Linear Wireless Sensor Networks as the Physical Layer of Smart Street Parking Systems

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Contribution to the State of the Art

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Abstract: Wireless sensor networks (WSN) represent a set of different technologies that, in cooperation with each other, form the basis for the realization of the physical layer of the concept of smart cities. Miniaturization of sensor devices and decreasing energy consumption, both for data processing and for mutual communication, as well as simple implementation and low cost, make WSN indispensable for a large number of different applications. Many of the applications imply a linear infrastructure that is subject to monitoring, and as such requires a linear deployment of sensor nodes. This form of WSN represents a special class of networks that we call Linear Wireless Sensor Networks LWSN. In this paper, we will describe the characteristics of these networks, the problems that are specific, as well as possible applications, and we will pay special attention to the application of LWSN in smart street parking lots.

Keywords: IoT, LWSN, Smart City, Street Parking, WSN

Introduction

The topology and architecture of WSN wireless sensor networks depend on several factors: the network application, the configuration of the terrain on which the network is implemented, the available technologies and the routing protocols that will be applied in the network. A special case are Linear wireless sensor networks LWSN, which in the topological view represent a linear structure of successively connected sensor nodes. A whole range of applications that monitor infrastructure of a linear nature require exactly this kind of sensor network architecture. Some of the most popular are:

Monitoring of highways: the large length of highways that need to be monitored without human presence makes it necessary to install a sensor network that will cover the entire length of the highway and perform the necessary readings such as: congestion and traffic interruption, traffic accidents, foreign objects on the road, weather conditions, speed violations, etc. [1].

Supervision of the electric power network: Supervisory systems for the transmission and distribution of electric power acquire a large number of parameters that enable more efficient planning of maintenance and exploitation of the network. Timely information can prevent problems in the network. Sensors can be used to measure voltage, temperature, humidity, irregularities in the network, etc. [2].

Monitoring of the border zone: One of the biggest problems in every country is the protection of the border zone and the prevention of illegal crossing of people and goods. Very long border lines and often inaccessible terrain represent difficulties that are neither easy nor cheap to solve. The only way for efficient monitoring is enabled by modern technologies, primarily wireless sensor networks. Different types of sensors are used for this, such as: cameras, thermal cameras, motion detectors, seismic sensors, etc. [3]. The collected data is delivered in real time to the center for monitoring the border zone.

Supervision of water pipelines, oil pipelines and gas pipelines: Distribution of oil and gas is carried out by branched and long networks of oil pipelines and gas pipelines. In addition to pipes, these networks contain pumps, control stations, various meters, etc. The entire infrastructure must be continuously monitored due to the importance and price of the raw material being transported, as well as possible dangers related to the flammability of substances and pollution of the natural environment (especially when it comes to underwater oil pipelines). Measurements are made of pressure in the pipes, temperature, flow, etc. The data is transmitted in real time in order to be able to react in time in case of any damage to the infrastructure. Measurements are made along the entire route, where a most of the route is not manually accessible [4] and the routes can be extremely long, up to several thousand kilometers.

Supervision of railway tracks: The safety and security of the railway road infrastructure is one of the key problems in the traffic of every country. WSNs provide a unique possibility of monitoring the entire route of the railway, regardless of its length and inaccessibility [5,6]. Timely notification of obstacles on the tracks, damage to the infrastructure, and irregularities in the operation of classic signaling is extremely important for saving human lives and property [7].

Monitoring of river flows: One of the most common applications of WSN is focused on measurements and readings of various physical quantities that quantitatively and qualitatively describe phenomena in nature. River flows are one of the most important natural resources of any country and it is necessary at all times to have accurate information on various aspects essential for the monitoring and management of watercourses. Traditional monitoring is slow, expensive and often impossible due to the circumstances on terrain. Sensors are most often used to measure water level, degree of water pollution, temperature, etc. [8].

In this paper, the authors will present the advantages of applying LWSN in linear smart parking lots. We will describe the comparative characteristics of individual network segments, specific problems caused by this form of infrastructure and possible solutions for optimization.

Related works

A large number of authors were engaged in research related to various possibilities of WSN application in smart parking systems. The aim of our research is to improve certain specific aspects essential for the functioning of the system. Here we will briefly mention only some of the research that was interesting to the authors of this paper when studying the problem.

