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ZigID: Improving visibility in industrial environments by combining WSN and RFID

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Abstract: The objective of this work is to provide decision-making processes with an updated/real picture of the mobile resources in industrial environments through a constant feedback of information. The combination of identification technologies and wireless sensor networks (WSN) is proposed as a key development to guarantee an accurate and timely supply of online information regarding the localization and tracking of the mobile wireless devices. This approach uses a cooperative and distributed localization system, called ZigID, which is a WSN based on a Zigbee network with radio frequency identification (RFID) active tags as end nodes. The WSN can recover not only the ID information stored at the tags attached to mobile resources, but also any other useful data captured by specific sensors for acceleration, temperature, humidity and fuel status. This paper also shows the development of ZigID, including devices and information flows, as well as its implementation in ground handling operations at the Ciudad Real Central Airport, Spain.

Key words: Radio frequency identification (RFID), Tracking, Wireless sensor networks (WSNs)
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1 Introduction

New management systems are steadily increasing their complexity due to pressing requirements for productivity and flexibility. This complexity becomes especially relevant when dealing with large industrial plants, airports or logistic centres where the usual control is too rigid and hard to manage, maintain and update (Thorne *et al*., 2007). For a modern system, however, finding an adequate response to a broad range of possible new situations must be business-as-usual; and this should apply even while the system is being modified or updated (Garcia *et al*., 2003). Therefore, flexible control becomes standard practice as it allows a division of the problem into smaller and more manageable ones. In this case, the system becomes distributed in its control, which makes a negotiated and cooperative process necessary to take decisions that affect more than one of these parts (Durfee, 1996). This situation requires an improvement in the connection between the real environment and the information systems (Sandholm, 1999). Enterprise resource plannings (ERPs) or other information/management systems have given place to new architectures, which need constant feedback of information from the real environment. This information is managed through artificial intelligence techniques such as Bayesian networks (Chalkiadakis and Boutilier, 2003), multiagent systems (Wooldridge *et al*., 2002), neural networks and fuzzy systems (Kosko and Burgess, 1998), making expert systems adapted to the environment (Russell and Norvig, 2010).

To obtain information from the environment, the systems need transparent identification technologies and quick communication protocols (Mao and Wu, 2007). The frequency identification (RFID) technology emerges as especially suitable for capturing information from the physical world, offering rapid responses and continuous tracking, and has become a standard for communication protocols, hardware implementations and information systems due to the electronic product code (EPC)-Global initiative (GS1, 2010). One of the problems of RFID is that, due to battery limitations, the reader is usually set so that it can only communicate for a distance of about 8–12 m with standard active (with batteries) tags—and this distance is necessarily smaller for more typical case of passive tags (not powered)—while there is no defined network topology to coordinate several readers.

This inconvenience can be directly minimized using mobile WSN (Xia *et al*., 2007; Sahinoglu *et al*., 2008). The current WSNs abstract the mobility, topology, scalability and communication between the information system and the mobile nodes in the network (Gezici, 2008). Besides routing information, which can be added to the submitted information package, more information can also be attached to this package (Akkaya and Younis, 2005). In this way, product/resource ID is also added to the information about the environment, captured by the sensors. All this information, together with the routing path, constitutes a complete information package in the WSN. Different researchers and companies have developed real industrial applications of WSN, with satisfactory results both for indoor (Ferrari *et al*., 2007; Morelli *et al.*, 2007; Rovňáková and Kocur, 2010) and outdoor (Sung *et al*., 2007) applications. For example, Ansari *et al*. (2009) focuses on specific technological developments to optimise battery life by suppressing the power consumption during idle periods, which could be an improvement to the system proposed in our paper. It has been conceived as a broader development.

However, most of the energy consumed by devices is used in the processes of activation, routing and sending of data via ZigBee. To reduce consumption and according to the regulations of the ZigBee protocol, the use of beacons is an available option. This is the way many authors try to reduce the duty cycle of nodes. Nevertheless, beaconing methods can not always be adapted to the requirements of RFID applications. Another way to reduce consumption is to use the time division beacon scheduling (TDBS) (Koubâa *et al*., 2008). Using this method, activation and de-activation beacons are sent, by final nodes, just when they need to start or finish the communication with their parents. Other works such as that presented in (Medagliani *et al*., 2010) also propose a combination of the technologies ZigBee and RFID. Still, in that case both networks overlap as RF is used to activate/de-activate ZigBee modules by using the specific characteristics of the protocols commonly used in RFID and originally designed to turn off the tags in the field of a reader when read (and to turn them on again to restart a read cycle). Therefore, RFID is not really used there to identify passing objects but to take advantage of some of its specific characteristics.

In (Sánchez *et al*., 2009), active RFID technology with sensors is used to monitor the surrounding elements. The objective in these cases is for all the elements to be capable of transmitting not only their identity, but also information regarding their physical condition. These elements are already known as “Smart Objects”, where they are located into is known as “Smart Environments”. The integration of RFID and WSN is apparent and, in the present paper, it can be named as wireless sensors and RFID for smart environments (WISSE) by Sánchez *et al*. (2009). However, the objective of the present work is not the development of a new protocol for a global use of active tags but rather to find the solution to a recurring problem through the fusion of RFID and WSN in one single platform. With a similar objective, in (Escribano *et al*., 2010) a device is designed which is capable of operating multiple communications modules simultaneously. In the designed system, both RFID and WSN are used in a way in which the information is collected through readers from active tags, and these readers are mounted on network nodes of a large scale personal area network (PAN).

