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Development of Wireless Sensor Network and Mobile Routing Integration

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Abstract:

This paper reveals that Robots, or in general, intelligent vehicles, require large amounts of data to adapt their behavior to the environment and achieve their goals. When their missions take place in large areas, using additional information to that gathered by the onboard sensors frequently offers a more efficient solution of the problem. The emergence of Cyber-Physical Systems and Cloud computing allows this approach, but integration of sensory information, and its effective availability for the robots or vehicles is challenging. This paper addresses the development and implementation of a modular mobile node of a Wireless Sensor Network (WSN), designed to be mounted onboard vehicles, and capable of using different sensors according to mission needs. The mobile node is integrated with an existing static network, transforming it into a Hybrid Wireless Sensor Network (H-WSN), and adding flexibility and range to it. The integration is achieved without the need for multi-hop routing. A database holds the data acquired by both mobile and static nodes, allowing access in real-time to the gathered information. A Human–Machine Interface (HMI) presents this information to users. Finally, the system is tested in real urban scenarios in a use-case of measurement of gas levels.

Keywords:* *wireless sensor network, mobile sensors, hybrid wireless sensor networks, Cyber-Physical Systems, urban environment monitoring

Introduction:

Wireless sensor networks (WSNs) allow for the acquisition of information when proximity from the sensors to the phenomenon and persistence over time is required [1,2]. WSNs have been applied to problems like logistics, traceability, emergency operations or urban environments [3,4,5,6,7]. In emergency response, WSNs can provide close monitoring with low cost, flexibility and scalability [8,9], as well as way of integrating robot into rescue teams [10], as a step towards Cyber-Physical Systems (CPS) for first response [11,12,13]. In urban environments, WSNs can help monitoring power systems, solid waste or water facilities. But traffic has attracted most of attention, since it is generally considered as one of the main problems affecting the health of city population. The number of vehicles has grown notably in recent decades; as has pollution. Pollution data are usually measured using an infrastructure of fixed sites. Such an infrastructure is limited, expensive and static. As a result, pollution and air quality data are limited. WSNs, on the contrary, are flexible and dynamic, and can be easily adapted to rural or urban environments. These features have made WSNs a valuable alternative for the way

Intelligent Transportation Systems (ITSs) are implemented nowadays. ITSs are a way of improving transportation efficiency and safety, but also to save energy and to reduce emissions of vehicles through a better management of available resources. But one of the obstacles to the implementation of new transport strategies is the limited amount of information on urban traffic. WSNs provide a mean to improve the amount and quality of the data available for planning and management in ITSs.

The effectiveness of WSNs depends strongly on the network coverage and connectivity provided by the sensor deployment. Even if sensor nodes are usually easy to install, once they have been placed they only way to improve the information they acquire is to add new nodes, or to re-deploy the existing ones. Thus, the strategy to select the locations of the nodes becomes a key feature for the performance of WSNs.

A complementary strategy is to provide mobility to the sensor nodes, for example by including a method for replacing the sensor nodes if they present a malfunction. Another option is to mount the sensor nodes onboard vehicles or mobile robots. This approach is valid not only for urban applications, but also for other use-cases, like disaster robotics [6]. Mobility of the sensor nodes can be found in mobile ad hoc networks (MANETs), defined as a set of wireless mobile nodes characterized as self-adaptive and infrastructure-less [9]. In vehicular ad hoc networks (VANETs), or in general, in vehicular sensor networks (VSNs), moving vehicles and infrastructure become nodes of a dynamic network. In general, a WSN including both static and mobile sensor nodes can be considered a Hybrid Wireless Sensor Networks (H-WSNs). Several authors have proposed VSNs for real-time data acquisition and monitoring [8], including solutions like cloud computing, fog-based event monitoring or high resolution maps in urban environments.

The existence of mobile nodes in VSNs (or, in general, in H-WSNs) can make difficult to ensure coverage. The development of a H-WSN must pay special attention to this feature.

A classical approach to design a WSN considers a flat architecture. However, this kind of network does not allow for applications with mobile nodes, since a constant reconfiguration of the network is then required. A hierarchical architecture can improve performance in these cases, decreasing delays, while improving the reliability of data transmission and connectivity of the network. However, special attention must be paid to the organization of the network. For instance, the use of a mobile sink can allow for a longer lifetime of sensor nodes avoiding multi-hop data collection.

