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An Energy Efficient Pedestrian Aware Smart Street Lighting System

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Abstract: *Conventional street lighting systems in areas with a low frequency of passersby are online most of the night without purpose. The consequence is that a large amount of power is wasted meaninglessly. With the broad availability of flexible-lighting technology like light-emitting diode lamps and everywhere available wireless internet connection, fast reacting, reliably operating, and power-conserving street lighting systems become reality. The purpose of this work is to describe the Smart Street Lighting (SSL) system, a first approach to accomplish the demand for flexible Public lighting systems.*

Keyword: *Energy efficient systems, User-centered design, Location-aware applications, Mobile computing, Wireless sensor systems, Lighting systems, Computing, Mobile technology*.

I. Introduction

This work presents the SSL system, a framework developed for a dynamic switching of street lamps based on pedestrians' locations and desired safety (or "fear") zones. In the developed system prototype, each pedestrian is localized via his/her smart phone, periodically sending location and configuration information to the SSL server. For street lamp control each and every lamppost is equipped with a ZigBee-based radio device, receiving control information from the SSL server via multi-hop routing.

Findings – This paper confirms that the application of the proposed SSL system has great potential to revolutionize street lighting, particularly in suburban areas with low-pedestrian frequency. More important, the broad utilization of SSL can easily help to overcome the regulatory requirement for CO2 emission reduction by switching off lampposts whenever they are not required.

II. System Overview And Prototype Implementation

Lighting systems are an important facility of cities, increasing the safety of road traffic participants on the one hand, and pedestrians' sense of security on the other. A constant lightening is the best solution in busy areas; however, it is definitely not in rural residential areas. In the former case, a lot of people are walking around all night long, moving from their workplace or a shopping tour to restaurants, cinemas, and bars. In the latter case, however, only a low number of residents and passersby using the streets During the night, coming from their work and moving to their homes (or the other way round). In such a scenario, the temporal need for lighted streets is, in relation to continuous illumination of streets, often incredibly small. As energy consumption (Or CO2 emission) is an issue of increasing interest, possible energy savings in public street lighting systems are recently discussed from sss

2.1 Smart street light requirement

The main problem of mercury and sodium steam bulbs, used in common street lighting systems up to now is their long switching interval time it takes some time to reach the full light intensity, and once switched off, it requires a pause of several minutes before it is possible to turn them on again. This disadvantage is not longer an issue when using the new LED technology. Beside its main characteristics, as they are low-power consumption and long durability, they offer (very) short switching times are almost unaffected from numerous switching (w.r.t. to their life time) can be switched back on right after they have been switched off are dimmable (from zero to 100 percent intensity and back to 0 percent) and can produce different colors. All these listed characteristics (expect the capability of lighting in different colors) are absolutely necessary requirements for a flexible, dynamic operating, Smart Street Lighting (SSL) system.LED technology is one step towards energy saving.

2.2 Aims and functional range of SSL

The practical usability of a system with functions as featured by SSL owes its existence several recent technological developments such as broad availability (as well as penetration) of smart phones with on-board

localization technology (global positioning system – GPS) and network capability allowing location-based services.
The premise for a comprehensive data service supply in urban and even in rural areas and radio technology like ZigBee allowing for a reliable and safe data exchange in wireless sensor networks (WSN) and further more thanks to multi-hop routing enables to structure wireless networks covering the area of i.e. a whole city.

2.3 Feature Extraction

The purpose of feature extraction block is to identify specific signatures of the disturbances in the system. For example, a short circuit and a capacitor-switching incident result in disturbed voltages with different features. The wavelet transform breaks down the error signal into different time-frequency scales. Each scale represents the error signal in the corresponding band. The energy content of the scale signals relative to the error signal changes depending upon the type of disturbance. Therefore, the relative amplitudes of the scale signals with respect to the error signal are selected as the discriminating features.

2.4 Decision Making

A function of decision making block is to discriminate type of disturbances (L-G fault and Capacitor switching) as precisely as possible. The characteristic of each disturbance, example a fault, Capacitor switching, depends on several factors for example [1] type of event, e.g. single-phase-to-ground or phase-to-phase fault,[2] location of the event, [3] time instant of event and [4] network configuration. In the decision making block, a probability functions is defined for the features and the decisions is made using the maximum linked (ML) criteria. This method is used here to discriminate various types of disturbances in a power system.

