Design and implementation of a generic hybrid Wireless Sensor Network platform

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***Abstract*— There exist several platforms of wireless sensor networks. Each of them has specific characteristics, such as hardware and software architecture, for example a processing unit, RAM memory, wireless technology. The complexity of novel application and the number of existing platforms have resulted in the design of hybrid wireless sensor networks. In this paper, we describe the architecture and implementation of a hybrid wireless sensor networks based on the Tmote sky sensor and Fox board platform. They use IEEE 802.15.4/ZigBee and Bluetooth respectively. The paper present a new model of sensor network which is a mixture of the both previous platforms using only IEEE 802.15.4 wireless technology. We have also compared IEEE 802.15.4 and Bluetooth. In this work, a generic platform of wireless sensor networks with several level of sensors has been presented.**

***Index Terms*— wireless sensork networks, embedded system, Bluetooth, 802.15.4.**

I. Introduction

Monitoring remote environments, observing microclimates, surveillance of customer behavior, military observations and other applications are the ways for researchers to explore wireless sensor network technology. This exploration is accentuated by the improvements in the Micro-Electro-Mechanical Systems (MEMS) and wireless communication technologies which make a pragmatic vision of WSN [1], [2]. However, the requirements and the constraints of sensors like energy management have resulted in the design of several different plaform of wireless sensor networks [3] with low power hardware which are not adapted for complex application. One of the most popular applications of wireless sensor networks is observing microclimate changes [4]. Observing changes is a very complex application and a lot of complex data is required. In this paper, we describe a new architecture with different layer of sensor nodes which is a hybrid platform of wireless sensor networks adapted for several areas. The hybrid wireless sensor platform presented in [5] with different types of sensor use different wireless technology for each types. Unlike our platform based on the Tmote sky [6] and Fox board [7] uses the same wireless technology. In general, the wireless technology used for low power sensor like Tmote sky is IEEE 802.15.4/Zigbee except for BTnode [8] which uses Bluetooth. For a powerful computing platforms like Fox board, we have previously chosen Bluetooth to make image transmission [9]. In this work, we have adpated the Fox board wireless interface to IEEE 802.15.4 and compared energy comsumption, plus delay between Bluetooth and IEEE 802.15.4. This paper is organized as follows : the next section is the related works, the description of the system is presented in the section III, a hybrid wireless sensor network plaftorm is described on section IV and experimental results are given in section V.

II. Related works

The recent advance in Micro-electro-mechanical system (MEMS) has enabled several platforms of wireless networks with different characteristics. Each of them has specific characteristics for precise applications. In [10], Hierarchical deployment of wireless sensor network has been defined with different types of sensing. This architecture describes four levels of platforms from the low-level to the high-level sensors nodes. The first level based on Spec node which is a single-chip node, is designed at Berkeley for ultra-low-cost production and low-power operation. This is followed by the generic sensing platform, the most popular today such as Mica2 (2001), Telos (2004) and MicaZ (2004). They are designed for general purpose sensing as described in [11], for agriculture, Mica nodes are used to detect temperature, light levels and soil moisture. Then, the high-bandwith sensor nodes using Bluetooth radio such as iMote developed in 2003 by Intel Research and BT node (2001) [12] . The last platform for high-bandwith sensing, communications, aggregation and gateway is the Stargate platform developed by Intel and sold by Crossbow Technology. In [5], a hierarchical hybrid platform based on MicaZ and Stargate is presented for the surveillance and monitoring of an archaeological site. However, in this platform, two wireless technologies are simultaneously used: IEEE 802.15.4 for both Stargate-MicaZ and MicaZ-MicaZ communications and IEEE 802.11b/WiFi for intra-Stargate backbone communications. In this paper, we present a new hierarchical hybrid platform using the same wireless technology at each hierarchical level and not communication between low-level sensors to facilitate directly data aggregation at the high-level sensors nodes. The Fox board which is the high-level sensors of this new hybrid platform can be adapted to several wireless technologies. That is why we defined it as a generic platform adapted for many applications.

