Energy Management Scheme for Wireless Powered D2D Users With NOMA Underlaying Full Duplex UAV

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ABSTRACT

Device-to-Device (D2D) communications underlaying Unmanned aerial vehicle (UAV) with its mobility extend the coverage and improve the data rate. In this paper, we propose an energy management scheme for wireless powered D2D users with NOMA underlaying full-duplex (FD) UAV. Here, the cellular transmitters (CTs) and D2D transmitters (DDTs) first harvest energy from the radio frequency (RF) signals of the UAV. Then, the CT communicates with the cellular receivers (CRs) using the FD-UAV as a relay. On the other hand, DDT communicates with its two D2D receivers (DDRs) using the NOMA. We formulate the problem as a mixed-integer non-linear programming (MINLP) form and then divide it into two sub-problems. In the first sub-problem, an optimal value of time allocation for energy harvesting (EH) for DMG is estimated, whereas, in the second subproblem, the power of DDT in each DMG is optimized using the variable changing technique. Finally, the joint time allocation and power control scheme is proposed to achieve the maximum energy-efficiency (EE). Numerical results demonstrated that the proposed scheme achieves better results as compared to the existing conventional NOMA and orthogonal multiple access (OMA) schemes.

CCS CONCEPTS

• **Mathematics of computing** → **Coding theory**; • **Computer systems organization** → **Peer-to-peer architectures**;

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KEYWORDS

D2D, Energy Efficiency, NOMA, Full Duplex, and WPCN.

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1 INTRODUCTION

D2D communications is a technique in which proximity devices communicate directly with each other with or without routing through the base station (BS). In this way, it offloads the data traffic and thus reduces the pressure from the BS. Also, D2D improves network spectral and energy efficiency (EE) by sharing the resources and supporting short distance communication [1]. Despite these advantages, D2D communications become more challenging when the infrastructure gets damaged. To address this challenge, researchers from both academia and industry proposed a new technology named as UAV [1].

UAV is a flying BS which is mainly used to set up the communication between the devices when the cellular infrastructure gets damaged. It acts as a static or mobile relay to extend the coverage and improve the quality-of-service (QoS) of the CEUEs. Also, by optimizing its trajectory, the communication links between devices are significantly improved which further results into higher throughput. Despite these advantages, it has been observed that both the UAV and D2D users are battery-constrained devices. It means they have a limited energy storage capacity which results in the degradation of an EE of the network. Hence, to prolong the lifetime of a battery, EH or wireless powered communication (WPC) have emerged as promising solutions [2]-[3].

The WPC is a harvest-then-transmit protocol and is a combination of the downlink wireless energy transfer (WET) and the uplink wireless information transfer (WIT) [2]. In the downlink WET, users devices harvest energy from the radio frequency (RF) signals to charge their battery. On the other

side, in WIT, the users' devices transmit information to the desired user using the harvested energy. However, both these processes have some limitations. In WET, the devices located far away from the BS harvest less RF energy due to their low signal power whereas, in WIT, these devices consume more energy during transmission. Also, in WIT, the users mostly used TDMA to transmit the information. However, in TDMA, each user used a specific time slot to transmit information, thus limiting the number of connections and reducing the data rate. To overcome these limitations and improve the fairness among the users, the power domain non-orthogonal multiple access (PD-NOMA) is proposed [4].

In PD-NOMA, the signals of different users are multiplexed at the transmitter's side using superposition coding. Then, the transmitter transmitted the multiplexed signal to the users through the same channel with different power levels. To decode the desired user's signal and reduce the intra-user interference, the successive interference cancellation technique is used at the receiver's side. In PD-NOMA, generally, a large amount of power is assigned to the far users and lesser to the near users [5]. The authors in [6] proposed an effective scheme to deploy the multiple UAVs for ground users under the condition that UAV transmits with its minimum power. The authors in [7] proposed the throughput maximization scheme under the mobile relaying system with respect to the power and trajectory constraints. The authors in [8] studied the energy-efficient scheme between the UAV and ground users with the condition that UAV wings consumed fixed energy. The coexistence of D2D in an underlay of UAV was first studied in [9]. The authors in [9] used one UAV to set up the communication between the D2D pair, and UAV travels from one-stop point to another to serve the other D2D pairs. The authors in [10] proposed the joint trajectory and precoding scheme for UAV-assisted NOMA networks. In the above-mentioned schemes, the authors did not consider the EE with respect to the limited battery power of the users. This motivates us to design this paper. In this paper, we integrate D2D, WPC, and NOMA at one platform to maximize the EE of the network.

