Light & Engineering
Vol. 28, No. 2, pp. 67–76, 2020

https://doi.org/10.33383/2019-030
Svetotekhnika #6, 2019, pp. 23–30

DETERMINATION OF ENERGY CONSUMPTION ACCORDING TO WIRELESS NETWORK TOPOLOGIES IN GRID-FREE LIGHTING SYSTEMS

Musa Çıbuk[1] and Mehmet Sait Cengiz[2]

[1]Department of Computer Engineering, Bitlis Eren University, Turkey
[2]Department of Technical Vocational School, Bitlis Eren University, Turkey
E-mails: mcibuk@beu.edu.tr, msaitcengiz@gmail.com

ABSTRACTS

While Wireless Sensor Networks (WSN) are used in various areas nowadays, they also come in front of us in the remote follow up and management of especially main street, road and city lighting systems and in autonomous applications relating with them.

This study has been conducted with the aim to determine the energy consumed by Wireless Sensor Network (WSN) based monitoring and management systems as per topological sequence of lighting systems with renewable energy sources (RES) in a grid-free environment. In this way it was aimed to maximize the life time of WSN which are formed by minimum energy consumption of lighting elements that store energy with accumulator-battery in grid-free RES lighting systems and which use this energy later on. Physical installation of lighting systems having different topological distributions will show differences with respect to costs, labour force and time. Starting from here on, different topologies for grid-free lighting systems have been created in simulation environment and they have been analyzed and an optimal solution has been searched for. Energy consumptions of each lighting system having linear, random and tree lighting topology have been determined during data exchange. For each topology lighting systems with 25, 50, 100 and 200 armatures have been designed and their energy consumptions for data exchange have been found. It has been seen that data packages were influenced at first degree from node hopping numbers within topology and as being parallel to this, it has been seen that topology consuming most energy was linear lighting and that topology consuming minimum energy was tree lighting.

Keywords: **l**ighting systems, wireless sensor networks, network topology, grid-free lighting

1. INTRODUCTION

Nowadays share of lighting in total energy consumption gets increased day by day. In order to provide sustainable and uninterrupted lighting service, there is need for smart lighting systems. For smart lighting WSNs are frequently used in automation, remote monitoring and remote control systems. Classic WSNs are composed of nodes that have been distributed randomly in an area or which have been previously distributed in a planned way and that have low capacities.

In this study, energy quantity being consumed during data exchange between nodes as per topological distributions in WSNs being needed in lighting systems has been investigated. For this purpose, by comparing energy quantities consumed during data exchange by lighting systems having different topologies in a road lighting have been compared and proposals have been made for optimum topology. In remote monitoring and control system being the subject of this study, nodes (Lighting Node – LN) record various parameters such as lighting level of armature, reduction in light flux as per the lighting level of first day, fog in the air, moisture ratio, air temperature, whether armature is energized or not, and angular placement of armature as per the ground in their memories and they transmit them to coordinating node (Coordinator Lighting Node – CLN). During data exchange between nodes, energy consumptions per armature change as per topological distribution. For the communication of armatures and to minimize the energy consumed during data exchange, it was tried to determine optimum topology that would increase energy efficiency.

2. WIRELESS SENSOR NETWORKS IN LIGHTING SYSTEMS

Sensor nodes can be generally distributed randomly or in an organized and dense way to a place desired to be observed. When a WSN is created, there is no need to determine location of sensor nodes in advance [1–4].

In literature, in many of the studies being conducted in lighting area, various WSN systems have been used for remote control and a smart system. While in studies being conducted as relating with lighting applications, generally Zigbee and GPRS based systems are preferred, it is seen that Zigbee based systems are more frequently used. Karun et al. (2014) have proposed a smart main street lighting commanding system by using Zigbee Network in the study they conducted [5]. Purpose of this system is to manage the lighting system with no human intervention. In a similar way, Srinath et al (2015), Zigbee have proposed an automatic street lighting control system by using network and sensors having emergency accident warning features [6]. Measurement stations being placed on the main street within the scope of study measure day light of main street and active-passive situations at certain intervals. Purpose is to reduce electrical consumption. Bhargavi et al. (2016), have worked on controlling energy consumption for a more efficient lighting system with remote control with Zigbee [7]. Priti Lahoti et al (2017) have achieved energy consumption of 60 % in the lighting system with remote control which they have proposed [8]. This system is controlled and managed remotely with micro controller and Zigbee. Besides, it was emphasized that it had lower costs when GPRS-GSM was used. It was recommended that it would be more correct to use Zigbee and GPRS-GSM together for remote monitoring-controlled smart road lighting systems with high energy efficiency.