In [9], a WSN that detects the occupancy of each of the parking space in the indoor parking system is analyzed. Each parking space has a sensor node that periodically signals the occupancy status visually or acoustically.

The GPS system for navigation was used in [10] as a way to model the availability of parking spaces. In this work, Poisson processes and algorithms based on artificial intelligence (modified version of the MIN-MAX algorithm) are used, which help the driver to choose a parking space that will be vacant with the highest probability. Magnetic and ultrasonic sensors are used for this.

In [11], a system for intelligent parking management was proposed, where the WSN consists of different types of sensor devices for vehicle detection in each of the monitored parking spaces. The system informs drivers about availability and guides them to a free space in the parking lot.

Here, we are particularly interested in parking spaces right next to city streets. In [12], one such system for free parking space management called Street Parking System SPS (Street Parking System) was proposed, which uses magnetic sensors for vehicle detection and ZigBee technology for wireless communication between sensors. The system showed 99% reliability in vehicle detection. A similar system was proposed in [13] where an LED display is used to indicate the available parking space.

A system that performs the detection of a free parking space and its reservation was proposed in [14]. The place is reserved based on the distance of the user and the recommended parking price, taking care to ensure that the total capacity of the parking lot is used evenly.

An innovative concept was proposed in [15], according to which the intelligence in the network is distributed and the decision-making is decentralized. The system is scalable since the addition of new network segments does not require re-engineering of the communication infrastructure, but fits into the existing network through the gateways that join them. Two types of sensors are proposed, magnetic and visual for vehicle detection.

The IoT system for parking in smart cities, based on cloud computing, is described in [16]. Ultrasonic sensors are used to detect the proximity of the vehicle to the parking lot and the occupancy of parking slots. Infrared sensors are used at the exit and entrance gates to help update the number of vehicles in the closed parking lot. Advanced optimization techniques are used to evenly distribute the load on city parking lots.

In [17], a system that uses IR sensors to detect the presence of vehicles in parking spaces is presented. The system consists of a monitoring module and a central module. The monitoring module consists of a ZigBee transmission unit, a LED display and a microcontroller that manages the data detected via the IC sensor. After the sensor detects the presence of a car, it sends information to the microcontroller to display the status of this parking space on the LED display and then sends this data via the ZigBee interface to the central module using a chain network topology.

Smart parking architecture

The architecture of smart parking is based on the application of sensors that perform readings of certain physical quantities and acquire data in the desired form. The entire system must be automated, without people involved, and meet the requirement of minimal energy consumption. Sensors are connected to the network wirelessly, since cabling is very expensive and inefficient. Wireless sensor networks obtained in this way are sometimes called PSN (Parking Sensor Networks) in the literature and have the following properties:

- Sensor nodes are stationary, installed usually on the surface of the asphalt surface, placed at relatively small distances from each other
- The topology of the network is linear and is determined by the topology of the roads
- The area covered by the sensor must not overlap with the areas covered by neighboring sensors, so that parallel multiple detection does not occur.
- The speed of the package formation depends on the speed of the vehicle's arrival at the parking place as well as the speed of its departure.
- Information on parking space availability is delivered in real time

WSNs collect data of interest from the desired location in real time. This data is transmitted to the place where it is processed and where it is possible to implement a large number of different user applications related to smart parking. An example of an application is checking availability, guiding you to a parking spot, and automatically booking and paying for parking via smartphone. Figure 1 shows the general architecture of the smart parking system.

Street parking lots

Modern technological development is largely focused on the need to improve the quality of people's

