An energy efficient pedestrian aware Smart Street Lighting system

Reinhard Müllner and Andreas Riener
Institute for Pervasive Computing, Johannes Kepler University Linz, Linz, Austria

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Abstract

Purpose – 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.

Design/methodology/approach – 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 smartphone, 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 research 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 CO_2 emission reduction by switching off lampposts whenever they are not required.

Research limitations/implications – The paper discusses in detail the implementation of SSL, and presents results of its application on a small scale. Experiments have shown that objects like trees can interrupt wireless communication between lampposts and that inaccuracy of global positioning system position detection can lead to unexpected lighting effects.

Originality/value – This paper introduces the novel SSL framework, a system for fast, reliable, and energy efficient street lamp switching based on a pedestrian's location and personal desires of safety. Both safety zone definition and position estimation in this novel approach is accomplished using standard smartphone capabilities. Suggestions for overcoming these issues are discussed in the last part of the paper.

Keywords Energy efficient systems, User-centered design, Location-aware applications, Mobile computing, Wireless sensor systems, Lighting systems, Computing, Mobile technology

Paper type Research paper

1. Intelligent street lighting to reduce CO_2 emissions

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

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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 are, in relation to a continuous illumination of streets, often incredibly small. As energy consumption (or CO_2 emission) is an issue of increasing interest, possible energy savings in public street lighting systems are recently discussed from different viewpoints. With the proposal of SSL[1], the research focus followed in this work is twofold: First, it recommends the application of improvements in light technology (e.g. the usage of light-emitting diode (LED)'s instead of common light bulbs), and second, it introduces an efficient, user-centered street lamp switching system. The main motivation for this work is derived from the fact that lighting accounts for more than 10 percent of electricity consumption in Germany and nearly 19 percent worldwide (Siemens, 2007a) (This corresponds to emissions of 1.6 billion tons of CO_2 per year, which is equal to the emissions produced by 500 million passenger cars). The potential for saving energy is quite large, but relatively easy to exploit. Simply replacing common bulbs with energy saving LED lamps can reduce energy consumption by up to 80 percent. (As a side effect, in the case of LED lamps, they last about 50 times longer than conventional light bulbs.) A timely switching of street lights according to pedestrians personal requests can add further energy savings.

1.1 Smart Street Lighting: requirements analysis

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.

1.1.1 LED technology – one step towards energy saving. Recent progress in LED-lamp technology research has lead to mass production, cheaper unit prices and thus, an increasing market penetration. Conventional street lighting systems installed by municipality governments are today more and more replaced by economic LED-based light sources. As one example, the electrics supplier Siemens offers an attractive deal (called "energy contracting") to force the broad application of LED technology (Siemens, 2007a). The company replaces common light systems with LED lamps free of charge. In return for the installation, they take money saved from lower energy consumption as a kind of loan repayment for some time. This model was also successfully transferred into cities. In Budapest, for example, Siemens replaces all the light bulbs in more than 33,000 traffic lights with LED's. The installation costs are lower than the savings generated from reduced energy consumption – the investment pays for itself. Even less developed countries can now take advantage of solutions such as the one offered by Osram. They will replace light bulbs in private homes with energy saving lamps free of charge. This is made possible by a project of the United Nations – the reduction in CO_2 emissions is converted into emission certificates that pay for the investment (Siemens, 2007b).

Nevertheless, and even with broad usage of energy conserving LED systems, further energy consumption (and CO_2 emission) reduction is still a big issue for public-lighting systems in order to help governments to reach the ambitious CO_2 threshold values as set, for instance, by the European Commission. The SSL system presented in this works should help to reach this goal by switching street lights only on if passersby are in vicinity, and off all the remaining time.

Outline. The rest of the paper is structured as follows. The next section gives a system and function overview, Section 3 presents related work in the field of user-aware, autonomous street lighting systems. Section 4 discusses system design considerations and explains the implemented prototype with help of a use case. The final Section 5 concludes the paper and gives some considerations for future extensions.

2. Aims and functional range of SSL

The practical usability of a system with functions as featured by SSL owe its existence several recent technological developments such as:

- broad availability (as well as penetration) of smartphones 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 furthermore, thanks to multi-hop routing, enables to structure wireless networks covering the area of, i.e. a whole city.