Another important issue in H-WSNs is network overhead. Routing protocols have to be adapted to limited time communication links. A proposed solution is using position aware routing protocols. Another proposal is dynamic routing [8]. While using MANETs can be a comparatively simple solution, the need for frequent topological updated undermines energy consumption. Security and privacy are also concerns when using MANETs, as well as adaptability and scalability. A more robust option is using H-WSNs, although the location of mobile and static nodes has to be carefully designed, particularly for the base stations. An alternative is employing mobile base stations or mobile sinks, and dynamic relocation. Optimization based clustering has been also proposed by several authors. As for security and reliability, H-WSNs allow for reliable and timely data communication, for instance using dynamic congestion control schemes.

Overview

The UIS is a static WSN. As such, it provides useful information on an area of interest, since it can be deployed with speed and flexibility to adapt to each case requirements. But once the network is deployed, the nodes stay at the same location. Obtaining additional information requires installing supplementary Transmitter nodes, and depending on the distance, also Receiver nodes, due to the limited range of ZigBee communications. Some use-cases require a different approach, such as the study of gas emissions. A significant amount of emissions in urban areas is linked to motor vehicles. Obtaining up-to-date information about the levels of some gases can be very relevant for traffic managers. But deploying a sensor network large enough to cover a whole city might be impractical. A way of obtaining the relevant data that traffic managers require is by means of sensors directly installed on vehicles. But some other applications require also the capability to measure environmental data in an adaptable fast way, such as in disaster robotics, where the collaboration with humans or dogs can be limited by the level of some gases. For those applications requiring additional flexibility in the acquisition of information, a hybrid version of the UIS network has been developed.

These features can be achieved by transforming the static WSN into a H-WSN by adding a Mobile node. The next sections describe the Mobile node architecture and implementation, and its integration with the WSN.

Architecture and Implementation

The Mobile node has been developed to improve the range and flexibility of the UIS. It has been designed to allow installation onboard vehicles, so the area under study can be modified without the need to re-deploy the UIS nodes. A modular architecture was desirable so that the set of sensors could be modified according to mission needs. At the same time, one of the requirements was to use the original nodes with as few modifications as possible. But since the Transmitter nodes send their data using the ZigBee protocol, they have a limited range, which is affected by the obstacles between emitter and receiver. To overcome this limitation, one possibility is to configure ZigBee nodes as routers, allowing multi-hop routing to take the data from the Transmitter nodes to the Receiver node. However, this option limits the flexibility of a mobile node, since it could only move around the position of already deployed nodes. To meet all the requirements a modular architecture was designed including a Receiver node and a configurable number of standard UIS Transmitter nodes, so that no hardware changes are required. The Receiver node gathers the information from the Transmitter nodes, and synchronizes it with the database in the external server via 3G or Wi-Fi (see Figure 1). In this way, the Mobile node can acquire data from areas without the need for previously deployed ZigBee nodes between the Receiver node and the area of interest.

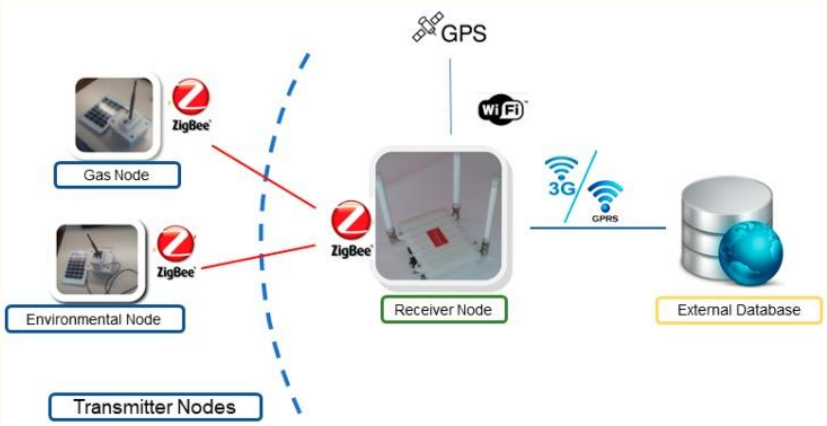

Figure 1

Architecture of the Mobile node.

