Multi-level Infrastructure of Interconnected Testbeds of Large-scale Wireless Sensor Networks (MI^{2}T-WSN)

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Abstract - *Wireless sensor networks (WSNs) have been used in different types of applications and deployed within various environments. Simulation tools are essential for studying WSNs, especially for exploring large-scale networks. However, WSN testbeds are still required for further testing before the real implementation. In this paper we propose a multi-level infrastructure of interconnected testbeds of large-scale WSNs. This testbed consists of 1000 sensor motes that will be distributed into four different testbeds. The variations of these testbeds will allow for implementing and testing algorithms and protocols that could be used for various applications and within several types of environment.*

Keywords: Testbeds, WSNs, simulation, MI^{2}T-WSN

1   Introduction

The proliferation of wireless communication technologies has enabled the development of wireless sensor networks (WSNs), which consist of a large number of small and cheap sensors with limited resources, such as computing, communication, storage and energy [1]. These sensor nodes are able to sense, measure and collect raw data from the environment, perform simple computations and then transmit only the required and partially processed data to the node responsible for fusion [2]. Sensor nodes may be deployed either manually at fixed locations or randomly into the field. After deployment, these sensor nodes start measuring various properties of the environment, such as light, humidity, temperature, barometric pressure, velocity, acceleration, acoustics and magnetic field, using the different types of sensor that may be attached to these nodes. The measured data will be transferred by a multi-hop infrastructureless architecture to a base station, where data will be manipulated and a decision can be taken.

WSNs have been deployed extensively in areas such as military operations [3], health monitoring [4], natural disaster management [5] and hazardous environments [6]. A large number of research publications have shown that WSNs are a promising approach that could provide future solutions for several problems. Although there are thousands of research publications in this field, there is still a gap between the research and the real implementation. Most of the research that has been done has used simulation tools (e.g. [7, 8]). Using a real WSN during the development phase is not an efficient method; it requires a great deal of effort to reprogram the motes, redeploy them and perform the testing again. Moreover, following the "trial and error" approach is an expensive solution and consumes too much time.

Using a small number of motes for testing purposes could not lead to reliable solutions for large-scale WSNs. On the other hand, using a large-scale WSN itself is not always possible. Running large-scale WSN experiments is difficult; deploying a large number of motes takes a considerable time, and programming each mote individually can quickly cause a significant bottleneck; moreover, the availability of a huge number of motes is a problem.

This paper proposes a multi-level infrastructure of interconnected testbeds of large-scale WSNs (Section 3). This testbed would remove the gap between the research environment and the real implementations, and it would facilitate advanced research in WSN technology. The proposed testbed is designed in such a way as to overcome the drawbacks of some of the current testbeds, which are explained briefly in Section 2.

2   Related Work

Testbeds have successfully been used to evaluate many aspects of wireless sensor networks. These testbeds have differed in many respects, such as hardware components, software architecture, network size, management system and user interface. A recent work by Steyn and Hancke [9] classifies WSN testbeds, on the basis of their features, into several categories: mainly server-based control; single-PC-based control; hybrid; multiple-site; in-band management traffic; and industrial testbeds.

Server-based control testbeds [10] are typically fixed testbed deployments with a central back-end, with various servers supporting the management and data-logging functionality. They can support large-scale experiments. However, they are costly to install and maintain. *Single-PC-*

based control testbeds [11] use a single PC as the central point, which is responsible for the management and data storage. They can easily be adapted into several scenarios, but they have limited features and cannot handle large networks. *Hybrid* testbeds [12] use several gateways in addition to the central server. A significant part of the management and control functions is done locally at the gateways. This architecture enhances the scalability of the testbed.

Multiple-site testbeds [13] are deployed over multiple sites and controlled from a central location. This deployment allows for testing in several types of environments and applications. They usually also have a large scale and can be used to realistically test WSNs for future large deployments. *In-band management traffic* testbeds [14] use additional software installed on the mote and the existing wireless communication channel to perform the management and control functions. This method enhances the scalability and flexibility of the testbed issues and reduces the cost of installation and maintenance. *Industrial* testbeds [15] take into consideration the harsh environment and several challenges that are associated with industrial applications, such as harsh wireless channels, interference and noise.

3   Proposed testbed

3.1   Overview

The proposed testbed could facilitate solutions to a number of challenges that arise in our current environment, such as pollution, health care monitoring, energy saving, pipeline leakage, situational awareness in underground mining and the like. Several solutions and products have been proposed or implemented; however, most of these solutions are complicated and expensive, not functional and difficult to maintain. Moreover, the testing facilities for these solutions are not accessible to all, may not be in real-time and may need to be run by a number of people.

