{C}_{t,l} d^{-n}_{i,l} h^2_{i,l} + \sigma^2_n}). \tag{3}$$

2) Time Switching (TSW) Model: For TSW model, we consider the device i receives power from device j and communicates with it simultaneously i.e., EH and ID is performed over same resource block k as shown in Fig. 1. All devices in the set $\mathbb{D}^S = \{1.... \mid N \mid\}$ are equipped with two types of receivers (i.e., ID and EH receivers). Received signal switches between these receivers on the basis of allotted time slots. We employ TSW scheme over a period T as elaborated in Fig. 2. During first time slot of $\alpha_1 T$ duration, energy is harvested from transmitted packets by EH receiver of device i. In the second time slot of $\alpha_2 T$ duration, information packets are transmitted by device j which are decoded by ID receiver at destination device i. Similarly during $\alpha_3 T$ slot, information is decoded by ID receiver of destination device j which is transmitted by source node i after harvesting energy in the first time slot i.e., $\alpha_1 T$. Here $\alpha_1, \alpha_2, \alpha_3$ are the fractions of period T and taken as $\alpha_1 + \alpha_2 + \alpha_3 = 1$. Moreover $\alpha_1 = \alpha$, $\alpha_1 = \alpha_2 = \frac{(1-\alpha)}{2}$ where α is TSW variable.

TABLE I
CONNOTATIONS AND VARIABLES ALONG WITH EXPLANATION

Notation	Explanation
$\mathbb{C}$, $\mathbb{D}$	Set of cellular users, set of D2D users
$\mathbb{D}^S$	Set of D2D users enabled with SWIPT mode
$\mathbb{R}$	Set of resource block $\mathbb{R} = \{1.... \mid K \mid\}$
α	TSW Ratio=α_1 (EH), α_2& α_3 are for ID
ϕ	Reliability Index to be $\geq \varphi$ for peer selection
$P^D_{r,i}$, $P^D_{t,j}$	Power received at i, Power transmitted by j
$d_{i,j}$	Distance between device i and j
$\mid h^2_{i,j} \mid$	Rician channel coefficients between i and j
$P^D_{t,m}$	Transmit power of interfering D2D device m
$P^C_{t,l}$	Transmitted power from l^{th} interfering CUE
$R_{i,j}$, $R_{j,i}$	Data rate of from j to i and i to j
$E_{H,i}$	Total EH by i
$EE^{D2D}_{i,j}$	Energy efficiency of the link between i and j
C^k	Uplink resource block set $\mathbb{R}x = \{1.... \mid K \mid\}$
eNB	evolved Node-B

We consider a constant transmit power of both device i and j, however it depends on TSW variable α for the duration a transmitter is switched ON.

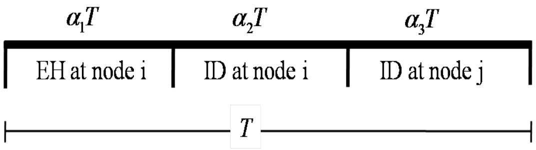


Fig. 2. During $\alpha_1 T$ energy is being harvested, information is being decoded in remaining two sub slots for a total duration T

The receiver of device i in D2D link will act as conventional information decoding receiver for entire time slot T when $\alpha = 0$ and same receivers will become EH receivers for entire block time T when $\alpha = 1$. Achievable data rates of device j to i is expressed as

$$R_{i,j} = \alpha_2 T log_2(1 + \gamma_{i,j}), \tag{4}$$

where $\alpha_2 T$ is the time slot when device j will transmit and information is decoded at receiver i. Data rate $R_{j,i}$ from transmitter i to receiver j is given as

$$R_{j,i} = \alpha_3 T log_2(1 + \gamma_{j,i}). \tag{5}$$

where $\alpha_3 T$ is variable time slot ratio during which information is being decoded at receiver j. Thus, the achievable information data rate for entire D2D link during time window T is given as

$$R^{D2D}_{i,j} = \frac{1-\alpha}{2} T \left[log_2(1 + \gamma_{i,j}) + log_2(1 + \gamma_{j,i}) \right]. \tag{6}$$

The total energy E^{D2D}_C which is consumed by the D2D devices i & j for information and energy transfer during three time slots is given as

$$E^{D2D}_C = T \left[\frac{P_T}{\eta} + P^{D2D}_{sys} \right] - E_{H,i}, \tag{7}$$

where P_T is the total transmitted power during three time slots, η is the efficiency of the power amplifier at the transmitter sides of both devices i and j. System power consumption at both devices is represented by P^{D2D}_{sys}, it includes power consumed by receiver, mixer and frequency synthesizers etc. $E_{H,i}$ is the total harvested energy during time slot of $\alpha_1 T$ duration and is comprised of

$$E_{H,i}{=}E^{direct}_{h,i} + E^{intf}_{h,i} + \sigma_n, \tag{8}$$

where E^{direct}_h is the energy harvested by i from transmitted signal of device j during time slot $\alpha_1 T$ and is given as

$$E^{direct}_{h,i} = \alpha \rho T P^{D2D}_{t,j} d^{-n}_{i,j} \mid h^2_{i,j} \mid, \tag{9}$$