Although usage of Zigbee technology in these studies increase energy efficiency, as Zigbee has low data transmission capacity, it remains to be insufficient in real time applications requiring high data transmission. For example, while Zigbee is sufficient in a system having 25 lighting armatures with respect to data exchange, Zigbee is insufficient in data exchange in long distance lighting systems with much more number of LNs. Since in intense data flow situations much more energy is consumed during communication between LNs and CLN, internal battery in relevant armatures is consumed quickly. Therefore this armature remains outside the system. In lighting, in remote control applications, the method that is used most after Zigbee is GPRS, GSM method. Within this context in various studies in literature in smart lighting system proposals remote control has been made with GPRS-GSM [9–12].

Due to low data transmission ratios of GPRS-GSM and Zigbee technologies and due to disadvantages such as infrastructure costs, in this study, nRF905 Transceiver, having lower cost, being current, having easiness of usage and very low energy consumption during data exchange, has been simulated [13]. Comparison of ZigBee, GPRS-GSM and nRF905 is given in Table 1.

3. WIRELESS SENSOR NETWORKS AND MAINTENANCE FACTOR RELATIONSHIP

Nowadays in smart lighting there is need for automation systems that provide uninterrupted lighting and that require less maintenance. Basic purpose in using WSNs in lighting systems is to create a structure that improves sight comfort and that needs less maintenance and which can be remotely controlled or has an autonomous structure. At this point in electrical facilities with RES feeding without grid connection, it has become a necessity to use WSN topologies having low energy consumption for automation, because in lighting systems with the effect of various negative conditions, maintenance factor gets reduced and energy consumption gets increased. Maintenance Factor (MF), Lamp Lumen Maintenance Factor (LLMF), Lamp Survival Factor (LSF), Luminaire Maintenance Factor (LMF), are composed of total impact of various parameters

Table 1. Comparison of ZigBee, GPRS-GSM and nRF905

	Frequency (MHz)	Modulation	Topology	Energy Consumption	Data Rate	Coverage Radius (m)	Multi-Channel Support
ZigBee	868/915/ 2400	BPSK, OQPSK	Star, P2P, Mesh	Low	250 kbps	10–100	No
nRF905	433/868 / 915	GFSK	–	Very low	250KBps, 1MBps 2MBps	250	Yes
GPRS-GSM	850/900/ 1800/1900	GMSK	P2P, P2M	High	56–114kbps	1000+	No

performance loss in lighting depending on reduction in light flux and optical effect (for LED lamps) [14–22]. Under normal conditions effects originating from WSN technologies and automation are not added to MF. But in lightings being managed with smart city applications or automation systems, when inefficient WSN impacts are added to MF, MF will fall further and it will increase energy consumption. In another way of saying, reduction in MF reduces efficiency and increases lighting costs. MF is used as a multiplier as it can be seen in illuminance level (E) relation in Equation 1 [16, 19, 22–24]. In equation 1, relationship of illuminance level and maintenance factor is seen.

$$E = \frac{I \cdot cos^3 \varepsilon \cdot \Phi \cdot MF}{h^2}, \quad (1)$$

where I is the luminous intensity value (cd), Φ is the luminous flux (lm), MF is the maintenance factor, h is the height of the luminaire from the ground (m), ε is the angle between the light coming from the armature to the surface and the normal of the surface.

4. APPLICATION OF WIRELESS SENSOR NETWORKS TO LIGHTING

WSNs are composed of sensor nodes which have been distributed randomly on an area or previously in a planned way and which have low capacities. Energy limitation of sensor nodes and difficulty in battery replacement are among the most important factors effecting WSN design. Besides development of application specific energy efficient environment access techniques bears significant importance. Energy consumption occurs most during data exchange. Application specific MAC design and studies that would minimize energy consumption in data exchange have been made [1, 2, 25, 26]. In this studies while it is aimed to have anticoincidence environment access, it is targeted to transmit data amount to be sent in minimum and effective way.

