

# Integrated Data and Energy Network (DEIN) System

Ilyes REZGUI

YAssine GANA

April 30, 2024



# Outline

1 State-of-the-art

2 System architecture and description

3 Properties

4 Future Work

## Selected Article

- Distributed Batteryless Access Control for Data and Energy Integrated Networks: Modeling and Performance Analysis [1]

# Distributed Batteryless Access Control for Data and Energy Integrated Networks: Modeling and Performance Analysis

Xinyu Fan<sup>②</sup>, Jie Hu<sup>③</sup>, Senior Member, IEEE, Yihua Zhao, Member, IEEE, and Kun Yang<sup>④</sup>, Fellow, IEEE

## 1. INTRODUCTION

**A. Background and Motivation**

ANY Internet of Everything (IoE) devices are powered by embedded batteries with limited capacity. In order to extend the lifetime of the battery, it can be frequently replaced, which substantially increases network maintenance cost. Harnessing energy from radio frequency (RF) signals [1], [2] is capable of prolonging the lifetime of IoE devices. The energy harvesting process can be used to extend the lifetime of IoE devices without energy harvesting [3], [4]. RF energy harvesting can be controlled by allowing *idle listening*, *idle detection* and *active power control* (APC) to actively sense RF signals, which is required to support the energy harvesting process [5]. In order to support wireless network nodes (WN) working with WEF, it yields a novel data and energy integrated network (DENN) [7]. This is a promising technique to achieve energy efficiency in future [8]. One of the typical applications of DENN is wireless sensor networks [9].

## Figure: Article 1

## Additional Readings

For a better understanding of the domain, we also read:

- Throughput Maximization and Fairness Assurance in Data and Energy Integrated Communication Networks [3]
- Integrated Data and Energy Communication Network: A Comprehensive Survey [2]
- Data and Energy Integrated Communication Networks for Wireless Big Data [4]
- Joint Uplink and Downlink Resource Allocation in Data and Energy Integrated Communication Networks [5]

# System Components

The system is composed of:

- Hybrid Access Point (HAP)



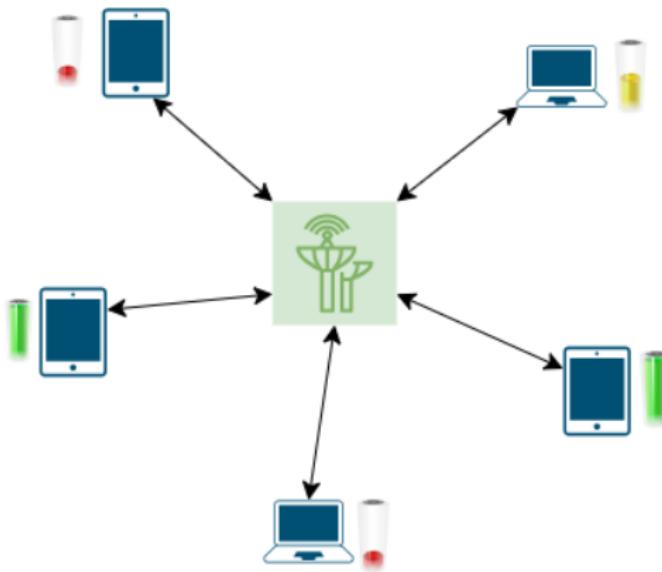
- Wireless Devices (WD)



# Components Description

- Hybrid Access Point (HAP): The central component with a stable source of energy. It acts as a pivot for simultaneous data and energy transfer to wireless devices via RF signals.
- Wireless Devices (WDs): Harvest RF energy for data download and upload operations during communication with HAP.

# System Architecture



# System overview

- A WD requests data from a HAP. The HAP sends both data and energy to the requesting WD and transmits energy to all other WDs as down-link transmission. The requesting WD uses some of the received energy to decode the data and stores the remaining energy through energy harvesting. Non-requesting WDs store all the received energy.
- A WD can only send data to the HAP. It consumes energy from its harvested energy for this transmission.

## Note regards Collision

We suppose that our system uses TDMA protocol to avoid collision.

