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Integrating Li-Fi Wireless Communication and Energy Harvesting Wireless Sensor for Next Generation Building Management

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ABSTRACT

Wireless sensors have been increasingly utilized in the design of next generation high performance buildings. When deploying wireless sensors, energy supply and data communication are the major concerns. Although energy harvest wireless sensors could automatically feed themselves by harvesting ambient energy, the presence of reliable energy sources to support dependable wireless transmission is a great challenge. The emerging Li-Fi technology is promising to fundamentally solve this problem. Li-Fi stands for Light-Fidelity, which is a new kind of wireless communication systems using light as a medium instead of traditional radio-frequency electromagnetic radiation. Li-Fi technology provides harvested energy to power wireless sensors with a unique advantage of power generation from the lighting system being controlled. The combination of Li-Fi and energy harvesting wireless sensor technologies could enable attractive features and bring in great benefits in the design of next generation high performance buildings because: (i) energy harvest sensors do not face the short-of-energy problem; (ii) Li-Fi enables much higher transmission speed compared to the existing RF electromagnetic technologies, thus, energy harvest sensors could easily deliver environmental parameters quickly for control purposes; (iii) energy harvest sensors could assist the building management team to understand the coverage area of the lighting system; (iv) the communication of sensor aggregated information can be naturally encrypted due to the combination of both technologies.

1. INTRODUCTION

Nowadays, a variety of emerging technologies has been utilized in high performance building applications, such as smart home or intelligent building (Daniel, 2009) (Chiara, 2010). Wireless sensor nodes integrate the functions of data sensing and communication, hence, they are very useful in scenarios of building environment monitoring and control. For example, a distributed wireless sensor network collects the temperature values of different locations in buildings, and sends the measurements to a central control computer to optimize the HVAC operation. It has been reported that the deployment of a wireless sensor network in building operation and management can lead to around 20% savings in energy usage and play a crucial role in green buildings (Donnell, 2008). When deploying wireless sensors, energy supply and data communication are the major concerns. The Radio Frequency (RF) chips usually have high requirement on the low power features, and the transmission capacity is often restricted, so sophisticated passive design is often needed (Fan, 2010) (Fan, 2012). Since battery powered wireless sensor requires a regular battery replacement, it is inconvenient and labor-intensive for long-term maintenance (Lu, 2011) (Lu, 2012). In order to mitigate the energy supply challenge, researchers have presented the energy harvesting powered wireless sensor network solution, which drives the operation of wireless sensors by ambient harvesting light or thermal energy (Huang, 2010) (Huang, 2011a). Later, in order to improve the communication distance and reliability issue of wireless sensors, researchers have investigated the network architecture of wireless sensors used in building monitoring and management applications (Huang, 2011b). However, even though the experimental case study has validated the feasibility of harnessing ambient energy to power wireless sensor systems recently (Huang, 2010) (Huang, 2011a), energy harvesting wireless sensors still face some challenges such as signal security, reliable ambient energy source, and the demand of higher data transmission speed.

In this paper, the emerging Li-Fi technology is introduced and reviewed. Li-Fi technology is promising to fundamentally solve these aforementioned challenges. In this work, a simple communication protocol is proposed to bridge Li-Fi and energy harvest sensors. The combination of Li-Fi and energy harvesting wireless sensor technologies could enable attractive features and bring in great benefits in the design of next generation high performance buildings, which is also discussed.

2. INTRODUCTION OF LI-FI TECHNOLOGY

Li-Fi (light fidelity) refers to the "visible light communication" (VLC) systems using light-emitting diodes as the transceiver to achieve high-speed communication, in a similar way as Wi-Fi (Rani, 2012). Li-Fi utilizes visible light as the medium instead of radio waves, so Li-Fi is viewed as the optical version of Wi-Fi in some sense. Li-Fi is an important component of Internet of Things (IoT), in which everything is connected to the internet. In the applications of IoT, LED lights can be used as internet access points. VLC signals represent information flow by switching LED bulbs on and off within nanoseconds. The Li-Fi subtly modulates the current supply to the LED lights at high speeds, thus the modulation carries the data onto the visible light. This on-and-off process is too quick to be captured by normal human eye. Fortunately, the LED lights are not disturbingly switched on and off, so users would not experience a headache when exposed to the lights.

The visible-light waves cannot penetrate through walls, so that the transmission range is shortened and the `information' is confined within the wall. However, this feature makes Li-Fi more secure from hacking, compared to the Wi-Fi, whose signal can be easily captured from outside. Direct line of sight isn't necessary for Li-Fi to transmit signal. Even light reflected off of the walls can help Li-Fi achieve the transmission rate of 70 Mbps, which is sufficient for many applications (Robyn, 2013). Well-known real-valued modulation schemes from radio frequency (RF) communication can be directly translated into the visible-light domain, to help achieve the modulation on the LED for Li-Fi: such examples include on-off keying (OOK), and pulse-amplitude modulation (PAM), etc.

