AN ARCHITECTURE FOR ENVIRONMENTAL MONITORING AND CONTROL IN MUNICIPAL SCALE

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Abstract: Advances in smart sensors, communication technologies and embedded computing allow to have an interaction between digital and physical worlds. This paper presents an architecture of combining ZigBee with Metropolitan broadband access networks in order to build an architecture for monitoring and control in a municipal scale. A prototype alarm system was implemented based on this architecture as a proof of concept. However there is a wider range of applications that can be designed using this architecture to provide reliable services for government and communities.

1 INTRODUCTION

City environments monitoring and control represent a class of municipal services with huge benefits for city management, government administration and society as a whole. The focus of this work is to present an architecture to integrate physical characteristics from the real world with computing systems through sensor and actuator networks, and devices connected in a metropolitan broadband access network (MBAN) to reach municipal scale.

Our proposed architecture uses the ZigBee standard for implementing sensor and actuator networks in a small scale that are connected through a gateway to the metropolitan broadband access network enabling to gather information and send commands to devices inside the environments from anywhere in the city.

ZigBee is a wireless technology for inexpensive, short range networks, ideal for control of a large number of devices and machine to machine communication over a network. Traditional sensors are not able to obtain particulars inputs and reporting the data in real time and with high spatial density as sensor networks are able to do (Horton and Suh, 2005). Due to these characteristics mentioned, ZigBee is largely used into field of automatic control, energy monitor, light control, home security, remote control and smart environments creation.

In this paper we present an architecture for monitoring and control in the city environments. We also describe some possible services that could be applied in city environments. An alarm system implementation based on our architecture is also presented, which is being developed in the city of Pedreira, Brazil. The next section presents related works and successful case studies. Section 3 introduces a background of metropolitan broadband access networks and the structure of the ZigBee standard. Section 4 describes in more detail the proposed architecture. Section 5 presents the implementation of an alarm system as a proof of concept. Finally, the last section presents the conclusions and the future works.

2 RELATED WORKS

Other works such as (Gniadek et al., 2008), (Morreale, 2008) and (Mainwaring et al., 2002) also implement sensor networks for environmental monitoring. Gniadeck (2008) presented their experience in building an infrastructure of combining ZigBee with Web Services for remote accessing and control of a network. A framework was developed based on above infrastructure to implement a traffic monitoring system.

Other implementation for traffic monitoring can be found in (Morreale, 2008), Street Corners network was deployed on the Kean University campus, which

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is a network architecture to integrate active and passive sensors information gathered from urban environmental sensing networks. Their implementation uses sensors from Crossbow Technology, Inc., that includes IEEE 802.15.4/ZigBee compliant processors.

Mainwaring (2002) presented a system architecture for real-world habitat monitoring, specially to monitor seabird nesting environment and behavior in a small island off the coast of Maine called Great Duck Island.

Discussions about design and metropolitan broadband access network implementation can be found in (Alexiou et al., 2005) and (Balhoff and Rowe, 2005). Case studies and successful deployment results of MBANs are presented in (Ford and Koutsky, 2005) and (Kramer et al., 2006).

We also propose an architecture for environmental monitoring which has some relations with mentioned works. However, our proposal presents considerable differences and benefits such: Two way communication system, where monitoring and also control over the environment can exist. Municipal scale monitoring and control, the area covered by this infrastructure is highly large. Diversity of services that can be offered to cities, the proposed architecture can be deployed in a wide range of environments, bringing to cities technology and comfort to its society.

3 TECHNICAL OVERVIEW

3.1 Metropolitan Broadband Access Network

A Metropolitan broadband access network can be defined as the integration of services, applications and the infrastructure of a communications network of a city. It works with high bandwidth transmission capacity and can support information from a wide range of services, all based on the Internet protocol (Mendes, 2006).

A MBAN can be classified according to the three layers model presented in Figure 1 (Miani et al., 2008).

A Metropolitan broadband access network can be based on four technologies: optic, wireless, dedicated access (e.g. ADSL, cable network and frame relay) or hybrid. The limitation of resources and the demand for transmission capacity are some factors that can be used to choose one of these technologies. A MBAN can also be classified according to the type of the points connected. There are three categories of connections: i) public buildings (schools, hospitals, etc); ii) private buildings (companies, industries); and iii) residences.

