Wireless Information Systems in Support of Green iSchools

Yuttasart Nitipaichit
Graduate Program in
Telecommunications and Networking
University of Pittsburgh
yun11@pitt.edu

Aylin Aksu
Graduate Program in
Telecommunications and Networking
University of Pittsburgh
aya8@pitt.edu

Maria Calle
Graduate Program in
Telecommunications and Networking
University of Pittsburgh
Universidad del Norte
mgc8@pitt.edu

Joseph Kabara
Graduate Program in
Telecommunications and Networking
University of Pittsburgh
jkabara@pitt.edu

ABSTRACT

Becoming a green iSchool requires information infrastructure development. Wireless information systems are important for information infrastructure development. This paper assesses how wireless information systems can support creating green iSchools. Wireless information systems can be built from wireless networks such as Wireless Local Area Networks (WLANs), Wireless Wide Area Networks (WWANs), and Wireless Sensor Networks (WSNs). Wireless networks can reduce the fossil fuel combustion from transportation while using fewer infrastructures than wired networks. A WSN can otherwise help increase energy efficiency for school buildings. With low cost energy efficient sensor nodes placing at multiple locations, data gathering can be more effective. And this in turn helps energy use in a school building be more efficient.

Keywords

Green school, green society, environment, global warming, wireless infrastructure, wireless information system, wireless network, sensor network, location estimation, mobile device, energy conservation, energy usage, waste management, paperless solution.

1. INTRODUCTION

An emerging environmentally sustainable society has influenced the broad research community to address environmental issues, in all aspects of research. One general concern is rising CO_2 emissions due to the development of industrialized nations and the growth of world population [1]. Fossil fuel combustion contributes more than 90% of CO_2 into the atmosphere [1]. Transportation and electrical energy generation are among the major sources of CO_2 emissions. In addition to CO_2 emissions waste disposal is another environmental issue. As the world population increases, so will the amount of waste generated. Current estimates are that the average office worker prints and disposes of 10000 pages of paper each year [6]. Moreover, the U.S. Environmental Protection Agency (EPA) estimates that more than 400 million ink and 100 million toner cartridges end up in landfills each year. Additionally, the cost of manufacturing, delivering, printing, and disposing the paper and toner cartridges must be included. Recycling can improve the efficiency of this process, but still requires the collection and reprocessing of the used materials. The disposal of refuse in the world is a problem that continues to grow with the development of industrialized nations and the growth of population. A green iSchool concept requires moving toward ecologically sustainable directions which should include at least these two objectives: conserving energy and reducing the amount of waste that goes to the landfill.

If iSchools will use electronic distribution of information to reduce their environmental impact, the distribution system itself must be designed to minimize energy usage, maximize the reuse of materials and operate in an economically attractive manner. One means of conserving energy and reducing waste is the use of wireless information systems, since the information need not be transported on a physical media (paper, disk) to users. Instead, users can access information from anywhere. Additionally, wireless networks are one means to overcome the “last mile” problem, since they require less wiring than wired network networks, reducing the amount of materials used to build the network [8].

However, if wireless information systems are to reduce the use of fossil fuel, the networks must use electrical energy as efficiently as possible. Approximately 70% of electric energy generated in the US employs a fossil fuel at the energy plant e.g. coal, natural gas, or petroleum [25]. Thus, to support the green concept, the design of wireless information systems must also consider energy efficiency. Recently, there have been efforts from wireless manufacturers to support the green concepts, e.g. the use of wind and solar energy for wireless base stations [16]. Additionally, an effective capacity planning can also help save energy [2], [3], [37].

Besides wireless information systems, green concepts can be extended to computing resources in an iSchool. Consider the case of computers used in an iSchool or company. Servers require 1 watt of cooling for every watt of power used for processing [22]. Therefore, energy efficient network design and effective capacity planning save electrical energy consumed by wireless network equipment in a school building and also save energy required for air conditioning units to pump the heat generated by the equipment out of the building.