III. System Description

A. The Acme Fox board

The ACME Fox Board has good features to support our sensor networks. The version of the Fox Board used is the

LX 416 with 4 MB of FLASH and 16 MB of RAM. It runs the GNU/Linux operating system on an ETRAX 100LX microprocessor, a 100MIPS RISC CPU made by Axis. The FOX board has two main fields of application:

- as a stand alone device to build a micro web server or other network devices as proxy, router, firewall, etc.
- as a core engine to plug onto a user board instead of a simple microcontroller

The board includes two USB host interfaces to which peripherals such as memory sticks, webcams, Wi-Fi, Bluetooth or IEEE 802.15.4/Zigbee dongles can be connected. A 10/100 ethernet interface provides a high bandwidth communication path and associated TCP/IP services such as a web server, FTP server, SSH, Telnet and the complete TCP/IP stack. The Fox Board *LX416* provide 4 MB of FLASH memory and 16 MB of RAM. Having chosen the computing platform, we focus on the identification of a wireless communication module based on criteria including power consumption, communication range, software support and especially availability in the consumer electronics market.

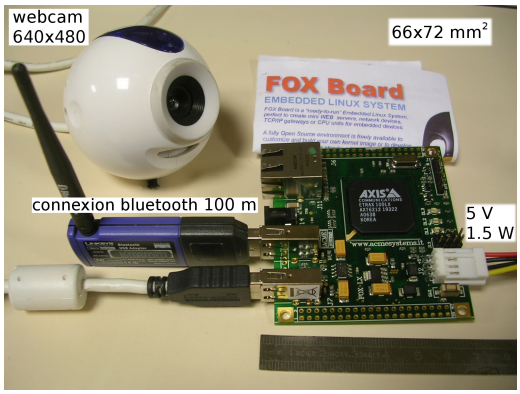

Fig. 1. The Fox Board with QuickCam Zoom webcam (pwc) and Bluetooth dongle

1) Bluetooth wireless technology: We have selected, amongst the various available wireless communication protocols (Wifi, Bluetooth, Zigbee), Bluetooth [13]. There is a tradeoff between availability of USB-Bluetooth dongles, open-source software support and moderate power consumption. Bluetooth is a radio standard and communications protocol primarily designed for low power consumption, originally with a short range based on low-cost transceiver microchips. According to [14], the difference between the Bluetooth standard and other wireless standards is that the Bluetooth specification includes both link layer and application layer definitions for product developers. The standard defines a uniform structure for a wide range of electronic devices to communicate with each other. The improvements of this technology are led by a group of major telecommunication and computer companies organized in the Special Interest Group (SIG). On the communication protocol level, we have worked on the L2CAP layer using the Host Control Interface (HCI), link between software and the hardware, which offers uniform programming methods. For programming with Bluetooth we need to adapt the BlueZ stack [15] to the embedded software development environment provided by the Fox board in order to cross-compile our applications. Bluez is an implementation of the Bluetooth wireless standards specification to support all core Bluetooth protocols and layers. Initially, The Fox board has been designed for grabbing image and transmitting it using Bluetooth.

B. The Tmote Sky

According to [16], Tmote Sky is an ultra low power wireless module for use in sensor networks, monitoring applications, and rapid application prototyping. The Tmote Sky belongs to the family of Telos motes which are USB devices. It is a mote platform for extremely low power, high data-rate sensor network applications. It has several sensors integrated and programming capabilities. For saving energy, it is in sleep mode during majority of the time and wake up as fast as possible to process, then back to sleep mode again. According to [17], it uses a USB controller from FTDI to communicate with the host computer and features the Chipcon CC2420 radio, which is an IEEE 802.15.4 compliant radio providing reliable wireless communication, for wireless communications. The key feature of the Tmote sky is listed below:

- 250kbps 2.4GHz IEEE 802.15.4 Chipcon Wireless Transceiver
- Interoperability with other IEEE 802.15.4 devices
- 8MHz Texas Instruments MSP430 microcontroller (10k RAM, 48k Flash)
- Integrated ADC, DAC, Supply Voltage Supervisor, and DMA Controller
- Integrated onboard antenna with 50m range indoors 125m range outdoors
- Integrated Humidity, Temperature, and Light sensors
- Ultra low current consumption
- Fast wakeup from sleep (<6μs)
- Hardware link-layer encryption and authentication
- Programming and data collection via USB
- 16-pin expansion support and optional SMA antenna connector
- TinyOS support : mesh networking and communication implementation