The LED lights can be dimmed while maintaining certain data transmission rates. So even when lights are dimmed due to power concern or other reasons, we still maintain communication reliably. In this sense, we can develop a low-power mode for Li-Fi, so that energy harvest sensors could still communicate with the Li-Fi even when the lights are "almost off". In the daytime, we can dim the lights to transmit data. The illumination could be less than ambient levels so they will not be noticed. There is a significant net saving in power usage for the entire system. This feature could also be particularly useful, when the building needs to be monitored while no one is in the building.

In electromagnetic sensitive areas such as hospitals, due to the consideration of electromagnetic interference, there are certain limitations of wireless technologies. But Li-Fi has the advantage of being able to be used in such scenarios. Both Wi-Fi and Li-Fi operate over the electromagnetic spectrum: Wi-Fi transmits on 2.4GHz or 5GHz radio frequency; nonetheless, Li-Fi uses the visible light spectrum. The wireless networking community has already realized a spectrum shortage crisis due to the huge increase of wireless traffic in this mobile era. The current Wi-Fi spectrum is close to full capacity, especially in the 2.4 GHz band. Severe interference is thus introduced and the transmission rate can be badly degraded. Considering the huge bandwidth of visible light, Li-Fi has almost no limitations on capacity. Li-Fi is expected to be much cheaper and more environmentally friendly than Wi-Fi. In the environments where Wi-Fi is not appropriate, Li-Fi can provide a high speed, and highly-available hotspot to offload the congested Wi-Fi traffic. VLC is running on irrelevant frequencies of Wi-Fi, and is considered as radio's good friend.

VLC can be used for transmission in both downlink and uplink direction. In this work, we only consider the single direction solution for cost reasons. VLC might be implemented for downlink only while Wi-Fi can provide a reliable uplink where congestion is usually less. For example, the LED light could be paired with a Wi-Fi receiver. The LED light is functioning as a Li-Fi transmitter to transmit data and control signal to the energy harvest sensors. The Wi-Fi receiver could receive the message from the sensors. Both the LED light and the Wi-Fi receiver can be connected to the backhaul of the central control computer by wired connection.

3. COMBINATION OF LI-FI AND ENERGY HARVEST

Recently, the demands of next generation building management have motivated a huge amount of research activity related to wireless sensing. Building operation monitoring and control would benefit from sensing that is deeply embedded in the environment for an extended period of time. In this case, it is desirable that the wireless sensing device (e.g., temperature sensor, humidity sensor, indoor air quality sensor): (1) has a long operating lifetime, and (2) is of compact geometry for easy deployment, and to ensure that the integrity of the structure being monitored is not compromised. The former constraints require that the node has sufficient on-board energy resources to sustain an active device for the deployment lifetime, and that the node is able to autonomously replenish energy. The radio frequency (RF) Wi-Fi chip is a good candidate to meet these constraints. For use in civil infrastructure, the RF chips can help to monitor different environmental conditions, and deliver the measurements to the central control computer or user's mobile devices. In the field of Internet of Things (IoT), most of the things will have an IP address, and could be connected by RF chips. Therefore, the future building management system would be integrated as part of the IoT system, and wireless sensors will be increasingly utilized in the design of next generation high performance buildings. When deploying wireless sensors, energy supply and data communication are the major concerns.

To solve the energy constraints, people have proposed the use of energy harvest sensors. Systems that harvest outdoor sunlight to support WSN systems have been prototyped and deployed in many countries. However, strong light conditions are rare or hard to access inside a building. Under these circumstances, the most accessible light is from a light bulb inside the rooms. In these relatively weak light conditions (compared to outdoor strong sunlight), the feasibility of indoor light energy harvesting to support the deployment of smart wireless sensor nodes for intelligent building environment monitoring has been investigated in the prior work (Huang, 2010). The authors have implemented a WSN system based on energy harvesting to collect environmental temperature in a typical office building. Experimental results have validated the feasibility of harnessing indoor light energy to power WSN systems for long-term reliable operation. Yet, this system only supports data transmission from wireless sensor nodes to wireless access point.