Another important design criterion in WSNs is network topology. Network topology is the connective relation between nodes. Basic logic in WSNs is the transmission of data obtained by nodes to coordinator node in some way. Basically connection forms of nodes with each other are divided into two parts such as single-hop and multi-hop as shown in Fig. 1. In lighting applications, lighting armatures which are used as sensor nodes are defined as Lighting Node (LN), and coordinator nodes that are used as management and data collection centres are defined as Coordinator Lighting Node (CLN).

In the connection model with single-hop, LN directly communicates with CLN. In connection model with multi-hop, CLN communicates with LNs within coverage zone of CLN through other LNs within coverage zone. For this reason as it is ap-

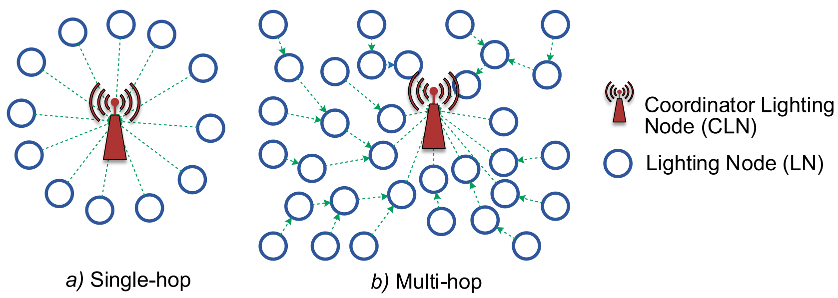

Fig. 1. WSN connection modes

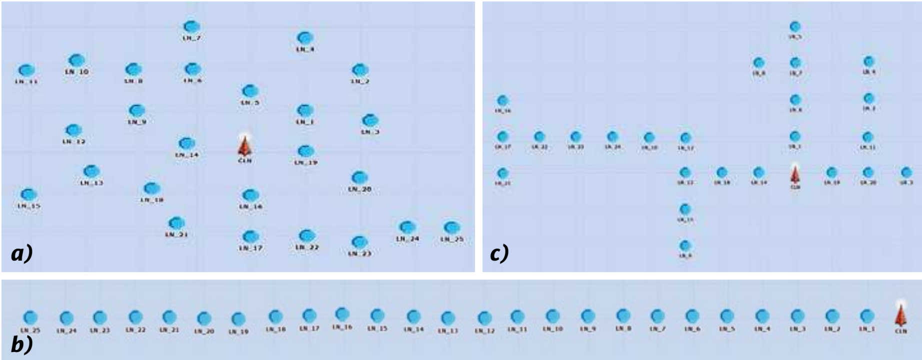

Fig. 2. Lighting topologies: a) random lighting topology; b) linear lighting topology; c) tree lighting topology

proached to CLN in the network, data exchange traffic of LNs gets increased. As being proportionate with this increase, energy consumption also gets increased. Since LNs which are fed with accumulator or battery in this example do not have grid connections, they rapidly consume their energies due to intense data exchange and they split from network.

In multi-hop WSNs, LNs have energy consumptions being different from one another. Because data exchange quantity is different for each LN. Since LNs which are close to CLN undertake the task of directing for LNs that are farther away, data exchange quantity is apparently different from other ones. This situation causes for LNs that are close to CLN to consume more energy. Therefore, when energy of LNs that are close to CLN is rapidly consumed, their communication with WSN is cut. LNs that are farther away as being connected to this LN split from the network even though their energies have not finished. That is meaning the data exchange is cut. In such situations in order for WSN application to be optimum, it is required to prefer method and topologies with which energy will be used efficiently.

