

# ENERGY-EFFICIENT INTEGRATION OF WSNS WITH ACTIVE RFID SYSTEMS

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**Abstract:** *Pervasive network nodes will be the foundation of Future Internet Systems. The main aim of this paper is to present a method for integrating wireless sensor networks with active RFID technology, in order to create pervasive network nodes that are aware of their features and are capable of advertising these features in a standard manner. The authors propose an energy-efficient approach to this technological challenge. They provide a proof-of-concept implementation of the presented integration method, thus demonstrating its performance (in terms of energy consumption) and its flexibility.*

**Key words:** *RFID, WSN, pervasive, energy-efficiency.*

## 1. Introduction

The concept that represents the foundation of pervasive communication systems is the so-called “Internet of Things”. This concept was first defined by MIT as a global network of intelligent objects. These intelligent objects are obtained by adding communications, processing and data acquisition capabilities to every day household objects, which are thus turned into pervasive objects that are context-aware and capable of interacting between them in order to provide comfort-enhancing services to the end-user [3]. From the perspective of the communication capabilities embedded into such objects, the Internet of Things is based on technologies such as RFID (Radio Frequency Identification) and WSAN (Wireless Sensors and Actuators Networks). These technologies are currently using proprietary protocols and require

standardization and integration initiatives in order to become interoperable.

The Internet of Things will be the base of 4<sup>th</sup> generation Internet systems (also known as Future Internet). The Future Internet Assembly (FIA) [6], a grouping of institutions and projects supported by the European Union, has defined the Internet of the Future as being located at the intersection of three domains, namely the Internet of Things, the Internet of Services and the Internet of 3D Environments (as illustrated in Figure 1). In such a Future Internet system, each intelligent object is supposed to provide a series of services to its users. These services need to improve the current web-services model by adapting to the user’s needs and requirements, in a natural, intuitive and context-aware manner. They will hence become real services (as opposed to simple software services), which will result from

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the aggregation of the micro-services that each pervasive, Internet of Things-like device will provide. In order to bind micro-services together, each network node has to be able to self-describe/advertise its capabilities, in a standard manner, so as to be integrated into more complex services. Thus, the need of defining a coding schema for identifying network nodes based on their capabilities emerges. A valid alternative for implementing such a coding/identification system is the active RFID technology, which the authors have used in their implementation.

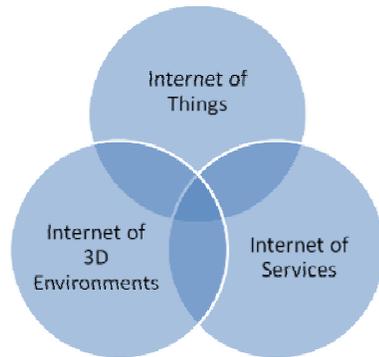


Fig. 1. *Future Internet as seen by FIA*

Having opted for active RFID as a capability identification technology, one needs to address the problem of integrating active RFID with current networks of pervasive devices. An interesting aspect regarding the two technologies is their complementarity, due to the fact that they have been initially developed with different purposes (RFID for identification, whereas pervasive sensor/actuator devices for the monitoring and control of ambiental parameters). Therefore their integration has a high potential of applicability. As stated before, the main objective of this integration is to create intelligent network nodes capable of self-describing their features (e.g. range, types of attached sensors, available transmission power

levels, frequency band etc.) and to provide information regarding the environment in which they operate. One will be able to integrate these nodes into services of different complexities and to interact with them in a standard manner, independent of the node type.

After having elaborated a taxonomy of the methods of integrating active RFID with pervasive wireless sensor-like nodes, the authors have designed and implemented their own integration method. This method consists of extending the capabilities of current off-the-shelf wireless sensor nodes, by adding RFID functionalities to such nodes. The authors have thus designed hybrid active RFID-WSN nodes, which can be incorporated into Future Internet-like systems. Based on the results of the experiments that they have conducted, the authors have fine-tuned their proof of concept system in order to meet the low energy requirements of autonomous pervasive devices.