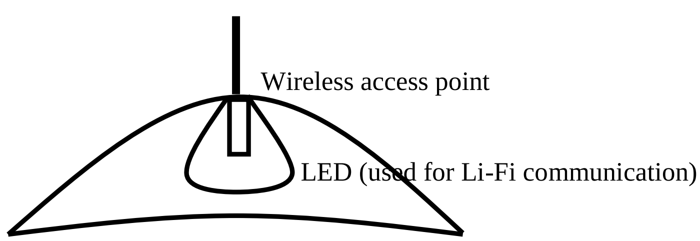

Figure 1: An illustration of the integrated design of Li-Fi/wireless access point

In this work, it would be interesting to see how a new energy feed – Li-Fi – could assist the energy harvest sensors and enable bi-directional data transmission. The combination of Li-Fi and energy harvesting wireless sensor technologies could enable attractive features and bring in great benefits in the design of next generation high performance buildings. The Li-Fi integration is envisioned as follows: (i) Due to the energy feeding from the Li-Fi LED light, the wireless energy harvest sensors could easily receive enough power, and thus do not face the short-of-energy problem. The dynamic combination of LED and energy harvest sensors is running like an 'easy-charger' for the wireless sensing system. (ii) Li-Fi enables much higher transmission speed compared to the existing RF electromagnetic technologies. In this way, energy harvest sensors could easily deliver environmental parameters quickly for control purposes. The high-speed characteristics also enable various possibilities for future monitoring applications. (iii) Energy harvest sensors could help identify the coverage of the LED lights. For example, all sensors that are covered by the LED could report to Li-Fi light signal reception. Based on the received signal report, Li-Fi could understand the coverage area of lighting. (iv) The communication of sensor aggregated information can be naturally encrypted. Because the visible light cannot go through walls, it is physically not possible for attackers to intercept the environmental monitoring parameters from Li-Fi based WSN system. Note when the proposed system is installed in rooms with strong sunlight, such as perimeter zone, the sunlight does not affect signal transmission, since sunlight is not Li-Fi coded signal, which will not interfere with visible light emitted from Li-Fi LEDs.

4. ARCHITECTURE OF NEXT GENERATION BUILDING MANAGEMENT SYSTEM

In prior sections, the advantages of integrating Li-Fi and energy harvesting techniques have been discussed. Based on their features and merits, we propose a hybrid network architecture and protocol.

4.1 Hybrid Wireless Sensor Network (WSN) System Architecture

The proposed hybrid Li-Fi/wireless sensor network is shown in figure 2. The whole system is composed of multiple compact wireless energy harvest sensor nodes, one Li-Fi/wireless access point, and a central control computer. The LED provides ambient lighting energy to sustain the operation of energy harvest sensors. In addition, the central control computer sends control signals (e.g., a command to start temperature sensing operation) to wireless sensors through the Li-Fi communication mechanism. On the other hand, through a wireless uplink link, these temperature values or other environmental parameters were transmitted to the access point and then displayed in the central control computer for observation and analysis.

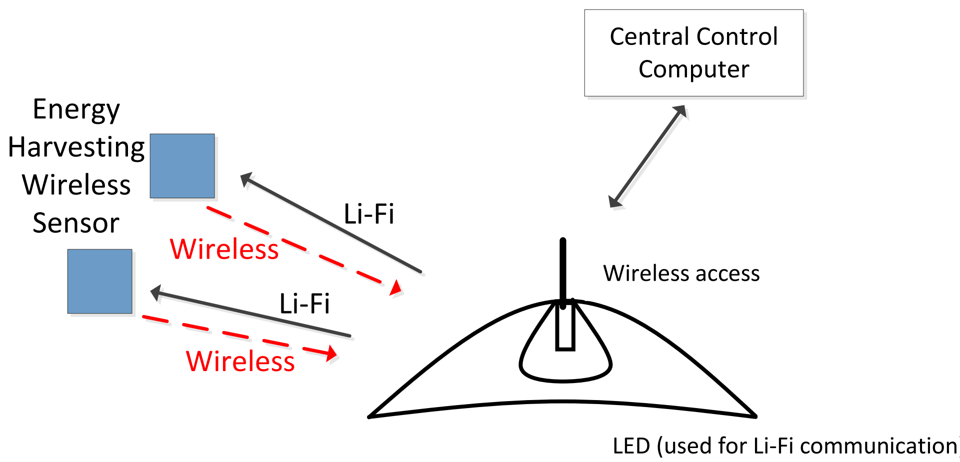

Figure 2: WSN System Architecture for Building Environment Monitoring

4.2 A Simple protocol to bridge Li-Fi and Energy Harvest Sensor

We need a communication protocol to bridge communication between Li-Fi and energy harvest sensor. To better exhibit the process of the communication protocol, we extract two typical scenarios, and discuss them in detail.