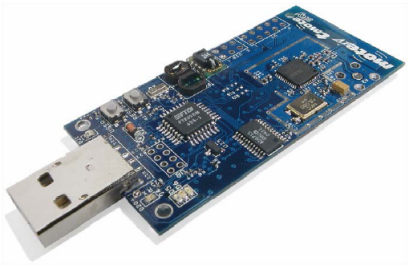

Fig. 2. The Tmote sky [16]

1) IEEE 802.15.4: This protocol offers Medium Access Control (MAC) sublayer and the Physical Layer (PHY) specification for Low-Rate Wireless Private Area Networks

(LRWPAN) [18]. 802.15.4 is designed for low data rate wireless connectivity and devices with no battery or very limited battery consumption requirements. Low rate and power consumption are the key features of Wireless Sensor Network. These features made us choose it for designing WSN. Because IEEE defines only Medium Access Control (MAC) sublayer and the Physical Layer(PHY) on the standard, alliances of companies named the ZigBee Alliance [19] specifie network and application layers (Fig.3) which formed ZigBee, thus the complete protocol stack for LRWPANs.

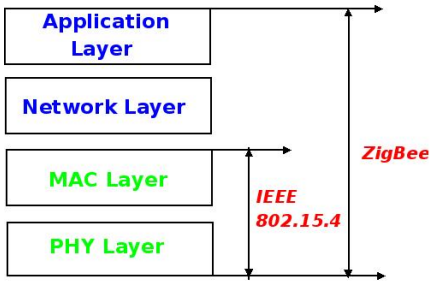

Fig. 3. The IEEE 802.15.4/ZigBee protocol stack architecture

2) Tinyos: TinyOS is an application-specific and event-driven operating system designed for sensor networks with limited resources [20]. The programming language using in TinyOS is nesC [21] which is an extension of C programming language designed for embedded systems. In nesC, programs are built out of components that are wired together to form whole program. The components are linked together by their interfaces. These interfaces are bidirectional and specify a set of functions to be implemented by their providers and users.

IV. The design of a hybrid wireless sensor network

In this section, we present our hybrid wireless sensor network platform based on the Tmote Sky and Fox board. 802.15.4 seems to be an interesting wireless technology which respond to WSN requierement. The Fox board is an generic platform and with its two usb hosts, we can adapt it to 802.15.4 by using integration 802.15.4/Zigbee dongle [22]. Then, we have found a TinyOS environment which support MAC primitives. Open-ZB [23] is an open-source implementation of the 802.15.4 protocol stack on TinyOS. In Fig.4, we show two levels of sensors. The first one is the Tmote Sky which senses environmental data. The second one is the Fox board platform, with high power processing unit, for more complex actions. The low power sensors communicate with the high power sensors using IEEE 802.15.4. Finally, the high power sensors communicate with the base station. The hierarchical hybrid platform defined here facilitates data aggregation when the Fox board receives information from the Tmote Sky and also allows to route data efficiently on Fox board communication backbone until the Base station. Data aggregation is an interesting way to save energy in WSN [24]. We can assimilate this model to a clustering system where the Fox board is a cluster Head and Tmote Sky is a cluster node. In [25], to conserve energy, the cluster head rotates most of the time. That is why to avoid the rotation in our network, the Fox Board, which has a lot of processing to carry out, will be connected to an unlimited power supply. This platform is interesting because it can be adapted to several areas due to the flexibility of the Fox board interface such as multimedia by added a webcam or to change wireless technology.

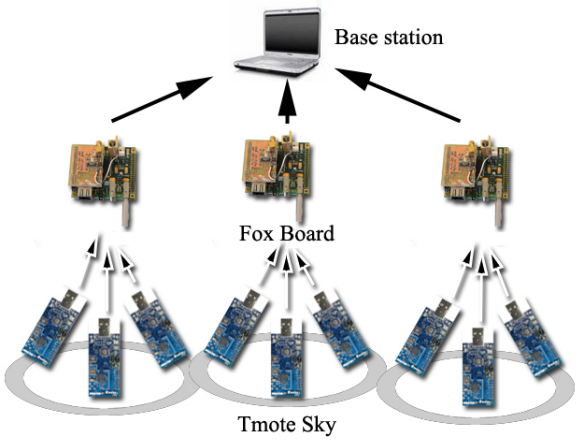

Fig. 4. Hierarchical hybrid plaform of Wireless Sensor Network

A. A network model for implementation

There exist two types of devices defined on the 802.15.4 specification : the first one is the Full Function Device (FFD) which requires a lot of processing power. The other one is Reduced Function Device (RFD) which is an extremely simple devices with very modest resource requierement and can only communicate with one FFD. FFD is capable to act as a PAN coordinator, coordinator, or an end device. An FFD device communicates with both of previous nodes, RFDs and other FFDs. The Fig.5 shows our network model where the Fox board is a FFD, PAN coordinator, and the Tmote Sky is a RFD which transmit data to a PAN coordinator.