Therefore, this paper approaches the combination of RFID to identify objects and WSN for transmission of the collected data, which drives the development of a cooperative and distributed architecture, called ZigID. This paper aims at the development of a complete system for a specific application that takes advantage, in an inclusive way, of different techniques found in the related literature.

2 ZigID architecture

This research proposes the combination of RFID and WSN technologies in a framework, called ZigID, to localize and track mobile resources at industrial environments. The feasible applications range from airports to factories or logistic centres, in which vehicles, products, pallets, machinery or employees comprise the activities. The proposed system is based on the development of a Zigbee wireless communication network of RFID readers that is capable of covering medium/long distances within specific zones over the whole industrial area (Zhao and Guibas, 2004).

2.1 Wireless sensor network with active RFID

As a communication network, Zigbee is selected for its characteristics of range, auto routing capability, low power consumption and a sufficient bandwidth. Zigbee is a specification of a set of high-level protocols of wireless communication for use with low-power digital radios based on IEEE 802.15.4 wireless personal area network (WPAN). Its main features are low power consumption, mesh network topology and ease of integration (nodes can be manufactured with very little electronics). Zigbee networks can adopt three alternative topologies: star, tree and mesh. For the current situation, the mesh topology is particularly well suited. It allows communications to be maintained even in the case of a Zigbee node breakdown by means of dynamically recalculating new routes, while covering medium/long distances. By using WSN based on Zigbee with RFID reader nodes, the ID information can be obtained over large distances. The communication architecture of a general airport is shown in Fig. 1.

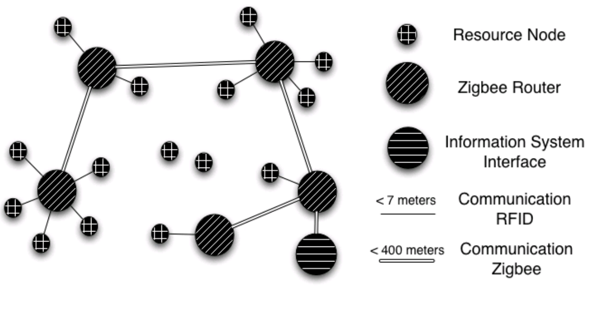

Fig. 1 Communication architecture for a general airport application

To summarise, the benefits of this combination of technologies are: (1) Better and more transparent flow of information. (2) The RFID identifies elements using EPC, which is a standard in all levels of the business model. (3) The WSN allows setting up networks to cover large areas in an easy and dynamic way, while RFID focuses on the identifications of items in specific zones. (4) The cost of the RFID End Nodes (10–12 USD) is low compared to other existing devices. (5) The battery consumption of the RFID End Nodes is really low compared with other electronic devices, such as mobile phones and radio devices. (6) Network re-routing is also possible in case of breakdown of one node in the WSN by using mesh topology.

2.2 ZigID definition

To take advantage of the technologies presented above as well as those resulting from their combination, a new architecture has been developed with the name of ZigID. ZigID is divided into three levels to facilitate the distribution of tasks and foster the cooperation among devices. The first of these levels is the End Node level, whose features are: small and unobtrusive size, low consumption (enabling battery supply), possibility of integrated sensors, short range coverage (8–10 m) and identification capabilities. The second level is the Router-Reader Level and its objective is to facilitate the communication and routing of the information among End Nodes and the information systems. The third level is the coordination level, which collects the distributed information across the network and provides an interface with the existing information systems (Fig. 2).

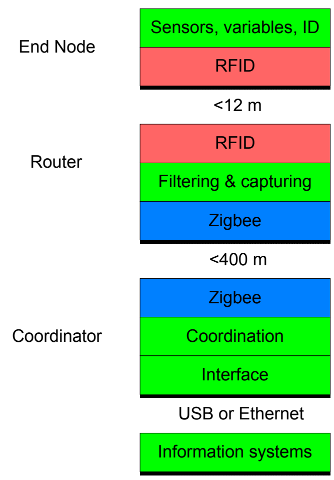

Fig. 2 ZigID architecture

3 ZigID devices

3.1 End node level

Hardware devices at this level are attached to the resources to be tracked. Their function is to communicate the identification and sensors information to the WSN through an active RF communication. We call it RFID+, as it includes identification and more information than that captured by sensors. At this level, there are some limitations such as battery life, computation capacity and communication bandwidth.

The proposed devices are based on active tags with sensors; which means that they must be powered by batteries. These devices are active tags with sensors that incorporate a microcontroller and a transceiver (Fig. 3). The microcontroller is a PIC16F819 by Microchip with low power consumption (7 μA) as it integrates nanoWatt Technology (Microchip, 2004). This microcontroller is in charge of managing the operations of the end node, which include communications with routers and data acquisition from sensors.