To narrow the gap between the research environment and the real implementations, we need to create a multi-level infrastructure of interconnected testbeds of large-scale WSNs (MI^{2}T-WSN). As shown in Figure 1, MI^{2}T-WSN could be used as a tool to open the door for future solutions. Moreover, MI^{2}T-WSN would facilitate advanced research in WSN technology, enable the conducting of large-scale experiments that are not feasible with traditional small-scale testbeds and help other universities and institutes to build similar or smaller testbeds. Its use could improve e-skills capabilities at several levels: e-literacy, e-business skills, and skills of ICT users, ICT practitioners and R&D practitioners.
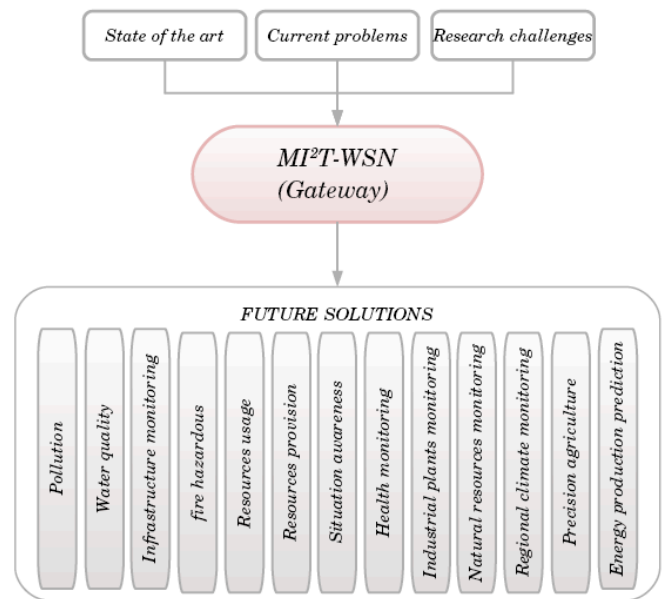

Figure 1. MI^{2}T-WSN could be the gateway for future solutions

3.2   Architecture

MI^{2}T-WSN is a large-scale wireless sensor network laboratory that consists of 1000 motes with heterogeneous sensing devices. Several types of sensor nodes (motes) have been used in the previous WSN testbeds, such as TelosB, SunSPOT, iSense and Waspmote. MI^{2}T-WSN will be built using "Waspmote", which is a new wireless sensor device, recently designed by Libelium [16]. The main characteristics of Waspmote are:

- Remote, real-time monitoring of more than 50 parameters, such as gases (CO, CO_2, CH_4), temperature, liquid level, weight, pressure, humidity, luminosity
- Robust, flexible and long-range communications (up to 40 km)
- Minimum power consumption (years of battery life)
- Easy to use: the language is C++ style
- Open source: open-source API, open-source compiler
- Many extra options: GPS, GPRS, solar panel, Bluetooth, etc.
- Several radio communication protocols: IEEE 802.15.4, ZigBee, RF (900MHz and 868MHz) and Bluetooth
- Certified by CE (Europe), FCC (EEUU), IC (Canada)

As shown in Figure 2, MI^{2}T-WSN consists of four testbeds. The indoor-lab testbed consists of 100 motes that are distributed inside a laboratory; the indoor-real testbed consists of 300 motes that are distributed in the offices, boardrooms and passages of a building; the outdoor-lab

testbed consists of 200 motes distributed above the roof; and the outdoor-real testbed consists of 600 motes distributed outside at multiple sites. Lab testbeds (indoor-lab and outdoor-lab) are distributed within a single area, which makes them easy to install and maintain. Moreover, the motes can be connected to a USB hub to provide them with the required power. Real testbeds (indoor-real and outdoor-real) are distributed in different locations, so require more effort to install and maintain. Power supply is also an issue, and they could require different sources of power such as batteries and solar panels. However, they will provide environments that are very close to those of the real-world applications.
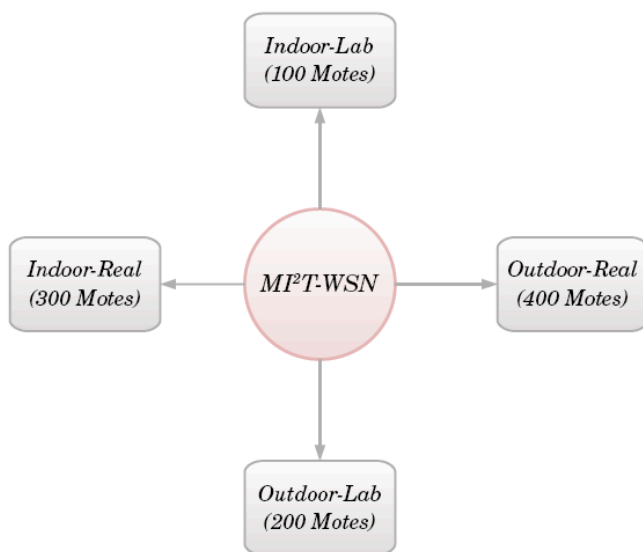
Indoor-Lab
(100 Motes)