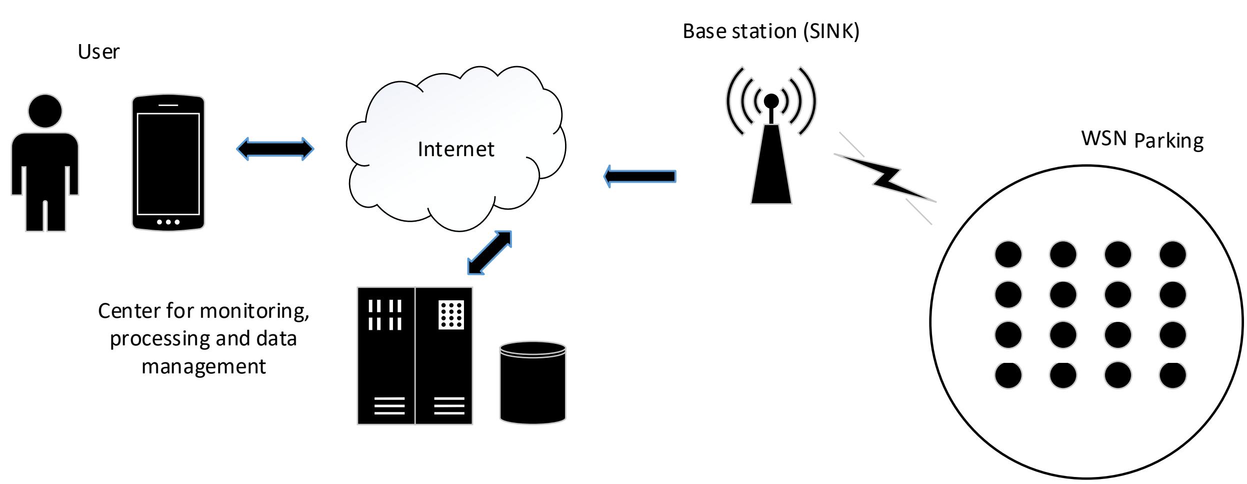

Figure 1. *General architecture of the smart parking system*

everyday life in many areas. In this sense, the idea of a smart city and IoT is a framework that provides unlimited possibilities for mapping the parallel existence of the physical and digital world and introducing new technologies into a whole range of segments of modern life. IoT has found its application in a large number of fields: industry, communications, data mining, agriculture, health, etc, but the concept of smart cities has opened up space for many new ideas where the final range cannot be anticipated. Smart parking is one of the most important segments of the smart city system, which can have the greatest impact on increasing the quality of life of its users.

Due to the constant growth in the number of cars, finding a parking space in the centers of larger cities has become an extremely big problem that has consequences for both car owners and society as a whole [18].

The number of closed parking lots in cities is limited, and in the centers it is never enough to meet the needs of drivers. For this reason, street parking lots are a very good solution to alleviate the problem. If drivers have real-time information about the availability of parking spaces and their exact location, the efficiency of parking in central city areas increases significantly. Wireless sensor networks are an ideal solution for managing street parking lots due to their low consumption and physical dimensions, as well as their low cost [19].

Street parking lots are areas on city streets, namely on the roadway, sidewalk or partially on the roadway and partially on the sidewalk, as can be seen in Figure 2 [20]. Drivers find this way of parking significantly more attractive than off-street parking lots or parking garages. Parking on the street enables closer contact with the objects that are the goal of the trip, in this way the least amount of time is spent for parking and walking to the goal. Street parking lots are interesting for drivers who have a short stay at the destination. However, these parking lots can also have a negative impact, which is reflected: in the reduction of road capacity, the speed of vehicle movement in the streets where these parking lots are located also decreases, there are often short interruptions or stoppages in the flow of traffic, and as a result, we have an increase in time journey and there is an increase in the emission of harmful gases, the risk of a traffic accident is increased for all participants in the traffic (vehicle driver, motorcyclist, cyclist, pedestrian, etc.). Street parking lots can be constructed depending on the parking angle (longitudinal parking, diagonal parking and vertical parking).

