Wireless Sensor Network for Intelligent Light Control

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Abstract

In this paper wireless sensor network and its usage in intelligent lighting control are discussed. Advantages and challenges of wireless sensor networks are explored as well as some practical examples are brought out. Energy efficiency or saving energy is one of the main focus areas throughout the world as the price of energy is increasing and environmentally friendly thinking will be more and more important among people. Wireless sensor network for lighting control is corresponding to this need by adding intelligence to the lighting systems, hence reducing energy consumption. But not just energy efficiency, intelligence in lighting systems brings many other improvements to people’s everyday life.

Keywords: wireless sensor networks, WSN, intelligent lighting, power consumption, energy saving, Zigbee, LED, GHG, IEEE, IETF, IoT

1. Introduction

People and governments are focusing more and more on decreasing energy consumption. The price of energy is increasing and governments are demanding for more energy saving solutions for less GreenHouse Gas (GHG) emissions. EUs goal is to reduce energy consumption by 20% in Europe by 2020 [1]. One of the biggest energy consumer is lighting [23], as seen in Figure 1.

Tenth of all produced energy is consumed by lighting in Finland in 2009 according to the Motiva [2] and globally even 20% [3]. In fact, in Finland household energy consumption is as much as the city of Oulu is consuming [4]. In some cases industry lighting takes even 40% of electricity. At schools lighting consumes typically 20% and in hospitals even one third of overall energy consumption [3]. This is due the demand that lighting must be always on. Some progress, however, has happened during the recent years. In households electricity that is consumed by lighting has been halved from 2006 to 2012 in Finland [5].

Even though the power consumption has been decreased due to energy saving lights, such as compact fluorescent lamps and LEDs, and some environmental modelling, such as turning light on and off depending the daylight, there are still many ways to optimize the lighting and thus saving energy. Wireless sensor networks are providing a way to do it by offering low-cost method for adjusting or turning lights off automatically when they are not needed.

Possibility to control lighting remotely makes wireless solution even more efficient and cost saving. Intelligent lighting can save energy up to 80% compared to traditional lighting system [4].

Lighting in overall is in turning point. On the other hand, lamp technology is developing rapidly. Energy saving lamps consumes only fifth of the energy than a traditional light bulb and lasts even ten times longer [6]. Furthermore, the intelligence in lighting is also evolving. Combining these two, lighting in the future will be more energy efficient yet it will be more than lighting. Intelligent lighting enhance people’s environmental comfort along with lighting can be used as guide or be interactive and informative [7]. Light pollution can also be diminished with intelligent lighting solution as unnecessary artificial light can be turned off [22].
Artificial lighting is needed both outdoors and indoors. Even though there have been already different kinds of solutions for energy savings, such as brightness sensors and photocell relays which are used for turning the lights off or on, they are operating underutilized and less integrated way. Usage of wireless sensor network for lighting control brings more savings on energy. But not just energy saving, but more flexible and effective way to control lighting. Lighting needs differs significantly on different occasions. By adding various sensors, such as occupancy sensors and photo sensors, controlling the lighting system can be made automatically.

Intelligent lighting offers many other benefits besides energy saving. Improved safety and effective fault detection are also a great advantage of using intelligent wireless sensor network for lighting. For example, if the lighting is integrated with household HVAC system (heating, ventilation and air conditioning), there are lot of possibilities how to improve occupants’ safety. Of course, such system can be build using wired network, but wireless system gives much more flexibility and is possible to set up even to old buildings where new cables might be impossible to install afterwards.

Markets of intelligent lighting is predicted to multiply over next ten years. The volume in 2020 is estimated to be over 7.7 billion Euros, where as in 2011 it was 1.8 billion Euros [8].

EnLight is a project that aims to advance intelligent lighting system development with 27 partners throughout Europe [9]. It is a three year project, funded partly by EU and EU member states. EnLight partners represents a wide perspective of lighting. There are innovative lighting and semiconductor companies as well as academic institutions. Their goal is to enhance LED technology together with integrated and intelligent lighting solutions. The aim is to reduce energy consumption by 40% compared to current LED systems. 20% of the savings is due the intelligent control of lighting. The project has stated saving strategies as: the right light, at the right amount, at the right place at the right time [10].