Indoor-Real
(300 Motes)

MI²T-WSN

Outdoor-Real
(400 Motes)

Outdoor-Lab
(200 Motes)

Figure 2.　MI^{2}T-WSN Testbeds

3.3　Implementation

MI^{2}T-WSN will be constructed in two phases. In phase one, the indoor-lab and indoor-real testbeds will be constructed. A simple web-based interface will be created to allow researchers, developers and students within our research institute and collaborating universities to access and use these two testbeds. In the second phase, the other two testbeds, outdoor-lab and outdoor-real testbeds, will be constructed. The interface will be enhanced to allow users, developers and administrators to access MI^{2}T-WSN remotely. Different types of manuals will be created, and multi-level training courses will be conducted. In this section, the focus will be on the first phase of implementation.

A Waspmote is a sensor device specially oriented to developers. Because of the commercial availability and the modular design of these devices, we have decided to use them as the basis of our testbeds. In total, 400 Waspmotes will be deployed inside the building. Each device has modular antennas that can be interchanged to support different wireless communication protocols (ZigBee, Bluetooth, GPRS) and frequencies (2.4GHz, 868MHz, 900MHz). Although they have limited on-board sensors, they can be expanded with a variety of modular sensor boards.

To communicate with the Waspmotes we will use several Meshlium gateways, also developed by Libelium. These gateways serve as an in-band management interface to facilitate OTA programming of the Waspmote devices. They will also be used to receive the sensor data sent by the Waspmotes using the ZigBee radio. The Meshlium gateway is a Linux-based router that supports multiple programming languages and can also be customised with up to five different modular radio interfaces: Wifi 2.4GHz; Wifi 5GHz; GPRS; Bluetooth; and ZigBee. As shown in Figure 3, the received sensor data can either be stored in the Meshlium file system, its own local data base or in an external data base (MySQL). The Meshlium gateway also provides a connection to the internet so that users can connect remotely to the testbed. Depending on where the gateway is deployed it can send the information to the internet using any one of the Ethernet, Wifi, or GPRS connections.

In the indoor-lab testbed, the sensor motes will be distributed in a grid network as shown in Figure 3. For constant power to the motes, two professional, testbed-grade 49-port USB hubs will be used to connect these motes to the power supply. In the indoor-real testbed, the motes will be distributed inside the building in different locations such as offices, boardrooms and passages. Each room will typically contain a small cluster of between two and four nodes. To practically power these devices without using too much of the available power outlets in the building, smaller AC powered USB hubs can be used. Each cluster can be connected to a hub and distributed in the room using active USB cables. All the sensor data will be sent wirelessly to the Meshlium gateways to store it locally or in an external data base.