Fig. 5. The Fox board and Tmote Sky

The PAN coordinator, according to the 802.15.4 MAC protocol, can select two operational modes. There are the beacon-enabled and non-beacon networks [26]. We have chosen the beacon-enabled networks mode. Between the two types of data transfer models in this mode the data transfers from device to coordinator has been chosen (Fig.6).

This data transfer model has been chosen because it allows to make a comparaison with another wireless technology using the same energy analyser on the Fox board presented in the next section.

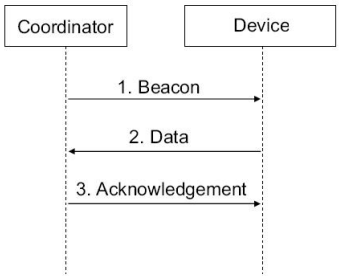

Fig. 6. Data transfert to the coordinator [26]

The design of wireless sensor network is difficult because hardware and wireless technological challenges has resulted in several sensor platforms and several wireless technologies. To solve the problem of hardware choice we have designed a hybrid wireless sensor network with several levels of sensors. But there is a dilemma, 802.15.4 is always better than Bluetooth for WSN? We thought it would be good to compare 802.15.4 and Bluetooth.

V. Experimental results

In this section, we describe the results obtained during the transmission of test data using on the one hand 802.15.4 and on the other hand Bluetooth. We focused just on energy consumption and transmission delay for the comparison. Comparison between board on Fig.5 and Fig.7 shows that we haved added on our experimental Fox board (Fig.7) several devices including GPS receiver to report the position of the Fox board, plus energy analyser to report current consumption of the Fox board.

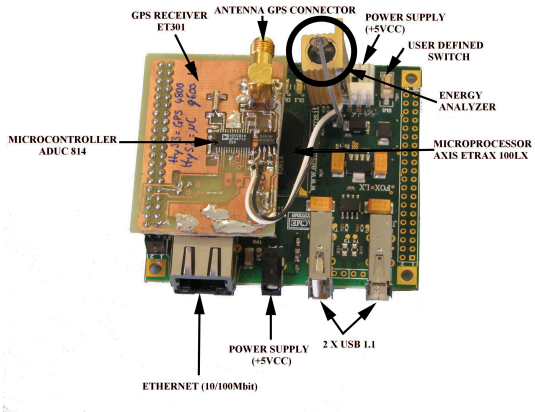

Fig. 7. *The Fox board with GPS and energy analyser*

The energy analyser on Fig.7 facilitate the study of the energy consumption of Bluetooth and IEEE 802.15.4.