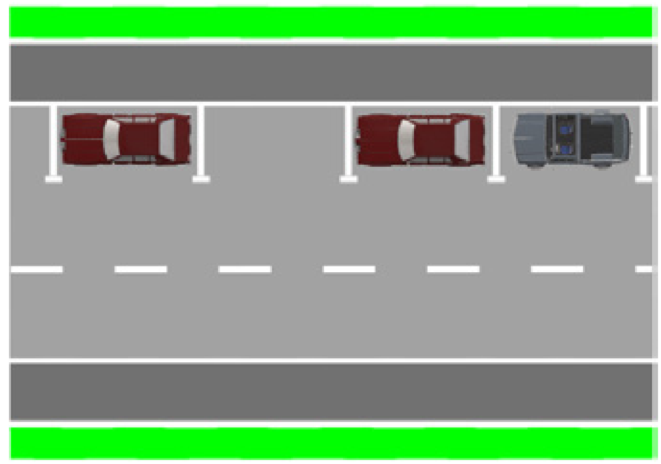

Figure 2. *The Street parking*

The problem with street parking lots is related to the possibility of their monitoring and integration into the smart parking system. Dispersion of parking spaces on a wider area that is a function of public use reduces the possible options for connection with the monitoring and control center. Here, there is no possibility for a ramp to the entrance to the parking lot or for centralized counting of entrances and exits and thus the occupancy of available parking spaces. A wireless sensor network is the only way to acquire data of interest from the terrain intended for street parking. Due to the topology of these parking lots, linear wireless sensor networks are imposed as the only supporting architecture. Implementation in practice, however, is accompanied by a whole series of specific problems.

Linear wireless sensor networks LWSN

In LWSN, sensor nodes are distributed in a linear structure. In this way, a two-dimensional network which is very narrow in one dimension and long in the other, is formed. As a consequence, communication in one hop to the sink in such networks is not possible, and the traffic generated in a node far from the sink will be transmitted to the destination using a large number of other sensors as relay nodes, so the data will be delivered with a delay that cannot be ignored

Sensors located closer to the sink represent a bottleneck in the data transmission network. The closer they are to the sink, the faster they drain their energy reserves, because the amount of data that the sensor as a relay node forwards to the LWSN increases significantly with the decrease in the sensor's distance from the sink, as can be seen in Figure 3 [21]. This is why it is necessary to somehow balance energy consumption in the network, which is a very challenging problem.

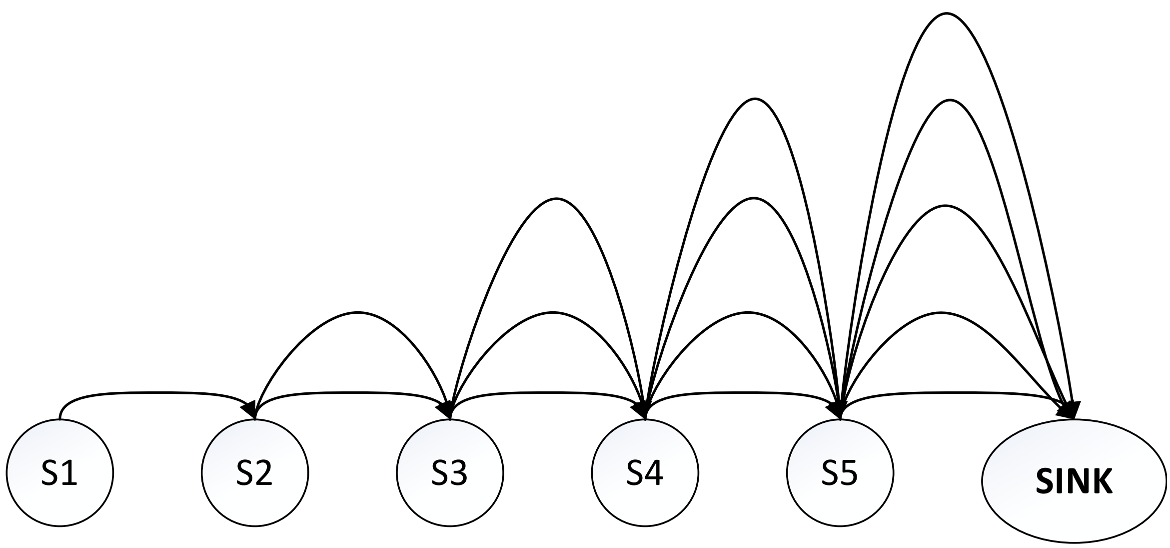

Figure 3. *Increasing traffic density with decreasing sensor-to-sink distance in LWSN*

This problem can be solved in two ways. The first implies inhomogeneous energy distribution in the network, and the second the implementation of appropriate energy-efficient data routing protocols. The first group of solutions includes, for example, a model in which the sinks are relocated in such a way that their new position enables a more even energy consumption of the associated sensors [22]. In this way, however, the system of linear WSNs is somewhat disturbed. There are a number of suggestions for solving the problem in another way. These proposals can be grouped into two categories [23]: multi-hop access and mobile data collection MDC (Mobile Data Collection).