Building these two testbeds requires the following equipment: Waspmote (802.15.4 SMA 2 dbi and 5 dbi), Meshlium gateways, sensor boards (e.g. event, smart city and prototyping), sensors (e.g. temperature, force and pressure, LDR, PIR, humidity and noise sensors), USB-220 V adapters, USB hubs, Waspmote expansion boards, Waspmote antenna modules (GPS, Xbee 900 MHz and GSM/GPRS module), extra memory (32 Gb storage Meshlium and microSD 2Gb card) and extra components required for the back-end network such as routers, switches, and servers (database and application)
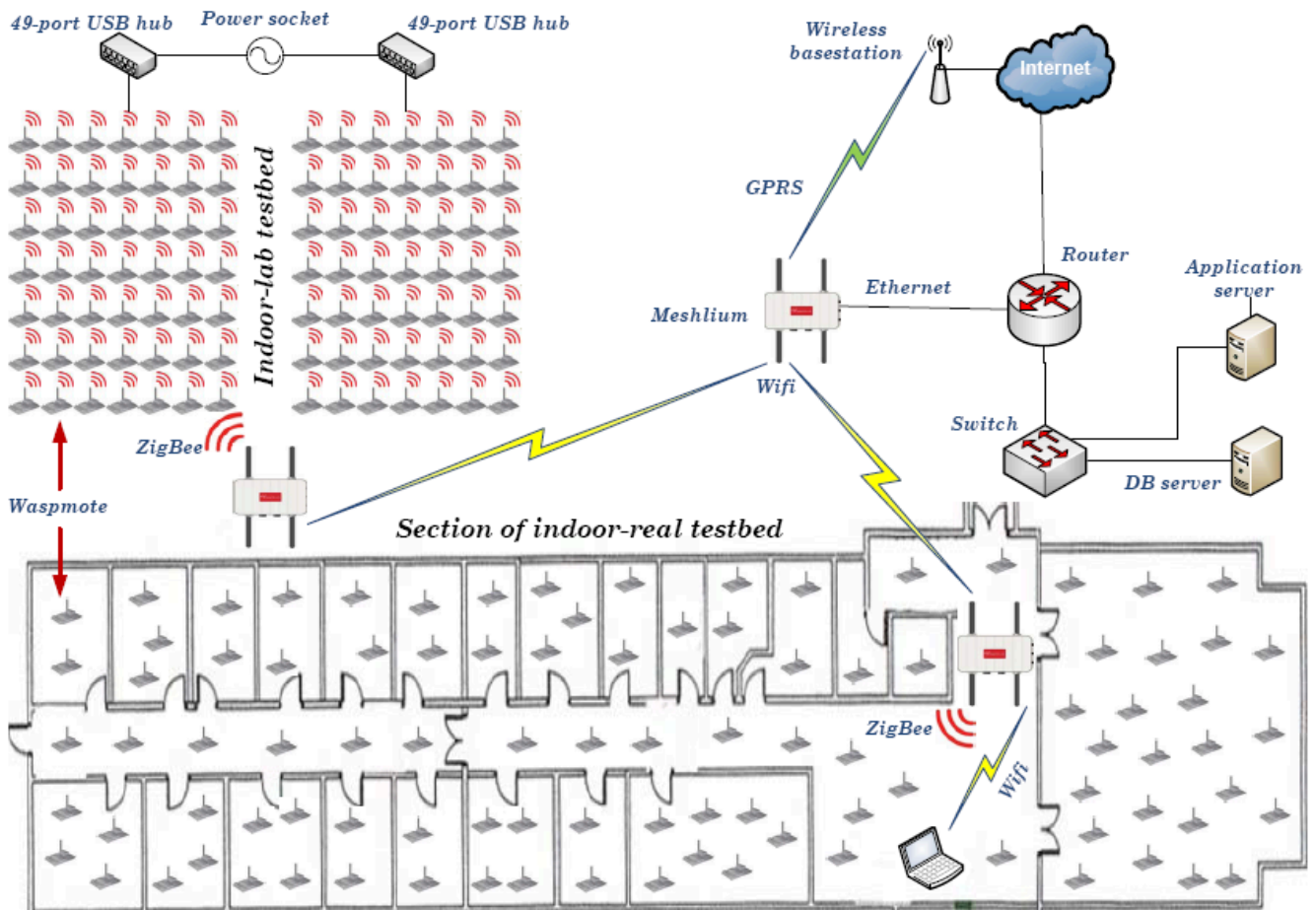
Figure 3. MI²-WSN network architecture

3.4   Accessibility

One of the main objectives of MI²T-WSN is to develop a real-time system that operates and analyses the environment continuously, and able to detect and report abnormal variations rapidly. MI²T-WSN should identify end-users' needs and requirements as well as operational constraints. In order to achieve these objectives, MI²T-WSN will use a web-based interface that can be accessed remotely, as shown in Figure 4. The interface provides a GUI to define and issue queries in the network and view their results, and can be customised by the end-user. The interface is able to detect and report abnormal variations and allows the end-user to report bugs and problems. The user will be able to book a specific testbed (e.g. indoor-lab) or even a certain number of motes within a specific testbed to use for a period of time.
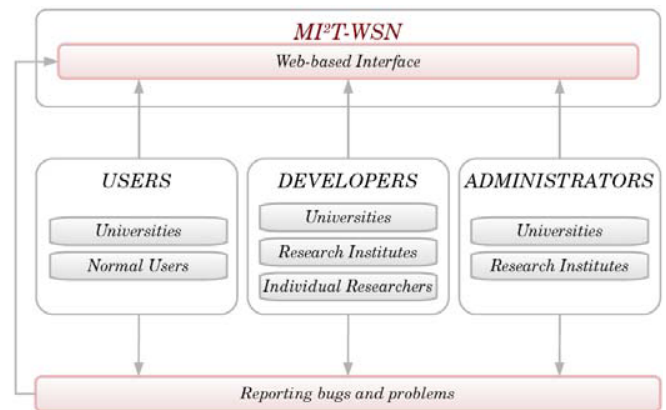