The rest of this paper is organized as follows: Section 2 presents a critical state of the art analysis of active RFID technologies, with emphasis on the conceptual methods of integrating active RFID with wireless sensor networks (WSNs). Section 3 will present the communications protocol and the underlying network architecture which the authors have developed in order to integrate WSNs with active RFID. Section 4 consists of a proof-of-concept implementation of the integration initiative presented in the previous section, based on the MicaZ WSN development platform [8] and on the TinyOS real-time embedded operating system. Section 5 presents the experiments that the authors have conducted in order to validate their work and the obtained results. Section 6 presents the main conclusions drawn by the authors and the future developments that the authors intend to implement.

## 2. Related Work

From the perspective of the applications that can be developed with them, hybrid WSN-RFID networks have a huge potential. When integrating the two technologies, one needs to take into account the requirements of the developed applications. Depending on these requirements, different options of integration are available. From a conceptual point of view, the authors have identified 4 categories of integration methods, which will be analyzed in the following.

### 2.1. Integration of RFID Tags with Sensors

In this case, one develops RFID tags which are capable of acquiring sensor data. These tags use RFID-specific protocols for transmitting both the RFID code, as well as sensor data. One can differentiate between RFID tags with embedded sensors (e.g. KSW - TempSens developed by KSW Microtec AG [7]) and RFID tags that can be connected to external sensors (e.g. Enterprise Dot tag developed by Axxess Inc [5]). The main drawbacks of this integration method are the limited communication capabilities of RFID protocols, which are usually point-to-point and do not allow for the implementation of mesh networks.

### 2.2. Integration of RFID Tags with WSN Nodes

This integration method consists of extending the capabilities of WSN nodes by adding features specific to RFID tags (i.e. the ability of transmitting an identification code). Such hybrid nodes are compatible with existing RFID protocols or can use proprietary protocols, which enable ad-hoc communications within a mesh network.

The CoBIs tags [1] fit into this category of integration methods. These tags have been designed to monitor environmental parameters. The tags interact with each other through a peer-to-peer proprietary protocol. Each tag transmits its unique ID, along with the data acquired from the sensors, to all tags within a 3 meters radius.

### 2.3. Integration of RFID Readers with WSN Nodes and Wireless Devices

This integration solution implies adding new features to RFID readers, by connecting them to a RF transceiver. Thus, the integration is obtained at the RFID reader level, by means of hybrid RFID readers (with the architecture depicted in Figure 2). Through this method the range of a RFID reader will be extended by adding the RF transceiver, which also offers ad-hoc-like routing features.

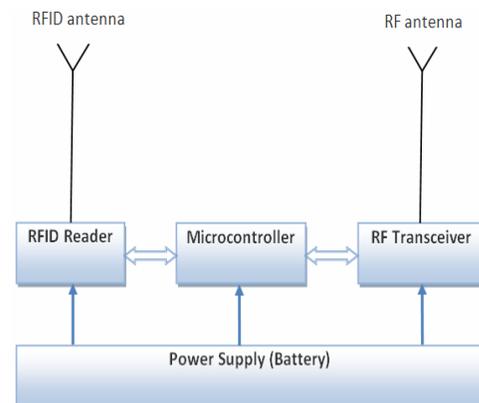


Fig. 2. *Architecture of a hybrid RFID reader*

The authors of [2] present such an integration approach, used for monitoring the public transportation system. The authors have extended the range of RFID readers by connecting a ZigBee module to each reader. The ZigBee modules enable the RFID network of readers to communicate

with the central server. Paper [4] presents a similar approach, in which the authors implement a network of ZigBee-enabled RFID readers.

#### **2.4. Middleware-Level Integration of RFID Devices with WSN Nodes**

In the case of this integration alternative, a physical separation between the RFID network and the WSN exists. The integration is obtained through a middleware that is shared by both networks. The middleware's role is to receive data from both the RFID tags and the sensor nodes, to filter, process and aggregate them according to a specific business logic. The resulting information is made available to the monitoring and control application that lies on top of this integration middleware. An example of such a middleware is Sybase's RFID Anywhere [9].