2. Wireless Sensor Network for Intelligent Light Control

Wireless Sensor Network (WSN) consists of group of nodes and sensors attached to them. Typically a node has radio transceiver, antenna, microcontroller with limited computational power and memory as well as energy source such as a battery [11]. The nodes forms a network with one or more central node that connects the network to the server, from where the end user or an operator can manage the network remotely.

Network type used in a sensor network is usually mesh topology, though it can be a simple star network or an advanced multi-hop wireless mesh network [11]. It means that every node can communicate with other nodes directly or via other nodes. There can be from a few nodes up to thousands of nodes in one network. And if one node fails, other nodes still can communicate. This makes the network reliable and redundant [12].

Figure 2 illustrates a typical multi-hop mesh network.

IEEE 802.15.4 is a standard which many wireless lighting solutions are based on. It is standardized in 2006 by the IEEE 802.15 (Institute of Electrical and Electronics Engineers) working group. The IEEE 802.15.4 standard specifies physical and MAC layers. Its target is to define a low-cost, low-speed ubiquitous communication between nodes. This standard does not offer any higher-level layers, but is a basis of other specifications, such as ZigBee and can be used with 6LoWPAN [13].

ZigBee is an open standard based on IEEE 802.15.4, specially designed for wireless sensor networks. It is low-powered, low cost and low complex, which makes it competitive among other competing technologies [14]. Data can be transmitted over long distances by passing data from one device to another. There is no need for central control unit, and data can be transmitted with low power since no long distance transmitting is needed. Data rate is relatively low, being 250 kbit/sec. It suits best for periodic or infrequent signal transmission, such as signal transmission from sensors [15].

Two-way communication allows transferring information from nodes to server node and vice versa. Lamp failure, status of the nodes, neighbouring node malfunction or measurements of energy usage can be received from the nodes. Whereas lamps can be adjusted or some system diagnostics can be fetched from the nodes whenever needed.

Each lamp has a unique identifier so that each and every one can be controlled and monitored remotely. This idea refers to Internet of Thing (IoT) where any
device or equipment have an identifier so they can be managed via internet [16].

2.1 Benefits

One advantage of Wireless Sensor Network is that it is easy to install to existing systems and environments. There is no need for expensive and sometimes even impossible wirings. Yet wireless sensor network offers full-featured control over lighting.

Controlling the system remotely saves time and money. Lighting network can be built so that from a single point can be controlled wide area of buildings, roads or any other lighting areas. If the network is built as two-way communication, not only controlling the system is adequate, but also receiving information from the lights as well. Real-time state (e.g. on or off), energy usage measurements and malfunction of lamps can be determined. This gives the facility management invaluable information of the usage of lighting system.

Sensors, such as motion detectors and brightness sensors, add intelligence to the system. Conjunction of several sensors makes perception even more accurate which enables very delicate lighting scenarios [7]. There are already many low-cost sensors on the market that can be implemented to lighting environment.

Wireless sensors can be installed much more flexible way than wired sensors. Places of the sensors are not dependent on where the control wire is possible to install. Instead, wireless solution provides a flexible and easily scalable way to place sensors were they actually should be in order to improve performance of lighting. Sensors and switches are removable which makes the system highly adjustable to meet any changes in the environment. Expanding the network is also much simpler compared to wired system as sensor nodes can be adapted to existing network with minimum workload and disruption [17].

2.2 Challenges

However, there are still challenges and drawbacks in the field of wireless sensor networks. Power consumption of the nodes is one of the biggest challenges [11]. Wireless sensors does not have fixed electricity cable attached, so they must have a power source of their own.

Communication, i.e. signal transmission consumes relatively much energy [18]. So, for saving battery, the most efficient operation is to make the node to shut off the radio transmitter whenever it is not in use. Also energy efficient protocols are worth consider when designing a wireless sensor network.

It is presumed that in a few years exists even millions of wireless networks in the world [19]. However, wireless networks are working at the same single frequency system. This leads to highly crowded and overlapping spectrums and signal interference. Gang Zhou et al. have presented a multi-frequency solution to gain high performance communication within a single WSN [19]. Problems with signal interference can be diminished for example by creating a point-to-point acknowledge mechanism. This mechanism is widely approved among researchers in the area of wireless network [20].