The multi-hop approach is always related to the hierarchical WSN architecture. In the general case, the hierarchical network in LWSN consists of three levels of sensor nodes:

1. BAN (Basic Sensor Nodes) basic sensor nodes perform the primary function of reading and measuring at the location of interest, basic processing and forwarding of data to higher levels.
2. DRN (Data Relay Nodes) relay nodes that aggregate the data collected from the lower level and forward the data to the first higher level.
3. DDA (Data Dissemination Node) nodes for extended access, this is an optional layer that can be located between the second layer and the control center if the architecture and size of the network require it. If it does not exist, the DRN nodes take over. The method of data transmission to the control center depends on the applied technology. It is usually one of the mobile access technologies (4G, 5G) or one of the satellite technologies. If the distances are shorter, some of the short-range wireless technologies can be used.

Figure 4 shows the classic architecture of a hierarchical linear wireless sensor network.

Nodes at one level can be organized into clusters, whereby only one of the nodes in the cluster is selected in some way and that one will forward the data of all other members of the cluster to a higher level, as well as the data collected by itself [23]. We call these nodes CH (Cluster Head). CH nodes form a chain structure with each other, where again based on different criteria (depending on the applied protocol), a Chain Head is chosen, which performs traffic aggregation and forwards all data to the Network Control Center (NCC).

