Convex optimization project

Ketan Sabne (CS20BTECH11043)
Chinasani Asish Sashank Reddy (CS20BTECH11010)

Guided by:Prof.Shashank Vatedka

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Title

Joint Optimization of Trajectory, Task Offloading, and CPU Control in UAV-Assisted Wireless Powered Fog Computing Networks

Abstract

This paper proposes a system that uses a rotary-wing unmanned aerial vehicle (UAV) to provide wireless power and fog computing services to ground sensors. An optimization problem is formulated to minimize the UAV's energy consumption, taking into account the piecewise nonlinear energy harvesting (EH) model, charging requirements of sensors, and velocity constraints of the UAV. An iterative method based on the successive convex approximation (SCA) theory is proposed to solve the non-convex problem. Simulation results show that the proposed scheme greatly reduces the UAV's energy consumption compared to benchmark schemes. It is also observed that the nonlinear EH model can result in higher energy consumption of the UAV as the circuit saturation threshold increases. Introducing velocity constraints reduces the variation of the UAV's velocity, avoiding drastic steering in the considered scenario.

Introduction

Background

The Internet of Things (IoT) requires a large number of sensors to collect and process data in various scenarios. However, the limited capacity of batteries makes managing the power sources of sensors a challenge, especially in large-scale IoT systems or harsh environments. Radio frequency (RF) signals have been proposed as a promising solution for wireless power transfer, as they are less affected by natural environments and have high flexibility.

In addition to power supply issues, delay-sensitive applications such as virtual reality and autonomous driving require computing capabilities that may not be met by traditional cloud computing. Fog computing (FC) has been proposed as a supplement to cloud computing, where computing tasks can be offloaded to nearby fog servers to reduce transmission and decision delay.

Introduction

Background

Combining RF-based EH and FC in a single system can address both power supply and computing capability issues in IoT systems. However, most existing works have only considered fixed-location fog servers and power stations, which may only provide limited coverage. This is especially challenging in large-scale IoT systems where sensors are positioned far apart. Recently, unmanned aerial vehicle (UAV) assisted communication has gained attention as they offer flexibility and mobility. UAVs can be deployed to alleviate the high deployment costs of dense fixed-location FCs and power stations. In summary, the combination of wireless power sources and fog servers can address both power supply and computing capability issues in IoT systems. However, deploying fixed-location fog servers and power stations can result in high costs, making UAV-assisted communication an attractive alternative. By using UAVs, the flexibility and mobility of the system can be improved while reducing deployment costs.

Introduction

Related work and Motivation

Recent research has focused on using Unmanned Aerial Vehicles (UAVs) to enhance wireless communication and computing capabilities in dynamic environments. There are two types of UAVs: fixed-wing and rotary-wing. Fixed-wing UAVs have high speed and heavy payload capabilities, but require continuous forward motion to stay in the air, which limits their maneuverability and communication range. On the other hand, rotary-wing UAVs can move in any direction and stay stationary in the air, making them more flexible and suitable for enhancing wireless charging and fog computing in dynamic scenarios.Researchers have explored various applications of UAVs, including using them as mobile energy sources and mobile fog servers to power and compute for IoT sensors.

Introduction

Related work and Motivation

For example, rotary-wing UAVs can deliver wireless energy to energy receivers and offload computing tasks from sensors to meet real-time demand. These tasks can be optimized to minimize energy consumption and system delay, while maximizing secrecy capacity and computation rates. RF-based EH function can also be used to harvest energy from RF signals transmitted by UAVs, rather than deploying conventional fixed energy stations.Overall, these studies suggest that UAVs can be a promising solution for enhancing wireless communication and computing capabilities in challenging environments.

Introduction

Related work and Motivation

In this paper, the authors propose a new approach for a rotary-wing UAV-assisted wireless powered FC network. Unlike previous works that only considered hovering or optimized the UAV's position without considering propulsion energy, the authors take into account the practical energy consumption model of rotary-wing UAVs and optimize their trajectory over a period of time. Additionally, previous works only used the linear energy harvesting (EH) model, but the authors adopt a more practical nonlinear EH model. Furthermore, they allow a certain amount of energy to be stored at the sensors for future use and discuss the impact of charging and storage requirements.

Problem Formulation and Solution

Problem Formulation

Let $Q = \{q_u[n], v[n]\}$ be the trajectory vector, $L = \{P_k[n], l_k[n]\}$ be the task offloading vector and $F = \{f_k[n], f_u[n]\}$ be the computing adjusting vector, $\forall n \in \{1, ..., N\}$ *and* $\forall k \in \{1, ..., K\}$.$E_{comp}[n]$ is the energy consumed by computing the offloaded data at the UAV, $E_{k,r}[n]$ is the energy harvested by sensor k in the n-th time slot. The optimization problem to minimize UAV's total required energy is formulated as

$$P_0 : \min_{Q,L,F} \sum_{n=2}^{N} E_{comp}[n] + \sum_{n=1}^{N} E_{fly}[n] \tag{1}$$

$$s.t. \sum_{i=1}^{n} E_{k,l}[i] + \sum_{i=1}^{n} E_{k,o}[i] \leq \sum_{i=1}^{n} E_{k,r}[i] \tag{2}$$

$$\sum_{i=1}^{N} E_{k,r}[i] - \sum_{i=1}^{N} E_{k,l}[i] - \sum_{i=1}^{N} E_{k,o}[i] \geq E_{end,k} \tag{3}$$

Problem Formulation and Solution

Problem formulation(contd..)