Even though there are many other innovations and solutions to solve these problems, continuous development is still needed to manage constantly growing amount of wireless sensor networks.

3. Case Brazilian Streetlights

Urban street lighting is a typical system where adding intelligence would bring a lot of energy savings. Here is one solution introduced. It is a public lighting scenario in Brazil. It consists of nodes attached to lamp posts or lighting points, forming a network of which can be remotely monitor and operate.

The existing public lighting framework consists of lighting points and attached brightness sensor as well as photocell relay for automatic switch of lights according to the brightness. It does not provide information on lamp failures or power supply or anything else in that matter for enhancing the quality of service [20].

IETF (Internet Engineering Task Force) has proposed a document, where are described requirements for routing in urban network [21].

- Number of nodes from 100 up to 10,000,000 (ten million)
- Distribution area from hundreds of meters to one square kilometre forming groups
- Battery lifetime up to 15 years.
- Frequency band ISM (Industrial, Scientific and Medical
- Nodes will have 5 to 10 neighbours to communicate
- Autonomous and self-organized enabling network protocol
- No interference for operational use when diagnostic or failure information is communicated.

Functional and non-functional requirements for used application are determined for depending on the project at hand. For this type of project, functional requirements include many points that should be taken into account [20].

- Node administration: node status; is it online or offline, battery’s and lamp’s remaining lifetime estimation
- Node control: switching on and off either a single lamp or neighbourhood or even entire city
- Automated actions, such as turning lights off in the morning when there are enough daylight
- Manual actions, meaning that an operator must be able to control any lights at any given time if needed
- Diagnostic and alarms. For example an alarm should be raised if a lamp failure occurs
- Information storage where for instance geo-coordinates of the lamp posts are kept.

At the top, there needs to be a control and monitoring application where the user or the operator operates and maintains the network. Some kind of visual display should also be provided.

For application project essential non-functional requirements are robustness and portability. Urban network may expand heavily in future roll-outs. For that reason it is essential that routing protocol is scalable. For detailed information of other requirements, refer to IETF: RFC 5548 (2009) [21].

In Figure 3 the application architecture is presented. Cell 1 is grouping some sensors, and the system is expandable by adding new cells as many as needed to cover all of the lighting points in the city.

**Figure 3. Application Architecture**

Protocol used in this work is IEEE 802.15.4 due to its robustness, low cost, low power consumption and simplicity. Network protocol is mesh-type, so nodes communicates in multi-hops to transmit the information to their destination. Two-way communication is used to meet the requirements of the IETF document. For example alarms, system and lamp statuses, and diagnostics can be fetched from the network. On contrary traffic direction, the network can be operated and actuated.

Conclusion of this project is that intelligent lighting system provides automation for control process, diagnostics and alarms. It also rationalizes energy consumption. Even though this project was around lighting, this kind of approach is suitable also in other areas as well, such as monitoring energy and water consumption, etc. [20].

4. **Results and discussion**

Saving energy becomes more and more important in the future. There are many innovations how to save energy. In the field of lighting one solution is to build up an intelligent sensor network that can be used to optimize power consumption. And not just energy saving, intelligent sensor network reduces maintenance costs by allowing maintenance and new feature settings remotely and to all at once.

Wireless solutions add more flexibility, scalability and more possibilities for intelligent lighting structures. However, standardization plays a great role what comes to evolution and growth on this area.

In overall, the area on Internet of Things is evolving rapidly. Markets will grow significantly in the future as energy efficient is becoming more and more ruling aspect of any industry. At the same time, lighting will change as the technology is developing for more intelligent hence more adaptable to meet the actual needs of lighting and peoples’ everyday life.

5. **Conclusions**

Continuous development of sensors and nodes are needed to face the problems there still are. Investing in this area is definitely future-proof and investments will pay themselves back by lower energy bills. As Internet of Things will actualize in the future, the intelligence in lighting will also increase. Not just energy saving, but also convenience in everyday life will most definitely augment. Furthermore, as stated already, there are still work to be done in standardization area so that more features and systems can be integrated together to a true intelligent system.

**References**


