Applied Computer Science, vol. 14, no. 1, pp. 5–15
doi:10.23743/acs-2018-01

Submitted: 2018-02-20
Revised: 2018-03-05
Accepted: 2018-03-20

road lights intelligent system, Internet of Things, GPS localization, MQTT message transmission protocol

Sebastian CYGAN[*], *Barbara BOROWIK*[**], *Bohdan BOROWIK*[***]

STREET LIGHTS INTELLIGENT SYSTEM, BASED ON THE INTERNET OF THINGS CONCEPT

Abstract

The paper presents a project of a street lights intelligent system, which allows for public savings, as a result of more efficient roads and pavements lights management. The system would operate based on the current location of vehicles and pedestrians. Because of this no additional costs or devices are required in smartphones or modern vehicles to indicate its location, as smartphones, smartwatches and most of modern cars are equipped with the GPS modules. But each smart street lamp needs to be equipped with a little module that communicates with the central system and which controls the work of lighting.

1. INTRODUCTION

Internet of Things is a concept, which assumes the possibility of connection to global Internet network many devices. Their quantity and possibility of mutual communication often allow to create autonomous, intelligent systems, freeing a human being from many daily activities (Mitchell, 2007; Ashton, 2017). According to forecasts in 2020 around 50 billion devices used worldwide will belong to the IoT (Markowski, 2017). Such rapid development of this branch of IT and electronics is caused by the increased need for complex systems, which would allow autonomously manage the work of intelligent vehicles, houses or whole cities (Mitchell, 2007; Stawasz & Sikora-Fernandez, 2016).

[*] ELTE GPS, ul. Medyczna 13, 30-688 Kraków, sebastian.cygan91@gmail.com
[**] Politechnika Krakowska, Instytut Informatyki, ul. Warszawska 24, 31-155 Kraków, cnborowi@cyf-kr.edu.pl
[***] Akademia Techniczno-Humanistyczna, Katedra Elektrotechniki i Automatyki, Bielsko-Biała, ul. Willowa 2, 43-309 Bielsko-Biała; E-mail: bo@borowik.info

It has been calculated, that roads and pavements lighting accounts for up to 20% of electricity generated by cities (Miller, 2016).

Intelligent street lighting system could allow for a significant reduction in public electricity costs. It would operate based on the current location of vehicles and pedestrians. If there would be no objects near the street lamp, then this device (depending on the configuration) could be turned off or could have its lighting power reduced. For this purpose there could be used such devices that nearly every one of us already has: smartphones, smartwatches or modern cars, equipped with the GPS modules (Markowski, 2017). In addition, each smart street lamp will be equipped with a little module that communicates with the central system and which manages the work of lighting.

1.1. Related works

The subject of effective management of street lighting has been often the subject of research especially during the last years. For example the authors of (Drechny & Kolasa, 2016) in their intelligent algorithm have used artificial neural network. Controlling of a street lighting depends on the intensity of a traffic (data can be obtained from the supervision center system) and may use the information concerning weather conditions (forecasted and current). A street lighting system may operate and control lamps in a zero-one mode (ordinary lamps) or may adjust the degree of the light intensity (LED light bulbs). Another concept has been proposed by the LonWorks technology. As part of the research in 2014 the University of Science and Technology (AGH) in Krakow had launched a pilot system that had supervised the work of public lighting in one of its car parkings (Ożadowicz & Grela, 2014). Besides the whole range of parameters allowing for monitoring energy consumption and detecting potential threats to energy infrastructure the system was allowing for both manual and automatic tuning based on data that was obtained from sensors of ambient light and of temperature. The whole system provides bigger reliability and significant savings in energy consumption. Poland, in the context of modern technologies, is an attractive market for the implementation of intelligent street lighting.

1.2. The use of mobile devices in transmitting the location of objects

Nowadays, the majority of people are equipped with modern smartphones, which besides their standard capabilities provided in traditional telephones, they also offer very specialized functions: GPS location, possibility of internet connection and they are based on advanced operating systems, on which own software can be implemented. Because of this no additional costs or devices are required in smartphones or modern vehicles to indicate its location. Modern cars are more and more often equipped already in factories with GPS modules and with devices that allow them for network connectivity.