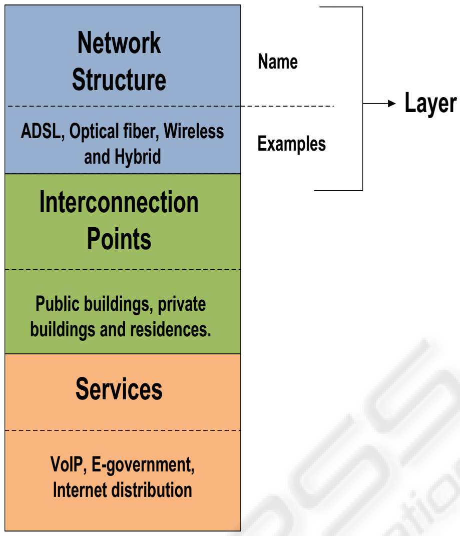

Figure 1: MBAN classification model.

Once the infrastructure is ready, several services can be made available for the metropolitan network users, as shown in (Ford and Koutsky, 2005) and (Bauer et al., 2002). Some of these are: Internet distribution, VoIP, e-government systems, information programs for education departments, and video sharing systems.

3.2 ZigBee and IEEE 802.15.4

ZigBee is a wireless communications standard managed by ZigBee Alliance, a group over 170 companies creating ZigBee related semiconductors, developing tools and products. Solutions adopting the ZigBee standard are embedded in consumer electronics, home and building automations, industrial control, sensor networks and so on. The ZigBee stack architecture is separated in a set of blocks called layers. Each layer performs a specific set of services for the layer above (ZigBee-Alliance, 2008).

The IEEE 802.15.4 standard defines the responsibilities of the physical (PHY) layer and medium access control (MAC) sub-layer. IEEE 802.15.4 has two physical layers that operate in two different frequency ranges, 868/915 MHz and 2.4 GHz. The MAC sub-layer controls access to the radio channel using a Carrier Sense Multiple Access/Collision Avoidance (CSMA-CA) mechanism. MAC layer responsibilities may also include transmitting beacon frames, synchronization, and providing a reliable transmission mechanism. The ZigBee specification defines the network (NWK) and application (APL) layers (Gutiérrez, 2007). Figure 2 briefly describes relevant layers and related information.

Figure 2: ZigBee stack architecture.

ZigBee was designed for low power applications and it fits well into embedded system and those markets where reliability and versatility are important but high bandwidth is not. Low power consumption enables to deploy ZigBee devices and sensors in wider areas where power supply is not presented offering extended battery life. ZigBee also offers support of large network size comparing to other technologies, it has the capacity of supporting over 64000 devices within a network, which makes it possible to deploy sensor at a very high density, which is essential to certain applications such as monitoring and control in a large scale.

4 SYSTEM ARCHITECTURE

Interfacing to the physical world involves exchanging energy between embedded devices and their environments. Usually, each device is either a sensor node or an actuator node. Sensor nodes translate a particular form of energy or a phenomena (light, heat, vibration) into information. Actuator nodes convert information into action over the environment around them (Estrin et al., 2002).

As stated earlier, the proposed architecture combines ZigBee wireless technology with Metropolitan broadband access network in order to create a large sensor/actuator network to monitor and control city environments such as hospitals, schools, health centers, government buildings, streets and other public spaces. This architecture allows an interaction between physical characteristics from real cities with computational tools, resulting in a system where information from real environments can be accessed and manipulated by specific communities, government employees, and also to be used to create smart environments.

The architecture lowest level consists of the sensor/actuator nodes that interact directly to the environment based on their physical characteristics. Nodes may be deployed around the environment in a large number. The sensor nodes transmit their data through the ZigBee network to the network gateway. The gateway is responsible for transmitting sensor data from the sensor patch through the Metropolitan broadband access network to the remote base station where a software application processes the data and finally such information is displayed to the users through an user interface. The same happens with the actuator nodes, however in an opposite way, data is transmitted by user commands from remote base stations to the actuator nodes which respond the request with actions over the environment. The architecture is depicted in Figure 3.

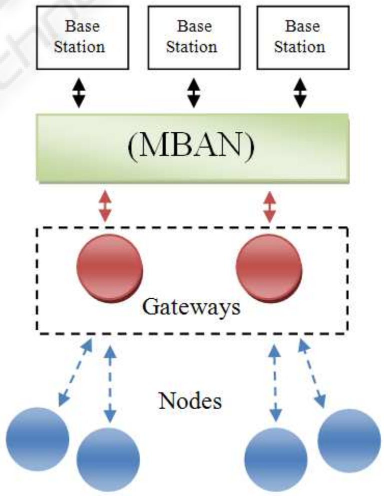

Figure 3: Architecture model.

