Poster: UAV-enabled Data Acquisition Scheme with Directional Wireless Energy Transfer

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Abstract

In this paper, we exploit an Unmanned Aerial Vehicle (UAV) as a data collector which first transfers wireless energy to an Internet of Things (IoT) node who then sends back the data packets to UAV. In particular, we present a resource allocation scheme for the data acquisition task by minimizing the overall energy consumption. We further investigate two optional allocations for wireless energy transfer time and data transmitting power as well as the applicable conditions. Numerical results show the adaptability of our allocation scheme with the varied value of channel-fading parameter and data size level.

1 Introduction

The emerging Internet of Things (IoT) aims at connecting everything by data acquisition from thousands of IoT nodes. However, there is a challenge for collecting data from rural areas due to the difficulty of deploying base stations and the low battery capacity of IoT nodes. The recent advances in Unmanned Aerial Vehicle (UAV) and Wireless Energy Transfer (WPT) bring the opportunities in solving the challenge of data acquisition of IoT in rural areas [2–4].

In this paper, we propose a novel UAV-enabled data acquisition scheme for IoT nodes deployed in rural areas. In our scheme, a UAV serving as a data collector will fly over the field containing IoT nodes and transmit wireless energy towards an IoT node via directional beamforming. The IoT node who harvests the energy can then transmit the data to the UAV. Fig. 1 shows an example of this procedure.

2 Overview of Our Scheme

2.1 Energy Minimization Problem

We investigate the energy consumption of UAV in the proposed scheme since UAVs have limited energy storage. In particular, we analyze the overall energy consumption during the procedure of wireless energy transfer from the

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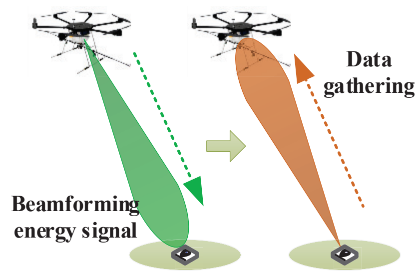


Figure 1. System design for UAV-enabled data acquisition scheme with directional wireless energy transfer.

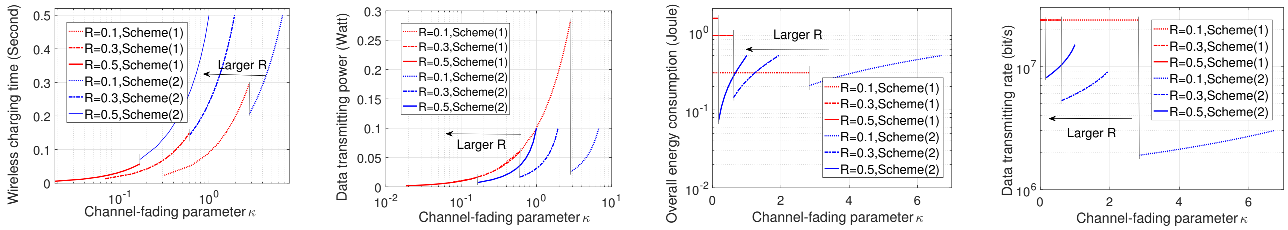
UAV to the IoT node and data acquisition from the IoT node to the UAV. We denote the overall energy consumption by $e_{overall}$. We then formulate the overall energy consumption minimization problem as follows.

$$(\mathcal{P}1): \quad \min_{p,T,\alpha\in(0,1)} \quad e_{overall}$$
$$\text{s.t.} \quad e_{EH} \geq e_{DT}, T \in (0, T^{\max}],$$

where e_{EH} denotes the harvested energy at the IoT node and e_{DT} is the energy consumption for data acquisition. Therefore, $e_{EH} \geq e_{DT}$ essentially implies that the sufficient energy supply from the UAV is necessary to ensure data acquisition. Moreover, we denote the time for the whole procedure (i.e., energy transfer and data acquisition) by T. Generally, $T < T^{\max}$ where $T^{\max}$ is the maximum time allowing for the whole procedure. We denote the proportion of time T for wireless energy transfer by α $(0 < \alpha < 1)$. Hence, the time for wireless energy transfer is αT and the time for data acquisition is $(1-\alpha)T$.

2.2 Resource Allocation Scheme

The optimal solution of $\mathcal{P}1$ can be derived by convex optimization [1]. In particular, we find that three joint system parameters significantly affect the optimal solution. Table 2.2 gives the definitions as well as the meanings of them. The term of σ^2 is average power of noise; ζ is energy conversion efficiency from radio frequency (RF) signal to electric energy; B is the bandwidth in data transmitting; $\mathrm{tr}(G)$ is the average gain of multiple up-link channel; $\mathrm{tr}(H)$ is the average gain of multiple down-link channel; $\mathrm{tr}(Q)$ is the power of the beam-forming energy signal, where we formulate these notations by Ref. [2].