1.3. Devices allowing to manage the work of street lamps

An important function of street lamps is the necessity to exchange data with the central server (based on the GSM network). There exist also a possibility of a hardware integration with street lamps, so the control over these lamps work could be performed.

An interesting option on the market is the one based on a Raspberry Pi (Retrieved from https://www.raspberrypi.org). It is a miniature computer that allows for connecting any device via USB or an Ethernet interface. Thanks to this it is possible for this device to quickly connect to the mobile network, while its dedicated distribution of the Linux operating system allows to run multiple applications on it. The entire such a system is very energy efficient, because it requires only approximately 500 mA in its normal operating mode.

1.4. A protocol enabling mutual communication of devices

The basis of every system consisting of a large number of devices is their mutual communication. Many dedicated protocols have been developed for the needs of IoT, in which the most important is the speed of data transfer, the smallest communication overheads and the ability to encrypt the transmission. It was established that the communication medium between all devices considered in the implemented project would be GSM network, because of its universality and the lack of the need to build a dedicated infrastructure. From the many Internet of Things protocols, the authors have selected the MQTT protocol ("MQTT Protocol", 2017), which is popular as it is used for example in Facebook Messenger ("Tops of 2016: digital", 2016).

2. THE PROPOSED SYSTEM

The main assumption of the project is the energy-saving mode, for which the period is searched, when the light emitted by street lamps can be diminished or reduced. By definition, it will be during late night hours, when the total traffic is negligible and there is no need to constantly illuminate roads and sidewalks. At these periods of time the work of lamps will depend on the proximity of vehicles and pedestrians moving around the city, i.e. the light will be dynamically adjusted to the speed and direction of objects' moving. Figure 1 presents the example of a graph showing the time function and the change of the street lamp working modes.

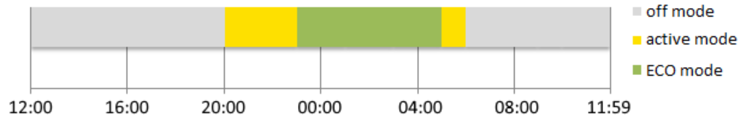

Fig. 1. Examples of street lamp work stages on the time function graph

Except for the periods of validity of the energy-saving mode (when the light emitted by the lanterns will be reduced) the system will only record data on the location of facilities and verify the efficiency of streetlights. Such data may allow to carry out a significant analysis of the traffic load at particular times of the day and they can enable quick response to possible failures of the street lighting network. In the energy-saving mode, by default all lanterns will work in low-power mode or completely blank (depending on the configuration).

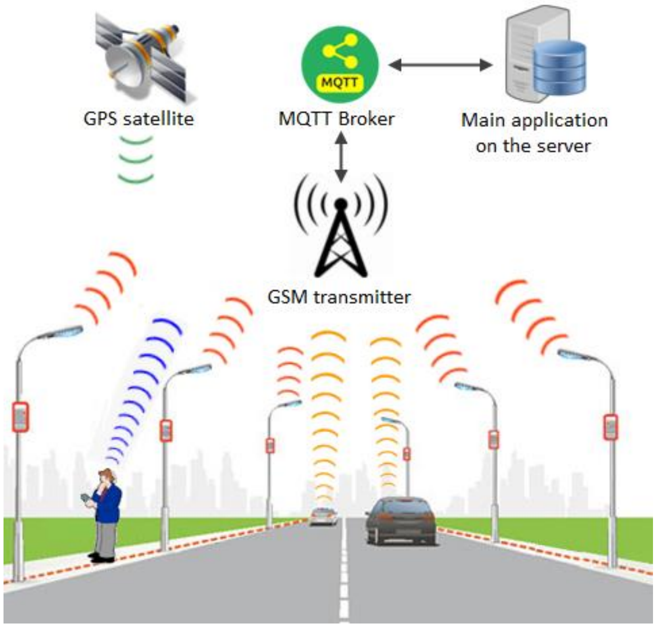

Fig. 2. Scheme of data exchange between objects in the system and the server – in the GPS technology users' and vehicles' mobile devices transmit their current locations to the server, and this allows for the management of street lamps by a central application

So each vehicle and every pedestrian moving around the city should have running a mobile application, which transmits the information about their current location to the central server. Based on these data, the main application will determine sequences of street lamps which will be successively starting their work, so to ensure the continuous lighting of roads and/or pavements for moving objects.

