# Powering Inaccessible IoT Devices Through a WPT-enabled Sustainable UAV Network

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***Abstract*—Powering Internet of Things (IoT) devices in hard to reach or hazardous locations could be prohibitive in terms of cost and safety. In this work, we demonstrate a thorough solution that tackles this problem using a network of unmanned aerial vehicles (UAVs) with wireless power transfer (WPT) capabilities. Given the large-scale IoT deployments of the future and the energy needs of the UAVs, we consider an infrastructure of charging stations for the UAVs that allow an uninterrupted and flexible UAV deployment based on the current energy needs of the IoT devices. Then, we exhibit an orchestrator that communicates with the entire infrastructure and handles the UAV traffic and energy decisions, as well as the digital representation and interaction of the network with the user.**

***Index Terms*—Unmanned aerial vehicles, Wireless power transfer, energy coverage, orchestrator, user interface.**

## I. Introduction

In dense urban environments, an effective monitoring using Internet of Things (IoT) devices is essential to manage assets, resources, and services efficiently. However, there are cases where the wireless devices are inaccessible and, thus, charging them is prohibitive. For instance, powering IoT devices attached on rotating machinery, dams, bridges, or contaminated areas by physical access would not only be expensive, but also dangerous. Therefore, novel ways of charging inaccessible IoT devices have to be studied that are safe and inexpensive.

During the last decade, the use of unmanned aerial vehicles (UAVs) has been suggested for tasks that require flexible deployment. UAVs have the capability to reach hazardous or inaccessible areas in an effective and inexpensive way. At the same time, wireless power transfer (WPT) has started gaining traction by providing radio frequency (RF) energy to IoT devices with wireless energy harvesting (EH) capabilities. Therefore, WPT-enabled UAVs could provide an inventive solution to the charging problem. Nevertheless, as the number of IoT nodes grows exponentially, the UAV network scales horizontally too, raising the following set of restrictions:

- To handle the large-scale IoT charging, an autonomous UAV orchestration is crucial to control the UAVs;
- The limited energy of the UAVs require the use of charging stations (CSs) deployed in the area [1];
- For safety reasons, there is a need for constant monitoring and actuation of the UAV network.

In this context, there are some works that study the wireless charging of inaccessible IoT with UAVs. In [2], a UAV-assisted wireless charging system for IoT devices addresses the problem of maximizing both the total energy and the minimum received energy individually. However, the focus is on designing the UAV trajectory and only one UAV is considered, therefore the UAV allocation problem is not addressed. In [3], the authors consider multiple UAVs and employ a dynamic bipartite matching with one-sided preferences. However, this work does not consider the need for autonomous operation using CSs.

To that end, in this work, we present a comprehensive architecture that considers a set of WPT-enabled UAVs that operate autonomously and charge IoT devices wirelessly. To satisfy the UAVs' energy needs, we assume a set of CSs with which the UAVs are associated to guarantee a safe operation. Then, we devise a matching theoretic algorithm to solve the UAV-CS association problem, based on the network traffic status and safety parameters, while taking into account the actual power supply needs of the UAVs. To visualize the procedure as well as monitor the UAV network, we develop an intuitive user interface that demonstrates key performance indicators (KPIs) and locations of the different network entities, while allowing the interaction of the user with the UAV network.

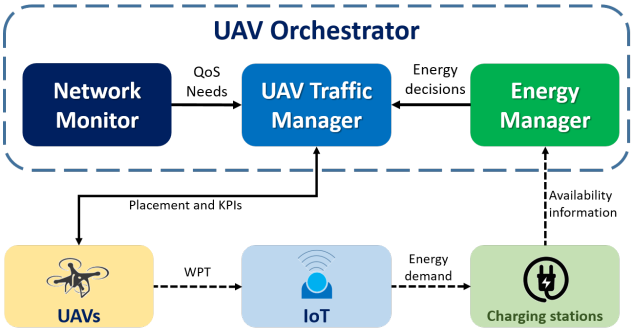


Fig. 1: Architecture of the proposed system

## II. System Architecture Overview

In Fig. 1, we demonstrate the proposed system architecture that consists of UAVs, CSs, and IoT. A UAV and a CS operator are responsible for the respective deployment having as an objective to increase their profits. The large-scale IoT network is equipped with EH antennas and is periodically charged by UAVs through far-field WPT. Additionally, to cover the energy requirements of the UAVs, a set of CSs is also distributed

Fig. 2: Custom UAV KPI monitoring and actuation platform

on the plane, while the orchestrator handles the UAV-CS association to guarantee a context-aware and safe operation. For the energy model of the UAVs, we consider our work in [5].