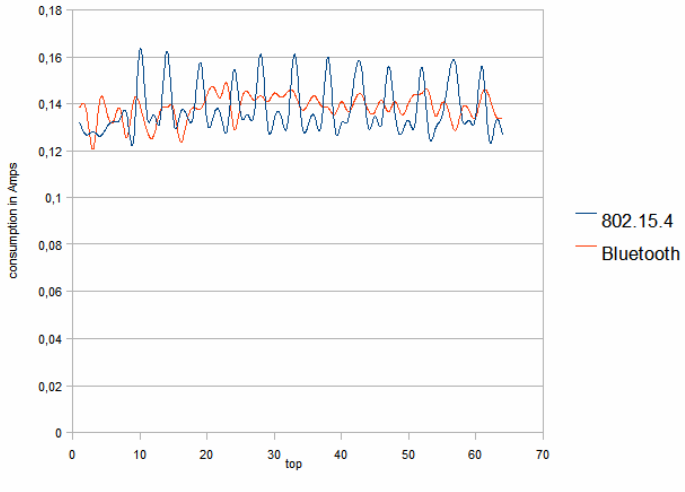

Fig. 8. *Energy consumption of the Fox board with 802.15.4 and Bluetooth*

The previous graph shows the energy consumption of the Fox board when we received continuous data stream from the Tmote Sky and laptop using respectively 802.15.4 and Bluetooth. By default, the Fox Board without activities use about 0.12A. We can see that there is a lot of peaks (0,16A) and it goes down about 0.12A with 802.15.4. We noticed that energy consumption of Fox board with Bluetooh is constant about 0.14A. The comparison between Bluetooth and 802.15.4 energy consumption shows that Bluetooth consumption is constant while IEEE 802.15.4 uses more energy with its peaks and goes down rapidly. These results show that constinuous data stream transmission using 802.15.4 is not better than Bluetooth. We can conclude that it is not only the choice of 802.15.4 wireless technology which permit to save energy but also the way to use the different modes. Indeed, to conserve energy, 802.15.4 devices need to be on sleep mode most of the time and wake up quickly to transmit and/or receive data and go back to sleep mode [27]. However, in this experiment we have changed constinuously the sleep mode on active mode and go back on sleep mode that is why we have not noticed the 802.15.4's energy consumption advantage compared to Bluetooth.

Comparison between Fig.9 and Fig.10 shows that there exist a very great difference between Bluetooh and IEEE 802.15.4 delay. About each 20 ms the messages are sent with Bluetooth while 802.15.4's delay between two messages is generally about 7000 ms. Indeed, for saving energy, the Tmote Sky is on sleep mode the majority of the time and wake up very quickly, about less than 6μs, to transmit data and go back in sleep mode. This feature used by the Tmote Sky and the transmission speed of each wireless technology mentioned above explain the network latency of 802.15.4 compared to Bluetooth where the devices are always on active mode. All of these previous experiments emphasize the importance of the sleep mode in 802.15.4.

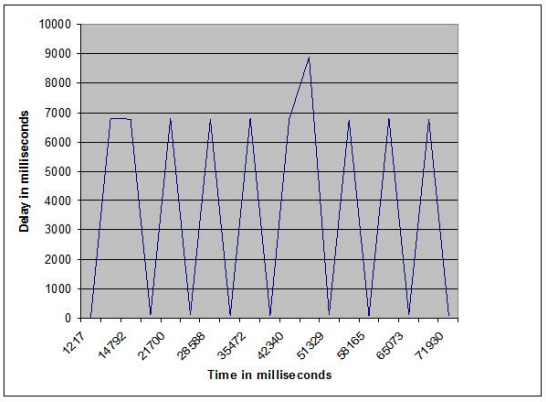

Fig. 9. *Delay transmission of the Fox board with IEEE 802.15.4*

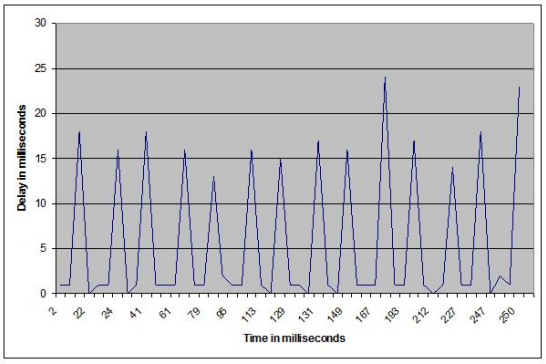

Fig. 10. *Delay transmission of the Fox board with IEEE Bluetooth*

For these small number of tests employed, named energy and delay, Bluetooth is a clear winner. However, other question such as Bluetooth scalability is a complicating factor in the selection of a wireless technology.

VI. Conclusion

In this paper, we have shown a new hybrid model of wireless sensor network plaform. This platform describe two levels of sensors with different abilities which is a generic platform adapted for many application. A new high-level sensor nodes based on the Fox Board platform is described on this hierarchical architecture where the Tmote Sky platform is a low-level sensor nodes. The flexibility of the Fox board platform which has usb host interfaces permit to change easily wireless technology in our network. We have compared two wireless sensor technologies. Experimental results shows that while IEEE 802.15.4 is adapted for WSN, Bluetooth offers interesting features better than IEEE 802.15.4. These results also show the importance of sleep mode power consumption in 802.15.4. We have constinuously used 802.15.4 and the active/sleep mode change frequently during the experiments use a lot of energy that is why we have not noticed the 802.15.4's energy consumption advantage compared to Bluetooth. The paper have demonstrated the tradeoff between advantages and disavantages of platforms and technologies selected.

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