1.1 Contributions

The main contributions of this paper are given as follows:

- An optimal value of power for DMG is estimated keeping the energy harvesting time constant.
- An optimal value for energy harvesting time is evaluated for DMG by fixing the power of the DDT and CT.
- A joint time and power allocation scheme is designed to maximize the EE of an overall network.

1.2 Organization

This paper is organized as follows: Section 2 describes the network model and the problem formulation. Section 3 elaborate the proposed scheme through which the formulated problem is solved. Section 4 evaluates the performance evaluation of the proposed scheme and compared with the existing NOMA

Figure 1: (a) System Model (b) Time Frame Structure.

Figure 2: Harvest-Then-Transmit Model.

and TDMA schemes. Finally, Section 5 concludes the paper with the future scope.

2 NETWORK MODEL

2.1 System Model with Assumptions

Consider a single cell downlink scenario in which the UAV serve the set of $\mathcal{D} = \{1, 2, \dots, d, \dots, D\}$ WP-DDGs, $\mathcal{I} = \{1, 2, \dots, i, \dots, I\}$ CT, and $\mathcal{J} = \{1, 2, \dots, j, \dots, J\}$ CR as shown in Fig. 1. Each WP-DDG consists of one DDT and two DDGs, r_1 and r_2 . The number of DDGs in each DDG is restricted up to two for reduce the communication delay and hardware complexity. Firstly, in time τ_e , the CTs, and the DDTs of each DDG harvest energy from the RF signals of the FD-UAV to store energy in its EH-module. Then, in time, $1 - \tau_e - \tau_d$, the CT first transfer the information to FD-UAV, and then in time τ_d , FD-UAV transfer the information to the CR to improve its data rate is shown in Fig. 2(a). On the other side, in time, $\tau_h = 1 - \tau_e$, the DDT used downlink PD-NOMA to communicate with its respective DDGs as shown in Fig. 2(b). It should be noted that in the proposed model, we used the FD- UAV as a relay to reduce the transmission delay. Without loss of generality, assume a Cartesian system to set the coordinate of the UAV. Let us consider that the UAV flies at a fixed height H from the ground within a finite time horizon T as shown in Fig. 1(b). If total time T is divided into M slots, i.e., $\mathcal{M} = \{1, 2, \dots, m, \dots, M\}$ with each having length λ , then the total time is represented as $T = \lambda M$. Then, the coordinate of the UAV during time slot m is given as $\mathbb{U}m = xm, ym, H$. Also, assume that the start and end locations of the UAV are represented as $\mathbb{U}_s t = x_s m, y_s m, H$ and $\mathbb{U}_e m = x_e m, y_e m, H$, respectively. If v_{max} is the maximum speed of the UAV, then the trajectory of the UAV at the m^{th} time frame holds the following inequality

constraint:

$$\|Um + 1 - Um\|^2 \leq v_{max}\lambda^2, \forall m \in \mathcal{M} \quad (1)$$

The Cartesian coordinates of the i^{th} CT and the j^{th} CR are given as $\mathbb{U}_i m = x_i m, y_i m, 0$ and $\mathbb{U}_j m = x_j m, y_j m, 0$, respectively.

2.2 Channel Model

2.2.1 RM. When one CT wants to communicate with a CR via the relay (FD-UAV), then both the CR and FD-UAV receive two different types of signals Non-Line-of-Sight (NLoS) and fading alongwith Line-of-Sight (LoS) signal. The aggregated path loss (PL) between the i^{th} CT to the FD-UAV alongwith LoS and NLoS signals is given as follows:

$$\overline{PL}_{i,s} = Pr_{i,s}^{LoS} PL_{i,s}^{LoS} + \left(1 - Pr_{i,s}^{NLoS}\right) PL_{i,s}^{NLoS}. \quad (2)$$