### A. *UAV-CS Association algorithm*

The UAV-CS association problem should be accomplished in a fair and profitable way for both UAV and CS operators, while aiming towards increased energy coverage of IoT devices, i.e., the ratio of the delivered energy to the total demand. Thus, we employ the powerful tools of matching theory [4] to obtain a suitable association that guarantees stability, in the sense that agents do not have incentive to change assignments after being matched. In typical matching games, the preferences of one operator do not depend on the other operator's choices. However, this assumption does not hold for the considered UAV-CS association problem due to "peer" effects that dynamically affect the performance of each UAV-CS association. These effects are called externalities [6] and we consider them in this work.

## III. UAV Orchestration and Monitoring

Although the orchestrator allows an autonomous operation, we developed a platform for KPI and UAV placement monitoring and actuation. The platform tranceives data through telemetry using the MAVlink communication protocol and updates in real-time the positions of the UAVs, their information details (i.e., battery level, status) and network as well as device-specific KPIs. In Fig. 2, we present the user interface of the custom-made platform. This platform will be presented in the demo session using simulated telemetry signals.

## IV. Performance Evaluation

To evaluate the performance of our orchestration algorithm, we conducted extensive simulations with 100 randomly-deployed IoT devices and validated the effectiveness of our proposed scheme. Specifically, we assume a WPT-enabled UAV network of 10 UAVs and 5 CSs. We examine the IoT network energy coverage for three different scenarios: a) a random association, b) an energy optimal association, and c) the proposed scenario that aims in accomplishing a fair and profitable association for all involved parties. As it is evident from Fig. 3, as the energy demand of each IoT device rises, the average energy coverage drops due to the fact that the UAVs

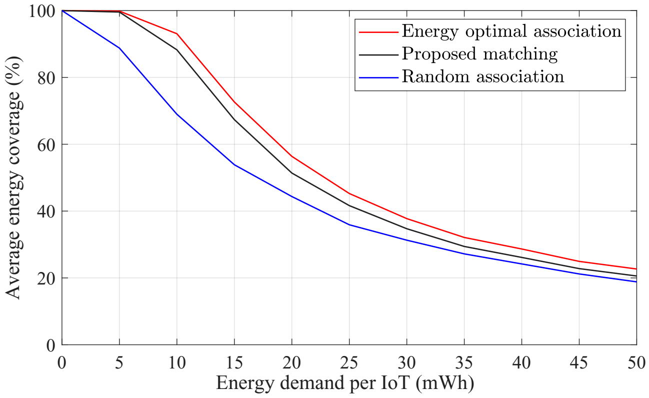


Fig. 3: Comparison of the average energy coverage for: a) random, b) optimal, and c) the proposed association scenarios

spend energy for hovering and WPT to satisfy the demand. Moreover, we notice that the energy optimal and the random UAV associations define the lower and upper bound for the energy coverage, while the proposed matching provides a near-optimal performance. However, it should be noticed that the energy optimal association does not consider the profitability and the fairness among the operators, which is the reason that the proposed matching is preferred.

## V. Conclusion

In this work, we presented a comprehensive architecture for a WPT-enabled UAV network that aims to provide energy coverage in a large-scale network of EH-ready IoT devices. To provide an autonomous and safe operation, we devised an orchestrator that employs a stable matching algorithm that considers externalities. Finally, we present the results in an intuitive user interface that demonstrates KPIs and locations of the different network entities and allows the interaction of the user with the UAV network.

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