If there would be no vehicles or pedestrians in the given area, messages would be sent to the street lamp, with the instructions to re-enter the energy-saving mode. The graphical concept of this system has been shown in Figure 2. The system project used the MongoDB database.

2.1. Dependencies between objects in the proposed system

The basis of the algorithm controlling the work of street lamps is obtaining the information about the location of individual objects (vehicles and pedestrians) moving around the area controlled by the system. Each of the street lamp in this area is characterized by important parameters used to identify it in the context of surrounding moving objects. The first such a parameter is the radius (expressed in meters). Within its range, objects are clearly classified as located within the area of a given street lamp. In addition to the obvious scenario, in which a vehicle's or a pedestrian's coordinates are evidently within the range of this street lamp (what is the case presented in Figure 3), it also may happen that the coordinates of two objects will cause omission of obtaining the information about the objects being found near this street lamp (this has been presented in Figure 4).

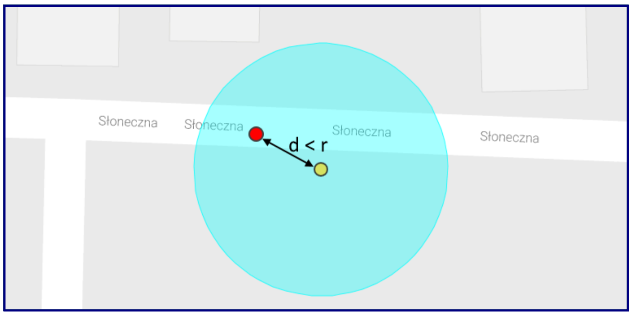

Fig. 3. The situation, in which the object is within the range of a street lamp (the distance is smaller than the defined radius of the visibility range of a given street lamp)

In this case, the algorithm performs the following operation: a straight line is determined between the two data points. Then, from the coordinates of the central point of this street lamp is determined a perpendicular line to line between the two points of the mentioned earlier object. The point of the intersection of these two lines determines the closest place to the street lamp, the distance of which is checked by the program. If it is smaller than the radius of the lamp, then the algorithm classifies the presence of the object as within its range.

The second parameter, that is used to identify the given street lamp in the context of surrounding moving objects is its street lamps group number and its sequential number within a given group.

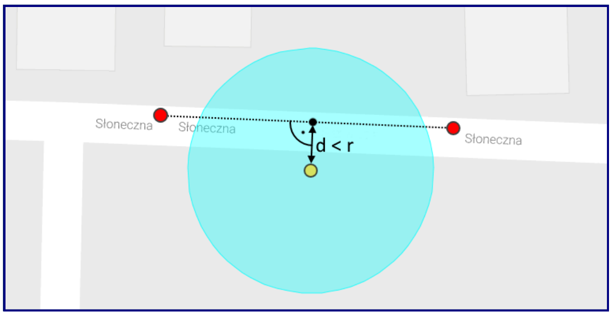

Fig. 4. The situation, in which the points of occurrence of an object have the location data that is not within the direct range of the given street lamp – however, based on the appropriate mathematical calculations, the algorithm recognizes the presence of an object within the area of the street lamp

These parameters serve to find out in which direction a given object is moving. It is particularly important when a given vehicle is traveling on a two-way road, in which street lamps are on both sides of the road. Based on these parameters, the algorithm is able to activate only a part of the street lamps for the needed a light road lane, consistent with the direction of the object movement, as it has been presented in Figure 5.