2.5 SSL features

Energy efficiency: power consumption and CO2 emission of street lights are limited to a minimum as they are only switched-on when they are “needed”. Soft on- and off-switching of lamps, which is possible with LED based bulbs (dimming), avoids disturbance of pedestrians with “fireworks-kind lighting effects”. Physiological impacts on the human body or negative effects on the environment, which are, according to (Osterkamp, 2007), projected consequences of continuously lit (street) lamps, are also excluded or limited to a minimum. Interactive safety (“Fear”) zones: reflects systems’ responsiveness to peoples’ individual needs for safety by allowing to expand/diminish the area that should be illuminated on a per user basis (configurable function on the end-user Device/Smartphone application). The default value yields a large illumination area to provide maximum safety from the beginning (and also for those users who do not want to use the SSL system in an interactive manner). Context awareness: is a feature of the system to operate fully in the back-ground. It is not strictly necessary for a user of the SSL system to explicitly execute an application on the user device (smart phone) to enable street lighting control –the smart phone deals with all the administration overhead in the background. However, if desired, it is possible for the user to interactively interact with the SSL system and change, for example, the size of the personal safety area or the intensity of the street lights. Privacy and security: control data automatically sent periodically from a user’s end device to the SSL server is fully anonymized. Previously exchanged information of a user is overwritten in the next cycle – the system does not generate neither traces a user history. To prevent unwanted system manipulation (e.g. for zones or lamppost positions), any SSL application requests an administration key (temporally valid) for all configuration-specific operations; user triggered operations are protected by a strong authentication mechanism. System expendability: characterizes the architecture of SSL. All the software components are designed extendable and scalable, allowing for later reliable service of bigger, saying “Megacity-wide”, facilities. Moreover, this framework design also allows a quick and easy integration of, e.g. future localization methods.

III. Ssl In Operation

3.1 Administration interface

The access to the administration interface is secured with a temporary valid administration key. Before the first usage of SSL, all the lampposts in the street lighting system have to be registered using an application on the administrator’s end device (smart phone). The registering process maps the physical address (ID) of the Zig Bee node on a lamppost with its GPS location. This step is required, as the utilized Zig Bee nodes are not capable of capturing GPS position on its own (it has to be noted that GPS sensors are available as extension boards for the nodes; however, due to the fact that lampposts have a fixed position and the high price of GPS boards, we have decided to assign a lamppost’s position manually). Location data are transmitted to the SSL server via HTTP connection and stored there into a spatial database. Once the street lamps are in the database, a web application is used for maintaining infrastructure zones (define/delete polygonal zones, add/remove lamp posts, etc.). Lampposts can be assigned to several zones, the administration is simplified by importing and exporting KML files in Google Earth (Google Earth provides sufficient accurate GIS functionality to successfully accomplish this task).

3.2 End user application

The SSL control application on the user device (smart phone) periodically transmits the actual user position and the adjusted radius of the safety (or "fear") zone to the SSL server. Once the server application retrieves new user data, it polls the spatial database for street lamps to be switched-on or -off (overlay of user's radial safety zone and polygonal infrastructure zone), assembles the corresponding command packets and sends them to the ZigBee nodes attached to each Lamp post using multi-hop routing. The shrinking and expanding pink colored oval represents the safety zone as adapted to the needs of one specific us.