and E^{intf}_h is energy harvested from interfering signal energy from other D2D transmitters operating at the same frequency as device i and free RF power transmitted by other CUE operating at same resource block k. E^{intf}_h is represented as

$$E_{h,i}^{intf} = \alpha\rho T(\sum P_{t,m}^{D2D} d_{i,m}^{-n} \mid h_{i,m}^{2} \mid + \sum_{l} P_{t,l}^{C} d_{i,l}^{-n} \mid h_{i,l}^{2} \mid) \tag{10}$$

where efficiency of EH receiver is indicated by ρ with which it scavenges energy and $\alpha = \alpha_1$ in (9). The link energy efficiency $EE_{i,j}^{D2D}$ of D2D link is calculated by taking ratio of achievable data rate on link and total power consumed by D2D pair during one time block T and is expressed as

$$EE_{i,j}^{D2D} = \frac{R_{i,j}^{D2D}}{E_{C}^{D2D}}. \tag{11}$$

Using (6) and (7) in (11), we get

$$EE_{i,j}^{D2D} = \frac{\frac{1-\alpha}{2} T \left[log_2(1+\gamma_{i,j}) + log_2(1+\gamma_{j,i})\right]}{T\left[\frac{P_T}{\eta} + P_{sys}^{D2D}\right] - E_{H,i}}. \tag{12}$$

B. Problem Formulation

We formulate the joint optimization problem of peer selection and TSW ratio allocation for a device i in a D2D SWIPT enabled network. The problem is formulated for a time period T with an objective of maximizing the link EE in $bits/joule$ as given in (12). Reliability Index (RI)$\phi_{i,j}$ of device j with i are incorporated in the problem to cater for the reliability aspect of the device j for device i. We consider two optimization variables, peer selection variable ζ_j and TSW ratio α_n. The peer selection variable ζ_j is a binary variable and will take a value 1 if the device$j$ is selected as a peer for device i, otherwise it is a 0. On the other hand TSW ratio α_n is a continuous variable and can take any value from 0 to 1. The optimization problem is formulated as follows:

$$\underset{(\zeta,\alpha)}{maximize} \sum_{j=1}^{N} \phi_{i,j}\zeta_j EE_{j}^{D2D}(\alpha) \tag{13}$$

$$\begin{aligned} s.t. \qquad & c_1 \ : \ E_{min} \leq \zeta_j \phi_{i,j} E_{h,i}^{direct} \leq E_{max} \\ & c_2 \ : \ \zeta_j \phi_{i,j} R_{i,j}^{D2D} \geq R_{min} \\ & c_3 \ : \ \zeta_j = \{0,1\} \\ & c_4 \ : \ \textstyle\sum_{j=1}^{N} \zeta_j = 1 \\ & c_5 \ : \ \textstyle\sum_{n=1}^{3} \alpha_n = 1 \\ & c_6 \ : \ \alpha_n \epsilon [0,1] \end{aligned}$$

The objective function as given in (13) is the maximization of link energy efficiency as given in (12) while ensuring constraints $c_1 - c_6$ are satisfied. Constraint c_1 defines the maximum and minimum bound on energy that can be harvested directly from transmitted power of device j during αT time slot; E_{min} & E_{max} are are the constant bounds on energy harvested directly from D2D peer which are set by algorithm during initialization phase while keeping in view the quality of service requirements. Constraint c_2 ensures link QoS with bound on minimum data rate requirement. Limit that i can be paired with maximum one device j at a time is ensured by c_3 and c_4 through $\zeta_j \in \{0,1\}$. TSW ratio (α) can take any value from zero to one (i.e., $\alpha_n \in [0,1]$) but cannot exceed 1 is ensured by constraints c_5 and c_6. When $\alpha_n = 1$ then transmitted power over complete time frame T is used for EH whereas on the other hand when $\alpha_n = 0$ then information will be decoded through T. The problem in (13) is a joint time switching ratio α control and stable matching of peers ζ. It involves both binary and continuous variables for optimization of EE. Therefore, is an NP-hard MILP problem. Hence, neither linear fractional programming nor integer programming can be utilized to solve the formulation directly. More so, two different approaches for mix integer optimization would result in unstable and inefficient resource allocation per joule of harvested energy. Thus, we decompose the original problem into two separate problems and solve it sequentially.

IV. ENERGY EFFICIENT PEER SELECTION AND TIME SWITCHING RATIO ALLOCATION (EPS-TRA) ALGORITHM

For any $DUE \in \mathbb{D}^S$ pair, the ultimate goal is the successful execution of transmission session along with maximization of link EE. It may be possible to optimize the EE in a conventional way without catering for reliability aspect of competing devices but in that case, the session may terminate prematurely or continue with intermittent transmission due to selfish nature of devices in disaster struck region. Problem in (13) is composed of two variable ζ and α which cannot be jointly solved for optimum resource allocation, therefore, we decompose the problem into two separate problems as follows:

- **TSW Ratio Allocation Problem**: TSW ratio α optimization using linear fractional programming.
- **Peer Selection Problem**: D2D Association through optimum selection of association variable.