where $PL_{i,s}^{LoS} = \Omega_{LoS} \left(\frac{4\pi d_{i,s}}{\lambda_0}\right)$, $PL_{i,s}^{NLoS} = \Omega_{NLoS} \left(\frac{4\pi d_{i,s}}{\lambda_0}\right)$, $Pr_{i,s}^{LoS} \tau = \frac{1}{1+ae^{-b\Theta_{i,s}-a}}$, and $Pr_{i,s}^{NLoS} = 1 - Pr_{i,s}^{LoS}$. Here λ_0 is the wavelength of the RF signal. Ω_{LoS} and Ω_{NLoS} are the LoS and NLoS signal loss arise due to the shadowing effect and fading. $d_{i,s} = \|\mathbb{U}_s - \mathbb{U}_i\|$ is the distance between the i^{th} CT and the FD-UAV, $\Theta_{i,s} = 180\pi \sin^{-1} \left(\frac{z_s}{d_{i,s}}\right)$ is an elevation angle between the i^{th} CT to the FD-UAV, and a and b are constant values. The channel gain between the i^{th} CCUE to the UAV, and the UAV to the j^{th} CEUE is given as follows:

$$h_{i,s} = \frac{1}{\overline{PL}_{i,s}}, \quad h_{s,j} = \frac{1}{\overline{PL}_{s,j}}. \quad (3)$$

2.2.2 DM. In this mode, the d^{th} DDT communicates directly with its two DDRs using NOMA. Therefore, the channel gain between the DDT and DDR r_1 and r_2 is represented as $h_{d,1}$ and $h_{d,2}$, respectively.

2.3 UAV Consumption and Charging Model

The power consumed by the UAV to serve the j^{th} CR is given as follows:

$$P_s^r = \alpha_s \sum_{j=1}^J \phi_{s,j} P_{s,j} + \beta_s, \quad (4)$$

where α_s represents the internal consumption losses, β_s is the offset losses, and $P_{s,j}$ is the transmission power from the UAV towards the j^{th} CR.

The power consumed by the hovering and hardware of the UAV during EH and IT process is given as follows:

$$P_s^{hd} = \sqrt{\frac{w g \rho}{2 \pi r_p^2 N_p}} + \left(\frac{P^m - P^s}{v}\right) v_s + P^s, \quad (5)$$

where w is the weight of the UAV, g is the gravity, and ρ is the density, r_p is the radius of the propeller, and N_p is the number of the propeller. P^m and P^s are the power consumed by the UAV when it is moving with full speed, and at the static position, respectively. In static position, i.e., $v_u = 0$.

Thus, the total power consumed by the UAV over t is given as follows:

$$P_s^t = P_s^r + P_s^{hd}. \quad (6)$$

The energy consumed by the UAV during time t from the wireless charger located at point $\mathbb{U}_s$ is given as follows:

$$E_s^c = P_u^t \left(\frac{\|\mathbb{U}_m - \mathbb{U}_c\|^2}{\|\mathbb{U}_m - \mathbb{U}_c\|^2 + \hat{U}} \right), \quad (7)$$

where $\hat{W} \approx 0.0001$ is a very small positive number.

The energy used in charging the battery of the UAV over t by the wireless charger is given as follows:

$$E_s^h = \eta P_{cs} \left(1 - \frac{\|\mathbb{U}_s - \mathbb{U}_c\|^2}{\|\mathbb{U}_s - \mathbb{U}_c\|^2 + \hat{U}} \right), \quad (8)$$

where η is the energy conversion efficiency, and P_{cs} is the signal power from the charging station.

The energy stored in the UAV at the end of time slot t from the wireless charger is given as follows:

$$E_s^{str} t = E_u^{str} (t - 1) + E_u^h - E_u^c. \quad (9)$$

2.4 WPCN Model

This model is a combination of WET and WIT processes. In WET, the devices harvest the energy from the UAV, and in WIT, the devices transmit the data to receivers using the harvested energy. If the total time for one frame is T , then the time consumed for WET and WIT process is denoted as τ_e and τ_d , respectively. Thus, the following equation holds:

$$\tau_e + \tau_d \leq T. \quad (10)$$

2.4.1 RM. In this mode, the CT communicates with the CR using the FD-UAV.

Case-I WET Process: The energy harvested by the i^{th} CT from the FD-UAV over τ_e is given as follows:

$$E_i^{eh} = \eta \tau_e P_s h_{s,i}, \quad (11)$$

where P_s is the transmit power of the UAV.