(a) (b) (c) (d)

Figure 2. Wireless energy transfer time αT, data transmitting power p, Overall energy consumption $e_{overall}$ and data transmitting rate r versus channel-fading parameter κ with varied size level R.

Table 1. Definition of joint system parameters

Definition	Meaning
$\kappa \triangleq \frac{\sigma^2}{\zeta \mathrm{tr}(QH)\mathrm{tr}(G)}$	Channel-fading parameter of joint up-link and down-link, where smaller κ indicates better channel condition.
$R \triangleq \frac{l}{T^{\max}B}$	Size level of transmitting data. It divides data size l by the product of system bandwidth B and the maximum time $T^{\max}$.
$P_{EH} \triangleq \zeta \mathrm{tr}(QH)$	Power of the received energy signal at IoT nodes. Higher energy transferring power leads to more harvested energy.

Therefore, by computing the three joint system parameters, we design a resource allocation scheme for allocating wireless energy transferring time αT and data transmitting power denoted by p (initiated by the IoT node). In particular, there are two allocation schemes corresponding to two different channel-fading parameter ranges (i.e., $\kappa \in (0, \kappa_1]$ and $\kappa \in (\max(\kappa_1, 0), \kappa_2)$ as follows:

$$\textbf{Scheme(1)} \begin{cases} \alpha T = 3\kappa R T^{\max} \\ p = 2\kappa P_{EH} \end{cases}, \text{when } \kappa \in (0, \kappa_1],$$

where $\kappa_1 = 1/(3R) - 1/2$ and supporting that $R \in (0, 2/3)$.

$$\textbf{Scheme(2)} \begin{cases} \alpha T = \dfrac{T^{\max}\left(-\frac{W(\tau)}{R\ln(2)} - \kappa\right)}{1 - \frac{W(\tau)}{R\ln(2)} - \kappa} \\ p = P_{EH}\left(-\frac{W(\tau)}{R\ln(2)} - \kappa\right) \end{cases}, \text{when } \kappa \in (\max(\kappa_1, 0), \kappa_2),$$

where $\kappa_2 = p^{\max}/(2^{R(1+p^{\max})} - 1)$ and supporting that $R \in (0, 1)$. Note that $W(\tau)$ is Lambert Function, $\tau = -\kappa R \ln(2) \times 2^{R(1-\kappa)}$ and $p^{\max}$ is the maximum threshold of data transmitting power.

Essentially, we can conduct our scheme at UAVs because of two feasible reasons. First, three joint system parameters are achievable in practical scenarios because $T^{\max}, B, \zeta, \mathrm{tr}(Q)$ are given by predefined systems and the terms of $\mathrm{tr}(G)$ and $\mathrm{tr}(H)$ are available via the precise channel estimation from multi-antenna array equipped at the UAV. Second, our scheme is adjustable when κ varies in its applicable range. Of course, there are some necessary interactions between the UAV and IoT nodes to achieve activation, positioning and power control. The further experiments on these interactions as well the mobility of UAV will be investigated in the future.

3 Numerical Results

We provide numerical results to evaluate the performance of the proposed scheme. In particular, we set $T^{\max} = 1$, $P_{EH} = 0.1$, $B = 15 \times 10^6$ bit/s and $p^{\max} = 1$. Particularly, results of *Scheme(1)* and *Scheme(2)* are represented by red curves and blue curves, respectively. Meanwhile, we use dotted line, dash-dot line and solid line to represent different settings of $R = 0.1, 0.3, 0.5$, respectively.

Fig. 2(a) and Fig. 2(b) show that wireless energy transfer time αT and data transmitting power p increase with the increased value of κ. This is because the larger value of κ implies the worse channel condition resulting in the higher transmitting power and longer wireless energy transfer time. Meanwhile, we also find that wireless energy transfer time of *Scheme(2)* is always larger than that of *Scheme(1)* due to *Scheme(2)* suits in worse applicable channel state. Moreover, the data transmitting power in *Scheme(2)* has a slower growth than that in *Scheme(1)*. Furthermore, Fig. 2 also shows that the larger value of R leads to the higher transmitting power and longer wireless energy transfer time.

Fig. 2(c) and Fig. 2(d) show the overall energy consumption and data transmitting rate against κ with varied size level R. We find that *Scheme(1)* can achieve the steady overall energy consumption and data transmitting rate against κ because of the adjustable wireless energy transfer time. Meanwhile, *Scheme(1)* consumes high energy while keep steady data transmitting rate with the increased value of R because wireless energy transfer time increases in *Scheme(1)*. Different from *Scheme(1)*, there is a growth of overall energy consumption and data transmitting rate *Scheme(2)*. This effect can also be explained by the worse channel state and non-adjustable overall transmission time in *Scheme(2)* consequently leading to higher energy supply from UAV and higher data transmitting power. There is a similar trend in data transmitting rate.

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