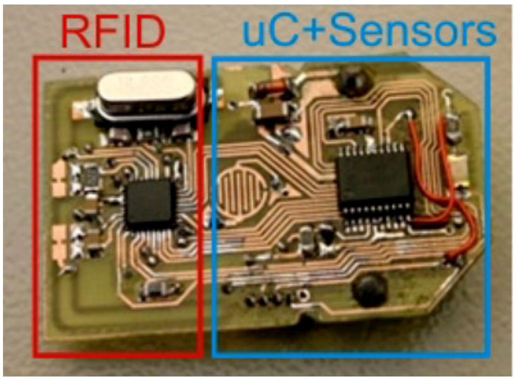

Fig. 3 End node prototype

The transceiver is an nRF905 by Nordic (2008), which is an RF transmitter/receiver that operates in the ultra high frequency (UHF) band to manage the communication between nodes and routers. It is configurable to work at 433, 868 and 915 MHz. It also has different transmission power modes from −10 to 10 dBm, providing a good relationship between range and power consumption. It is commanded through a Synchronous Serial Port, SPI. Other elements of the node are the antenna, sensors and batteries. The antenna is a dipole printed on the board. The node can operate different sensors to measure temperature, acceleration (shocks), fuel or other chemical elements among others.

Two conventional rechargeable AAA batteries have been used to power the prototype. A Cr2032 Li Button Coin cell was first tested but it did not provide enough autonomy for the required communication ranges in the airport application. After some tests, autonomy has been estimated at around 2845 h with the AAA batteries, for a duty cycle where there is an RF communication every 2 s with a duration of approximately 0.1 s in each transfer. This measurement has been undertaken at 10 dBm, which is the highest power the device can manage, but that is not likely to be required in most applications. In most cases, End Nodes are attached to vehicles, so it is possible to power them using the vehicles battery, maximizing the lifetime.

3.2 Router level

The second level is in charge of routing the information to the coordinator. This level uses two communication protocols. The first one is used for RF communication, which receives information from the End Nodes. The second one is used for Zigbee connection (network of readers), which routes the information through the wireless network until it reaches the coordinator.

A significant asset of Zigbee for this application (or Zigbee-like networks based on IEEE 802.15.4, as top-most layers are not necessarily required) is its characteristic of dynamic auto-routing between nodes, which provides excellent reliability in the flow of information to the coordinator. This feature is very useful in case of break-down/disconnection of nodes and allows adding new devices to the WSN in a dynamic way. Another function of this device is the filtering of unnecessary information, such as redundant identifications or not well-defined information, to avoid jamming.

The elements that constitute the router (Fig. 4) are as follows: an nRF905, in charge of RF communication, and a JN5139 by NXP Semiconductors (2011). The JN5139 is a module that enables the implementation of Zigbee networks and that is available in two versions: normal and high power. The high power module JN5139M02 has been used for this development as it can provide an output power of 19 dBm, which can make a possible theoretical range of up to 4 km as specified in the IC data-sheet (NXP Semiconductors, 2011); although its actual performance for a reliable enough connection is approximately 400 m in a real environment. JN5139 also includes microcontroller features to control serial communications and input/output pins. The JN5139 manages the Zigbee network and the RFID communications, as well as the buttons and light emitting diodes (LEDs) in the device (Fig. 4).

The routers composing the second level modules are outdoor modules to be placed at fixed locations. The best option is to plug them into the power grid. In isolated places, the use of high power rechargeable batteries with alternative power sources, such as photocells, would provide them with additional autonomy. Specific battery management functions have also been implemented to increase battery life (Section 3.4).

3.3 Coordinator level

The coordinator level connects the WSN with the existing information systems. The information captured by the WSN is properly formatted in XML or submitted in a query to a database. The coordinator submits an XML file to an EPC repository developed by Floerkemeier *et al*. (2007), which is accessible to the rest of departments in the company. There is only one coordinator device in the WSN, which has been called "PAN coordinator". Firstly, it selects the frequency channel to be used by the network (usually the one with the least detected activity). It then starts the network and allows child nodes to connect to it. It can also provide message routing, security management and other services, which will be detailed in the data model definition.

The prototype shown in Fig. 5 has been developed to allow direct universal serial bus (USB) communication with a personal computer; future developments will also include Ethernet communication and power over Ethernet (PoE).