$$\sum_{n=1}^{N} \frac{\lambda K f_k[n]}{C} + \sum_{n=1}^{N-1} l_k[n] = D_k \tag{4}$$

$$\sum_{i=2}^{n} \frac{\lambda K f_u[i]}{C} \leq \sum_{k=1}^{K} \sum_{j=1}^{n-1} l_k[j] \tag{5}$$

$$\sum_{i=2}^{N} \frac{K \lambda f_u[i]}{C} = \sum_{k=1}^{K} \sum_{j=1}^{n-1} l_k[j] \tag{6}$$

$$q_u[n+1] - q_u[n] = v[n]\frac{T}{N} \tag{7}$$

These are constraints.Also,The energy consumed by local computing in the n-th time slot is $E_{k,l}[n]$.$E_{fly}[n]$ is the aerodynamic power consumption of the UAV in time slot n.$l_k[n]$ is the amount of data that can be offloaded by the k-th sensor in the n-th time slot.

Problem Formulation and Solution

Solution

As we can see in above problem statement objective function is non-convex and also, some constraints are also non-convex.problem P_0 is non-convex, which has no known solution. Therefore,we are using SCA based solution method to convert it to convex.New problem which is converted to convex is

$$P_0' : \min_{Q,L,F,V_a[n],V_b[n],x_k[n]} \sum_{n=2}^{N} E_{comp}[n] + \sum_{n=1}^{N} \overline{\overline{E_{fly}[n]}} \tag{8}$$

s.t

$$\sum_{i=1}^{n} E_{k,l}[i] + \sum_{i=1}^{n} E_{k,o}[i] \leq \sum_{i=1}^{n} \overline{E_{k,r}[i]} \tag{9}$$

Problem Formulation and Solution

Solution(contd..)

$$\sum_{i=1}^{N} \overline{E_{k,r}[i]} - \sum_{i=1}^{N} E_{k,l}[i] - \sum_{i=1}^{N} E_{k,o}[i] \geq E_{end,k} \tag{10}$$

$$\log_2(H^2 + x_k[n] + P_k[n]\frac{\beta_0}{\sigma^2}) = \frac{l_k[n]}{\lambda B} \tag{11}$$

$$x_k[n] \geq ||q_u[n] - q_k||^2 \tag{12}$$

By using the mathematical variable substitutions and SCA based algorithm, P_0 has been transformed to P_0' which can be solved using by cvxpy library. sample code is written check .ipynb file for it.

Algorithm SCA

Algorithm The Proposed SCA-Based Solution Algorithm

1: Initialize UAV's trajectory $q_u^l[n]$ and velocity $v_l[n]$, iterative number l $=$ 1, and a maximum iterative number L_{max}, tolerance error ϵ ;
2: Repeat Solve the problem P_0' for given $q_u^l[n]$ and $v_l[n]$ and denote the optimal solution as $q_u^*[n]$ and $v^*[n]$.
3: Update $q_u^{l+1}[n] = q_u^*[n]$ and $v_{l+1}[n] = v^*[n]$.
4: Calculate $\epsilon 1 = \sum_{n=1}^{N} ||q_u^*[n] - q_u^l[n]||$
5: Update iterative number $l = l + 1$;
6: Until $\epsilon 1 \leq \epsilon$ or the maximum iterative number has been reached.
7: Obtain all the optimal solutions

Simulation

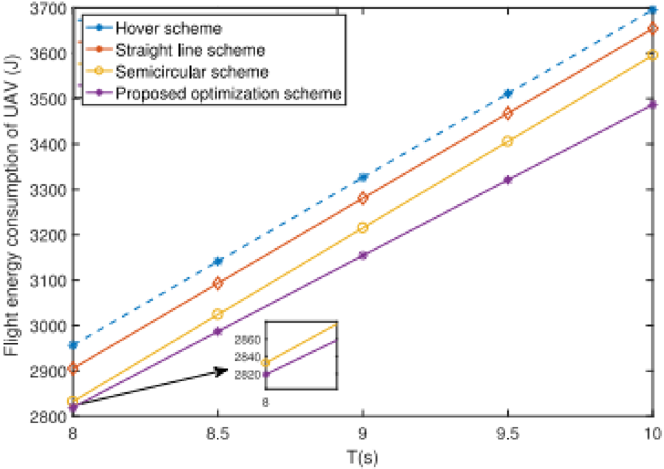

Figure: Comparison of UAV's energy consumption of four different schemes

Conclusions

Conclusions

- The paper proposed a system design for a rotary-wing UAV-assisted wireless powered FC network.
- The goal was to minimize the energy consumption of the UAV while completing charging and computing tasks for ground sensors within a given time period.
- The practical propulsion energy model of rotary-wing UAV and the piecewise nonlinear energy harvesting model were considered. and An effective solution method based on SCA was designed to tackle the non-convex problem.
- Simulation results showed that the proposed design can provide high-quality services for the sensors under different parameter settings and sensor distribution scenarios.

Conclusions

Conclusions

- The harvested energy of the sensors using the linear EH model had an obvious bias compared to that obtained by the nonlinear EH model.
- Increasing the circuit saturation threshold Pth resulted in the UAV moving closer to the sensors, which may result in higher energy consumption of the UAV.
- introducing a velocity constraint ensured that the velocity variation of the UAV was relatively small, which avoided drastic steering of the UAV in their considered scenario.
- The proposed design showed promising results in providing high-quality services for ground sensors in a wireless powered FC network assisted by a rotary-wing UAV.
- The study found that careful consideration of energy harvesting models and UAV energy consumption is necessary for efficient operation of the network.