Case-II WIT Process: The signal transmitted by the i^{th} CT to the FD-UAV over $1 - \tau_e - \tau_d$ is given as follows:

$$\begin{aligned} y_{i,s}^{RM} &= \underbrace{\sqrt{P_i \psi_i h_{i,s} x_{i,s}}}_{\text{Desired Signal}} + \alpha_{i,s} \sum_{i' \neq i}^I \underbrace{\sqrt{P_{i'} \psi_{i'} h_{i',s} x_{i',s}}}_{\text{Co-Channel (CCI)}} \\ &+ \underbrace{\sqrt{P_s h_{s,s} x_{s,s}}}_{\text{Self Interference (SI)}} + \underbrace{\zeta_{i,s}}_{\text{AWGN}}, \end{aligned} \quad (12)$$

Here, $\alpha_{i,s}$ is the resource block indicator. If $\alpha_{i,s} = 1$, then the RB is allocated to the i^{th} CT to transmit an information to the FD-UAV, and otherwise $\alpha_{i,s} = 0$, and ψ_i represents the fraction of channel coefficient available for transmission from i^{th} CT to the FD-UAV.

The Signal-to-interference noise ratio (SINR) using (12) is calculated as follows:

$$\Gamma_{i,s}^{RM} = \frac{P_s \psi_i |h_{i,s}|}{P_{i'} \psi_{i'} h_{i',s} + P_{s,s} h_{s,s} + \sigma^2}. \quad (13)$$

The signal transmitted by the FD-UAV to the j^{th} CR is given as follows:

$$y_{s,j}^{HM} = \sqrt{P_s \nu_j h_{s,j} x_{s,j}} + \sum_{d=1}^D \sqrt{P_d h_{d,j} x_{d,j}} + \zeta_{s,j}, \quad (14)$$

where ν_j denotes the fraction of channel coefficient available for transmission from the FD-UAV to the j^{th} CR.

The SINR using (14) is calculated as follows:

$$\Gamma_{s,j}^{RM} = \left(\frac{P_s \nu_j |h_{s,j}|}{\sum_{d=1}^D P_d h_{d,j} + \sigma^2} \right). \quad (15)$$

The data rate using (13) and (15) are calculated given as follows:

$$R_{i,s}^{RM} = \frac{B}{2} (1 - \tau_e - \tau_d) \log_2 (1 + \Gamma_{i,s}^{RM}). \quad (16)$$

$$R_{s,j}^{RM} = \frac{B}{2} \tau_d \log_2 (1 + \Gamma_{s,j}^{RM}). \quad (17)$$

where $\left(\frac{B}{2}\right)$ denotes the two hops of RM.

The data rate from the i^{th} CT to the j^{th} CR using FD-UAV is defined as minimum of $R_{i,s}$ and $R_{s,j}$ which is given as follows:

$$R_{i,j}^{RM} = \alpha_{i,j} \frac{B}{2} \min\{R_{i,u}^{RM}, R_{u,j}^{RM}\}, \quad (18)$$

where $\alpha_{i,j} = \{\alpha_{i,s}, \alpha_{a,j}\}$.

2.4.2 DM. In this mode, the d^{th} communicates directly with the DDRs over time $1 - \tau_e$.

Case-I WET Process: The energy harvested by the d^{th} DDT from the FD-UAV over τ_e is given as follows:

$$E_d^{eh} = \eta \tau_e P_s h_{s,d}, \quad (19)$$

Case-II WIT Process: The multiplexed signal transmitted by the d^{th} DDT to the r_1 DDR using downlink PD-NOMA is given as follows:

$$y_{d,r_1}^{DM} = \underbrace{\left(\sqrt{P_d \theta_{d,r_1}} h_{d,r_1} x_{d,r_1} \right)}_{\text{Desired Signal}} + \underbrace{\left(\sqrt{P_d \theta_{d,r_2}} h_{d,r_2} x_{d,r_2} \right)}_{\text{NOMA Interference } I_{d,r_1}^{no}} + \underbrace{\zeta_{d,r_1}}_{\text{AWGN}} + \underbrace{\sum_{d' \neq d} \alpha_{d',d} \sqrt{P_{d'} h_{d',r_1}} x_{d',r_1}}_{\text{Co-channel interference } I_{d,r_1}^{co}} + \underbrace{\sqrt{P_i h_{i,r_1}} x_{i,r_1}}_{\text{Cross Channel interference } I_{i,r_1}^{cr}}, \quad (20)$$