To ensure the objective is achieved, we propose a robust algorithm that can guarantee successful and reliable session along with maximizing the link EE through EH. The Algorithm-1 gives the pseudo code of EPS-TRA.

Contending devices $(j \subset \mathbb{D}^S)$ are selected on the basis of mutual reliability $\phi_{i,j}$ from device i to j. In case of more than one devices qualify the criterion of reliability (i.e., $\phi_{i,j}(:, j > 1) \geq \varphi$) then devices are marked as reliable and next stage of Algorithm -1 commences. System is initialized with random $\alpha^{R_{min}}$ and $\alpha^{E_{max}}$,

Algorithm 1 Energy Efficient Peer Selection and Time Switching Ratio Allocation (EPS-TRA)

```
Input: $T$, $\rho$, $\eta$, $P_T$, $P_{sys}$, $E_{max}$, $R_{min}$, $\phi_{i,j}$
Output: $\zeta_{i,j}$, $\alpha^{R_{min}}$, $\alpha^{E_{max}}$, $EE^{R_{min}}$, $EE^{E_{max}}$
1. if ($j \geq 2$ i.e., more than one acknowledging devices) Then
2.   if ($\phi_{i,j} \geq \varphi$) %% RI is greater than certain threshold do
3.       Initialize $\alpha^{R_{min}}$ & $\alpha^{E_{max}}$ from [0,1]
4.       Put $\alpha_1 = \alpha^{R_{min}}$ & $\alpha_2 = \alpha^{E_{max}}$
5.       Select peer association $\zeta_{i,j}$ using Algorithm 2
6.       Update $\alpha^{R_{min}}$ & $\alpha^{E_{max}}$ with Algorithm 3
7.       Compute $EE^{R_{min}}$&$EE^{E_{max}}$ using Algorithm3
8.       if ($\alpha^{R_{min}} \neq \alpha_1$ & $\alpha^{R_{max}} \neq \alpha_2$) do
9.         Return to line -4
10.      else
11.        Terminate Algorithm 1 (Converged)
12.      end if
13.  end if
14. end if
```

QoS constraint R_{min} and maximum amount of harvestable energy E_{max}. Best association ζ with the most suitable device in terms of link EE is selected using Algorithm-2 and based on results of Algorithm-2, $\alpha^{R_{min}}$ and $\alpha^{E_{max}}$ are updated through LFP using Algorithm-3 while addressing the priority constraint. Algorithm-1 continues with multiple iterations until convergence is achieved i.e., $\alpha^{R_{min}}$ and $\alpha^{E_{max}}$ remains same over two consecutive iterations. Thus, EE for best associated D2D link is computed after the convergence is achieved. While amidst iterations when Algorithm-I has not converged, then $\alpha^{R_{min}}$ and $\alpha^{E_{max}}$ would not be optimum for D2D link to score maximum energy efficiency.

A. Peer Selection (PS) Problem

There can be only one device j from set $\mathbb{D}^S = \{1.... \mid N \mid\}$ which can establish a direct link with device i for energy sharing. Optimum association variable ζ depends on multiple factors and can take on single value from set $\{0, 1\}$ which is validated through constraint c_4 in (12). A one-to-one stable matching can be established based on mutual preferences of $i, j \in \mathbb{D}^S$ with the aim to maximize the EE of the link. Problem is initialized with random $\alpha^{R_{min}}$ & $\alpha^{E_{max}}$ and association $\zeta_{i,j}$ with one device j is determined using Branch and Bound Algorithm. Subsequently, $\alpha^{R_{min}}$ or $\alpha^{E_{max}}$ are updated based on bounded constraint in the system out of $c_1$or $c_2$in (12). Iteration continues until the value of $\alpha^{R_{min}}$ and $\alpha^{E_{max}}$ remains same for consecutive iteration. PS problem is designed as under with ζ defining the link association variable:

$$\underset{(\zeta)}{maximize} \sum_{j=1}^{N} \phi_{i,,j} \zeta_j EE_j^{D2D} \tag{14}$$

$$s.t. \qquad c_1, c_2 \,\&\, c_4$$

B. Time Switching Ratio Allocation (TRA) Problem

Link Energy Efficiency i.e., $EE_{i,j}^{D2D}(\alpha)$ is a function of $\alpha_n \in [0, 1]$ which is a continuous variable. Time switching ratios for information decoding and energy harvesting at the receivers of i and j are controlled by α. Problem for optimizing D2D link EE $(bits/joule)$ can be represented as with $\zeta_j = 1$

$$\underset{(\alpha)}{maximize}\, \phi_{i,j} EE_j^{D2D}(\alpha) \tag{15}$$

$$s.t. \qquad c_1 \,\&\, c_2$$

Problem in (15) is a linear fractional non-convex optimization problem which cannot be solved through disciplined convex optimization programming tools due to its fractional form. Linear Fractional Programming (LFP) is used in problems where relations among variables in constraints are linear and objective function constitutes a ratio of two linear functions. It includes the transformation of the fractional problem to its equivalent linear convex non-fractional form [29] represented as

$$\underset{(y)}{maximize}\, F(y) = py + g \tag{16}$$

$$s.t \; Gy \leq h, \, y \geq 0$$

$$G^{'} y \leq h^{'}, \, y \geq 0$$

The details are discussed in Appendix A. We employ Lagrange decomposition and Karush-Kuhn-Tucker (KKT) conditions to solve the LP in (16). Corresponding Lagrangian is given by

$$\mathcal{L}_j^{EE}(y, \lambda) = py - \lambda_1(Gy - h) - \lambda_2(G'y - h'). \tag{17}$$