Mobile devices can be another important part of wireless information systems. To support the green concept, one must consider using suitable mobile devices. For example, laptop computers, which use energy aware hardware and software to maximize battery life, can be used to replace more energy intensive desktop computers [36]. Additionally, digital books can also reduce the use of paper which in turn reduce the amount of waste and conserve energy from the process of paper production such as cutting trees, transporting to a factory, etc [9]. Supporting green iSchools requires the integration of these components efficiently and user-friendly.

Additionally, estimating the location of mobile devices such as laptops with wireless, or phones with Bluetooth (BT) communication ability, can also support a green iSchool. The location of devices can create services where users can use information from the nearest source. Moreover, indoor location estimation can be used to find the best access points so that wireless devices will use less energy and, in turn, will have longer lifetime. Therefore, using mobile devices and indoor location estimation techniques together can reduce the overall energy usage.

2. Mobile Devices

As wireless information systems are important for green iSchools, they also require mobile devices. Using mobile devices is energy efficient since most of them are designed with energy management functionalities to maximize useful battery life. However, all electronic devices require an effective recycling program. There exist several types of mobile devices, each designed to support different user needs. Mobile devices for green iSchools can be classified into three categories: Handhelds, Laptops, and Digital books.

2.1 Laptops

Laptop computers now employ specialized integrated circuit (IC) technology, newer CPUs operate at low voltage resulting in reduced energy expenditure rates. Additionally, to maximize time between recharging, laptop computers implement sophisticated energy management schemes [11]. As a consequence, laptop computers use much less energy compared to desktop computers.

Laptop computers can replace desktop computers for most of the school and office applications such as word processing, spread sheet, web browsing, etc. Since laptop computers use much less energy than their desktop counterparts, in addition to offering mobility, they can be part of greening of iSchools.

Most laptop computers also have Wi-Fi capability, allowing better mobility and saving additional energy if a school also has a WLAN (Wireless Local Area Network). For example, during summer, students or faculty do not need to work in office but they can instead bring their laptops to work at a school patio outside the building which in turn helps saving energy from lights and air conditioning.

2.2 Handhelds

Previously, handheld devices were bulky, energy hungry, and had limited functionality; thus, a Personal Digital Assistant (PDA), cell phone, and positioning system (GPS) required three separate units. The separate units also caused a waste disposal issue since one user requires multiple devices in order to have all functionality. However, these features are now often integrated into a single unit capable of high speed data transfer, web browsing and GPS location tracking [7]. Handheld devices offer more mobility but less computational capability compared to laptop computers. However, handheld devices have been designed to conserve energy so that a user can use them longer between recharging. Since longer battery life is preferable to all users, handheld device manufacturers have to comply with this feature in order to compete in the market. Therefore, handheld devices are another component capable of supporting a green iSchool.

2.3 Digital Books

Recently, digital books had become popular as the electronic paper display technology (or e-Ink technology) is commercially available. Electronic paper displays (EPDs) differ from other types of displays. First, EPDs employ polarized ink molecules, giving them a paper-like high contrast full view angle appearance [24]. Second, EPDs are bi-stable and use very low energy. EPDs do not use energy while showing static text or pictures in the display but only need energy during display transition e.g. during webpage loading or page turning. Therefore, the battery life of devices that use EPDs will last longer when using applications that keep the display steady for a long time such as reading digital books. Lastly, EPDs have a thin and lightweight form factor allowing digital book devices to be thinner and lighter than many laptops. Thus, digital books equipped with EPDs enable readers to feel more comfortable while reading and holding a digital book in their hands.

Using digital books can support the green concept since they use less energy and help reduce the use of paper in schools. As an example, all assignments and class lecture documents can be in digital format. Moreover, students will likely use school printers less often to print out academic papers that is available in digital format since they have no trouble reading them directly from digital books because of its paper-like property. Additionally, a digital book can store thousands of electronic books allowing users to store as many digital documents as they would like without having to carry heavy bags full of books.