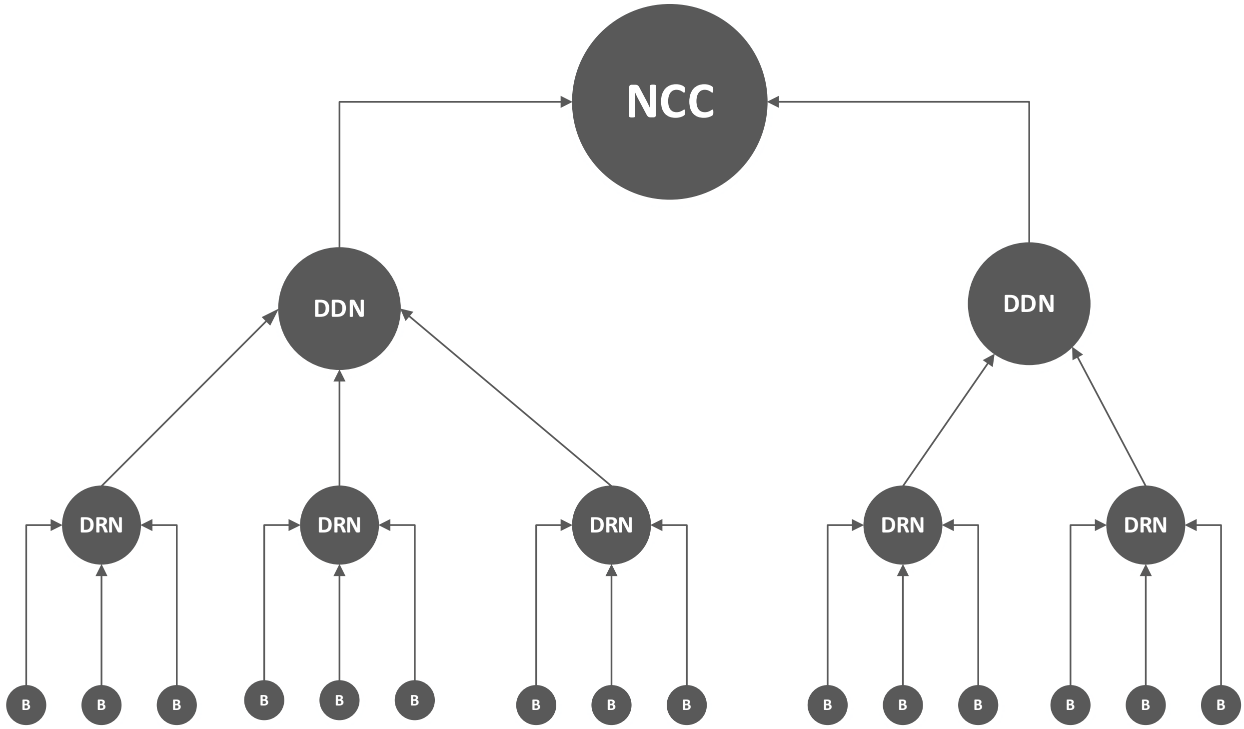

Figure 4. *Hierarchical architecture of LWSN network*

The MDC approach uses mobile nodes that periodically, when needed, or randomly visit each sensor node in the network, download the collected data from each node and transmit them to the sink. The advantage of LWSN for the application of mobile nodes compared to WSNs with other topologies is that the layout of the nodes is known in advance and, given the chain structure, is easy to navigate. Mobile elements can move on the ground as UGV (Unmanned Ground Vehicle), through water as AUV (Autonomous Underwater Vehicle) or through the air as unmanned aerial vehicles or UAV (Unmanned Aerial Vehicle) [24]. Underwater mobile nodes have a limited field of application and are not of interest here. Due to the configuration of the terrain, land mobile nodes cannot always perform all the necessary movements, so it may happen that the acquisition of data from certain parts of the network is missing. In addition, these devices have large delays due to the low speed of movement, which depends on the conditions on the ground. UAVs move three-dimensionally in space and do not have the limitations of terrestrial mobile elements, and due to the specific conditions of application in LWSN, they prove to be the only possible solution. The problem of the consumption of batteries needed to drive the UAV is overcome by the element returning to its destination or going to the next station, where its batteries can be replaced or recharged.

UAV can be used at different levels of the network in a wireless sensor network. At the lowest level, UAVs can play the role of basic mobile SN sensor nodes, whose primary task is to read various data from the field and deliver them to the processing site. The use of UAVs at this level significantly expands the sensor field beyond the area covered by static sensors. If UAVs are used at the second level of the wireless sensor network as relay nodes, all network communication with higher levels is done via the UAV. Readings on the ground are still taken by static sensors arranged and grouped appropriately. The use of UAVs at the third level of the wireless sensor network implies that several UAVs are used in the network, which collect data from the basic level directly from SN or from relay nodes. If a multi-hop network is used at lower levels, further communication is carried out according to distributed sinks or directly with the NCC. Figure 5 shows the case where the UAV is used on the third layer of the network architecture.

LWSNs applied in street parking lots can be kilometers long. The multi-hop architecture covering