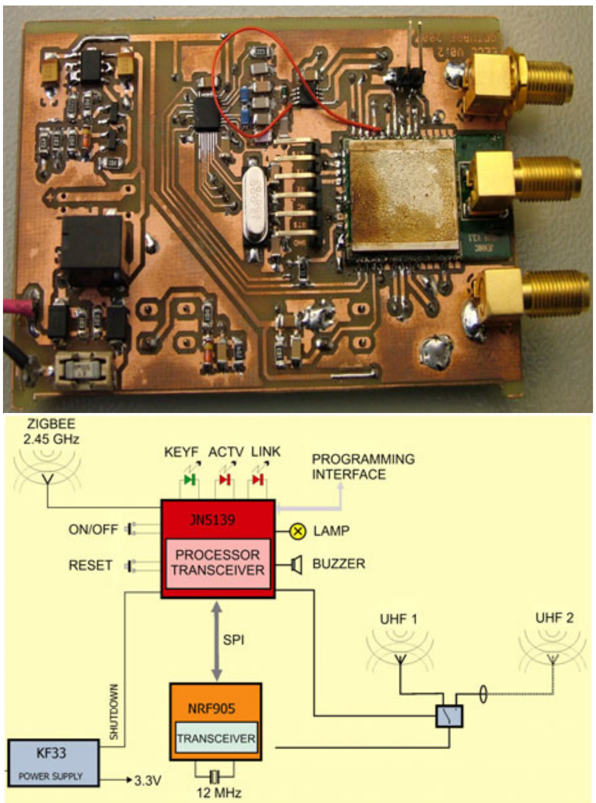

Fig. 4 Prototype of router node

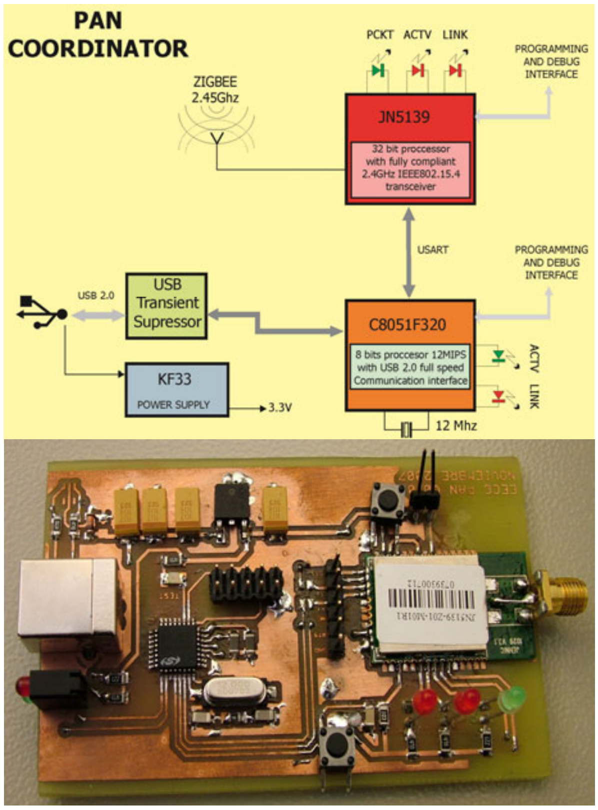

Fig. 5 Prototype of the Coordinator Node

3.4 Software techniques to improve energy efficiency

Energy efficiency is a key point because the End Nodes and some of the Router Nodes are mobile devices that can only incorporate small batteries. A specific firmware implementation with energy optimisation allows an adapted management of the power-supply. The energy consumption in the communications tasks can be directly controlled by software (Wen *et al.*, 2008). Brief modifications on the implemented code—as those presented below for Zigbee and RFID deployment—can produce significant improvements.

The proposed mobile distributed system is composed of many RFID readers (at Router Level) which are situated in the main parking position and the hangars for resources, so almost all the devices are grid powered. The only few battery powered RFID readers located at isolated places use active RFID technology, whose power consumption is much lower than that in passive RFID readers. A battery powered RFID reader has almost the same lifetime as that of a tag, on its own, or combined with a reader, follow the communication protocol shown in Fig. 6. Besides, the tags are connected to the batteries of the vehicles, reducing consumption even more. The autonomy of a battery powered RFID tag is estimated at approximately 2845 h using two conventional AAA rechargeable batteries.

Most of the energy consumed by the router-reader devices is used in the processes of activation, routing and sending of data via Zigbee. According to the regulations of the Zigbee protocol, there is the option available of using beacons to ensure communication. Nevertheless, this beacon mode has not been used in our application, and the time division beacon scheduling (TDBS) (Koubâa *et al.*, 2008) has been preferred. This mode allows us to use our own "periodic beacon frames" to switch off the devices, which are reactivated after a period of time has passed.

The first approach to the operation of the node is shown in Fig. 6. This does not follow the standard RFID communications declared by EPC or International Organization for Standardization (ISO) for passive tags, as range and reliability requirements the tags proposed here are active. The node remains in ultra low power mode (sleep) until an interruption is triggered by the watch dog timer (WDT). When this happens, the microcontroller changes the transceiver mode (nRF905) to reception. Then, if a carrier wave is detected, the node stays awake waiting for a beacon; otherwise, it goes back to sleep mode. After that, if the nRF905 receives a correct beacon within a preset period of time, the microcontroller turns the transceiver to the transmitting mode and sends the related information of the tag (ID, sensors, etc.). At this point, the nRF905 turns to reception mode waiting for an acknowledgement (ACK) from the router. If the ACK comes from the router, the node turns to long sleep mode. Otherwise, the system goes back to waiting for a correct beacon. The variable T_{max} is in charge of returning the node to the sleep mode if the duration of the communication is too long.