3. Wireless Networks

Laptop computers and other mobile devices supporting green iSchools, require wireless networks to support wireless information systems. Wireless information systems can be built from Wireless Local Area Networks (WLANs), Wireless Wide Area Networks (WWANs), and Wireless Sensor Networks (WSNs). Figure 1 depicts the overall architecture of a wireless information system for green iSchools.

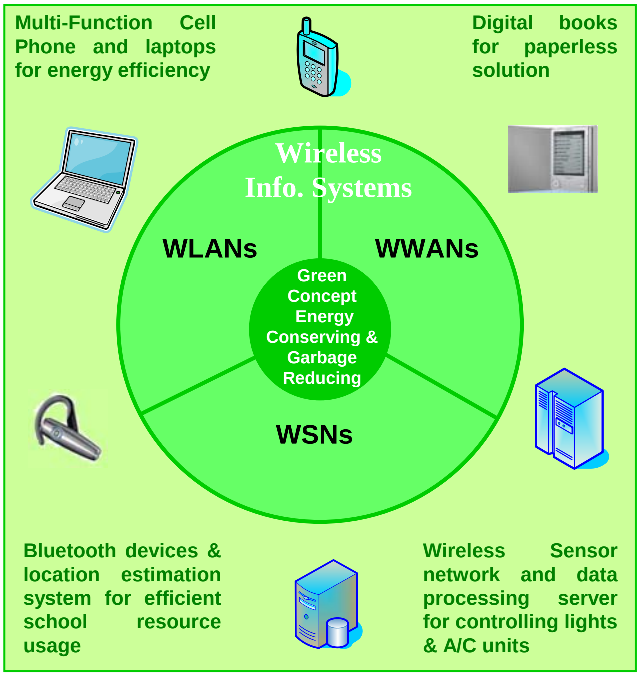

Figure 1. The overall architecture of wireless information system infrastructures for green iSchools.

3.1 Wireless Local Area Networks (WLANs)

As WLAN devices become cheaper, smaller and faster, there has been a significant growth in the number of people who use WLANs. WLAN services have now become mandatory in many schools. Compared to conventional wired LANs (Local Area Networks), WLANs can provide mobility without losing the speed demanded by the users. 802.11g WLANs typically provide speeds of 54Mbps and 802.11n WLANs speeds of 600 Mbps, compared to wired LAN speeds of 100Mbps or 1000Mbps [32-35].

Additionally, a WLAN uses an access point (AP) to connect without cabling to multiple users. Each access point has an average range about 30m indoors and 70m outdoors [31]. Therefore, WLANs are suitable in hot spot areas such as the school building, library, etc.

A WLAN can make an iSchool greener since it offers mobility and uses less infrastructure materials compared to LANs. However, early generation WLANs are not designed to be energy efficient since WLAN access points were designed solely for maximum speed and implicitly assumed unlimited energy resources. Currently, energy efficiency of WLANs varies depending on factors such as WLAN card design, hardware interaction, software, protocol design, etc [13]. The key issues to support a green iSchool are to employ WLAN protocols which help conserve energy, and to build networks which require minimum transmit power. Additionally, network protocols use more power to mediate channel access, if sufficient capacity does not exist [31]. Capacity planning and energy efficient design of WLANs are also key issues to supporting a wireless information system in a green iSchool. We can use capacity planning using a demand-based design to achieve this goal. Section 5 describes this capacity planning design in more detail [3].

3.2 Wireless Wide Area Networks (WWANs)

WLANs can be used for indoor networks and small outdoor networks, but they are not suitable to support large service area because of their limited coverage [31]. Wireless information systems will be much more useful if the coverage area is large allowing users to access information anywhere and anytime. We consider WWANs are suitable in this case.