where $P_d^{DM} = \left(\frac{\beta \eta \tau_e P_s g_{u,i}}{1 - \tau_e} \right)$ and $P_{d'}^{DM}$ are the transmit power of the d^{th} and d'^{th} DDT, respectively. α_{d,r_1} and α_{d',r_1} are the power allocation factor assigned to r_1 and r_2 DDR. x_{d,r_1} and x_{d,r_2} are the signals between the d^{th} DDT to the r_1 DDR, and that between the d^{th} DDT to the r_2 DDR, respectively. x_{d',r_1} is the co-channel interfering signal from the d'^{th} DDT to the r_1 DDR. $\alpha_{d',d}$ represents the co-channel interference, i.e., $\alpha_{d',d} = 1$, then d'^{th} and d^{th} DDT occupies the same RB, otherwise $\alpha_{d',d} = 0$. Assume that $h_{d,r_1} > h_{d,r_2}$

Now, the SINR received at the r_1 DDR using (20) is given as follows:

$$\Gamma_{d,r_1}^{DM} = \frac{\beta \eta \tau_e P_s h_{s,d} \alpha_{d,r_1} h_{d,r_1}}{I_{d,r_1}^{no} + I_{d',r_1}^{co} + I_{i,r_1}^{cr} + \sigma^2 1 - \tau_e}. \quad (21)$$

According to the principle of SIC, the SINR received at the r_2 DDR from the d^{th} DDT is given as follows:

$$\Gamma_{d,r_2}^{DM} = \frac{\beta \eta \tau_e P_s h_{s,i} \alpha_{d,r_2} h_{d,r_2}}{I_{d',r_2}^{co} + I_{i,r_2}^{cr} + \sigma^2 1 - \tau_e}. \quad (22)$$

Now, the data rate of the r_1 and r_2 DDR is given as follows:

$$R_{d,r_1}^{DM} = (1 - \tau_e) B \log_2 \left(1 + \Gamma_{d,r_1}^{DM} \right). \quad (23)$$

$$R_{d,r_2}^{DM} = (1 - \tau_e) B \log_2 \left(1 + \Gamma_{d,r_2}^{DM} \right). \quad (24)$$

The total data rate of the d^{th} DMG is given as follows:

$$R_d^{DM} = R_{d,r_1}^{DM} + R_{d,r_2}^{DM}. \quad (25)$$

2.5 Energy Efficiency Model

The EE of RM is calculated as follows:

$$EE_{i,s}^{RM} = \frac{\sum_{i=1}^I R_{i,s}^{RM}(\tau, P_i)}{\sum_{i=1}^I R_{i,s}^{RM}(\tau, P_i) + \sum_{j=1}^J R_{s,j}^{RM}(\tau, P_j)} \quad (26)$$

where $E_i^c = \tau_e + \tau_d P_c + \tau_d P_i$. Here, $\tau \in \{\tau_e, \tau_d\}$, $\alpha \in \{\alpha^{RM}, \alpha^{DM}\}$, and P_c is the power consumed by an internal circuits.

The EE of DM is calculated as follows:

$$EE_d^{DM} = \frac{\sum_{d=1}^D R_d^{DM}(\tau, \theta)}{E_d^c}. \quad (27)$$

where $E_d^c = \tau_e + \tau_d P_c + \tau_d P_d$, and $\theta \in \{\theta_{d,r_1}, \theta_{d,r_2}\}$.

2.6 Problem Formulation

In this paper, our goal is to maximize the EE of an overall network with respect to the time and power. The mathematical formulation of the problem is described as follows:

$$P.F. : \max_{\tau, \theta} EE_d^{DM}, \quad (28)$$

$$\text{s.t. } C_1 : \tau_e + \tau_d \leq T, \quad C_2 : \tau_e, \tau_d \geq 0,$$

$$C_3 : R_{d,r_1} \geq R_{d,r_1}^{\min}, R_{d,r_2} \geq R_{d,r_2}^{\min}, \forall j \in \mathcal{J}, d \in \mathcal{D}$$

$$C_4 : E_d^c \leq E_d^{eh}, C_5 : \frac{\|\mathbf{U}_s m + 1 - \mathbf{U}_s m\|^2}{v} P_s^{hd} + E_s^c \leq E_s,$$

$$C_6 : \theta_{d,r_1} + \theta_{d,r_2} \leq 1, C_7 : \theta_{d,r_1}, \theta_{d,r_2} \geq 0, \forall d \in \mathcal{D}.$$

In the above-mentioned problem, constraint C_1 ensures that the time consumed in WET and WIT process in one time frame must be less than T . Constraint C_2 represents the non-negative WET and WIT time. Constraint C_3 implies the minimum data rate requirements of the r_1 and r_2 DDRs. C_4 ensures that the energy consumed by the d^{th} DDT should be less than the harvested energy. Constraint C_5 implies that UAV must retain an energy less than the stored energy in its battery to reach the charging station. Constraint C_6 ensures the upper limit of the transmission power of the DDTs, and C_7 ensures the non-negative power transmission.