Figure 4. Remote access through a web-based interface

Three categories of users will have access to MI²T-WSN: users, developers and administrators. The "user" represents the normal users who are interested in running simple experiments that consist of simple networks to test different types of applications. The "developer" represents

the developers and researchers who would like to implement and test state-of-the-art algorithms and protocols and also those who would like to develop new algorithms or protocols. The administration right is only given to those universities and research institutes that are actually participating in building these interconnected testbeds. The administrators will be able to control MI^{2}T-WSN remotely and they will be responsible for fixing any reported problems.

In order to ensure a strong end-user involvement and maximise long-term project impact, comprehensive manuals will be prepared for the users, developers and administrators. A library of open-source code and projects will be accessible through the web-based interface. Multi-level training courses will be provided for students and researchers in addition to the on-line training courses.

3.5 Research direction

Figure 5 proposes a research direction for implementing, testing or developing state-of-the-art or new protocols and algorithms. This framework encourages researchers to perform three steps before the start of real-world implementations:

- **Simulation tools:** Simulation is essential for studying WSNs, especially testing new algorithms, applications and protocols. The scalability of protocols should be validated by simulation to ensure that they will perform well even in very large networks. However, relying on simulation alone could be insufficient, and more tests should be done using testbeds.
- **Lab-testbeds:** Compared with real-testbeds, lab-testbeds provide more flexibility in terms of fast programming and testing. Therefore, it is recommended to start with lab-testbeds, especially for new algorithms and protocols.
- **Real testbeds:** The real-testbeds allow the researcher to test the new algorithms or protocols in an environment that is close to the real-world environment. The researcher will have to modify and enhance his or her algorithm or protocol to be more suitable for real-world applications.

There is a flexibility in this framework in terms of the path that the researcher can follow to reach the real-world implementation. This path depends on the type of network and applications that will be used in the real-world implementation. For example, if the researcher is planning to implement a new algorithm that will be used only in the outdoor environment, then the best path would be simulation, outdoor-lab testbed, outdoor-real testbed and finally real-world implementation. However, a researcher who is designing a general protocol that is supposed to be used in different types of environment could start with simulation and then test the new protocol using all four types of testbed.

MI^{2}T-WSN can be considered as a large-scale WSN. However, a researcher who is planning to use the implemented algorithm or protocol in a very large network that consists of tens of thousands of motes will still need to use the simulation tools again to validate the scalability issues of this algorithm or protocol before the real-world implementation.
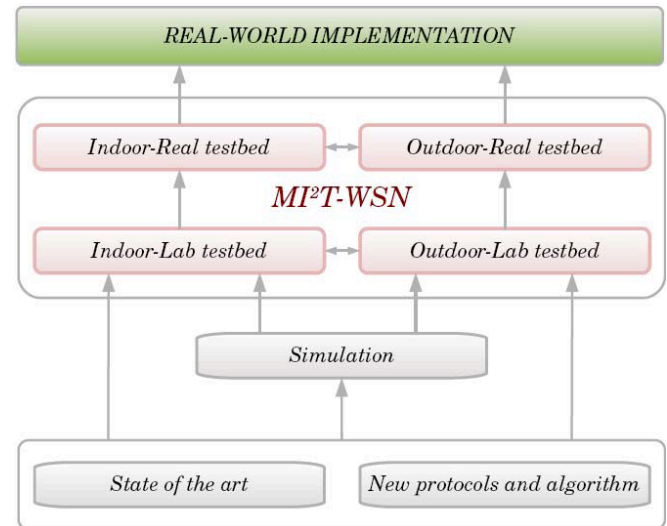

Figure 5. Research direction

4 Conclusion

In this paper, we have proposed a multi-level infrastructure of interconnected testbeds of large-scale WSNs (MI^{2}T-WSN). MI^{2}T-WSN is designed in such a way as to overcome the drawbacks of existing WSN testbeds. Moreover, it differs from them in several aspects that make it unique as a laboratory. MI^{2}T-WSN is a large-scale WSN that consists of a multi-level infrastructure of indoor and outdoor testbeds. MI^{2}T-WSN is a multi-disciplinary testbed that can be used for several applications and environments. MI^{2}T-WSN can be accessed remotely using a web-based interface. Moreover, it will help other universities and research institutes to build similar or smaller testbeds.

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