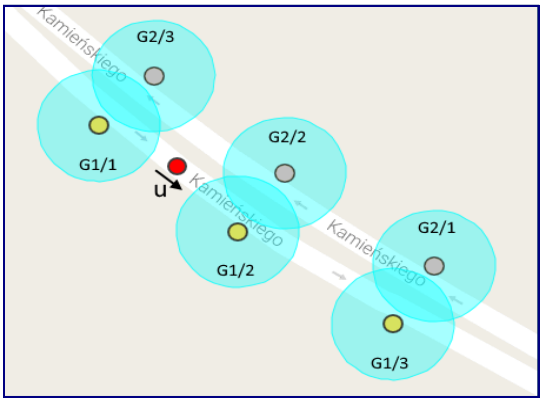

Fig. 5. The situation, in which there are street lamps on both sides of a two-directional road – the algorithm will activate only the correct set of available street lamps on one side of the road, based on determining a given lamp group number and its sequential number within a given group

2.2. The algorithm controlling the work of street lamps

The algorithm that controls the work of street lamps operates only during the energy-saving mode, when (depending on its configuration) the light of street lamps is dimmed or lamps shine with less intense light.

A simplified block diagram of the algorithm activating street lamps is shown in Figure 6.

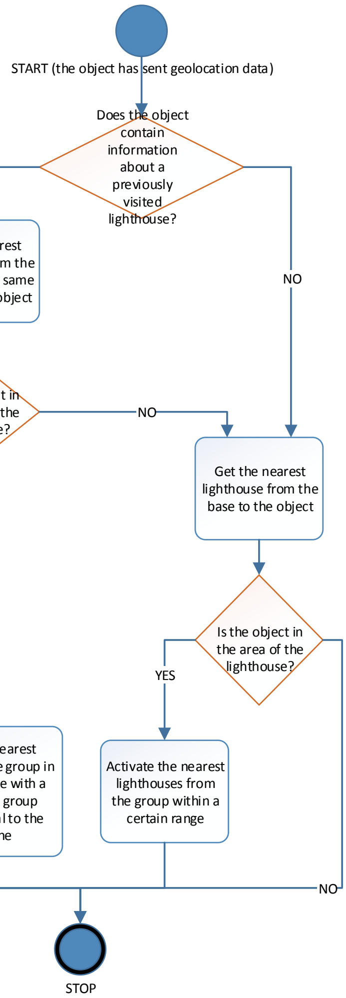

Fig. 6. A block diagram of an algorithm that activates street lamps, after receiving data about an object moving towards this lamp – in the case of pedestrians, it is not necessary to check the state of the previous lamp number within the group of lamps

Because each street lamp may have defined different hours of energy-saving mode (for example, the lamps located in the middle of a city may have a requirement of a longer work in a normal mode), the global ECO mode for the proposed system is determined by algorithm, as:

– start – the street lamp with the first minute of the first hour of the activation of the energy-saving mode,
– end – the street lamp with the last hour of its activation in the energy-saving mode or sun dawn, if it occurs earlier.

The scheme of the logical connections between street lamps and their groups is shown in Figure 7.