As the battery life is an important issue in this application, some considerations are made to the RFID tag operation in order to increase the autonomy of the node:

1. The sleep time has to be adapted to the requirements of the identification process. These requirements are: identifications per second, range, velocity of resources and transfer time. If there is a

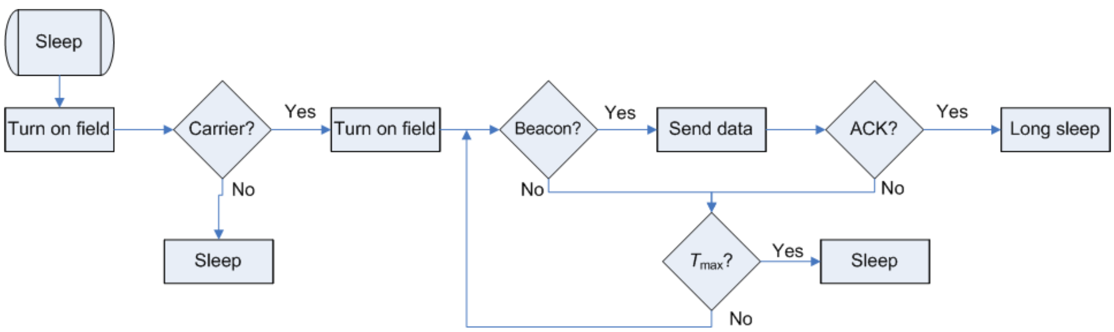

Fig. 6 Operation of the End Nodes

large range to be covered and a fast communication exchange, the sleep time of the communication chipset will be decreased accordingly.

2. The anti-collision protocol used make tags turn to sleep mode after a successful reading in every reading cycle.

For the Zigbee communication, some software improvements are also included to increase the autonomy of the system:

1. Any node will increase the transmission power step by step until it finds another node of the network in its neighbourhood to cover the distance with the minimum energy. This process is performed at the starting-up of the network or on recovery after a communication cut, maintaining the transmission power for the rest of time.

2. By changing the corresponding weights, higher priority is given to the routing paths with more routers connected to a wall power supply.

3. The data is filtered from incoming events before transmitting it through the Zigbee network (i.e., rejecting redundant or unnecessary information).

4. The operation mode of the node is driven by battery status. For example, if battery level is low, the device will not act as router, but will only transmit its own events.

The software programs for the Zigbee modules and RFID modules have been developed in "C" as all the corresponding application programming interfaces (API) by NXP Semiconductors (2011) are sufficiently well documented to make this possible.

4 ZigID: information flow

To coordinate the distributed devices, a data model needs to be defined to describe the information flow that satisfies global requirements. The data model defines the Object Event as the main data-sharing object in the network, and the Management Event as the internal information required to maintain the functionality on the network. The Object Event is serialized in the router node and it is communicated to the rest of the WSN. The steps of the data transfer in the WSN are defined in Fig. 7 as follows:

1. The End Node keeps the ID information in the local memory while its sensors take data from the environment.

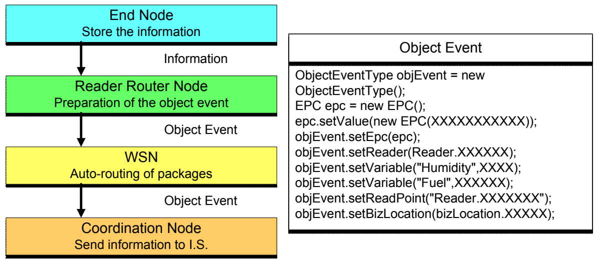

Fig. 7 Information flow based on the Object Event

2. The Router-Reader Node receives the information through the RF connection (RFID) at 50 kB/s in packets of 16 bytes.

3. The router node prepares the Object Event.

4. The sent Object Event is routed in the WSN at 250 kB/s.

5. The Coordinator receives the Object Event and sends the data to the existing information systems (EPC repository).

The "Object Event" is a software structure that represents the identification process. It can include more information than just a simple identification (i.e., sensed data). The "Object Event" may include the value of the variables of the sensors, the identification timestamp and the EPC identification, in the case when the End Node communicates with the Reader-Router Node. It may also include information about the Reader-Router Node, such as its location, the ID of the reader it is connected to or its business process. Then, this Object Event is transmitted through the network. When the package reaches the coordinator, it defines an XML file, which transmits the data to the information system. The next step is the application layer. In the example discussed below, this includes a dynamic connection to Google Earth. The information regarding the nodes is shown on the Google Earth tool as a layer of resources; the tool presents information about the position and the information represented in the Object Events.

The other type of object defined in the data model is a management package that contains status information about the End Nodes and Router-Reader Nodes; information such as the state of the batteries, problems with the antennas, routing problems, unavailable/broken devices or Zigbee exceptions. Many of these exceptions are caught by specific functions of the Zigbee stack. With a proper definition of these events, the coordinator can manage different situations, generating alarms or providing specific instructions. These events are sent every "alive time" by each router node to the coordinator (Fig. 8).