2.1 System overview

The SSL system is composed of the following components:

- lampposts with embedded ZigBee motes;
- a central SSL server;
- a radio base station, operating as communication interface between the server and the lampposts;
- server applications: "Super-Administrator" (application for principal system configurations), "Web-Application" (especially for administering lampposts and lighting zones); and
- end user devices (smartphones) with localization capability (GPS), and smartphone applications for both administrators (e.g. to register lampposts) and regular users (e.g. for interacting with the system, i.e. to set the safety zone/"fear range" or for sending their position).

In particular, the SSL system offers the following features:

- *Energy efficiency*: power consumption and CO_2 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 (smartphone) to enable street lighting control – the smartphone 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.

3. Related work

Research in user/context-sensitive street lighting can be subdivided into the two major fields:

(1) electronics and electro technology; and

(2) information and communication technology.

Our related work overview will be complemented by a paragraph on systems that are already commercially available or on the way to be introduced into market.

3.1 Electronics and electro technology

Current work in this field deals with the use and the increase of efficiency of power LED's (Chen *et al.*, 2008), e.g. by:

- biasing intelligent heat dissipation methods (Petroski *et al.*, 2010);
- more efficient lamp activation electronics for the adaption of lighting with regards to power supply irregularities;
- economical usage of photo voltaic technology in street lighting by using a maximum power point tracker based on accumulator charge regulation (Costa *et al.*, 2009);
- optimization of local illumination by improving optical lenses for LED lamps (Nuttall *et al.*, 2008); or
- development of power electronic ballast that facilitate for already existing conventional types of illumination to be dimmed in a more efficient way (Liu *et al.*, 2007; Chung *et al.*, 2005; Maizonave *et al.*, 2006).

3.2 Information and communication technology

Research in this area is mainly focused on alternatives in street lighting control and a rationalization in the management of street lighting. This is complemented by supervision of functional disorders and environmental parameters plus remote control of operative parameters as a first step toward increased automation in the management of street lighting. The compatibility and interoperability of new systems with existing (inflexible, central controlled) infrastructure is in the center of research (Wouters *et al.*, 2008; Li *et al.*, 2009). A strikingly high activity in research in this field can be observed in the Chinese region.

With regard to steer-by-wire systems, the research focus is on the improvement of communication between substations or communication nodes (here: street lamps or groups of street lamps) by means of "PowerLineCommunication" (PLC) (Cho and Dhingra, 2008; Liu *et al.*, 2008; Wang *et al.*, 2006). As a steer-by-wireless means of communication, research is centered on the classical mobile-radio communication techniques global system for mobile (GSM), general packet radio (GPRS), and complemented by ZigBee (Caponetto *et al.*, 2008; Denardin *et al.*, 2009b; Denardin *et al.*, 2009a; Iordache *et al.*, 2008). Lee *et al.* (2006) reports on research using ZigBee as an alternative option to PLC for single groups of street lamps. Their work is focused on error detection like short circuits that cannot be detected by PLC. Denardin *et al.* (2009a) stated that ZigBee is an important (the optimum) communication technology for this kind of applications and investigates the special requirements for efficient routing algorithms to cope with difficulties for radio transmission caused by buildings. Furthermore, they observed that large-scale (e.g. city wide) lighting systems would require highly scalable real time operating systems in order to guarantee reliable operation at any point (street lamp) and for each user (pedestrian).

Most approaches combine different communication technologies within a system and mostly GSM or GPRS is used for the communication between base station and substations, while PLC or radio technology like ZigBee is used for data exchange between substation and the end points (street lamps) (Caponetto *et al.*, 2008).

3.3 Street Lighting Systems in operation

The city of San Francisco operates a LED-based street lighting system since 2007. The system operates automatically and adjusts the brightness of the illumination by means of integrated photo sensors and according to the current brightness of the moonlight [2]. In some councils of Germany, a system is operating since 2009 that allows users to activate a path, identified by a six-digit code, for 15 minutes via telephone. Integration into existing, conventional street lighting systems is possible[3]. In contrast to the features of SSL, this system has a number of disadvantages:

- a entire street is lit – not only the part actually needed by the pedestrian;
- the user has to call the "street lighting system" operator and then to enter the street identification code, therefore, this system is not operating attention-free;
- the user has to register before using the system; and
- if the street should be lit for more than 15 minutes the user has to call again after time lapse.