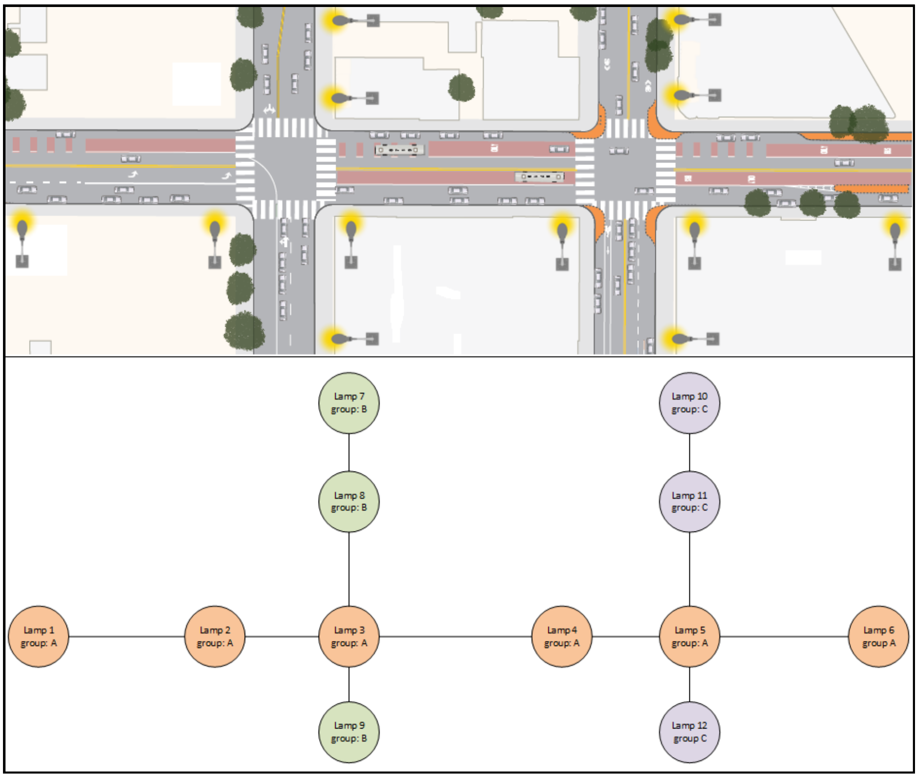

Fig. 7. An example of a mapping of street lamps networks to the form of logically connected objects, characterized by belonging to appropriate groups (corresponding to individual streets)

Assuming the activation of the algorithm one minute earlier than the minimum duration of the ECO mode is necessary to prevent the situation, when exactly at the moment of its inception the given place will go into darkness, and only the next data obtained from mobile devices will cause the street lamp to be reactivated. In turn, in summer time, a situation may occur, when the sunrise will come earlier than the morning hours of the energy-saving mode, and the operation of the algorithm should end, recognizing the sunrise. The additional necessary functionality that this algorithm has it is to cause diminishing these street lamps, near which there have been no more vehicles or pedestrians. The solution has been solved in the following way: in the central application there is a function called cyclically (by default every 10 seconds), which for previously activated street lamps checks the following relationships:

- is the current time greater than the parameter declared for this lamp, which defines the minimum delay value that is needed to diminish the device after its previous activation;
- whether within an immediate vicinity of this lamp exist any other active objects;
- are there any other objects in its bigger neighborhood (around 1000 m by default) that move towards this given lamp (here is taken into account the azimuth parameter of the last data obtained from the given vehicle).

In the case that the program would determine the logical value *true* for each of the above conditions, then such a device would return to the energy-saving mode. The above assumptions make it necessary to set the additional flag for each lamp, defining the possibility of switching a given device into energy-saving mode by the algorithm. In a consequence, the system will not reduce the intensity of light of these lamps, for which the current time is not included in the duration of the ECO mode. Major difference in actions taken by the algorithm depends on whether a particular data obtained from a mobile device has been sent by a vehicle or by a pedestrian. It was assumed that the speed of the mo-vement of people is so small that there is no need to check the direction, in which they are heading. In this case, the algorithm works as follows: it determines the activation of a street lamp within the same group of devices, in which the person was previously located (if such an information is available). A distance of the activated elements of the lighting network from the pedestrian location - it is a parameter, configurable by the administrator, and by default it has value of 300 m in each direction. In the case of vehicles it is important to know, in which direction the given object moves. Having this information the system is able to activate successive lamps in the appropriate sequence, consistent with the direction that the given vehicle moves.

Presence of an object within the range of a lamp causes switching on the devices within a given lamp group and within the distance calculated from the following formula:

$$d = \frac{v}{\alpha \cdot 0,1}, \tag{1}$$

where: d – is a distance from a point [m],
v – is a given vehicle movement velocity [km/h],
α – is a coefficient, defined by the program [unit] (by default equals 1).

