

Demo Abstract: How Fuzzy Logic can enhance Energy Management in autonomous Wireless Sensor Nodes ?

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Abstract—Power management is an important issue in the design of Energy Harvesting Wireless Sensor Networks (EH-WSNs). In this kind of networks, each Energy Harvesting Node (EH-node) must dynamically adapt its performance in order to avoid power failures while maintaining a good quality of service. The power management policy is implemented on each node by a Power Manager (PM). In this demonstration, the behaviour of Fuzzyman, a novel PM based on fuzzy control, is introduced. The performance of this PM is also shown in terms of energy budget and throughput for a given protocol. Moreover, the benefit of using emerging wake-up radio technology is also demonstrated.

I. INTRODUCTION

Nodes that constitute typical Wireless Sensor Networks (WSNs) are powered by individual batteries of limited capacity, and maximizing the lifetime of such systems is a perennial issue. Indeed, when the stored energy is exhausted, refilling the energy could be expensive or impossible if the network is dense or if the nodes are deployed in harsh environments. A more viable solution is to equip each node with at least one energy harvester (EH), and to allow the sensors to be entirely powered by the energy harvested in their environments, *i.e.* the amount of energy consumed never exceeds the amount of energy harvested over a long period of time. It is possible to significantly extend the lifetime of the network if the harvested energy is persistent.

Power management is an important issue in the design of EH-WSNs. In these networks, each Energy Harvesting Node (EH-node) must dynamically adapt its performance to avoid power failures, while maintaining a good quality of service. The power management policy is implemented on each node by a Power Manager (PM). Designing a PM is challenging because the harvested energy is time varying, and the amount of energy that will be harvested in the future is hard to predict. In this work, Fuzzyman is used, a novel PM based on fuzzy control theory [1]. Because of the unpredictability of the harvested energy, fuzzy control theory constitutes an appropriate framework to tackle the problem of designing PM.

Moreover novel Ultra-Low Power (ULP) Wake-up radio Receivers (WuRx) [2], [3], which can always listen to the channel with negligible power consumption, are enabling pure-asynchronous communication protocols, which further reduce the overall power consumption of the communication. EH and ultra-low power radio receivers play a complementary role,

then they can be combined to significantly increase the energy efficiency of EH-WSNs.

In this demonstration, we propose to show the enhancement of fuzzy control energy manager optimized for EH-WSNs and pure-asynchronous MAC protocol, which exploits a state-of-the-art ULP WuRx. The key demonstrated features are:

- Showing Fuzzyman behaviour by pointing out the evolution of the fuzzy sets according to the harvested energy.
- Comparing Fuzzyman to a state-of-the art PM in term of energy budget allocated to EH-node for the future period.
- Comparing ULP WuRx-based protocol to a state-of-the art MAC in term of throughput to evaluate the efficient use of the energy budget.

II. IMPROVING ENERGY EFFICIENCY IN EH-WSNs

This section briefly introduces the technical concepts used in the demonstration to improve energy efficiency in EH-WSNs.

A. Fuzzyman power manager

A big challenge in EH-WSNs is to deal with the time-varying behavior of the harvested energy. Drained periods during which almost no energy is available can occur, for example during night time if solar energy is harvested. Therefore, dynamic performance adaptation must be done using power management policies, implemented on each EH-node by a PM.

Fuzzy control theory aims to extend the existing conventional control system techniques for a class of ill-modelled systems, *i.e.* fuzzy systems [4]. Because of the unstable and hard to predict behaviour of the harvested energy, EH-nodes are usually hard-to-model systems. Therefore, fuzzy control theory constitutes an appropriate framework to design PM for EH-nodes. Accordingly, we proposed Fuzzyman in [1], a PM for EH-nodes that relies on fuzzy control theory.