Even in the recent past, WWANs were limited to voice communication only which might not be useful for wireless information systems. However, WWANs are now available for both voice and high speed data communication allowing various types of applications such as email, internet, etc. However, compared to that of WLANs, the speed of WWANs is still limited even when using the high speed third generation network (3G network). Thus, when higher bandwidth is demanded, collaboration with WLANs is still necessary.

WWANs use base stations (BSs) as a central point for connecting to mobile devices. WWAN's BSs have larger coverage area than WLAN's APs but it is still limited. The size of coverage area for each base station depends on many factors such as the environment and territory type, the radio power transmitted, etc. Consequently, to cover larger service area WWANs require several BSs. Even though the use of green energy such as wind and solar energy for wireless base stations is currently available, they are still expensive and limited. One critical constraints of WWANs is the amount of energy required to transfer information. The amount of energy required is an exponential function of the distance between a mobile device and its BS. Therefore, to maximize energy conservation, an efficient capacity planning such as demand base wireless network design must be employed [2].

3.3 Wireless Sensor networks (WSNs)

While WLANs and WWANs distribute data, a Wireless Sensor Network will measure the environment and produce data. A Wireless Sensor Network (WSN) is built from nodes (computers) with the following properties: ultra low power consumption, small size, limited computational capability, and low cost devices [30]. Recent technology in electronic devices has enabled the development of advanced wireless sensor nodes that have smaller size, lower power consumption, and even higher computational capability. Since WSNs are easy to deploy, they can be used for various applications including environment monitoring [26], structural monitoring [27], medical care [28] [29], disaster surveillance system [28], etc. Modern wireless technology advances make development of WSNs more feasible than it was in the past and their versatility makes WSNs increasingly interesting.

Wireless information systems can include WSNs to collect information and Wireless LANs and WANs to disseminate information. WSNs can help to increase energy efficiency, since they can be used for building environment monitoring. Consider the case of sensor nodes placed to collect data such as room temperature and the number of people in the room [30], [38]. Data can be used to control air conditioning units and lights in a building. Placing low cost energy efficient sensor nodes at multiple locations makes data gathering more effective and done with a smaller environmental impact than wired sensors.

4. Sensors and Actuators

A general definition of a sensor is a device that responds to a physical stimulus, such as heat or sound, and transmits a result. A WSN is built with small devices able to respond to one or several stimuli and transmit the information using a radio link [12]. Sensors use electronic circuits that minimize energy usage [4].

Information gathered by the sensors can be used to modify the variable they are measuring using actuators, which are devices able to manipulate some other devices. Recall the previous example of monitoring the temperature and lights in classrooms. Connecting actuators to switches in classrooms allow turning the lights on or off, according to the information generated by the sensors.

4.1 Sensor Motes

Sensor Mote is the generic name given to a node in a WSN. Motes are small computers with limited processing capability, a small memory and limited energy supply. Motes can transmit the information they collect over short distances via radio [12]. Figure 2 shows one example mote, Crossbow's Mica2, with the three main parts of a Mote: the upper part contains the sensors, the middle level has the processor and the radio and the lower part is the space for batteries.

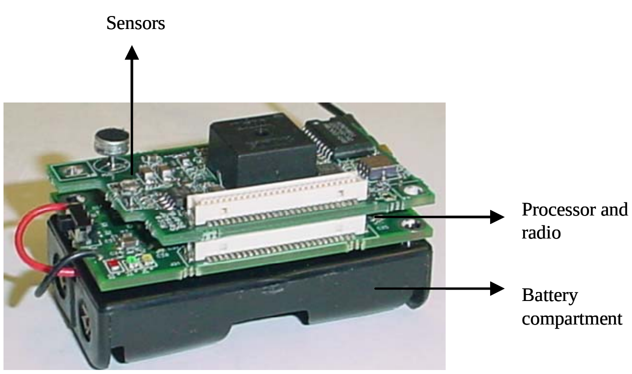

Figure 2. Components in Crossbow's Mica2

A WSN may use hundreds of nodes in a particular application, e.g. to adequately monitor all classrooms in an iSchool. These motes must be designed to last for years. The important issue to support a green iSchool is directly related to extending mote lifetime. Additionally, motes can also harvest energy from different sources, such as light to increase lifetime. However, harvesting systems are limited and motes at this stage in technology development cannot work indefinitely, thus WSNs must be designed to conserve energy as much as possible [12].