IV. 4. Figures

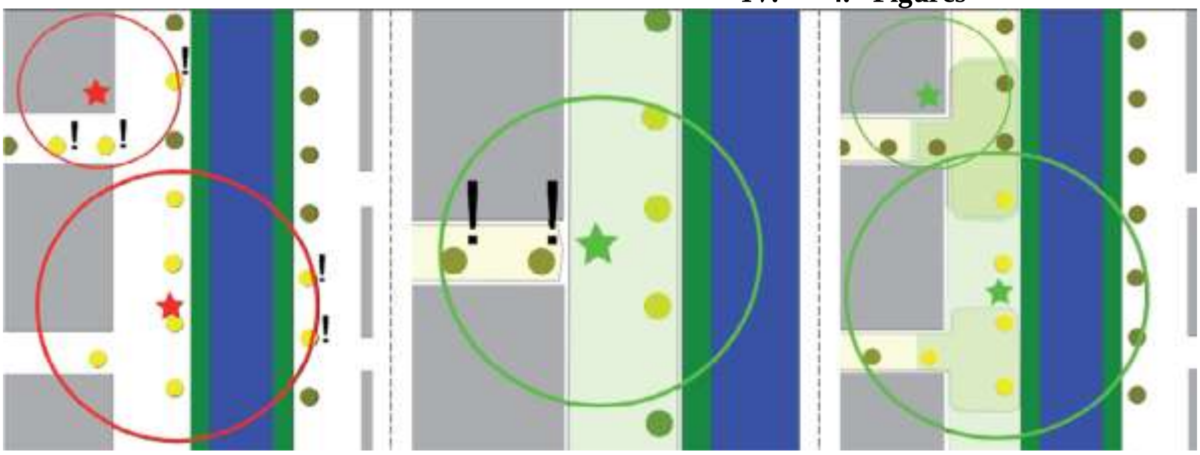

Fig.1 Models for switching street lights

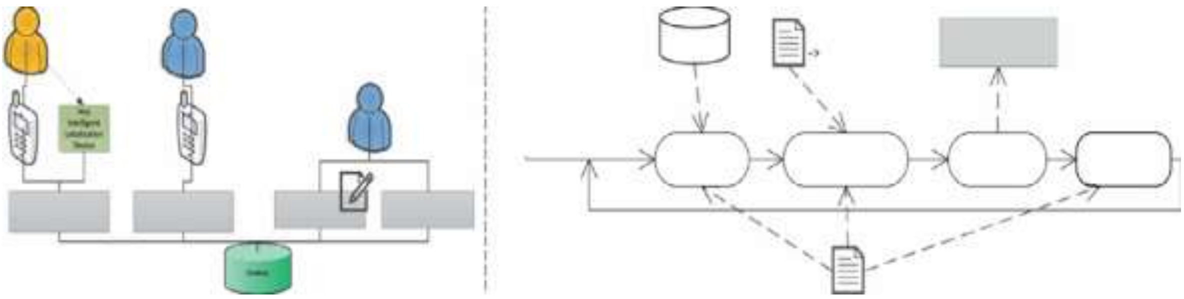

Fig. 2 Data exchange between users' and administrators' end devices and SSL

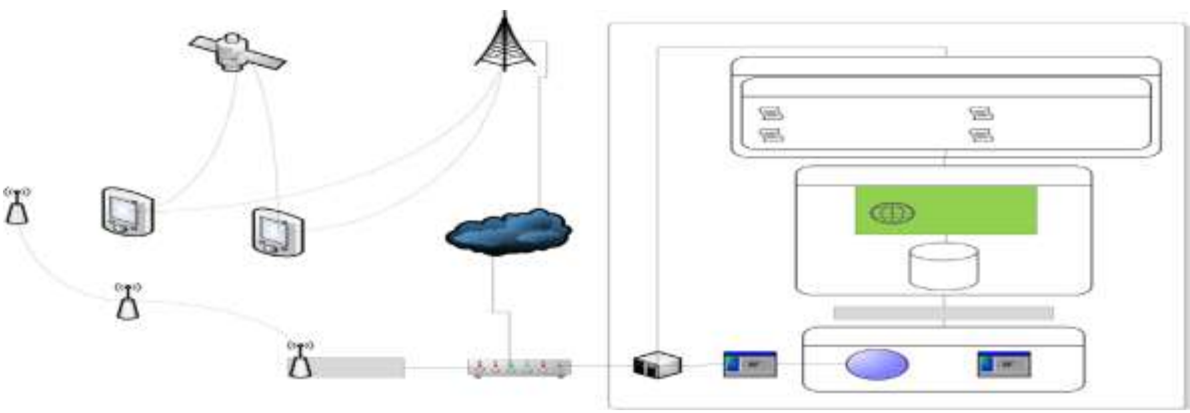

Fig.3 Overview of the SSL system architecture

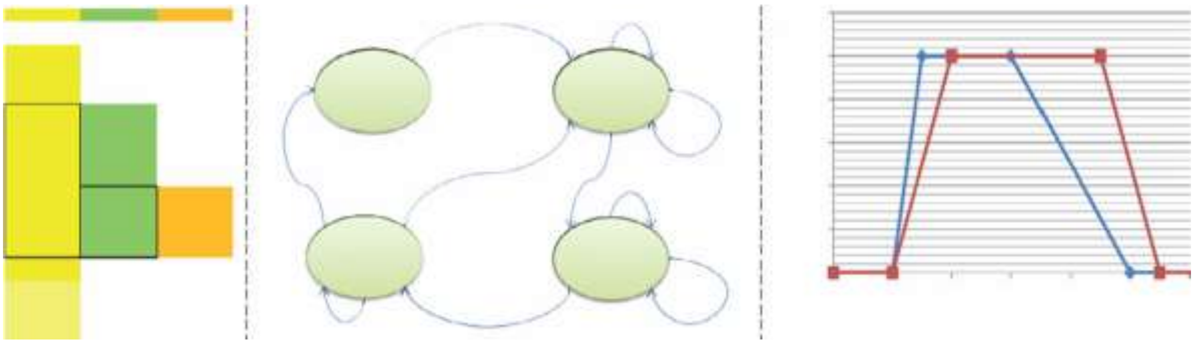

Fig. 4 Structure of the different command packets (left), time flow of brightness control (center), different gradients of lamp brightness (right)