An example set of nodes included in the Mobile node is shown in Figure 1. In this case, a Gas node and an Environmental node are included as the Transmitter nodes, together with the Receiver node. It is worth notice that Transmitter nodes may contain several sensors, which can be changed from one experiment to another depending on the mission requirements. For instance, the Gas node can be equipped with different sets of gas sensors, including CO_2, CO, O_2, VOC or NH_3.

The Mobile node has two possible working modes: local mode and networked mode. In both modes, the Transmitter nodes acquire and process data from the environment, and send them to the embarked Receiver node. The modes differ in the way that a frame is constructed prior to store it in the local table, and to synchronize it with the external database. The implementation had to meet the requirement of using the original nodes with as few modifications as possible. Thus, changes have been limited to the Receiver node software. These modifications have consisted in the creation of two additional software configurations according to the two different working modes. This software configuration has to be selected offline, previously to the start of an experiment. Thus, it is possible to increase the communication range of the existing sensor nodes without the need for integration of a new radio segment with the Transmitter nodes, or the development of new connection strings with the external server according to this new communication link. At the same time, it is possible to use any type of Transmitter node already in use by the static network.

Local Mode

In this mode, the Mobile node is seen by the network as a single, multi-sensor node. To do so, an enhanced frame is constructed containing the information from all the sensors present in the Transmitter nodes within the Mobile node.

Once data from all the sensors have been received, the Receiver node builds an enhanced frame with data from all of them, includes location data and updates the internal database. Synchronization is then performed with the external database (via 3G or Wi-Fi, if available), where the information appears as data from a single node. A simplified protocol message flow diagram for this working mode is shown in Figure 2.

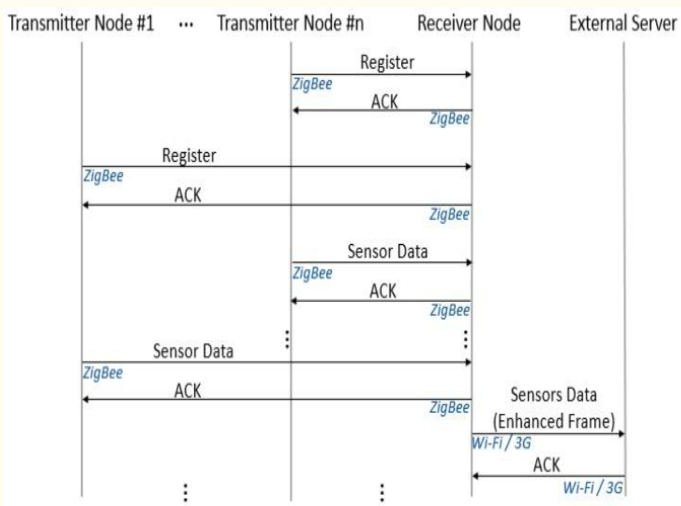

Figure 2

Simplified protocol message flow diagram for the local mode.

Networked Mode

In the networked mode, when data from any of the Transmitter nodes are available, a frame is constructed and sent to the embarked Receiver node. A frame may contain information from one or several sensors from the same Transmitter node. The Receiver node updates its internal database, and then synchronization with the external database takes place via 3G, or Wi-Fi if it is available. A simplified protocol message flow diagram for this working mode is shown in Figure 3. Figure 4 shows examples of frames with data from a Gas node. The frame contains measurements from three sensors: NH_3, temperature and humidity. Location is obtained by means of a GPS node, acting as an additional Transmitter node. This way, more positioning data are available.