4.2 How they use energy

Motes use energy for different tasks, and analyzing energy usage in each of them allows WSN designers to employ energy in the most efficient way possible. Recall all motes have at least a sensing device, a small computer and a radio communication circuit. Each component uses energy according to the particular functions it must perform and the hardware used for executing the operation.

Consider again the temperature sensing application in the classrooms of a green iSchool. A WSN may inform when the temperature in the classroom falls below a certain limit comfortable for people, such as 20 degrees Celsius. A variation in temperature of 2 degrees may still be comfortable for people in the classroom, thus the measurement does not require to be very precise or very often, and the application may be implemented with simple devices. The opposite situation occurs in a processing food factory where a difference of 2 degrees in temperature may be enough to damage or change the quality of particular items. The example probably requires more advance motes which may then use more energy if they need to work often in order to keep a precise monitoring of the situation.

The goal in the implementation of a WSN is to fulfill the task required (e.g. temperature monitoring) while maximizing the network lifetime. To achieve this goal, WSN designers need to estimate the energy used by each element in the network and they do that using energy usage models.

4.3 Models for Energy Use

The models contain information necessary to calculate energy spent by motes when performing different tasks. The models describe energy usage by the processing, sensing and radio parts of the mote. One example model assumed that the radio consumes the most significant amount of energy, thus neglecting the processing and sensing parts [13]. However, it is not clear if there are actual hardware devices whose energy usage is accurately modeled by this work [14].

Other models perform measurements on particular hardware motes in order to determine the energy usage by all parts. One example of these models shows results for Mica2 [15]. The model estimates energy usage by the sensors, the CPU and the radio executing different functions such as transmitting and receiving data.

5. RESULTS

To maximize the energy efficiency of wireless data systems, the supporting networks must be designed so that data is transferred with the minimum amount of energy. This section describes some of the methods necessary for building an energy efficient wireless data system, including, placing WLAN APs, determining user locations and protocols for sensor networks.

5.1 WLAN design

All laptop computers in a WLAN connect through a device called Access Point (AP). To conserve energy, the number and location of APs in an iSchool requires planning which must consider service availability and demand on the network. Thus, a WLAN must cover all floors in the iSchool and the network should support as many users and applications as required. Additionally, the type of WLAN devices must also be energy efficient.

To summarize, the design should include the following information:

- Energy efficient devices
- Physical properties of the service area (e.g., building size, room environment, amount of different rooms)
- User traffic information (e.g., user location, user activity level).
- Characteristics from the building affecting wireless signals, such as construction materials and floor layouts.

- Wireless signal interference from neighborhood.

Demand-based WLAN design is an example of this design. The task of demand-based WLAN design is to place a sufficient number of APs to cover a given service area [3]. The technique uses heuristic solution techniques and parameters such as transmit power level, frequency channel of an AP, environment type, and traffic demand to/from wireless users, to determine the number of access points and their configuration for WLAN setup in iSchool buildings. We present a technique to determine the minimum number of APs required to provide an adequate level of service to the users. The technique was tested considering WLAN traffic demand on the fourth and fifth floors of the School of Information Sciences at University of Pittsburgh.