As a conclusion of the state of the art analysis in the field of integrating active RFID systems with WSNs, one can state that current approaches imply either adapting existing RFID readers, either developing a complete solution (software and/or hardware) from scratch. Both these solutions are costly, limited to a specific application and difficult to integrate into complex systems. None of the previous research initiatives aims to employ RFID for creating pervasive devices that can advertise their capabilities. Consequently, the present paper intends to fill this void, by designing network nodes that are aware of their features and are able to promote these features to the applications and users that employ them.

Based on the analysis of similar implementations, the authors propose an original solution for integrating IEEE 802.15.4 WSNs with active RFID systems. This solution is based on the MicaZ WSN development platform, which is recognized

in the research community as being one of the most reliable WSN platforms. The authors have developed a software integration solution. This solution consists of a network architecture and a communication protocol that enables the incorporation of RFID specific features into a WSN. Through this architecture, "classic" WSN nodes are capable of acting as a RFID reader or as a RFID tag, while keeping their wireless sensor functionality. The authors have opted for this alternative due to its flexibility. Hence, the designed hybrid nodes can be easily adapted in order to be integrated into any WSN that is based on the IEEE 802.15.4 standard. The authors have chosen IEEE 802.15.4 at the expense of other active RFID technologies (e.g. WiFi, Bluetooth, DASH7), because most WSNs use IEEE 802.15.4 at the MAC layer. Therefore, the integration is more straightforward.

#### **3. Network Architecture and Protocol**

The aim of this section is to describe the integration solution designed by the authors, in terms of the network's architecture and of the principle of operation for each category of hybrid wireless nodes that are part of the network.

The network designed by the authors (with the architecture presented in Figure 3) has a cluster tree topology. The network consists of 3 types of hybrid nodes, as follows:

- Tag nodes - active RFID nodes, capable of transmitting sensor data alongside the RFID code. Tags broadcast this data periodically to the parent RFID reader located in their range. When it is not transmitting, the sensor node is switched into sleep mode, thus significantly reducing the power consumption and increasing battery life. Tag-reader communications are based on the IEEE 802.15.4 standard.

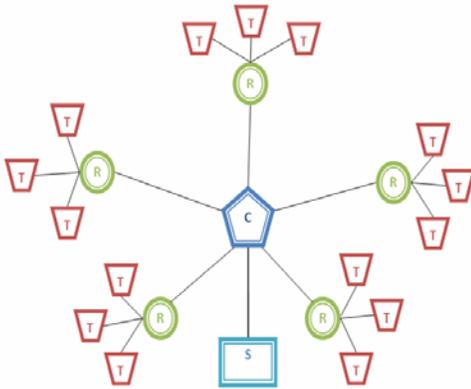


Fig. 3. Architecture of the hybrid WSN-RFID network (*T* - tags, *R* - readers, *C* - coordinator, *S* - server)

- Reader nodes - periodically receive data from tags within their range, to which they answer by means of acknowledgements (ACK). Readers forward data received from tags to the network's coordinator node. Reader nodes are always powered-on (either from batteries or from mains), embedding RFID reader functionality and ZigBee router functionality (FFD - Full Function Device). Reader nodes form, alongside the coordinator, an IEEE 802.15.4 network. Tags connect to this network, but their role is limited. Namely tags are not capable of routing data through the network.

- Coordinator node - its main role is to initialize and form the IEEE 802.15.4 network of reader nodes and to be the gateway between the WSN and the monitoring and control server, to which it is connected through USB or Ethernet.

### 3.1. Principle of operation

The hybrid WSN-RFID network designed by the authors operates based on the TTF (Tag Talks First) principle. In other words, each tag periodically sends a packet to its parent reader node. The packet's payload consists of sensor data and the RFID code.

Readers that receive this data successfully, confirm this event using an acknowledgment sent to the tag. The acknowledgement mechanism is required in order to solve errors due to collisions that occur in environments with a high tag per reader density. The reader forwards tag data to the coordinator. In its turn, the coordinator acknowledges the successful reception of data, and sends received data to the network's monitoring and control server. The authors have opted for the TTF principle of operation, as opposed to the ITF (Interrogator Talks First) principle of operation, in order to reduce the tag's energy consumption. Thus the tag operates in sleep mode for a predetermined period of time and wakes-up periodically in order to acquire sensor data and to send this data to the RFID reader, alongside the associated RFID code.