Management Event

```
ManagementEventType objEvent = new
ManagementEventType();
objEvent.setTypeNode(Node.XXXXX);
objEvent.setReader(Reader.XXXXX);
objEvent.setBattery(XXXX);
objEvent.setPowerCommunication(XXXX);
objEvent.setRountingInformation
("Route.XXXXXXX");
objEvent.setBizLocation(bizLocation.XXXXX);
objEvent.setProblem(Problem.XXXXX);
```

Fig. 8 Management event

5 Application in ground handling management at an airport

ZigID in its current form might be applied to many different industrial settings. An opportunity aroses to implement this new architecture at the Ciudad Real Central Airport in Spain, regarding the localization and tracking of the mobile resources involved in ground handling (GH) management. This airport began its operations at the beginning of 2008 in Ciudad Real, with focus on the low cost market. Therefore, in order to reduce the costs associated with GH operations, airline management and other airport operations, the goal of the project was to develop a WSN to enhance visibility in the terminal, thus improving the management of the mobile resources.

5.1 Current situation in ground handling airport operations

The crisis in the world economic markets has forced airlines to modify the way they operate to improve productivity and reduce costs. Modern airports can be extremely complex systems, as they often involve governmental organizations, private companies, airlines, aircraft operations and airport operators. New ideas such as Common Use are being exploited to reduce costs and improve productivity. The concept of the Common Use continuum indicates that airport operators can gain centralized control over facilities and technologies, increase passenger processing options, and acquire shared use efficiencies as they move away from exclusive use towards Common Use (Belliotti, 2008). Airport common usable space is defined as the space in which any airline may operate and is not specifically dedicated to a single airline. In this model, all airline usable airport space is available for use by any airline. The goal of the full Common Use model is to minimize the amount of time any given airline resource is idle, as well the utilization percentage of the airport. In a full Common Use airport, airlines are served on the ground with no preferences as happens in the air traffic control process. To manage resources properly, computer software and systems are put in place to perform complex calculations, monitor usage, track resources and provide status reporting.

In our Common Use model, GH companies are the key because of their central role, as they provide service to different kinds of incoming flights, airlines, passengers and cargo operations. While working in a dynamic, safe and restricted-share environment, these companies need to reduce costs and offer accurate results to fulfill the service contracts they have with airlines so as to avoid dunning charges. In most cases, GH companies are directly contracted by the airlines as suppliers. Therefore, they can reduce costs by optimizing the use of resources used to assist incoming flights. This optimization is achieved through the reduction of the number of resources and the improvement of the time they are required in assisting a flight, i.e., through productivity improvement. Performing this optimization requires new real time visibility systems such as the developed ZigID.

5.2 ZigID at the Ciudad Real Airport

The proposed combination of the WSN and RFID has been implemented at the Ciudad Real Central Airport in Spain. This is a small airport with a demand based on low cost companies and cargo operations. The airport management aims at improving the productivity of the GH resources that assist incoming flights by trying to reduce delays, overloads and overstaffing, through improving the visibility of resources and their status. This produces a cost reduction as demanded by low cost companies.

The design of the airport is based on a hub with four aircraft parking positions by the gates (Fig. 9).

Close to the main parking area there is a secondary larger area for long-term parking.

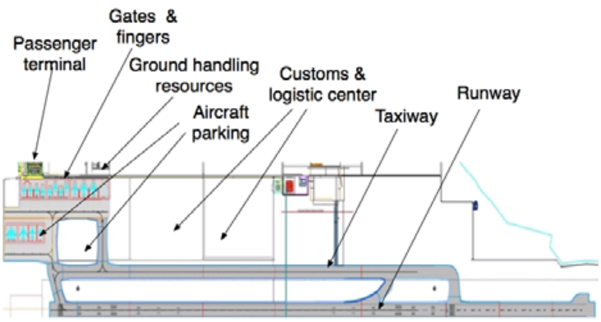

Fig. 9 Ciudad Real Central Airport

In an attempt to improve operations, the proposed solution allocates resources to incoming flights through the WSN. The first main requirement from the airport staff is the need for a dynamic increase in the visibility of the environment, which is provided by a step-by-step deployment. This means that the proposed WSN needs a dynamic topology and a data model that can be adapted to the new requirements or definitions (Ilic *et al*., 2009). The second main problem is the management of the mobile nodes with low power consumption on the WSN (Loredana, 2010), fault detection and auto diagnosis.

The topology of the WSN is shown in Fig. 10. End Nodes are attached to the mobile GH resources, while Router-Reader Nodes are situated in the main parking position and the hangars for resources. With this solution, the distance between routers is always less than 400 m. Furthermore, alternative paths have been defined for all routes. The coordinator node is placed by the computer that runs the software tool; i.e., at the management area inside the passenger terminal.

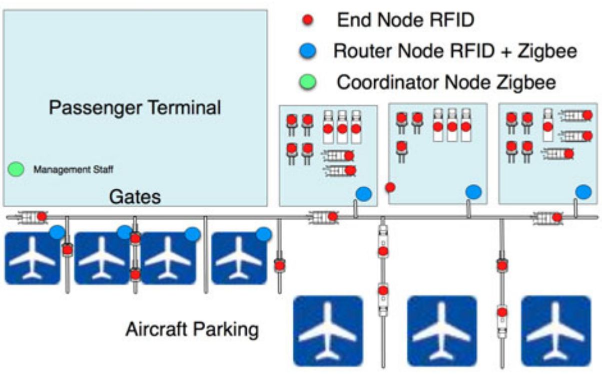

Fig. 10 WSN on the airport

The use of EPC allows the information of this WSN to be shared between the involved air transport agents in a transparent way. The airport agents need to share information between GH companies, airlines, airport suppliers and air traffic control in real time. As well as management information, the WSN can also offer information such as: (1) Administrative information: the system can control working hours, productivity, statistics of performance, logs, identification of errors, etc. (2) Security information: the WSN can generate alarms when the tracked resources are left in security zones or dangerous places such as taxiways or in the path of airplanes.