According to the related approaches, SSL is even better and innovative as it:

- operates fully wireless (ZigBee, GPS);
- the control of street lights is location aware and user centered (attention free in normal operation); and
- allows for instant interaction and intervention if needed.

4. System overview and prototype implementation

4.1 Design considerations

4.1.1 Radial safety zones and polygonal infrastructure zones. Using only radial zones around the user to determine which street lamps should be switched-on/-off is the easiest way for implementation, but has several disadvantages as shown in Figure 1. For instance, people (system users) staying in areas like buildings would trigger the activation of street lamps as there is no possibility to discriminate between "on the street" and "in a building" based on the location alone or the current location of a user would also, by mistake, switch-on lamps on the opposite side of a street or river (leftmost image). It is even not enough to limit "active" street lamps to that located in the street, where the user is moving/staying currently. Problems would occur, e.g. on street crossings or intersections (Figure 1, center image). To avoid all these drawbacks, we propose to use zones not only for the system user (radial), but also for the lamps

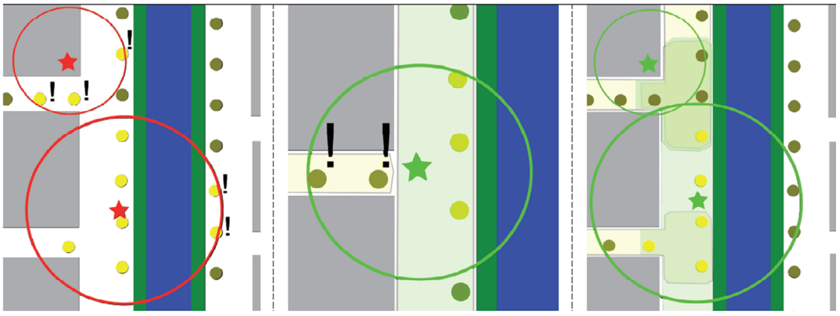

Figure 1. Models for switching street lights

Notes: Radial-user zone only (left), radial-user zone, plus-street zone (center), user zone and overlapping polygonal-lamp zone (right); Gray areas represent buildings, blue symbolizes obstacles (roadway, river), yellow points are illuminated street lights, stars stands for user locations, circlesrepresent the desired safety/"fear" areas of users currently activatable (polygonal infrastructure zones). It has to be noted here that the convenient definition of zones is one of the most critical success criterion of the SSL system. Street lamps might only be switched-on/-off on overlapping user and infrastructure zones (Figure 1, rightmost image). Furthermore, as indicated in equation (1), a time constraint has to be fulfilled (last known user position must be within a certain time domain). More formally this can be described as:

$$\begin{aligned} z \in Z, l \in L, u \in U \quad & on(l) \equiv \exists z, \exists u : inside(l,z) \wedge inside(u,z) \\ & \wedge\, active(l) \wedge active(z) \quad \wedge\, distance(u,l) < r \wedge age(u) < t \end{aligned} \tag{1}$$

Equation explanation. *z* is a zone, an element of the zone set *Z*, *l* is a lamp, an element of the lamp set *L*, *u* is a user, an element of the set of users *U*; *on(l)* describes the state of lamp *l*; *Inside(l, z)* is true, if and only if lamp *l* is located within zone *z; active(l)* resp. *active(z)* describes that lamp *l* resp. Zone *z* participate, since these entities can be deactivated by administrators; *distance(u, l)* describes the distance between user *u* and Lamp *l*; *r* describes the (interactively changeable) distance threshold – for potential illumination, the distance between user and lamp has to fall below *r*; *age(u)* describes the age of known user position data. *t* is the time threshold. If *age(u)* exceeds *t*, the user position *u* is considered as outdated.

4.1.2 Wireless street lamp control. The open architecture and the requirement for extending existing (LED based) street lighting systems demand for a fully wireless communication between users, street lights, and the background intelligence (SSL server). Owing to recent advancements in WSN devices and protocols, reliable operation is not longer an issue. As the volume of data to be exchanged between the multitude of street lights and SSL server is fairly low and the distance between the individual lampposts is in the range of 30-50 m, radio based ZigBee nodes using multi-hop routing would be the optimum choice (and have, therefore, been chosen for the SSL system presented in this work).