5. SELECTION OF OPTIMUM TOPOLOGY

In literature various studies have been made as relating with WSN topologies [3, 4] and as no study has been observed in lighting applications relating with effectiveness of WSN topologies, this has created motivation for this article. In this study, it was aimed to compare the all energy amount consumed by all LNs in WSNs having different topologies. To make analysis, modelling method has been preferred in simulation environment. Physical realization of a real application in WSNs causes for labour loss and costs. In this situation, it is found out that first of all a simulation of application being planned to be designed which would generate results that are close to actual ones is required.

Modelling of developed WSN application was made in Riverbed Modeller simulation environment. Riverbed Modeller is the network simulation software where simulation of all network projects can be made [27]. Monitoring the behaviour of network projects being created provides opportunity to realize various processes such as performance analysis and testing of superiorities. While designing model behaviour, ProtoC language which takes C language as basis and which is specific for software is being used.

Riverbed Modeller enables for simulations with discrete event basis to be made for the analysis of both the behaviour and performance of network model being developed [28].

When WSN is designed, for having an application that is close to actual one, for LNs the features of Nordic platform have been taken as reference. Nordic nRF905 which supports multi-channel communication has been used. In Table 2 technical specifications of nRF905 can be seen [13].

Table 2. The nRF905 Specification

Parameter	Value	Unit
Minimum supply voltage	1.9	V
Maximum transmit output power	10	dBm
Data rate	50	kbps
Supply current in transmit	@ –10	dBm
output power	9	mA
Supply current in receive mode	12.5	mA
Temperature range	–40 to +85	°C
Typical sensitivity	–100	dBm
Supply current in power down mode	2.5	µA
Channel switching time	<650	µs

Table 3. Simulation Parameters for Random, Linear and Tree Topology According to 25, 50100 and 200 LN Scenario

Scenario	Topology	LN coverage radius (m)	CLN count	Network area (m^2)	Simulation time (s)	Distance between nodes (m)
25 LN	Linear	145	1	2500×100	300	100
	Random	145	1	2000×2000	300	variable
	Tree	145	1	2000×2000	300	100
50 LN	Linear	145	1	5000×100	300	100
	Random	145	1	2000×2000	300	variable
	Tree	145	1	2000×2000	300	100
100 LN	Linear	145	1	10000×100	300	100
	Random	145	1	2000×2000	300	variable
	Tree	145	1	2000×2000	300	100
200 LN	Linear	145	1	20000×100	300	100
	Random	145	1	2000×2000	300	variable
	Tree	145	1	2000×2000	300	100

Table 4. Energy Consumption Values of Nordic Platform

Bandwidth (KHz)	Data rate (bps)	Power consumption type	Power consumption (W)
100	5,95E+05	P_{Tx}	0.0330
		P_{Rx}	0.0366
200	1,19E+06	P_{Tx}	0.0900
		P_{Rx}	0.0384
		P_{Sp}	0.0003
		P_{LPL}	3,75E-05

Two types of nodes are designed in simulation environment and they are CLN for central management point and LN for armatures. For the topological distribution of lighting system, random topology has been designed to represent rural areas, linear topology has been designed to represent road and tunnel lighting, and tree topology has been designed to represent branch-main street-road lighting, Fig. 2.

For each of random, linear and tree topologies, 4 different scenarios being composed of 25, 50, 100 and 200 LN have been created and simulations have been made. Simulation parameters of scenarios being created can be seen in Table 3.

Energy consumptions of Nordic nRF905 radios that are used in node models in simulation environment can be seen in Table 4.

One of the parameters effecting energy consumption is the sizes of data exchange packets that are used in WSNs. In WSNs that are developed within context of this study, 3 different types of packets have been used. Packet types and sizes can be seen in Table 5.

Schedule packets has been used to transmit channel information being assigned by CLN to LNs. Control packets are used by LNs to join the network directly and for the continuity in network. LNs use Relay packets to join the network through other nodes.

6. MATHEMATICAL MODELS

In this study, by adding the energies consumed by *n* pieces of LN and 1 piece of CLN during Sleep Mode, LPL and packet exchange, energy consumption amount is calculated. Here very low power consumptions originating from other parameters, which can cause power consumption have been neglected [1, 2]. Energy amount required for a node to obtain a packet (P_r) is found as per equation (2).