The data obtained from ZigID is presented in a user interface that can run/show the state of the resources in different ways (Fig. 11). This visualization tool helps the airport management to identify possible conflicting situations, thus improving the decision-making process. On the left, the interface shows the time information and the resources that are free in the hangar. The application has a player with a time bar; which can be forwarded or rewound to obtain the history of the information caught by the WSN. On the right, there are four pictures showing the incoming aircrafts and all the resources that are attending the flights. The resources identified by the WSN are shown in this interface around the aircraft.

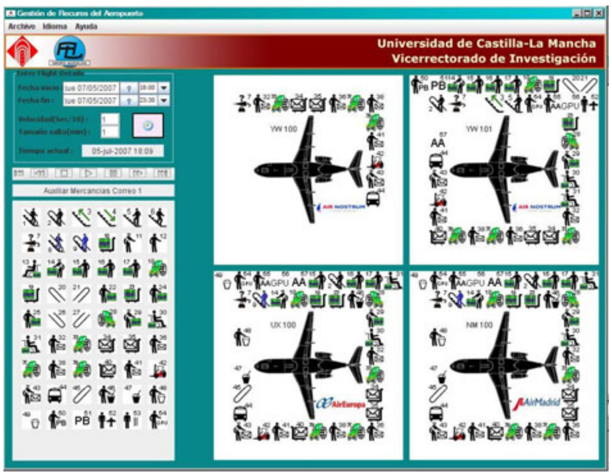

Fig. 11 Visual Interface of the application

The feedback of the airport staff was very positive indeed as they considered that with a brief look at the interface they could obtain a well-formed picture of the state of all the GH resources at the airport. As an extension of its possibilities, the airport staff wants the Multiagent System technology to improve decision-making in real time. To improve short-term planning, the business expert system is permanently updated with the data from WSN.

6 Conclusions

In this paper, we study the development and implementation of ZigID, a WSN based on RFID as identification technology and on Zigbee as communication technology. The existing RFID and Zigbee abstract the lower layers of the WSN. This work focuses on the development of the hardware, its deployment, the definition of the data model and the specifications for final requirements. The aim of the WSN is to cover large distances in the environment, while performing identification at defined zones with a flexible data model, which allows new devices or new information to be added dynamically.

The proposed WSN is based on a three-level architecture consisting of an End Node Level (RFID+), a Router Level (RFID+Zigbee) and a Coordinator Level (Zigbee+Database). Following the requirements of this outdoor mobile application, energy efficient management is necessary. This work proposes different software techniques based on power adaptability, ultra low power consumption modes and efficient routing to achieve low consumption ratios.

Complementing the WSN, a visual software tool has been developed to manage the GH resources that assist the incoming flight in the Ciudad Real Central Airport, Spain. This software was tested by the airport staff, who did not take long in getting familiar with the application and were very positive in their response to this tool.

References

Akkaya, K., Younis, M., 2005. A survey on routing protocols for wireless sensor networks. *Ad Hoc Networks*, **3**(3):325-349. [doi:10.1016/j.adhoc.2003.09.010]

Ansari, J., Pankin, D., Mähönen, P., 2009. Radio-triggered wake-ups with addressing capabilities for extremely low power sensor network applications. *International Journal of Wireless Information Networks*, **16**(3):118-130. [doi:10.1007/s10776-009-0100-6]

Belliotti, R., 2008. Common Use Facilities and Equipment at Airports. A Synthesis of Airport Practice. Airport Cooperative Research Program, ACRP Synthesis 8. Transportation Research Board, USA.

Chalkiadakis, G., Boutilier, C., 2003. Coordination in Multiagent Reinforcement Learning: A Bayesian Approach. ACM, p.716.

Durfee, E.H., 1996. Planning in Distributed Artificial Intelligence. Foundations of Distributed Artificial Intelligence, John Wiley & Sons, Inc., New York, NY, USA, p.245.

Escribano, J.G., Garcia, A., Wissendheit, U., Loeffler, A., Pastor, J.M., 2010. Analysis of the Applicability of RFID & Wireless Sensors to Manufacturing and Distribution Lines trough a Testing Multi-Platform. IEEE International Conference on Industrial Technology, Viña del Mar, Chile, p.1379-1385. [doi:10.1109/ICIT.2010.5472510]

Ferrari, G., Medagliani, P., Piazza, S., Martalò, M., 2007. Wireless sensor networks: Performance analysis in indoor scenarios. *EURASIP Journal on Wireless Communications and Networking*, **2007**(1):41. [doi:10.1155/2007/81864]

Floerkemeier, C., Roduner, C., Lampe, M., 2007. RFID application development with the Accada middleware platform. *IEEE Systems Journal*, **1**(2):82-94. [doi:10.1109/JSYST.2007.909778]

Garcia, A., Mcfarlane, D., Thorne, A., Fletcher, M., 2003. The Impact of Auto-ID Technology in Material Handling Systems. 7th IFAC Conference of Intelligent Manufacturing Systems, Budapest, Hungary.