3 PROPOSED SCHEME

In this section, we propose an algorithm for problem (28) to maximize the EE by jointly optimizing the energy harvesting time and power allocation. To solve the problem (28), we first change the variables [9].

$$\tau_d = 1 - \tau_e = \frac{1}{\lambda}, P_d \alpha_d = \frac{1}{\alpha_d P_d}, \forall d \in \mathcal{D} \text{ and } P_i = \frac{1}{P_i}, \forall i \in \mathcal{I}. \quad (29)$$

such that the variable satisfy the convex constraint

$$\lambda > 1 \quad (30)$$

Now, the problem in (28) is rewritten as follows:

$$\begin{aligned} P.F. : & \max_{\tau, \theta} EE_d^{DM}, \\ \text{s.t.} : & \lambda > 1, \frac{1}{P_d} \leq (\lambda - 1) \eta P_d h_{s,d}, \\ & : \frac{1}{\lambda} \log_2 \left(1 + \frac{h_{d,r_1}}{P_d \theta_{d,r_1} I_{d,r_1}^{no} + I_{d',r_1}^{co} + I_{i,r_1}^{cr} + \sigma^2} \right), \\ & : \frac{1}{\lambda} \log_2 \left(1 + \frac{h_{d,r_2}}{P_d \theta_{d,r_2} I_{d',r_2}^{co} + I_{i,r_2}^{cr} + \sigma^2} \right), C_5 - C_7 \end{aligned} \quad (31)$$

where $\Sigma_{i=1}^I \frac{1}{\lambda P_i} + 1 - \frac{1}{\lambda} \eta P_s + P_c$ and $\Sigma_{d=1}^D \frac{1}{\lambda P_d} + 1 - \frac{1}{\lambda} \eta P_s + P_c$.

To solve the problem (31), we use the logarithmic inequality

$$\begin{aligned} \frac{1}{\rho} \log_2 1 + \frac{1}{uv} & \geq \frac{2}{\rho} \log_2 1 + \frac{1}{\bar{u}\bar{v}} + \frac{2}{\bar{\rho}\bar{u}\bar{v} + 1} \\ & - \frac{1}{\bar{\rho}\bar{u}\bar{u}\bar{v} + 1} u - \frac{1}{\bar{\rho}\bar{v}\bar{u}\bar{v} + 1} v - \frac{\log_2 1 + \frac{1}{\bar{u}\bar{v}}}{\bar{\rho}^2} \rho \end{aligned} \quad (32)$$

which follows from the convexity of function $\log_2 1 + \frac{1}{uv} \rho$.

For $u = \frac{\theta P_d}{h_{d,r_1}}$, $v = \frac{h_{d,r_1}}{\theta P_d} + \Sigma_{d' \neq d}^D \frac{h_{d',r_1}}{P_{d'}} + \frac{h_{i,r_1}}{P_i} + \sigma^2$, $\rho = \lambda$, $\bar{u} = u^\ell = \frac{\theta P_d^\ell}{h_{d,r_1}}$, $\bar{v} = v^\ell = \frac{h_{d,r_1}}{\theta P_d^\ell} + \Sigma_{d' \neq d}^D \frac{h_{d',r_1}}{P_{d'}^\ell} + \frac{h_{i,r_1}}{P_i^\ell} + \sigma^2$, $\bar{\rho} = \rho^\ell = \lambda^\ell$.