The KKT conditions corresponding to (17) are given as

$$\frac{\partial \mathcal{L}}{\partial y} = p - \lambda_1 G - \lambda_2 G' = 0 \tag{18}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda_1} = Gy - h = 0 \tag{19}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda_2} = G'y - h' = 0 \tag{20}$$

Taking λ_1 as slack variables i.e., $\lambda_1 > 0$ and $\lambda_2 = 0$ i.e., binding. Consequently, solving equations (18) and (19), we get

$$\lambda_1 = \frac{\phi_{i,j} R_{i,j}^{D2D}\left(\rho P_{H,i} - P\right)}{2\phi_{i,j} R_{i,j}^{D2D}(TP - \rho T P_{H,i}) + 4R_{min}\rho TP}, \tag{21}$$

$$y = \frac{\lambda_1 \left(\phi_{i,j} T R_{i,j}^{D2D} - R_{min}\right)}{\phi_{i,j} R_{i,j}^{D2D}\left(\rho P_{H,i} - P\right)}. \tag{22}$$

TSW ratio α for our original LF optimization problem in (15) can be obtained using y in (22) through back substitution with constraint on QoS i.e., R_{min} as

$$\alpha^{R_{min}} = 1 - \frac{2R_{min}}{\phi_{i,j} T\left[log_2(1+\gamma_{i,j}) + log_2(1+\gamma_{j,i})\right]}, \tag{23}$$

where $\alpha^{R_{min}} = \alpha$ is the TSW ratio when minimum data rate R_{min} is taken as constraint. This condition is required to uphold when requirement for high data rate is more pronounced and given priority over energy harvesting. In such a situation devices have to transmit large chunk of data with minimum delay and maximum integrity.

Now, taking λ_2 as slack variables i.e., $\lambda_2 > 0$ and $\lambda_1 = 0$ i.e., binding. Thus, solving equations (19) and (20), we get

$$\lambda_2 = \frac{\phi_j R_{i,j}^{D2D}\left(\rho P_{H,i} - P\right)}{2\rho P_{H,i}(\phi_j T^2 P - E_{max})}, \tag{24}$$

$$y = \frac{\lambda_2 E_{max}}{\phi_j R_{i,j}^{D2D}\left(\rho P_{H,i} - P\right)}. \tag{25}$$

TSW ratio α (with minimum harvested energy as constraint) can be obtained from (25) through back substitution as

$$\alpha^{E_{max}} = \frac{E_{max}}{\rho T P_{H,i} \phi_{i,j}}. \tag{26}$$

where $\alpha^{E_{max}} = \alpha$ is the TSW ratio when maximum harvested energy E_{max} is taken as constraint. Such condition are required to be met when device needs more power for its self sustenance and perpetual connectivity with the network. This happens with two reason i.e., either devices are only connected for energy sharing or requirement for data rate are minimal e.g text messages etc. In (21) and (24), λ_1 and λ_2 are Lagrange multipliers satisfying the Lagrange gradient equation i.e., $\nabla f = \lambda \nabla g$ which is unpacked as KKT conditions in (18), (19) and (20).

C. Computational Complexity Analysis

Main computation of EPS-TRA Algorithm lies in single layer iteration which converges to near-optimum solution after completing N sequential iterations. Reliability of competing nodes is computed over a threshold under a loop and in worst-case scenario all N nodes meet the criterion. QoS, EH and EE computations are carried out for N nodes with a similar number of constraints. Asymptotic complexity of algorithm is of the order $O(N) = 2N + 2N^2 + \{Yalmip\,Solver\,Complexity\}$, which is of order $O(N^2)$, excluding time complexity of Yalmip binary optimization solver.

Algorithm 2 Peer Selection (PS) Algorithm

```
Input: $T$, $\rho$, $\eta$, $P_T$, $P_{sys}$, $E_{max}$, $R_{min}$, $\phi_{i,j}$
Output: $\zeta_{i,j}$
for k=1:j do
    Calculate $R_{i,j}^{D2D}(:,k)$ from (3)
    Calculate $E_{H,i,}^{D2D}(:,k)$ from (8)
    Use constraints $c_1$, $c_2$, $c_4$
    Calculate $EE_{i,j}(:,k)$ from (14)
end for loop
Solve using Branch and Bound Algorithm to get $\zeta_{i,j}$
$\zeta$ should satisfy the condition $\sum_j \zeta_j = 1$
```