Gezici, S., 2008. A survey on wireless position estimation. *Wireless Personal Communications*, **44**(3):263-282. [doi:10.1007/s11277-007-9375-z]

GS1, 2010. The EPCglobal Architecture Framework. http://www.gs1.org/gsmp/kc/epcglobal/architecture/architecture_1_4-framework-20101215.pdf [Accessed on Oct. 11, 2011].

Ilic, A., Andersen, T., Michahelles, F., 2009. Increasing supply-chain visibility with rule-based rfid data analysis. *Internet Computing, IEEE*, **13**(1):31-38. [doi:10.1109/MIC.2009.10]

Kosko, B., Burgess, J., 1998. Neural networks and fuzzy systems. *The Journal of the Acoustical Society of America*, **103**(6):3131. [doi:10.1121/1.423096]

Koubâa, A., Cunha, A., Alves, M., Tovar, E., 2008. TDBS: a time division beacon scheduling mechanism for ZigBee cluster-tree wireless sensor networks. *Real-Time Systems*, **40**(3):321-354. [doi:10.1007/s11241-008-9063-4]

Loredana, A., 2010. An information-theoretic approach for energy-efficient collaborative tracking in wireless sensor networks. *EURASIP Journal on Wireless Communications and Networking*, Article ID 641632.

Mao, J., Wu, Z., 2007. Optimal distributed resource allocation in a wireless sensor network for control systems. *Journal of Zhejiang University-SCIENCE A*, **8**(1):106-112. [doi:10.1631/jzus.2007.A0106]

Medagliani, P., Ferrari, G.Marastoni, M., 2010. Hybrid Zigbee-RFID networks for energy saving and lifetime maximization. *Remote Instrumentation and Virtual La-*

boratories, **7**:473-491. [doi:10.1007/978-1-4419-5597-5_37]

Microchip, 2004. PIC16F819 Datasheet. http://ww1.microchip.com/downloads/en/DeviceDoc/39598e.pdf [Accessed on Oct. 11, 2011].

Morelli, C., Nicoli, M., Rampa, V., Spagnolini, U., 2007. Hidden Markov models for radio localization in mixed LOS/NLOS conditions. *Signal Processing, IEEE Transactions on*, **55**(4):1525-1542. [doi:10.1109/TSP.2006.889978]

Nordic, 2008. nRF905 Datasheet. http://www.nordicsemi.com/eng/content/download/2452/29528/file/Product_Specification_nRF905_v1.5.pdf [Accessed on Oct. 11, 2011].

NXP Semiconductors, 2011. JN5139M02 Datasheet. http://www.jennic.com/products/modules/jn5139_modules [Accessed on Oct. 11, 2011].

Rovňáková, J., Kocur, D., 2010. TOA estimation and data association for through-wall tracking of moving targets. *EURASIP Journal on Wireless Communications and Networking*, Article ID 420767. [doi:10.1155/2010/420767]

Russell, S., Norvig, P., 2010. Artificial Intelligence: a Modern Approach. Prentice Hall Englewood Cliffs, NJ.

Sahinoglu, Z., Gezici, S., Güvenc, I., Corporation, E., 2008. Ultra-Wideband Positioning Systems: Theoretical Limits, Ranging Algorithms, and Protocols. Cambridge University Press, UK.

Sánchez, T., Kim, D., Canepa, G.H., Koumadi, K., 2009. Integrating wireless sensors and RFID tags into energy-efficient and dynamic context networks. *The Computer Journal*, **52**:240-267.

Sandholm, T., 1999. Distributed Rational Decision Making. Multiagent Systems: a Modern Approach to Distributed Artificial Intelligence. MIT Press, Cambridge, MA, USA, p.201-258.

Sung, J., Lopez, T., Kim, D., 2007. The EPC Sensor Network for RFID and WSN Integration Infrastructure. IEEE Computer Society, p.618-621.

Thorne, A., Barrett, D., Mcfarlane, D., 2007. Impact of RFID on Aircraft Operations Processes. White Papers, Aero-ID. Cambridge.

Wen, Y.F., Chen, Y.Q., Pan, M., 2008. Adaptive ant-based routing in wireless sensor networks using energy delay metrics. *Journal of Zhejiang University-SCIENCE A*, **9**(4):531-538. [doi:10.1631/jzus.A071382]

Wooldridge, M., Weiss, G., Ciancarini, P., 2002. Agent-Orientes Software Engineering II. LNCS, Springer-Verlag, Berlin, Germany. [doi:10.1007/3-540-70657-7]

Xia, F., Tian, Y.C., Li, Y., Sung, Y., 2007. Wireless sensor/actuator network design for mobile control applications. *Sensors*, **7**(10):2157-2173. [doi:10.3390/s7102157]

Zhao, F., Guibas, L., 2004. Wireless Sensor Networks: an Information Processing Approach. Morgan Kaufmann Pub.