V. Conclusion

In this paper, we have presented the SSL system, a framework for fast, reliable, and power efficient street lamp switching based on pedestrians' location and personal desires of safety (increased or reduced illuminated area all around a passersby).In the developed prototype user location, detection as well as safety zone definition and announcement of other configuration information is accomplished using standard smart phone capabilities. An application on the phone is periodically sending location and other information to the SSL server. For street lamp control, each and every lamppost is extended with a ZigBee-based radio device, receiving control information from the SSL server via multi-hop routing. In the conducted experiments, we have confirmed that the application of the SSL system has great potential to revolutionize street lighting, particularly in suburban areas with low pedestrian frequency. More important, the broad utilization of SSL can easily help to overcome the regulatory requirement for CO2 emission reduction by switching off lampposts whenever not required.

5.1 Potential issues

Experiments have shown that objects like trees, trucks, sales booth, etc. between two lampposts can interfere with wireless communication between ZigBee nodes. For reliable operation of SSL, the operating distance as well as the robustness of the Wireless communication has to be enhanced, e.g. by using more powerful antennas or signal amplifiers. Owing to the system inherent positioning accuracy of GPS (in the range of few meters) in combination with low-cost GPS receivers, the resulting inaccuracy can lead to unexpected lighting effects. This basic infrastructure weakness can be overcome by using differential GPS (DGPS) or other more precise positioning systems available in future (e.g. Galileo).

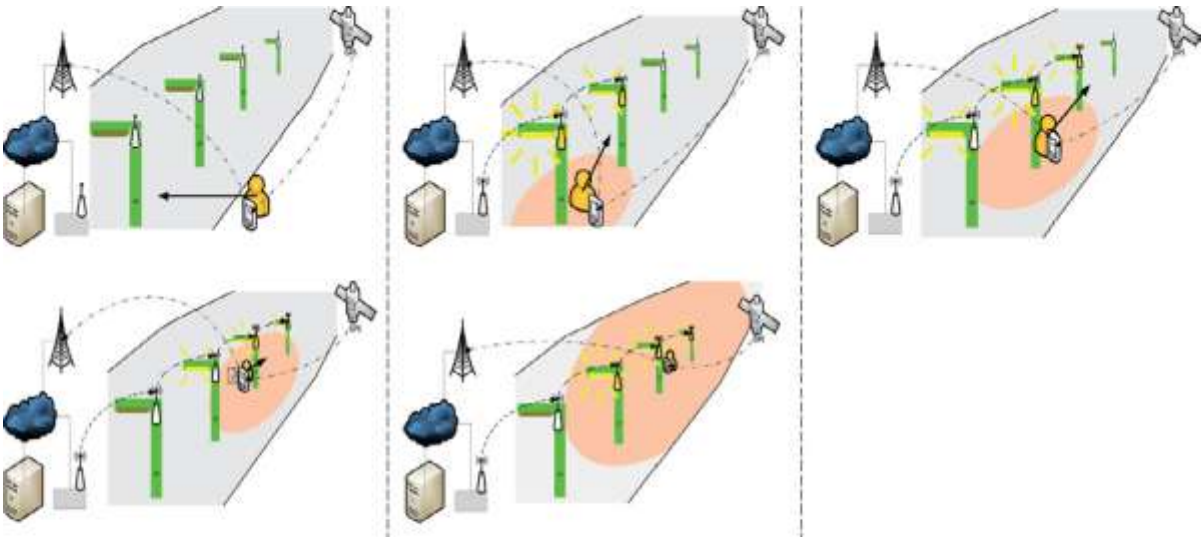

Fig.5 Behavior of user-aware street lamps

SSL is designed for low frequented areas, therefore positioning inaccuracies due to signal reflections are projected to occur rarely. Another issue arises from the usage of two-dimensional zones. As a consequence, only one layer of stacked facilities can use SSL; however, this restriction could be neglected in the projected field of application (low frequented areas).

5.2 Concepts for SSL system extensions

The proposed SSL system is currently available in a very limited prototype, tested on small-scale only. Nevertheless, we see much potential in extending the presented system in different directions. Decentralized pedestrian control: in order to provide reliable operation of the SSL system even for pedestrians without end device (smart phone), movement detection sensors could be integrated into lampposts and connected to their ZigBee node. The ZigBee device takes over the function of an end device and sends data packets to neighboring nodes and/or the SSL server. Passerby location anticipation: based on dynamic localization data as walking speed and direction of movement, the position of a pedestrian can be anticipated at least for some time. As a result, the interval for sending end device data to the SSL server could be extended, leading to increased efficiency of end device and server and reduced data traffic. Door state sensors: entrance doors of buildings send a “switch-on” command of persons coming out instead of their end devices. Leads to higher reliability and faster reaction of SSL.

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