The demand-based design model and the developed heuristic solution technique result in a network employing five APs. Based on traffic demand, three of the APs (AP1, AP2, and AP3) are located on the fourth floor. Two APs (AP4 and AP5) are located on the fifth floor. The basic service area (BSA) of each AP is shaded in a different color, and each color is associated with the frequency channel assigned to that AP. Green, blue and pink represent the BSAs of APs operating at channels 1, 6 and 11, respectively. Figure 3 presents signal coverage from three APs located on the fourth floor to the area of the fourth floor while Figure 4 presents signal coverage from two APs located on the fifth floor to the area on the fourth floor.

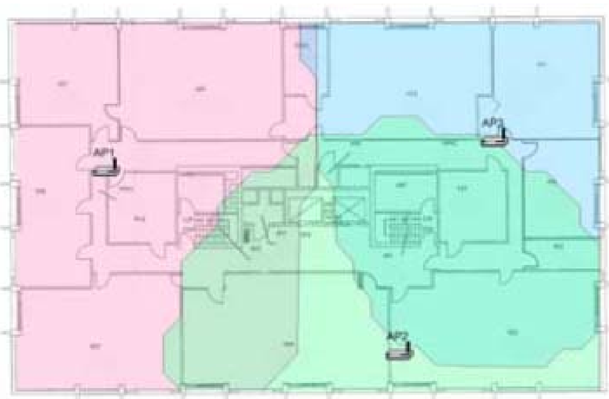

Figure 3. Signal on 4th floor from 4th floor

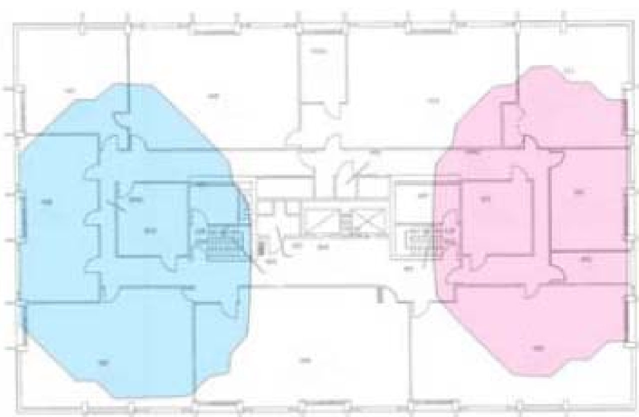

Figure 4. Signal on 4th floor from 5th

The process of assigning frequency channels in the heuristic solution technique coordinates the channels assigned to APs on different floors to limit interference in the network. Figure 5 depicts overall signal coverage on the fourth floor. The signal penetrating from each floor is superimposed on the contour plot of the other floor. The demand node assignment is represented by different colors as listed in Figure 5. For example, the demand node assigned to AP1 is green, and the demand node assigned to AP2 is blue. We can see that the pink demand nodes on the fourth floor are assigned to AP4 on the fifth floor [3].

Figure 5. Overall signal coverage and demand node Assignment on the 4th floor

5.2 Wireless Sensor networks

We implemented a WSN using Mica2 motes in the School of Information Sciences at University of Pittsburgh, in order to test the energy usage of the motes [12]. An energy usage model was created based on measurements of the Mica2 hardware platform when the radio was *On Transmitting* (OT), *On Receiving (OR)* and *Off*. The model reveals for this particular platform the energy required for transmitting is roughly twice the energy required for receiving. Additionally, energy usage from the CPU is one thousandth of the energy required for communication [14].

The lifetime of the network depends on the application and the communication schemes used. Experiments employed the Gossip-based Sleep Protocol (GSP) transmitting information 12 times per second, which may be useful in applications such as the food processing example [5]. According to our estimation for this application, one Mica2 mote using 2 AA batteries, 1200 mAh each, has a lifetime close to 66 hours, so the motes are dead in less than three days [12]. Our future work includes improving GSP to make it more energy efficient.