Algorithm 3 TSW Ratio Allocation (TRA)

```
Input: $T$, $\rho$, $\eta$, $P_T$, $P_{sys}$, $E_{max}$, $R_{min}$, $\phi_{i,j}$
Output: $EE_{i,j}$, $\alpha^{R_{min}}$, $\alpha^{E_{max}}$
$\sum_j \zeta_j = 1$ for device $j$
Calculate $R_{i,j}^{D2D}(j)$ from (3)
Calculate $E_{H,i,}^{D2D}(j)$ from (8)
Solve (15) through LFP and Lagrangian with $c_1$ & $c_2$
    if ($\lambda_1 > 0$ && $\lambda_2 = 0$) do $\Rightarrow R_{min}$ (QoS) as constraint
        Find $\alpha^{R_{min}}$ from (23)
    elseif ($\lambda_1 = 0$ && $\lambda_2 > 0$) do $\Rightarrow E_{max}$ as constraint
        Find $\alpha^{E_{max}}$ from (26)
    end if
Calculate $EE_{i,j}(\alpha^{R_{min}})$ & $EE_{i,j}(\alpha^{E_{max}})$ from (15)
```

V. PERFORMANCE EVALUATION

In this section, we discuss our results in a bid to demonstrate the performance of our EPS-TRA algorithm. We investigate the effect of different independent variables (Transmit Power, length of Time block, Data rate and Harvested Energy) on the TSW selection variable α_j and link energy efficiency while satisfying the constraints in our designed problem. EE is directly derived from α but the trend varies with the choice of constraint. Table 2 shows the values of different parameters considered for performance evaluation. Independent Poisson Point Process (IPPP) has been used for distributing nodes $j \subset D^S$ around i. Transmission between two nodes (50m apart) has been considered following Rician prorogation loss model in corridor environment for a minimum Path Loss Exponent (PLE). For uniform channel response, coverage area has been considered a circle with radius of 50m (Area equals 7.65 Km^2).

TABLE II
IMPORTANT PARAMETERS OF PROPOSED APPROACH

Parameter	**Symbol**	**Value**
Channel Iterations	-	10^3
Algorithm-1 Converges Iterations	-	2
Confidence Interval	σ	85%
Time unit	T	1
Energy harvesting efficiency	ρ	0.4
Power dissipated within system	P_{sys}	0
Transmit amplifier efficiency	η	0.8
Reliability Index Threshold	φ	0.27
D2D coverage area	πr^2	7.65 km^2

A. Transmit Power (P_T) *and Time Block* (T)

Fig. 3(a) and Fig. 3(b) shows the relationship of $\alpha^{R_{min}}$ and EE respectively with respect to transmit power with QoS as primary bounding constraint. An increasing trend is observed in energy harvesting time ratio with increase in transmit power (i.e., more time is allocated to energy harvesting when more transmit power is available). Here R_{min} is the binding constraint and when it is satisfied, the rest of the time is allocated for energy harvesting. it can also be observed that when the time block (T=4) is more than again more time is allocated to energy harvesting as the QoS constraint is satisfied in less time duration. In Fig. 3b the link energy efficiency decreases with increase in transmit power. As data rate requirement is fixed so if resources in the form of power or time are increased then all these additional resources will contribute towards more EH at the receiver node. Effects of power on $\alpha^{R_{min}}$ and EE are more significant at low power levels for small time blocks and smoothens when α reaches its maximum extreme. With increase in the time frame (T), effects of increasing power are less pronounced. When Time block (T) is small then optimum alpha & EE is contingent upon transmiting power thus varying more with the change in power level. However, with increasing time block length, as more time is available for EH after meeting R_{min} thus assuring greater value for alpha closer to upper limit ($\alpha_n \epsilon [0, 1]$) therefore at extreme ends of alpha, trend generally appear as similar with little variations due to increase in power levels between 2~2.7 W.

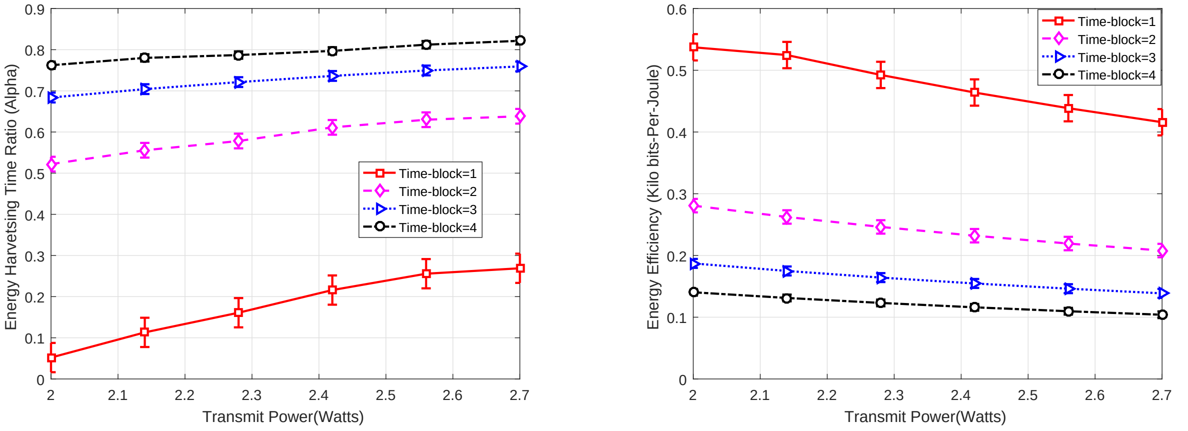
Similarly, Fig. 4(a) and 4(b) shows the effect of P_T and T on α and EE when primary bounding constraint is defined by maximum allowable harvested energy. EH duration decreases significantly with transmit power resulting in an increase of link EE. In this case, primary requirement is affixed with EH requirement and once this is met then all the excess of resources will directly contribute towards better QoS of established link. Decreasing slop of α becomes more gradual as it approaches zero however it barely meets the lower end in the presence of EH constraint.