By using a TTF strategy, tags do not have to be permanently attached to the reader network. This gives them flexibility in choosing between networks available at a certain moment in time and migrating between networks. If one had implemented an ITF strategy, the tag node would have needed to permanently stay awake in order to listen to queries from readers. This would have resulted in increased energy consumption.

### 4. Pilot Implementation

As mentioned before, in order to prove the capabilities of the integration method proposed by the authors, a functional network core was implemented, using the MicaZ platform. Each MicaZ sensor node is equipped with the MTS400 sensor board (that contains temperature, humidity, pressure, lighting sensors and a 2 axis accelerometer). The coordinator node is connected to the MIB-520 USB programming board, thus acting as a gateway between the WSN and the central server.

From a software-firmware perspective, the implemented hybrid WSN-RFID nodes use the TinyOS real-time operating system, one of the state of the art operating systems for pervasive devices. For each category of nodes (i.e. tag, reader and coordinator) a TinyOS application was developed. These applications are proof-of-concept implementations of the network's operating principles presented in the previous section.

The block diagrams of the tag, reader and coordinator TinyOS applications are presented in Figure 4. The applications' components are represented by nodes of the graph, while the interfaces between these

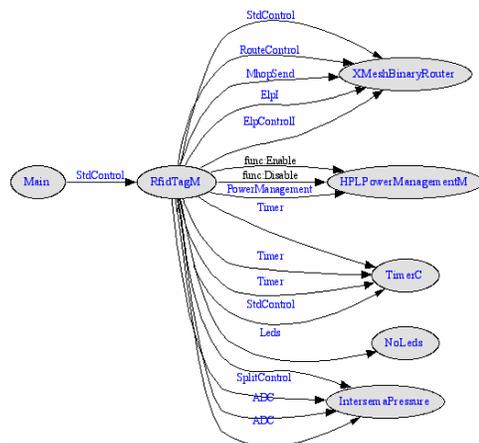


Fig. 4a. Diagram of the TinyOS tag application

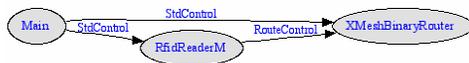


Fig. 4b. Diagram of the TinyOS reader application

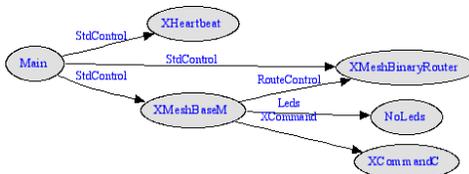


Fig. 4c. Diagram of the TinyOS coordinator application

components are represented by the transition edges of the graph.

### 5. Experiments and Results

The main goal of the experiments conducted by the authors was to evaluate the performance of the designed integration method in terms of energy efficiency. The tested scenarios consisted of a hybrid RFID-WSN network with one coordinator, one reader and a variable number of tags (1, 2, 3, 4 or 5 tags). The tags were placed in a circle, at a distance of 1.5 meters around the reader. Thus, equal operating conditions for every tag were obtained. A sniffer node was used as an IEEE 802.15.4 protocol analyzer. The sniffer was employed to capture and analyze functional parameters, such as total number of transmitted packets (per node), number of retransmissions and number of dropped packets.

The authors have analyzed how the tag's average current consumption is influenced by the number of tags/reader ( $N_t$ ) and by the interval between transmissions ( $T_{TX}$ ). In order to measure a tag's average current consumption, the authors have developed an automated measurement system (illustrated in Figure 5).