4.2 The SSL system: implementation details

4.2.1 Hardware settings. For the SSL server a common desktop PC with Linux (or Windows plus Cygwin) operating system can be used. The required performance is mainly determined by the size of the SSL system (number of users, update frequency of user location data, facility size, i.e. number of street lamps, number, and complexity of infrastructure polygons). On the application side, the SSL application written in platform independent Java code is supported by an Apache Web-Server providing internet based access from administration or end-user devices (PCs, smartphones) and a PostgreSQL database management system with PostGIS[4] extension. The software for the ATMega128L based ZigBee nodes (MICAz MPR2400 on each lamppost, MIB600 Ethernet interface as link between SSL server and distributed nodes) was developed in TinyOS 1.1.15. The internet connection for receiving users' HTTP requests from their smartphones is not a big issue as the size of one user data packet is less than 400 bytes. For an overview of the system architecture see Figure 2.

4.2.2 Hardware – software link.

SSL database. The structure of the underlying database model is shown in Figure 3. Of interest are the following special features. The user session ID in the user table is, due to privacy reasons, stored as UUID, the field "umode" contains information about the size of a user's safety zone (fear level), and the "timestamp" is used to adhere

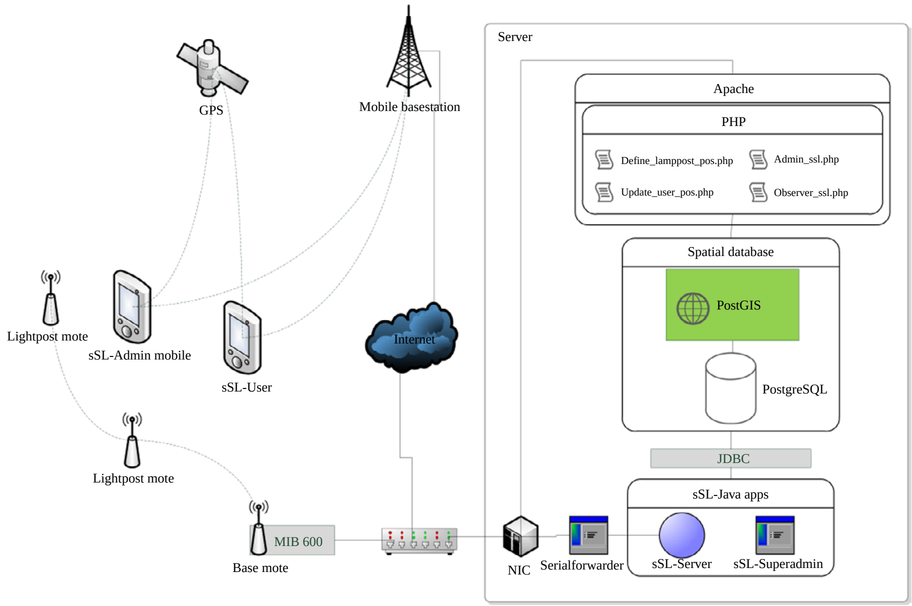

Figure 2.
Overview of the SSL system architecture

User	Lamppost	Realm	Config	Config : ckey
Uid	Lid	Lid	Ckey	AdminKey
Udirection	Lpoint	Rpolygon	Cvalue	AdminKeyValidThrough
Uvelocity	Lenabled	Rname		SRID
Umode		Renabled		UserMaxAge
Utimestamp				
Upoint				

Figure 3.
Database scheme with major tables and fields

only to current users location information. In the lamppost table, “lpoint” is the geographic position of the corresponding street light, the boolean field “lenabled” allows to enable/disable street lamps individually (disabled lamps are not affected by user-triggered switching operations). The realm table stores infrastructure polygons which can again be individually enabled or disabled (“renabled”). Finally, the configuration table contains general configuration data, the field “SRID” stands for Spatial Reference IDentification and is used for high-performance perimeter queries on GPS data (transformation of sphere to plane projection).

Data exchange operations:

- *User end devices with SSL server.* This component has mainly to control two tasks (Figure 4, left image). First, it provides an interface between user end devices (smartphones) and the SSL server for transmitting user data (position, safety zone size, etc.), which is used by the server application (see below). Second, it assists the administration interface in its functions (gathering data like lamppost definitions from end devices and prepare them for database storage, defining and changing infrastructure zones, activating/deactivation street lamps, and generally maintaining the SSL system).