B. Minimum Data Rate (QoS) and Path Loss Exponent (n)

Fig. 5(a) and Fig. 5(b) shows the relationship between minimum data rate, and energy harvesting time ratio and EE. It can be observed that as the minimum data rate requirement is increased, link can withstand the desired QoS, therefore time duration for EH is minimized. In this case, system focuses on spectral efficiency, thus, increased data rate requirements of the two users can be fulfilled. System first fulfills the requirements of QoS through ID and in the remaining time EH is performed. When requirement on system for ID is increased then the lesser time will be available for EH (i.e., α decreases). There may be the case when link needs to divert all of its resources for ID putting $\alpha = 0$, thus, receiver of device i in D2D link will act as a conventional ID receiver for entire time slot T. Furthermore, as the Path loss Exponent (n) is increased then more propagation delays are imposed and more transmitted RF is lost resulting in a reduction in harvested energy at the receiver (i.e., smaller α). Fig. 5 investigates the effects of QoS constraint on EE (bits/joules) of the link which increases with the increase of minimum data rate required (R_{min}) to meet QoS. As R_{min} increases then the significant portion of available time slot is devoted to ID in (15) thus, increasing the final objective function with constant resources (i.e., power, spectrum and time).

C. Maximum Harvested Energy (E_{max}) *and Efficiency of Energy Harvesting* (ρ)

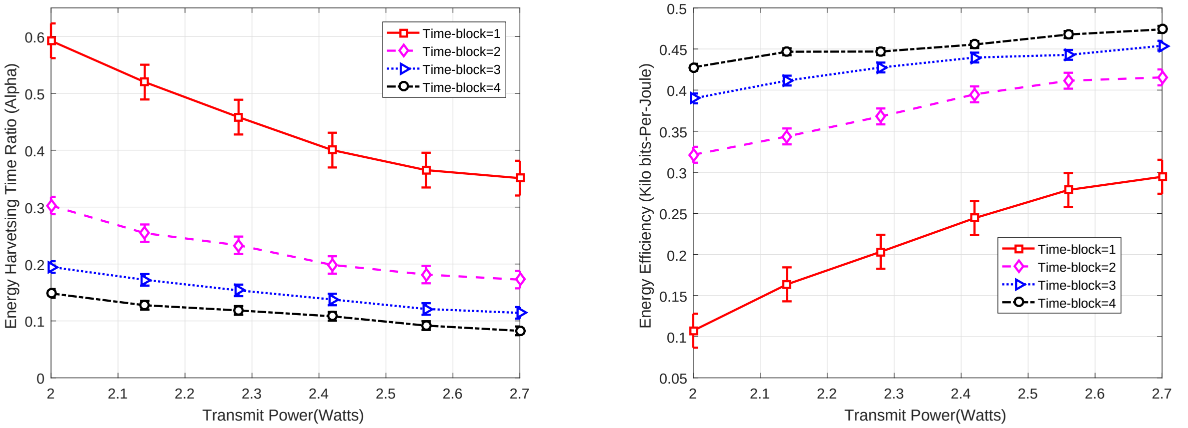
Fig. 6 depicts the effects on α when maximum harvest-able energy is constrained and varying. In this case, there is no limit on the minimum data rate required to ensure QoS, thus, priority is given to harvest-able energy. Increase of α will be proportional to EH



(a) Variations in TSW ratio α with respect to P_T & T which ultimately defines harvested energy.

(b) Impact of P_T and T on link EE which decreases with constant QoS requirements.

Fig. 3. **VARIATIONS OF α (a) AND EE (b) WHEN R_{min} IS CONSTRAINED**



(a) Duration of harvested energy $\alpha^{E_{max}}$ decreases when maximum allowable energy is limited.