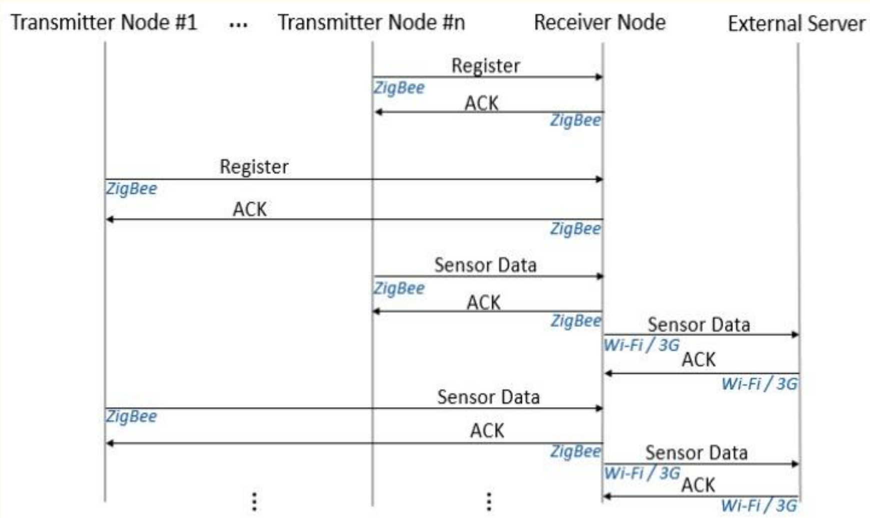

Figure 3

Simplified protocol message flow diagram for the networked mode.

Integration with the H-WSN

The data acquired by the sensors on the Mobile node are available to any user through the database, like the data from any other sensor in the static network. The Wireless Sensor Network is then transformed into a Hybrid Wireless Sensor Network (H-WSN), managing data from both static and mobile nodes indifferently. It shows the integration of the Mobile node (in the right-hand side) with a static WSN (in the left-hand side), resulting in a H-WSN. The Receiver node acts as a mobile sink, granting coverage for the Transmitter nodes whenever 3G or Wi-Fi coverage is available without the need for multi-hop routing or dynamic relocation methods, which can reduce operating lifetime of the nodes due to increased communication. By transforming the WSN into H-WSN the resulting system gains flexibility, since a Mobile node can be deployed to obtain data from an area not covered by static nodes (for instance, in cases where some pieces of evidence make the area worth studying after the original deployment of the network). Robustness can also be increased with the use of a Mobile node to substitute malfunctioning static nodes.

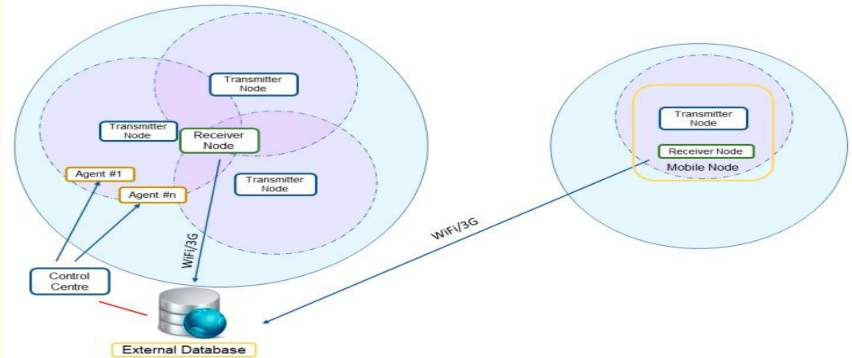

Figure 4

Integration of the Mobile node to create a Hybrid-Wireless Sensor Network.

The external database is the input for an HMI developed for this application using LabVIEW, making possible to present the information obtained by the different sensors, and related to their locations. The user can configure what sensors' information is shown, according to the deployed nodes, including static nodes. For instance, it shows how the user can see the available measurements for CO_2, CO, O_2, NH_3, ozone (O_3), atmospheric pressure, relative humidity and temperature, at the beginning of a route.

In contrast with the local mode in the networked mode the strategy allows for acquiring a larger amount of data, since the update and synchronization of the databases takes place every time a new data is obtained by any sensor. Thus, the slow dynamics of a sensor does not limit obtaining more data with a faster one.

Conclusion:

This paper concludes that a modular mobile node has been implemented, capable of using different sensors according to mission needs. The mobile node has been integrated with an existing static network, adding flexibility and range to it and transforming it into a Hybrid Wireless Sensor Network. Integration has avoided the need for multi-hop routing, which can reduce the operating lifetime of the nodes due to increased communication. Two different integration modes have been developed: local mode and networked mode. Data gathered with the mobile node have been presented to the user in real-time, by means of a Human–Machine Interface showing data from a database synchronizing the information gathered by the mobile node, which may include information from other static nodes as well. Finally, the system has been tested in real urban scenarios in a use-case of measurement of gas levels and environmental data.

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