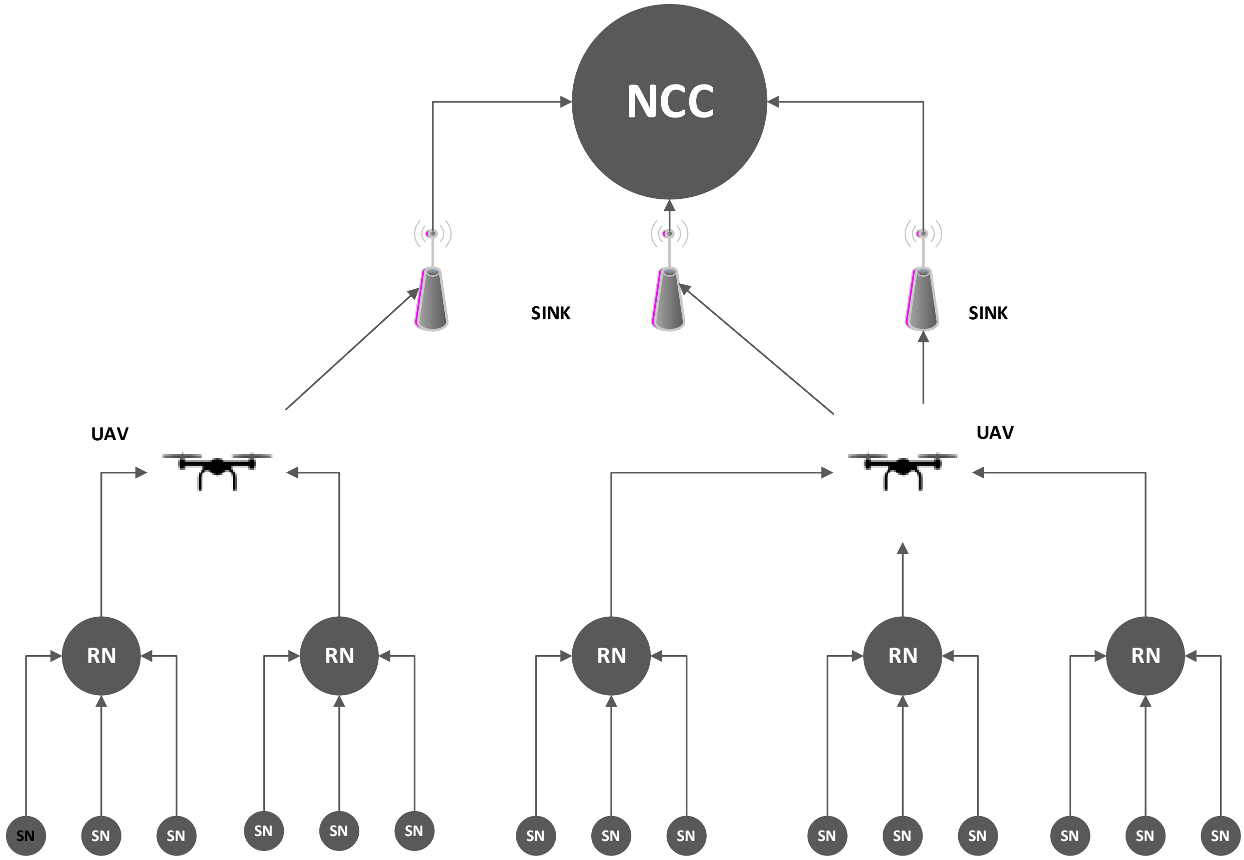

Figure 5. *MDC architecture of LWSN with application of UAV on the third layer*

these networks should deliver all collected data to the NCC processing point. Due to the length of the network and large propagation routes, energy in these networks is consumed relatively quickly. UAV devices have the ability to replenish energy as well as replace batteries, meaning that energy in these networks is a less critical resource. The UAV collects data from each node individually or from relay nodes where data aggregation is performed from a lower level, which causes a significant delay in the network, which is not a critical problem in Multi-hop networks. The UAV stores the data it collects along the route in a buffer, until it reaches the range zone of the higher layers of the network, and only then does it deliver. If the buffer capacity is exceeded, some of the packets are irretrievably lost.

Both approaches can be used in urban areas to acquire data from smart parking lots. However, the authors recommend a multihop architecture. The problems accompanying this type of architecture are primarily related to limited power supply capacity, and it is necessary to find suitable transmission protocols that will optimize energy consumption.

Conclusion

Parking in the centers of large cities is one of the most frustrating activities for their residents and visitors. Given that the concept of smart cities is primarily intended to raise the quality of life of all participants to the highest possible level, it is clear that smart parking lots represent one of the most important segments. Data collected from the scene in real time, transmitted through the appropriate infrastructure and used on simple applications provide a platform that provides drivers with all the necessary services that enable easy parking even in the most complex conditions. In this paper, we based ourselves on the description of the infrastructure suitable for a smart parking system in the conditions of street parking, which are very attractive in the absence of closed parking spaces in the city center. Two possible architectures of linear wireless sensor networks are presented. Both approaches can be used in urban areas to acquire data from smart parking lots. However, the authors recommend a multihop architecture. The problems accompanying this type of architecture are primarily related to limited power supply. Tt is necessary to find suitable transmission protocols that will optimize energy consumption, and the authors plan to focus on this segment in their further research.

REFERENCES

[4] M. A. Kafi et al, "N/A - A Study of Wireless Sensor Networks for Urban Traffic Monitoring: Applications and Architectures," Procedia Comput. Sci., vol. 19, pp. 617–626, 2013.

[5] J. Yu and X. Zhang, "A Cross-Layer Wireless Sensor Network Energy-Efficient Communication Protocol for Real-Time Monitoring of the Long-Distance Electric Transmission Lines," Journal of Sensors, vol. 2015.

[6] G. S. Sankar and S. Angadi, "Wireless Sensor Network for Border Monitoring", The International Journal Of Engineering And Science (IJES), pp. 65– 68, 2013.

[7] W.Z. Khan et al, "Oil and Gas monitoring using Wireless Sensor Networks: Requirements, issues and challenges", In2016 International Conference on Radar, Antenna, Microwave, Electronics, and Telecommunications (ICRAMET), pp. 31-35, Oct. 2016.

[8] G. Shafiullah, A. Gyasi-Agyei, and P. Wolfs, "Survey of wireless communications applications in the railway industry," in Proc. 2nd Int. Conf. Wireless Broadband Ultra Wideband Commun., Sydney, NSW, Australia, p.65, 2007.