- *SSL server to lamppost ZigBee nodes*. The server-application polls the spatial database periodically to get the light posts, which have to be illuminated, assembles the corresponding command packets and sends them to the ZigBee nodes (Figure 4, right image).

Operation of ZigBee nodes. A specific ZigBee node called "base node" acts as link between the SSL server and all the other ZigBee nodes attached to the lampposts (it acts as gateway encoding incoming and outgoing information into Ethernet or ZigBee conform data packets). The ZigBee nodes on the lampposts have two functions. As the system operates using multi-hop routing, they act as router or relay stations for data packets not designated for themselves. The second function is to control the LED lamp in the street light via the commands "on", "off", and "brightness control". The subsequent structure of communication packets is indicated in the leftmost image of Figure 5. To avoid disturbance, the brightness gradient is smooth, fading in when a person enters a zone and fading out when the user leaves a zone again. Three parameters are responsible for that:

(1) fade in time;

(2) high time; and

(3) fade out time (see rightmost image of Figure 5).

The diagram in the center of Figure 5 shows the time flow of information exchange. Note that the application is designed very flexible – each and every street lamp has its own triple of time behavior as described before.

4.2.3 End device (smartphone) applications. All SSL (administrative and user) end-device applications are realized in platform independent J2ME Java code. Thus, they could be executed on standard smartphones (minimum requirements are CLDC1.1, MIDP2.0, and the capability for location detection). For bandwidth conserving data transmission from an end device to the SSL server, data are wrapped into a HTTP request header (i.e. as arguments of an URL). In normal operation the server responds, again for saving bandwidth, with no acknowledgment; only in case of errors information is sent to the end device (smartphone).

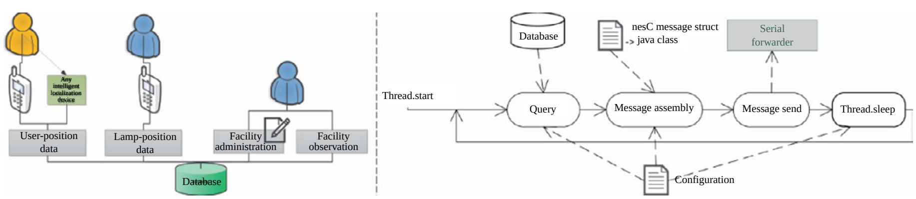

Figure 4.
Data exchange between users' and administrators' end devices and SSL server, facility administration and observation (left); server application operation (right)

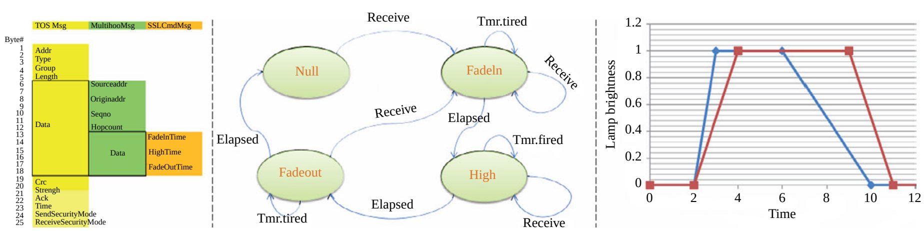

Figure 5.
Structure of the different command packets (left); time flow of brightness control (center); different gradients of lamp brightness (right)

Administration application. The main administration application deals with the assignment of position information to lampposts as outlined in the leftmost image of Figure 6. Before accessing the corresponding application, and providing information for the diverse lampposts, the administration key has to be entered (Figure 7, leftmost and center images). After successful registration, administrators can add, update or delete street lamps in the database (street lamp ID has to be provided manually, the geographic position of the same is detected automatically), for details, see the leftmost picture in Figure 6 or the following example of an URL to define a new street lamp.

```
http:// <ServerAdress>: <ServicePort>/ssl/define_lamppost_pos.
php?
AID = <8-Digit-AdministrationKey>&LLightID = <LampAdress>&
LLongitude = <GPSLongitude>&LLatitude = <GPSLatidude>&LSave =
<SaveOrDelete>
```

User application. The user application normally running in the background, periodically detecting and transmitting localization information together with the adjusted size (radius) of the safety zone to the SSL server (rightmost diagram in Figure 6).