Now, the sum rate is rewritten as follows:

$$R_d, \lambda, P \geq \varphi_{d,r_1}^\ell \lambda, P \quad (33)$$

$$\begin{aligned} \text{where } \varphi_{d,r_1}^\ell \lambda, P &= \frac{2}{\rho^\ell} \log_2 1 + \frac{1}{u^\ell v^\ell} + \frac{2}{\rho^\ell u^\ell v^\ell + 1} \\ & - \frac{1}{\rho^\ell u^\ell u^\ell v^\ell + 1} u - \frac{1}{\rho^\ell v^\ell u^\ell v^\ell + 1} v - \frac{\log_2 1 + \frac{1}{u^\ell v^\ell}}{\rho^{\ell 2}} \rho \end{aligned} \quad (34)$$

With the feasible points λ^ℓ, P^ℓ of (31), we have

$$\delta^\ell = \Sigma_{d=1}^D \frac{\varphi_{d,r_1}^\ell \lambda^\ell, P^\ell}{\Psi \lambda^\ell, P^\ell} \quad (35)$$

where $\Psi \lambda^\ell, P^\ell = E_d^c$

At the ℓ^{th} iteration, the following convex program is solved to generate the next feasible point.

$$\max_{\lambda, P} \Sigma_{d=1}^D \varphi_{d,r_1}^\ell \lambda^\ell, P^\ell - \delta^\ell \Psi \lambda^\ell, P^\ell \quad (36)$$

We propose an algorithm to solve the EE maximization (36). The initial point λ^0, P^0 for (36) is easily located by random search such that it satisfies the constraints in problem (31).

Algorithm 1 Joint Time and Power Allocation Algorithm

Initialization:

- Set the feasible points: λ^0, P^0 .
- $\iota = 0$.
- Set Maximum tolerance value $\epsilon = 10^{-2}$
- $\delta^0 = \Sigma_{d=1}^D \frac{\varphi_{d,r_1}^0 \lambda^0, P^0}{\Psi \lambda^0, P^0}$

1: repeat

2: Solve (28) to achieve the optimal value of $\lambda^{\iota+1}, P^{\iota+1}$.

3: Set $\delta^{\iota+1} = \Sigma_{d=1}^D \frac{\varphi_{d,r_1}^{\iota+1} \lambda^{\iota+1}, P^{\iota+1}}{\Psi \lambda^{\iota+1}, P^{\iota+1}}$

4: $\iota = \iota + 1$

5: until Convergence

3.1 Power Allocation

This algorithm addresses power allocation for EE maximization problem (28) where the harvesting time value is fixed as $1 - \tau_e = \frac{1}{\lambda^*}, \lambda^* > 1$. Now, the equation (28) is rewritten as follows:

$$\begin{aligned} P.F. : & \max_P EE_d^{DM} \\ \text{s.t.} : & \theta_d P_d \leq \lambda^* - 1 \eta P_s h_{s,d} \\ & R_{d,r_1} \geq \lambda^* R_{d,r_1}^{\min}, R_{d,r_2} \geq \lambda^* R_{d,r_2}^{\min}, \end{aligned} \quad (37)$$

To solve the non-convex problem (37), we used the inequality derived in (32).

Let $u = \frac{1}{\theta P_d h_{d,r_1}}$, $v = \theta P_d h_{d,r_2} + \Sigma_{d' \neq d}^D P_{d'} h_{d',r_1} + P_i h_{i,r_1} + \sigma^2$, $\rho = 1$, and $\bar{u} = u^\ell = \frac{1}{\theta P_d^\ell h_{d,r_1}}$, $\bar{v} = v^\ell = \theta P_d^\ell h_{d,r_2} + \Sigma_{d' \neq d}^D P_{d'}^\ell h_{d',r_1} + P_i^\ell h_{i,r_1} + \sigma^2$, $\bar{\rho} = \rho^\ell = 1$.

Then, the numerator of objective function in (37) is rewritten as follows:

$$R_d^{DM} \lambda^*, P \geq \bar{\varphi}_d^\ell \lambda^*, P \quad (38)$$

At the ℓ^{th} iteration, the following convex program is solved to generate the next feasible point.

$$\max_{\lambda, P} \Sigma_{d=1}^D \varphi_{d,r_1}^\ell \lambda^\ell, P^\ell - \delta^\ell \Psi \lambda^\ell, P^\ell \quad (39)$$

$$\text{s.t.} \quad \theta_d P_d \leq \lambda^* - 1 \eta P_s h_{s,d}$$

$$R_{d,r_1} \geq \lambda^* R_{d,r_1}^{\min}, R_{d,r_2} \geq \lambda^* R_{d,r_2}^{\min}, C_6 - C_7$$