# Formal Definition of State Machine

## State Machine

$$P = \langle C, V, A, T \rangle$$

- C: finite set of control states.
- V: finite set of variables.
- A: finite set of actions on V.
- T:  $\subseteq C \times A \times C$  be a finite set of transitions.

# Formal Definition of the WD State Machine

## State Machine for the WD

- C: Idle, DataTransmission, SignalReception.
- V: id: int,  $id - sender$ : int, Es: int, maxEWD: int, EneToDecode: int, EPCK: int, EWD: int.
- T: Sending Data, Data Sent, Signal Requesting, normal harvesting, parallel harvesting

# How does the system work

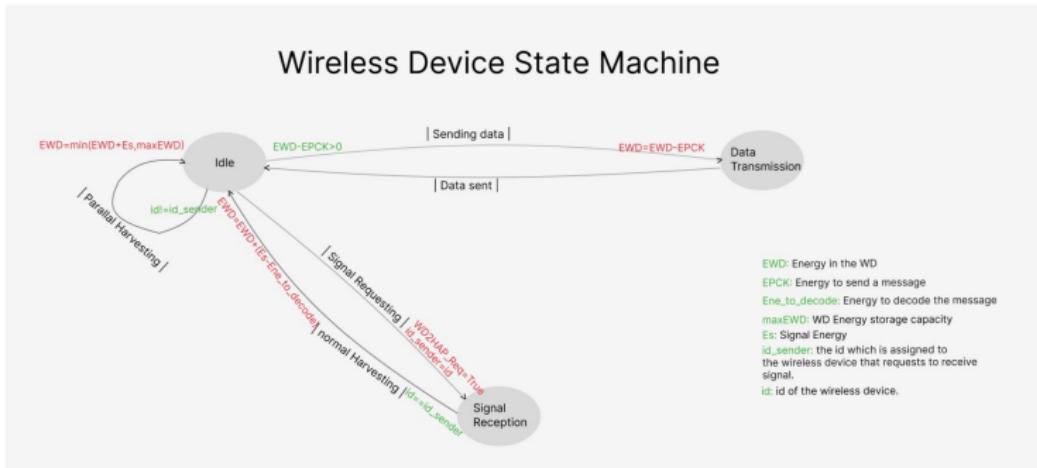


Figure: Wireless device state machine

# Formal Definition of the HAP State Machine

## State Machine for the HAP

- C: Idle, DataReception, SignalTransmission.
- V: id: int, *id – sender*: int.
- T: Signal Sending, Message Receiving,Finishing Data Reception,Finishing Signal Transmission

# How does the system work

## Hybrid Access Point State Machine

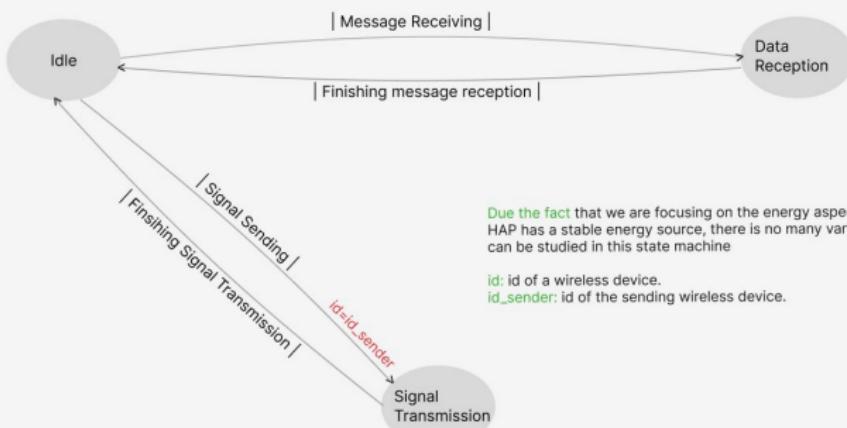


Figure: HAP state machine

# Proposed Properties

## Reachability

- The SignalReception state can be reached eventually by a WD (WD0,WD1 and WD2).

## Liveness Properties

- When a HAP is transmitting a Signal, One WD (WD0,WD1 or WD2) should eventually be receiving it.
- When a WD is in the state of SignalReception, the other WDs should be in the state of Idle.

# Proposed Properties

## Deadlock

- Ensure that deadlock never occurs.