[9] З. Ж. Аврамович, Г. Дюканович, Г. С. Радич, Г. Попович, „Опыт и возможности применения беспроводных сенсорных сетей на железнодорожном транспорте", 10–ая международная конференция „Системы безопасности на транспорте, Любляна, Словения, април 2017.

[10] N. Zhang, et al, "Optimization Scheme of Forming Linear WSN for Safety Monitoring in Railway Transportation," International Journal Of Computers Communications & Control, pp. 800-810, Dec 2014.

[11] K. S. Adu-Manu et al "Water quality monitoring using wireless sensor networks: current trends and future research directions," ACM Transactions on Sensor Networks (TOSN), vol. 13, no. 1, p. 4, 2017.

[12] A. Bagula , L. Castelli and M. Zennaro, "On the design of smart parking networks in the smart cities: An optimal sensor placement model", Sensor., 15: 15443-15467, 2015.

[13] S. Lee, D. Yoon and A Ghosh, "Intelligent parking lot application using wireless sensor networks" In Proceedings of the International Symposium on Collaborative Technologies and Systems. pp. 48-57, 2008.

[14] S.V. Srikanth et al." Design and Implementation of a prototype smart parking (SPARK) system using wireless sensor networks", In Proceedings of the International Conference on Advanced Information Networking and Applications Workshops. pp. 401-406, 2009.

[15] J. Gu et al. "Design and implementation of a street parking system using wireless sensor networks" In Proceedings of the 10th IEEE International Conference on Industrial Informatics. pp. 1212-1217, 2012.

[16] S.V. Reve and S. Choudhri, "Management of car parking system using wireless sensor network", Int. J. Emerg. Technol. Adv. Eng. 2: 262-268, 2012.

[17] J. Yang, J. Portilla, T.Riesgo, "Smart parking service based on wireless sensor networks" In Proceedings of the 38th Annual Conference on IEEE Industrial Electronics Society, pp. 6029-6034, 2012.

[18] M. Alam et al. "Real-time smart parking systems integration in distributed ITS for smart cities", Journal of Advanced Transportation, pp. 1-13, 2018.

[19] A. Mishra et al. "Low cost parking system for smart cities: A vehicle occupancy sensing and resource optimization technique using IoT and cloud pass", International Journal of Scientific and Technology Research, pp. 115-122, 2019.

[20] H.C. Yee and Y. Rahayu, "Monitoring parking space availability via ZigBee technology", Int. J. Future Comput. 3:377, 2014.

[21] A. Singh, A. Kumar, A. Kumar and V. Dwivedi, "Radio frequency global positioning system for real-time vehicle parking", International Conference on Signal Processing and Communication (ICSC), pp. 479–483, 2016.

[22] Z. Zhang et al." A Street Parking System Using Wireless Sensor Networks", International Journal of Distributed Sensor Networks, Vol. 2013.

[23] M. S. Tomić, Parkiranje i parkirališta, Beograd: Univerzitet u Beogradu, Saobraćajni fakultet, 1995.

[24] M. Noori and M. Ardakani, "Characterizing the traffic distribution in linear wireless sensor networks", IEEE Communications Letters, vol. 12, no. 8, pp. 554-556, Aug. 2008.

[25] L. B. Saad, and Bernard Tourancheau. "Sinks Mobility Strategy in IPv6-based WSNs for NetworkLifetime Improvement." International Conference on New Technologies, Mobility and Security (NTMS), IFIP, 2011, Paris, France

[26] Y. K. Yousif et al, "A review of data collection approaches in linear wireless sensor networks (LWSNs)", 1st International Conference on Green and Sustainable Computing (ICoGeS) 2017.

[27] G. Đukanovic and G. Popović, „Ušteda energije u WSN upotrebom UAV i dinamičke arhitekture mreže", XVII međunarodni naučno-stručni simpozijum INFOTEH-JAHORINA, Vol.17, 2018.

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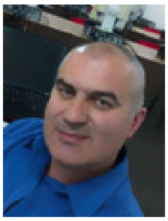

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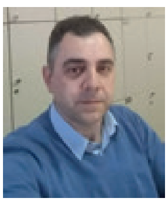

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