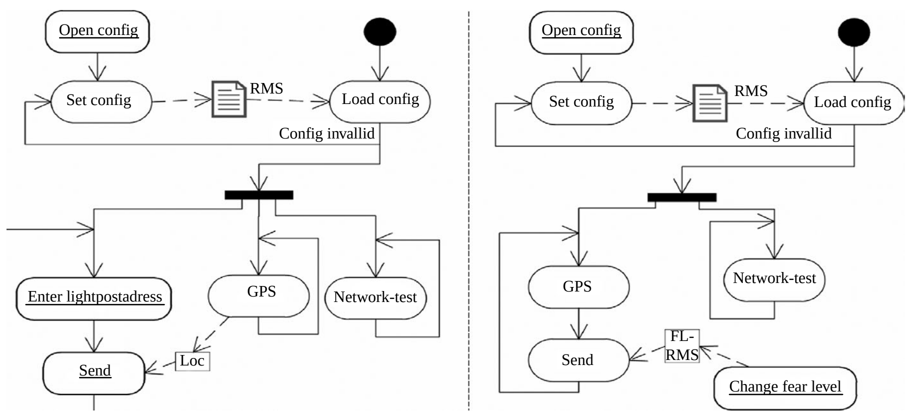

Figure 6.
Time flow of administration (left) and user (right) applications running on end devices (smartphones)

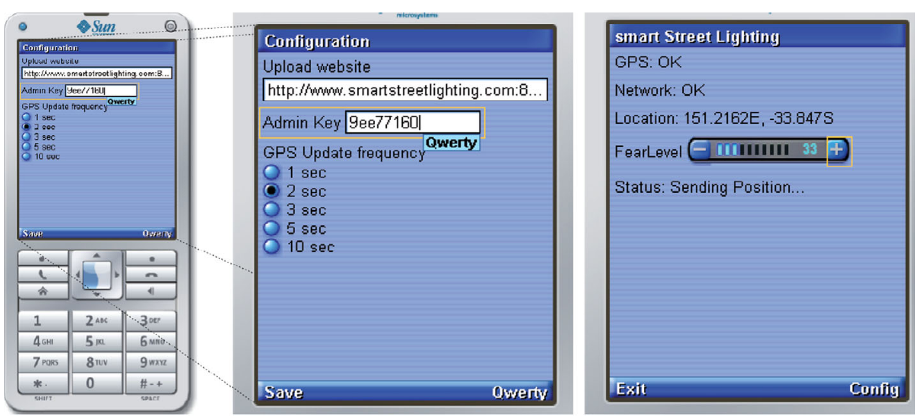

Figure 7.
SSL administration interface (left, center) and user interface (right) on the end device (smartphone)

Nevertheless, users have the opportunity to interact with the SSL system, e.g. by changing the safety zone ("fear level") dynamically as shown in Figure 7 (rightmost picture). User identification is, for privacy reasons, provided using a randomly generated, temporary ID. For additional security, a user data integrity check mechanism has been added to prevent unauthenticated system access, e.g. by hackers or criminals. Subsequent, an example of an assembled URL is shown.

```
http:// <ServerAdress>:<ServicePort>/ssl/update_user_pos.php?
UID = <temporal-UserID>&ULongitude = <GPSLongitude>&
ULatitude = <GPSLatidude>&UDirection = <User-Direction>&
UVelocity =   <User-Velocity>&UMode =   <Fear-Level>&hash =
<Authentication Key>
```

In order to prevent that distant unauthorized persons pretend a user's position near a street lamp, together with the standard information an authentication key is transmitted to the SSL server to allow an integrity check of user's data. The key is generated based on the actual data to be sent and the previous data set. With this strong mechanism, wiretapped information cannot be used (illicitly) for a second time.

4.3 SSL in operation

4.3.1 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 (smartphone). The registering process maps the physical address (ID) of the ZigBee node on a lamppost with its GPS location. This step is required, as the utilized ZigBee 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 lampposts, etc.). Lampposts can be assigned to several zones, the administration is simplified by importing and exporting KML files in Google Earth as shown in Figure 8 (Google Earth provides sufficient accurate GIS functionality to successfully accomplish this task).