The goal of Fuzzyman is to compute the energy budget that EH-node should use during a future period according to the residual energy of the battery at the end of the previous period. As a fuzzy logic controller [4], Fuzzyman is made of three units: the fuzzification unit, the inference engine, and the defuzzification. The fuzzification module aims to transform the physical inputs into fuzzy sets compatible with the inference engine. A fuzzy set consists of an interval for the range of the input value, and an associate normalized membership function describing the degree of the confidence of the input belonging

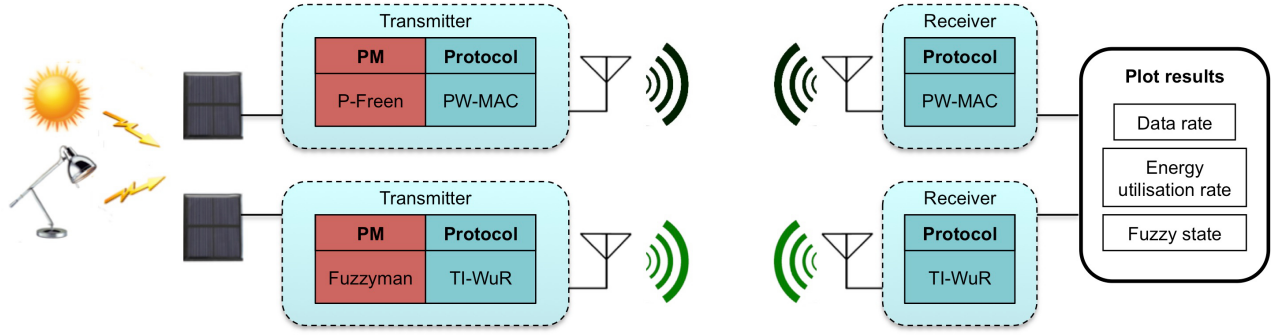


Fig. 1: Demonstration testbed showing Fuzzy control energy management enhancement.

to this range. The inference engine is the core of the controller. It is responsible for creating the control actions in fuzzy terms according to a rule base. Finally, the defuzzification unit maps the controller outputs to an energy budget that can be accepted by the node.

B. MAC protocol leveraging Wake-up radio

When the traffic is low, traditional pseudo-asynchronous schemes based on preamble sampling and relying on duty cycling, such as PW-MAC, are used [5]. In these approaches, each node is most of the time in the sleep state, and regularly wakes up to check the channel for incoming packets. As nodes frequently wake up while no incoming packets are pending, idle listening is usually a significant source of energy waste.

Emerging ULP WuRx enable pure-asynchronous communication. In this approach, each node is equipped with an ULP WuRx, which allows a continuous channel monitoring while consuming orders of magnitude less power than traditional transceivers [3]. These devices wake up the node microcontroller using interrupts when a specific signal, called Wake-up Beacon (WuB), is detected. One of the main benefits of ULP WuRx is to enable pure-asynchronous communication that can significantly increase the energy efficiency of communications, and reduce the latency. This simple protocol is denoted TI-WuR (Transmitter-Initiated) [2].

III. TESTBED DEMONSTRATION

The platform PowWow developed by the IRISA laboratory is used for the demonstration. PowWow node embeds the MESC architecture for energy harvesting, the Texas Instruments CC1120 radio chip for communications, and a super-capacitor as storage device. When TI-WuR protocol is used, the ULP WuRx from [3] is added to the node, and the so-obtained platform is shown by Fig. 2.

Fig. 1 shows the testbed that will be used for demonstration. It consists in two communications that use a different channel to avoid collisions. Both are point-to-point communications between an EH-node equipped by 28 cm² photovoltaic cells, and a sink that receives data from the EH-node. The first communication is the referenced one implementing P-Freen, a state-of-the-art PM, and PW-MAC. PM the second embeds both Fuzzyman and TI-WuR.

Performance of both communications will be displayed on a

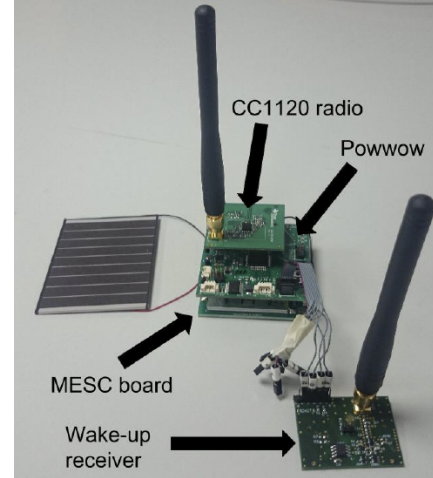


Fig. 2: PowWow platform used for demonstration equipped with a ULP WuRx.

screen by showing at run-time the energy budget provided by PMs and the throughputs achieved by protocols.

For the use of Fuzzyman, a specific display will show the evolution of the fuzzy sets according to the harvested energy.

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