Figure 3 denotes the initialization phase of the Li-Fi and the energy harvesting (EH) integration. When Li-Fi turns on, the LED light broadcasts a "START" signal to all sensors in the coverage area. Once the energy harvest sensors receive the "START" signal, they will enter the initialization mode and set up a connection with Li-Fi by replying an "ACK" signal. Thus, a connection based on the visible light communication has been established between the Li-Fi and the energy harvest sensor.

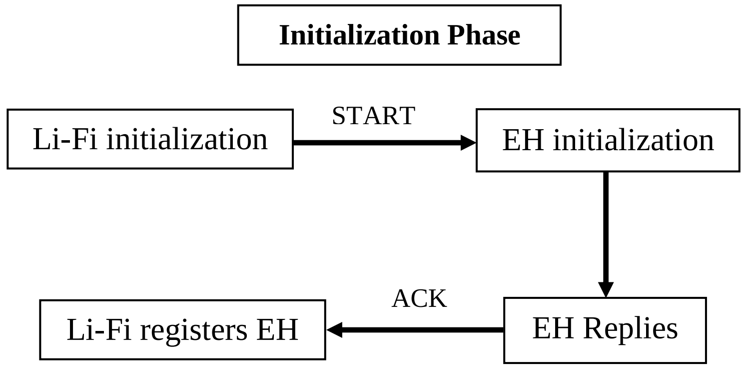

Figure 3: Initialization phase to bridge Li-Fi and energy harvest sensor

Figure 4 denotes the normal control phase of Li-Fi and energy harvest sensors. When the central control computer tries to probe the status of the sensor nodes, the computer would let the Li-Fi send out a "REQUEST" to the energy harvest sensor. After receiving the request, the energy harvest sensor starts the process of collecting data. Then the energy harvest sensor delivers the data back to the LED. The central control computer then processes the data and sends out the "CONTROL" signal to the energy harvest sensor. In addition, the system could also work under the low-power mode. In the low power mode, the LED light is dimmed to very low brightness, which cannot be used for task illumination but is strong enough to support the operation of the energy harvest sensors.

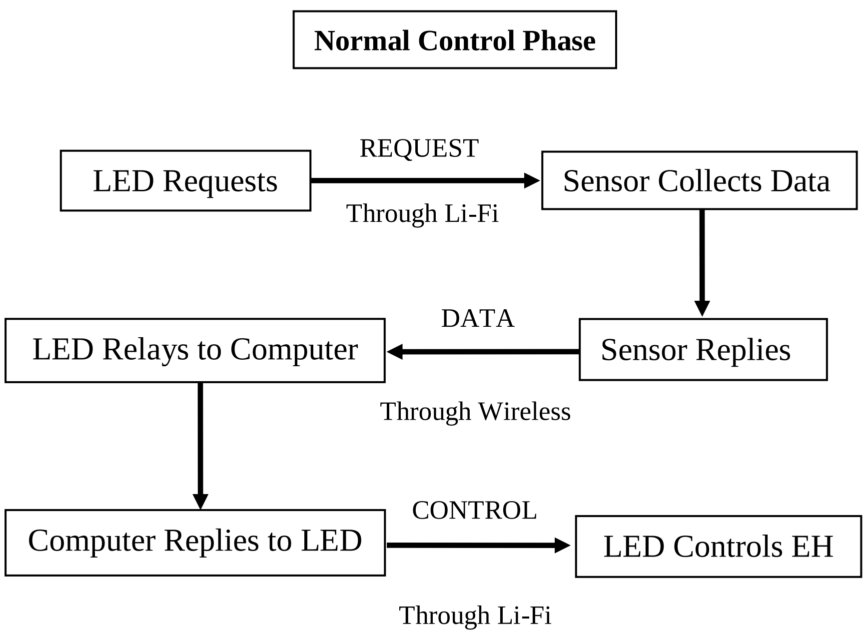

Figure 4: Normal control phase to bridge Li-Fi and energy harvest sensor

5. CONCLUSIONS

The Internet of Things is becoming the next hot topic in the building management community. The recent availability of Li-Fi provides a promising technology to improve the data communication with sensors, and fundamentally solve the energy-feeding problem of energy harvest sensors. In the proposed design, energy harvest wireless sensors could automatically feed themselves by harvesting ambient energy from LED light. Energy harvest sensors could also directly communicate with the LED through Li-Fi communication. In this work, a simple communication protocol is proposed to bridge Li-Fi and energy harvest sensors. The integration of Li-Fi and energy harvesting wireless sensor technologies could enable attractive features and bring in great benefits in the design of next generation high performance buildings. Future research to validate the proposed application is encouraged.

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