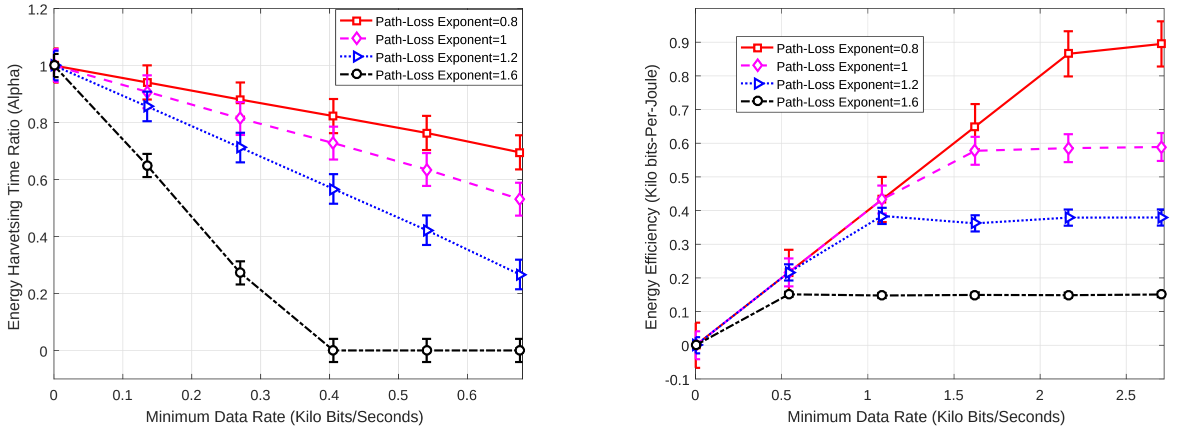
(b) EE (bits/joules) is linked inversely with $\alpha^{E_{max}}$ when primary constraint is placed on maximum harvestable energy.

Fig. 4. **VARIATIONS OF α (a) AND EE (b) WHEN E_{max} IS CONSTRAINED**

requirement of device i and after meeting this constraint less of time is devoted to ID. As E_{max} is increased then α has to be made larger to harvest more energy but in this case, time for ID will reduce and when $\alpha = T$, then receiver i in D2D link will act as a pure EH receiver. Another way to increase the harvested energy is to make better the EH efficiency of the receiver i which is also evident from plots corresponding to different ρ. Fig. 6 shows the effects of increasing α thus reducing the link EE (bits/joule). If more time is allocated for EH then time span for ID will reduce proportionally, hence reducing the EE of the link. This means as more energy is being scavenged from transmitted power then a lesser time is spared for ID which results in reduced data rate transmission over the link.

D. Comparison with Uniform Allocation of Alpha (α)

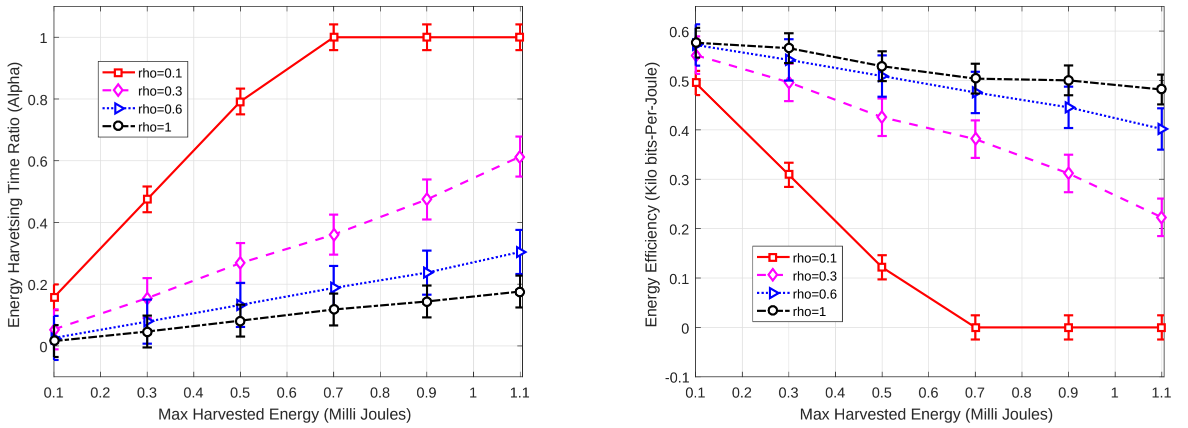
To validate the performance and robustness of our approach, we have compared the energy efficiency calculated through EPS-TRA algorithm with uniformed selection of TSW ratio (α) (i.e., uniform allocation of time slots for ID and EH). Fig. 7 shows a significant difference between two energy efficiencies in bits/s plotted against increasing minimum data rate requirement which validates an increase of 300% in energy efficiency once proposed approach is adopted. Both plots show an abrupt change initially however they fluctuate gradually around their stable value when $\alpha^{EPS-TRA} \Rightarrow 0$ and $\alpha^{uniform} \Rightarrow \theta\,(uniform\,value)$. In EPS-TRA algorithm, value of α is computed based on the constrained requirements of ID and EH whereas, when allocation of time slots is kept uniform then irrespective of change



(a) Time slot for energy harvesting ($\alpha = \alpha_1$) decreases with increasing requirement of ID on the system to ensure QoS

(b) Variation of link EE (bits/joule) with R_{min} and Path Loss Exponenet. More the requirement for ID better will be the EE

Fig. 5. **VARIATIONS OF α (a) and EE (b) WITH RESPECT TO QoS CONSTRAINT AND PATH LOSS EXPONENT (PLE)**



(a) Variability of α when E_{max} is constrained. Increased requirement for energy entails corresponding increase in α

(b) Variation of link EE (bits/joule) with E_{max} and ρ. More the requirement for EH will reduce the D2D link EE

Fig. 6. **VARIATIONS OF α (a) and EE (b) WITH RESPECT TO MAXIMUM HARVESTED ENERGY AND EH EFFICIENCY** (ρ)

in constraints system response remains same (i.e., inefficient utilization of resources and bad QoS of D2D link). Therefore, dynamic selection of α is important for defining the time fractions for ID and EH which lead to an optimized EE of the link.