5.3 Using Indoor Location Estimation Techniques

Consider the scenario depicted at Figure 6. The student wants to reach an online book at the library database. Upon estimating her laptop's location, the wireless system at the school connects her laptop to the closest wireless access point, AP1 in this case. Dashed circles with different colors show different ranges for different transmission energies for the laptop. AP1 is the wireless access point that this laptop can communicate with the least energy usage. Even in this basic scenario, the laptop can maximize its lifetime by using energy management and location estimation techniques.

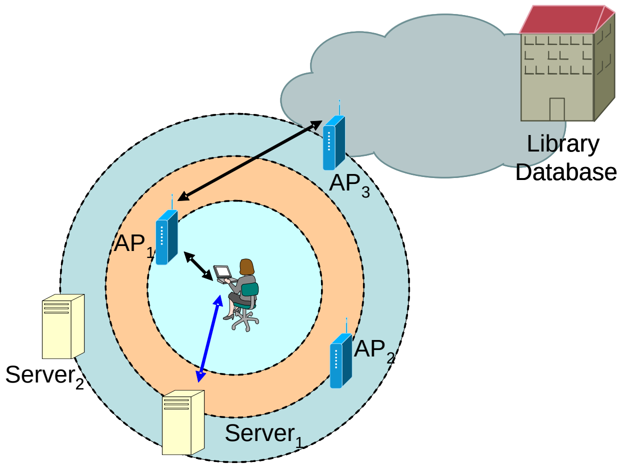

Figure 6. Energy efficiency based on location estimation. Black and blue arrows are WLAN and Bluetooth connections, respectively.

Global Positioning System (GPS) technology has been used for outdoor localization of an arbitrary object with increasing accuracy. However, GPS cannot perform accurately indoors due to severe attenuation and multipath interference from obstacles. Hence, there is a need for an indoor localization method which can provide similar results to GSP. There are several indoor location techniques such as Active Badge [17] using infrared signals, and RADAR [18], Nibble [19] and SpotON [20] using RF-based location determination. The location of a wireless device may be used as a proxy for a user's location.

As Bluetooth devices become more widespread, it may be possible to use them to estimate the location of people in a building. Bluetooth (IEEE 802.15) is a communications protocol primarily designed for low energy usage, low cost and short range [21]. Bluetooth supports a variety of applications which include cell phone to headset or headphone data exchange, and wireless PC input and output devices such as a mouse, keyboard and printer. Using BT communication eliminates cables between printers and PC's or laptops which have BT capability. We used the received signal strength information from mobile Bluetooth devices to determine the position of Bluetooth enabled devices such as BT identification badges, BT enabled mobile phones, etc., inside a working area [10]. The study uses neural network method for reducing the positioning error for location estimation. According to the simulation results, we observe that this technique can provide 75 cm positioning error on the average. Considering the example in Figure 6 again, the student can connect to the nearest computer server using the least amount of energy. Also, generally, the distance between two APs or even two servers that are in different rooms are larger than 75 cm. Therefore, this method can distinguish between two APs or two servers, and can direct the user to the correct device.

Using location estimation along with energy management techniques can support a green iSchool by providing less battery usage for mobile wireless devices and longer lifetimes.

6. CONCLUSION

Wireless information systems can support green concepts in iSchools. However, without careful planning wireless information systems will not be as energy efficient as possible. This paper presents several possibilities using mobile devices, Wireless Local Area Networks, Wireless Sensor Networks and location estimation. Results of our research can be used in different applications contributing to decrease energy usage within the normal activities in iSchools, e.g. climate control in classrooms and energy-efficient use of computing resources such as networks and computer servers.

Apart from the use of green energies, energy efficient network design and effective capacity planning are important in network design. The example in the paper shows demand-based WLAN design minimizes the number of access points needed to provide the required level of service to the users, decreasing both equipment cost and energy usage. Additionally, the amount of waste equipment will be reduced.

Wireless Sensor Networks applications can benefit from using the GSP protocol. However, a node lifetime of less than three days makes the application expensive, so further research is required to increment node and network lifetime as much as possible.

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