## Safety

- Always ensure that the energy stored in WD (EWD) is less than or equal to the capacity of WD.
- In the future, A WD can never be Transmitting Data if one of the other WDs is Receiving data.

# Verification of the properties with UPPAAL

Apuru

```
***** Reachability:
E< W0. SignalReception
E< W1. SignalReception
E< W2. SignalReception
E< W3. SignalReception
***** Liveness Properties:
W01.SignalTransmission → W02.SignalReception or W01.SignalReception or W00.SignalReception
W01.SignalReception → W00.Idle and W02.Idle
W02.SignalReception → W00.Idle and W01.Idle
***** Deadlock checking:
All not deadlock
***** Some Properties:
All W0. EWD < W01.capacity
All W01. EWD < W01.capacity
All W02. EWD < W02.capacity
All W03. EWD < W02.capacity
E< not W02.DataTransmission and (W00.SignalReception or W01.SignalReception)
E< not W03.DataTransmission and (W01.SignalReception or W02.SignalReception)
E< not W01.DataTransmission and (W00.SignalReception or W02.SignalReception)
Requires
E< not W02.DataTransmission and (W00.SignalReception or W01.SignalReception)
```

Verifier  
Solver  
Insert below  
Suppress  
Commentaries  
Clear results

Commentaire  
At some point in the future, W02 is not in the state of DataTransmission, and at the same time, W00 is in the state of SignalReception or W01 is in the state of SignalReception.

# CSMA/CA Based DEIN network

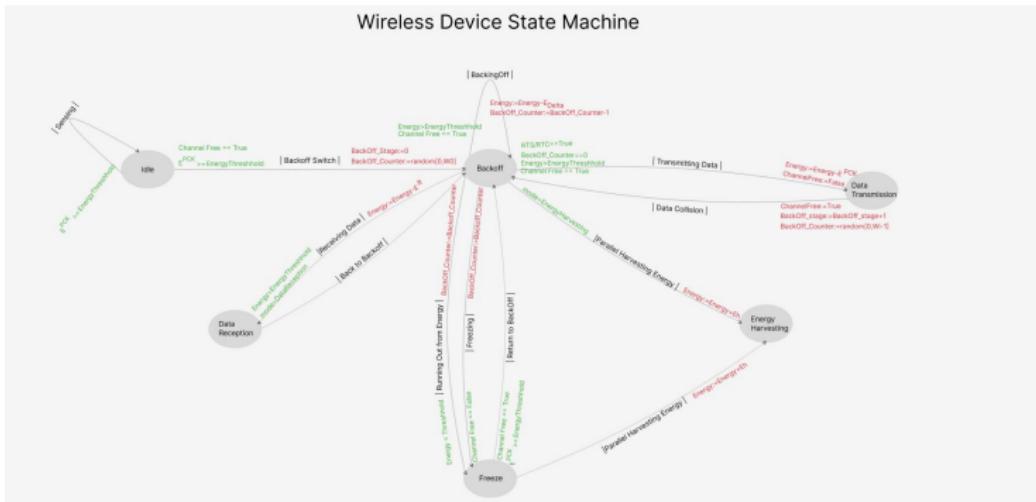


Figure: State machine of a WD Implementing CSMA/CA

- [1] Xinyu Fan et al. "Distributed Batteryless Access Control for Data and Energy Integrated Networks: Modeling and Performance Analysis". In: *IEEE Internet of Things Journal* (2023).
- [2] Jie Hu et al. "Integrated data and energy communication network: A comprehensive survey". In: *IEEE Communications Surveys & Tutorials* 20.4 (2018), pp. 3169–3219.
- [3] Kesi Lv et al. "Throughput maximization and fairness assurance in data and energy integrated communication networks". In: *IEEE Internet of Things Journal* 5.2 (2017), pp. 636–644.
- [4] Kun Yang et al. "Data and energy integrated communication networks for wireless big data". In: *IEEE access* 4 (2016), pp. 713–723.

- [5] Qin Yu et al. “Joint Uplink and Downlink Resource Allocation in Data and Energy Integrated Communication Networks”. In: *KSII Transactions on Internet and Information Systems (TIIS)* 11.6 (2017), pp. 3012–3028.