VI. Conclusions and Future Work

In this paper, we have proposed a novel approach to select a peer for SWIPT based on RI and EE of D2D link. Concept of EH in parallel with ID has been implored at point-to-point communication level to help devices sustain catastrophes and remain connected. Time switching technique has been implored to harvest energy and decode information simultaneously. Formulated mix integer problem of EE in bits/joule has been optimized separately through BAB and LFP. An iterative algorithm has been proposed to calculate α (EH ratio) with a focus to maximize the EE of link. Numerical results have proved the effectiveness of our approach and have shown that EE depends on prioritization of different constraints. The proposed concept can further be investigated to include a power control for more dynamic channel modeling. Incentive mechanism can be devised and included in the problem to lure more selfish users for sharing their resources. Beam forming, waveform optimization and proposed TSW can be integrated to meliorate system's overall efficiency.

Appendix

The linear fractional program can be transformed to an equivalent non-fractional form such that available convex optimization techniques can be used to solve it. We use

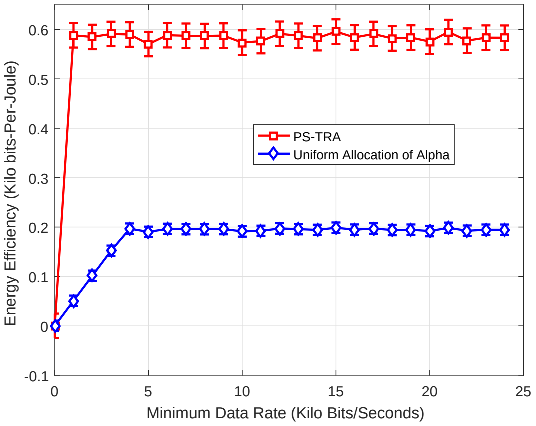


Fig. 7. Comparison of EE (bits/joul) of proposed approach with random selection of α

the conceptual idea that LFP is the generalization of LP thus to go ahead with, we assume that the feasible region $S = \{\alpha \in R^n : A\alpha \leq b, \alpha \geq 0\}$ is non-empty and bounded. Denominator $dx + \beta > 0$ because if $dx + \beta < 0$ then solution for LFP cannot be found. LFP is our case resembles following

$$\underset{(x)}{maximize} Z = \frac{cx + \alpha}{dx + \beta}, \tag{27}$$

$$s.t \quad Ax \leq b, \; x \geq 0$$

where, $A = (a_1, a_2, ..., a_m, a_{m+1}, , ...a_n)$ is a $m \times n$ matrix, $b \in R^m$, $x, c, d \in R^n$, $\alpha, \beta \in R$.

We use the method proposed in [29] for transforming the linear fractional problem in (15) to equivalent Linear Problem (LP) represented as

$$F(y) = py + g \tag{28}$$

$$s.t \; Gy \leq h, \; y \geq 0$$

$$G^{'}y \leq h^{'}, \; y \geq 0$$

where, $G, G' = (g_1, g_2, ..., g_m, g_{m+1}, , ...g_n)$ is a $m \times n$ matrix, $h, h' \in R^m$, $y, p \in R^n$, y is a $(m \times 1)$ column vector, c is a $(1 \times n)$ row vector and g is a constant, p, and g are the parameters derived for objective function and y is the new transformed LP controlling variable. Applying transformation method proposed in [29] on objective function in (15), we get

$$p = -\frac{\phi_{i,j} R_{i,j}^{D2D}}{2}\left(1 - \frac{\rho T P_{H,i}}{TP}\right), \tag{29}$$

$$g = \frac{\phi_{i,j} R_{i,j}^{D2D}}{2\rho T P_{H,i}}, \tag{30}$$

$$y = \frac{\alpha}{-\rho T P_{H,i} x + TP}. \tag{31}$$

where $P = \frac{P_T}{\eta} + P_{sys}^{D2D}$, $R_{i,j}^{D2D} = log_2(1 + \gamma_{i,j}) + log_2(1 + \gamma_{j,i})$. Now, transforming the constraint c_1 in (15) to its equivalent constraint for LP in (28) with G and h given as

$$G = \frac{\phi_{i,j}}{2} R_{i,j}^{D2D}\left(T - \frac{\rho P_{H,i}(T - R_{min})}{P}\right), \tag{32}$$

$$h = \frac{T\phi_{i,j} R_{i,j}^{D2D} - 2R_{min}}{2TP}. \tag{33}$$

Similarly, applying same transformation on c_2 in (15), we get

$$G' = \rho T P_{H,i}\left(T\phi_{i,j} - \frac{E_{max}}{TP}\right), \tag{34}$$

$$h' = \frac{E_{max}}{TP}. \tag{35}$$

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