4.3.2 End user application. The SSL control application on the user device (smartphone) 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

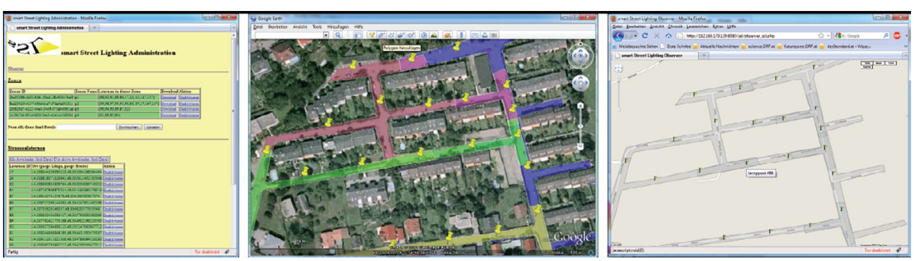

Figure 8.
Zone and street lamp administration (left); Google Earth (center) and Google Maps (right) representation of streets, infrastructure zones, and street lights (lampposts)

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 lamppost using multi-hop routing. Figure 9 shows the operation of the user sensitive SSL application. The shrinking and expanding pink colored oval represents the safety zone as adapted to the needs of one specific user.

5. Conclusion and future work

In this research 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 smartphone 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 CO_2 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). SSL is designed for low frequented areas, therefore positioning inaccuracies due to signal reflections are projected to occur rarely.

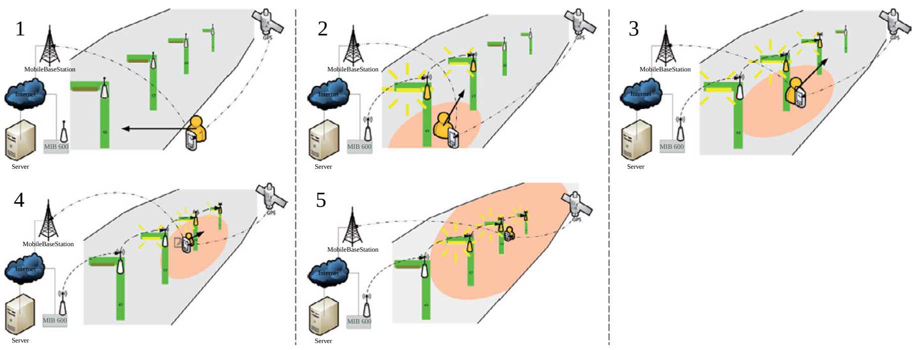

Figure 9.
Behavior of user-aware street lamps

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 (smartphone), 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.

Notes

1. In the context of this research work, “SSL” is an abbreviation of Smart Street Lighting, not to be confused with the common shortcut for secure socket layer.
2. www.civiltwilightcollective.com (accessed 18 February 2011).
3. www.dial4light.de (accessed 18 February 2011).
4. PostGIS adds support for geographic objects to the PostgreSQL object-relational database, available at: http://postgis.refractions.net (accessed 17 February 2011).

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About the authors

Reinhard Müllner received his university-entrance diploma in Electrical Engineering in 1999. After some years in industry as software developer he enrolled in Computer Science at Johannes Kepler University (JKU) in Linz, Austria. He graduated recently with a BS in Computer Science and is currently a Master Student of Pervasive Computing at JKU. Reinhard Müllner is the corresponding author and can be contacted at: reinhard.muellner@gmx.net

Andreas Riener carried out his PhD at the Institute for Pervasive Computing, JKU Linz, Austria from which he received his PhD degree in 2009. In his PhD thesis, he has confirmed driver-vehicle interfaces as complex configurations of technological system components and services, and implicit interaction therein as a major research challenge. In a substantial part of his thesis, he dealt with implicit interaction modalities based on vibro-tactile sensations and notifications affecting the driver-vehicle feedback loop. Since 2009, he is a Postdoctoral Research Fellow at the same institute. Andreas Riener is and was engaged in several EU- and industrial-funded research projects, for instance in cooperation projects with Siemens AG or in the FP7 FET-Open project SOCIONICAL. His research interests include multi-modal sensor and actuator systems with a focus on implicit human-computer interaction. Furthermore, he is interested in driver vital state recognition from embedded sensors and context-sensitive data processing. His core competence and research focus is context-aware computing and implicit interaction influencing the driver-vehicle interaction loop.