The lower limit of the determined distance by default equals 300 m, while the upper limit equals 1000 m. Because of this, for fast-moving vehicles the algorithm activates street lamps from a greater distance, what is to ensure adequate lighting of the proper part of a road.

Next, the system checks the following sequential device number within the group. If the previously visited lamp was the one with the number smaller than the current one, the street lamp with a bigger number or equal to the current device number in the group is activated. The algorithm works analogously in the opposite direction. If the vehicle does not store the information about the previously visited street lamp, then a default value (set up within the program) equal to 250 m is assumed in every direction within the same device group.

The above assumptions require that the following attributes need to be stored by individual elements of the collection within the system:

– vehicles and pedestrians – must store an identifier of the previously visited street lamp;
– a street lamp must store the number of its lamp group and the next device number within this group.

Additionally, each vehicle and every pedestrian stores a parameter value of a time stamp of the previously visited device. The central application continuously periodically calls a function that removes the reference to the previous lamp numbers if the object for a certain time (by default 1 minute) has not registered its presence within one of the lamps with a given group.

This prevents from cases in which objects that do not send its location for a longer period of time will be considered from the point of view of the previously activated lamps, where this information would usually no longer be reflected in reality.

3. CONCLUSIONS

The presented project of the system would certainly allow for the significant energy savings, taking into account all-night lighting of streets and pavements. The concept of the proposed system allows for dynamic adaptation of lamps to the current location of objects moving around the city, what ensures high efficiency of energy consumption. In recent years, these types of pro-ecological projects have been very popular as well as are willingly financed by various institutions ("Polska rynkiem rozwojowym dla inteligentnego oświetlenia ulicznego", 2016). In the proposed system the costs of extra instrumentation of objects moving around the area are eliminated through the use of commonly used mobile devices. The project could in the future become a part of Smart Cities.

REFERENCES

Ashton, K., (2017, October 7). That 'Internet of Things' Thing. *RFID Journal*. Retrieved from http://www.rfidjournal.com/articles/view?4986

Drechny, M., & Kolasa, M. (2016). Sztuczna sieć neuronowa wspomagająca sterowanie oświetleniem ulicznym. *Rynek Energii*, *2*, 90–95.

Markowski, A., (2017, May 25). *Niezbyt jasno pod latarnią*. Retrieved from http://www.forumsamorzadowe.pl/artykuly/artykul/209,0,45,0,niezbyt_jasno_pod_latarnia.html

Miller, M. (2016). *Internet Rzeczy. Jak inteligentne telewizory, samochody, domy i miasta zmieniają świat*. Warszawa: PWN.

Mitchell, W. (2007). Intelligent cities. *e-Journal on the Knowledge Society*. Retrieved from http://www.uoc.edu/uocpapers/5/dt/eng/mitchell.pdf

MQTT Protocol. (n.d.). Retrieved October 7, 2017, from http://mqtt.org

Ożadowicz, A., & Grela, J. (2014). Street Lighting – nowoczesne oświetlenie przestrzeni publicznych. Automatyka budynkowa w infrastrukturze inteligentnych miast – Smart Cities. *Napędy i sterowani*, *16*(6), 104–108.

Polska rynkiem rozwojowym dla inteligentnego oświetlenia ulicznego. (n.d.). Retrieved October 7, 2017, from http://lighting.pl/Wydarzenia-branzowe/raporty-i-analizy/Polska-rynkiem-rozwojowym-dla-inteligentnego-oswietlenia-ulicznego

Project Raspberry Pi. (n.d.). Retrieved October 7, 2017, from https://www.raspberrypi.org

Stawasz, D., & Sikora-Fernandez, D. (2016). *Koncepcja smart city na tle procesów i uwarunkowań rozwoju współczesnych miast.* Łódź: Wydawnictwo Uniwersytetu Łódzkiego.

Tops of 2016: digital. (n.d.). Retrieved October 7, 2017, from http://www.nielsen.com/us/en/insights/news/2016/tops-of-2016-digital.html