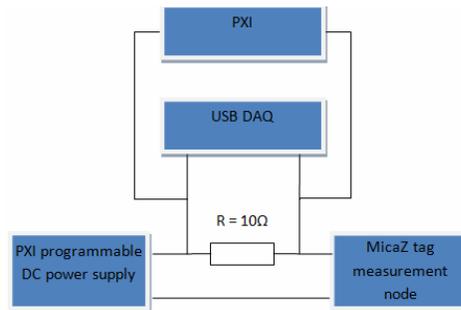


Fig. 5. Architecture of the measurement system

At the software level the measurement system uses a LabVIEW application developed by the authors. This application

controls the power supply (i.e. NI-PXI 4110), acquires data from the two DAQ boards (i.e. NI USB-6008 and NI-PXI 6251) and computes the average current consumption for each tested scenario.

Figure 6 presents the results obtained by the authors, in regard to the variation of the average current consumption ( $I_{average}$ ) for a hybrid WSN-RFID node, as a function of the transmission period. One can notice that as the transmission period increases, the current consumption decreases. This is due to the fact that the node's duty cycle decreases (i.e. the node spends more time in sleep mode thus consuming less power). Most importantly, one can notice that the designed hybrid node draws roughly five times less current (in the worst case scenario of  $T_{TX} = 50$  ms) as compared to a reference node, which uses a typical WSN protocol. Hence, by using the approach proposed by the authors a significant improvement can be obtained in terms of energy efficiency. As illustrated in Figure 7, for a typical scenario in which a node sends data every 10 seconds, an average battery lifetime (for continuous operation based on two AA alkaline batteries with a 2000 mAh capacity) of approximately 1 year can be obtained. In the case of a typical WSN node, the battery lifetime was measured to be 3.36 days.

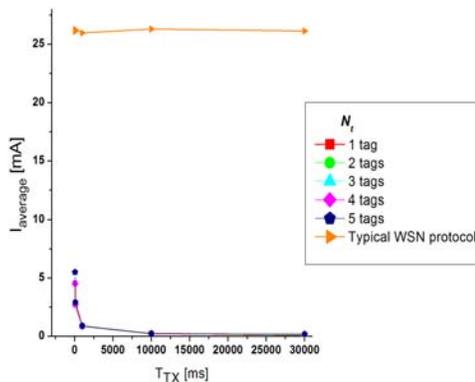


Fig. 6. *Average current consumption vs. transmission period*

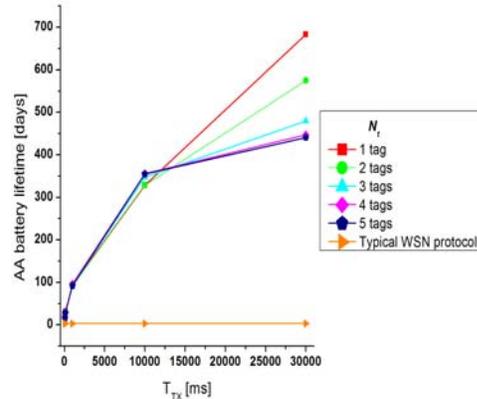


Fig. 7. *Battery lifetime vs. transmission period*

## 6. Conclusions

Through this paper the authors have designed, implemented and tested a solution for ensuring the convergence of pervasive WSN-like devices with the active RFID technology. The presented solution is meant to capitalize the unexplored potential of the two complementary technologies, by creating a network of hybrid nodes that are capable of promoting their features and functionalities to the applications that use them. Thus hybrid nodes provide micro-services that can be integrated into complex services, by using a middleware as a data aggregator.

The authors have opted for a very versatile and flexible integration solution, based on the MicaZ development platform and on the hardware abstraction services provided by the TinyOS embedded operating system. The communication protocol developed by the authors is an energy efficient one, based on “sleep” periods. For the worst case scenario, it draws approximately five times less current compared to a standard high power WSN protocol based on permanent active listening.

As a solution for further enhancing the energy efficiency of the hybrid network,

the authors intend to develop a solar energy harvesting system, for increasing the autonomy of the nodes.

All things considered, the integration method presented by the authors has proven its feasibility, both in terms of its applicability, as well as in terms of its energy related performance. From the integrator's perspective, it is an almost ideal solution, because it is based on off-the-shelf hardware platforms, and only involves software-firmware level development.

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