The number of remote base stations probably will increase in parallel with new services. This reason is because different environments should be monitored and controlled by different people or companies. For example, informations about all health centers should be concentrated in a base station where people are capable to monitor and control these environments. Information about traffic monitoring should be transmitted to its specific base station and so on.

4.1 Services

A wide range of services can be developed using the proposed architecture, and the most of them can be used for government administration proposal. Depending on the cities needs new environmental monitoring and control solutions can be developed, improvements in existing infrastructures can be made to achieve a high spatial resolution, artificial intelligence can be applied in some cases creating smart environments with a certain level of autonomy.

5 CASE STUDY: ALARM SYSTEM

In our deployment, we are using XBee OEM RF Modules from Digi International, Inc. to develop an alarm system in Pedreira, a city localized in south east of Brazil. Pedreira has a Metropolitan broadband access network since 2007, it was a project developed in agreement between the State University of Campinas (UNICAMP) and the government of Pedreira. The network infrastructure is constituted by a optical backbone and wireless digital radio communication as presented in Figure 4, which connects the city health centers, hospitals, schools and other important buildings.

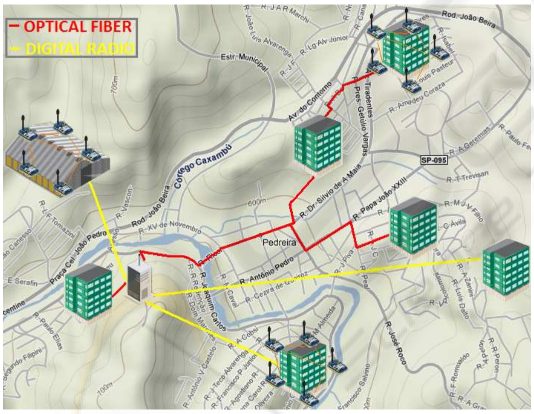

Figure 4: MBAN of Pedreira.

The XBee OEM RF Module was engineered to meet IEEE 802.15.4 standards and support low-cost, low-power wireless communication. The module operates within the ISM 2.4 GHz frequency band. It can operate in different topologies either point-to-multipoint or ZigBee/Mesh topologies, depending on the firmware configuration inside the module and for what application is destined (Digi, 2008).

The gateway was developed using the same module described above using an USB interface board, which takes all data collected from nodes around the environment and by a computer software transmits all information through a TCP connection over the MBAN to a remote base station. For software implementation was used JAVA language. The OEM RF Module and the USB interface board is presented in Figure 5.

Figure 5: USB interface board.

The nodes embedded around the environment use the same OEM RF Module to communicate with the gateway. The module is mounted in a manager board presented in Figure 6, which is used to implement sensor and actuator nodes, this solution also enables to collect information from other instruments through serial interfaces RS232, TTL 5V and TTL 3.3V, where data gathered is transmitted via ZigBee network to the gateway.

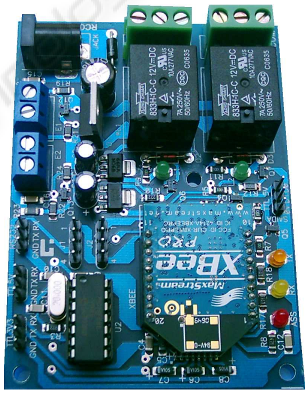

Figure 6: Sensor and actuator board.

The alarm system is being implemented as a proof of concept which consists of two motion sensors that monitor intrusion in a public building from the city of Pedreira. The sensors are spread through the environment, when a minimal motion is sensed by one of the sensors a signal is sent to the gateway. The gateway collects the signal and forwards a message over the MBAN to a base station localized in other building inside the city. The user interface receives the message, processes it and alerts the user that one of the sensors was activated. Also the user has the possibility to control a device inside the environment in anytime.

6 CONCLUSIONS

City environments monitoring and control represents an important class of municipal services and an interesting application of sensor/actuator networks in municipal environments. Our proposal differs from other works specially for offering control over the environment instead of just monitoring. Another benefit is the large scale infrastructure provided to cover city areas and the diversity of services that can be integrated in municipal scenario.

Our alarm system is the first implementation for monitoring and control in such infrastructure. However, future works are expected which includes the design and implementation of new applications, development of new hardwares for specific tasks, creation of a platform to group data from related environments in order to organize the base station and the types of monitoring and control. Pervasive computing also are being studied to be applied in some future implementation to achieve a certain level of intelligence in public spaces.

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