3.2 Time Allocation

This algorithm solves the harvesting time optimization problem in the slack variable of λ with the use of maximum harvested power in D2D communication as follows:

$$P_d = (\lambda - 1) \eta P_s h_{s,d} \quad (40)$$

Therefore, the max-min sum-rate problem with fixed harvested energy is given as follows:

$$\max_{\lambda} \min_{d \in \mathcal{D}} \frac{1}{\lambda} \log_2$$

$$\left(1 + \frac{(\lambda - 1) h_{d,r_1} g_{r_1}}{\lambda - 1 h_{d,r_2} g_{r_2} + \Sigma_{d' \neq d}^D h_{d',r_1} g_{r_1} + h_{i,r_1} g_{r_1} + \sigma^2} \right) \quad (41)$$

Next, the objective function in (41) can be approximated by using the inequality (32) for $u = \frac{1}{(\lambda - 1)}$. Let $u = \frac{1}{(\lambda - 1)} h_{d,r_1}$, $v = (\lambda - 1) P_d h_{d,r_2} + \Sigma_{d' \neq d}^D P_{d'} h_{d',r_1} + P_i h_{i,r_1} + \sigma^2$, $\rho = 1$, and $\bar{u} = u^\ell = \frac{1}{\theta P_d^\ell h_{d,r_1}}$, $\bar{v} = v^\ell = \theta P_d^\ell h_{d,r_2} + \Sigma_{d' \neq d}^D P_{d'}^\ell h_{d',r_1} + P_i^\ell h_{i,r_1} + \sigma^2$, $\bar{\rho} = \rho^\ell = 1$.

Then, the numerator of objective function in (37) is rewritten as follows:

$$R_d^{DM} \lambda^*, P \geq \bar{\varphi}_d^\ell \lambda^*, P \quad (42)$$

At the ℓ^{th} iteration, the following convex program is solved to generate the next feasible point.

Figure 3: Comparative Analysis: (a) Optimal Value of TA for DM v/s Path loss exponent (b) Optimal Value of TA for DM v/s Path loss exponent (c) Energy Efficiency of network v/s Transmit power of UAV.

4 PERFORMANCE EVALUATION

In this section, performance of the proposed scheme is evaluated. The simulation parameters used in the evaluation are taken from [2] as shown in Table 1. The UAV and charging station is located at coordinates (400,400,60) and (200,200,60), respectively.

Fig. 3(a) describes the variation in optimal value of TA

Table 1: Simulation Parameters

Parameters	Values	Parameters	Values
Cell Layout	Hexagonal	a, b	9.6, 2.9
Cell Radius	60 m	Bandwidth B	20 MHz
Area	800 m x 800 m	z (elevation)	60 m
λ_0	0.125 m	Ω_{LOS}	1
$\Omega_{NLOS}, \mathcal{I}$	12, 10	α_u, N_p	4, 5
β_u	6.8	P_{cs}	10 W
P_u^{max}	25 dBm	P_i^{max}	25 dBm
w, r_p	1 Kg, 20cm	P^s	0.5 W
v, t_{max}	15 m/s, 15	E_i^{eh}	15 KJ

for DM with respect to the path loss exponent. The result shows that the proposed JMSTA achieves the optimal TA in between the DM and HM. This happened because the link quality in DM is much better than that in HM due to short distance between the DDT and DDRs in each DMG.

Fig. 3(b) shows the graph between the optimal value of TA for DM with respect to the path loss exponent. The results in graph implies that the proposed scheme in both the uplink and downlink scenarios achieve 1.34% and 0.1% approximately equals to the optimal value.

Fig. 3(c) shows the impact on the EE of a network with respect to the transmit power of UAV. The results shows that when the transmit power of UAV increases, then the proposed scheme achieves higher EE as compared to the pre-existing NOMA [2] and OMA [8] scheme. This happened because with an increases in transmit power of UAV, the DDT users harvest large amount of energy from the UAV and easily transmit the information to DDRs, resulting into an increase in EE of the DMG.

5 CONCLUSION

In this paper, we have proposed the energy efficient resource allocation scheme for wireless powered D2D Users with NOMA underlaying FD-UAV. Here, the DDTs first harvest energy from the RF signal of the FD-UAV, and then

communicate with the DDRs using NOMA technique. The formulated problem is in a MINLP form, so to solve this we divide it into two sub-problems. In the first sub-problem, an optimal value of power is estimated, whereas in the second sub-problem, an optimal vale of energy harvesting time is calculated using the concept logarithmic equality. Finally, a joint time and power allocation algorithm is designed to maximize the EE of the DMGs. In future, we will extend this scheme to a multiple UAV scenario.

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