Table 5. Packet Types and Sizes Used in WSN

Packet type	Length (bit)
Schedule packet (Psch)	variable
Control Packet (Pctrl)	32
Relay Packet (Prly)	52

$$P_R = \frac{L_{pkt}}{R_{ch}} * P_{Rx}. \quad (2)$$

Calculation of energy to be used in radio transmission for the transmission of a packet by any LN desiring to send data has been shown in equation (3) [1, 2].

$$P_T = \frac{L_{cp}}{R_{ch}} * P_{Tx}. \quad (3)$$

When number of LN nodes in network is n, consumed energy amount (E_T) that is consumed by $N_C = n.LN+CLN$ pieces of nodes in total is calculated as shown in equation (4) [1, 2].

$$E_T = \sum_{n=1}^{N_C} \left\{ \left(P_R * N_{Rpkt}\right) + \left(P_T * N_{Tpkt}\right) + P_{Sp} + P_{LPL} \right\}. \quad (4)$$

where

P_{Tx} is the transmitter power ;

P_{Rx} is the receivers power;

P_{Sp} is the sleep power;

P_{LPL} is the low sleep power;

E_T is the total energy of nodes;

N_{Rpkt} is the total number of packets received by all nodes;

N_{Tpkt} is the total number of packets transmitted by all nodes

P_R is the power consumption per received Packet;

P_T is the power consumption per transmitted packet;

C_N is the node count;

R_{ch} is the channel data rate (bps);

L_{pkt} is the packet length (bit).

7. RESULTS AND DISCUSSIONS

For WSNs simulation of which has been made within context of this study, node numbers have been determined as 25, 50, 100 and 200. As topology, linear, random and tree distribution have been selected, total energy consumed by all nodes (*n.LN+CLN*) for 3 lighting topologies simulation of

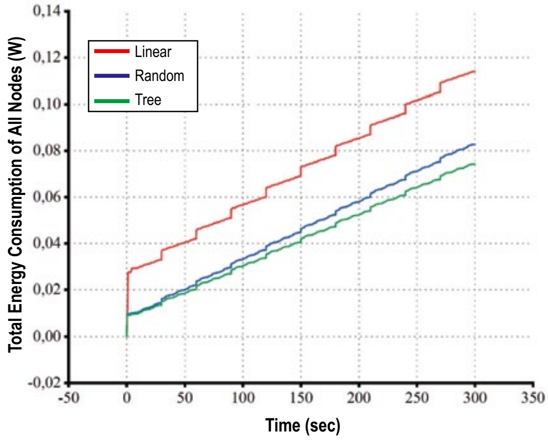

Fig. 3. Consumed total energy by 25LN+CLN

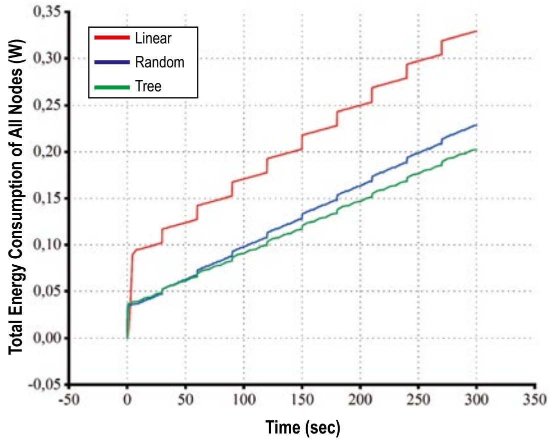

Fig. 4. Consumed total energy by 50LN+CLN

which has been made, has been shown. In all graphics it is observed that in the first seconds of simulation energy consumption has rapidly increased because during first participation of LNs in the network, all LNs consume energy together. When LNs are energized for the first time, they use control and relay packets often to join the network. After participation in network is realized, LNs send control and data packages periodically with less frequency. LCN consumes energy for each LN it adds to the network. In the scenario having 25 LN, total energy consumed by 25 LN+CLN is shown in Fig. 3. It can be seen in Fig. 3 that total energy consumptions of 25LN+CLN in simulation environment are respectively 0.114, 0.0827 and 0.0743W in linear, random and tree topologies.

According to this, in an electrical grid having 25 lighting devices, topology that consumes most energy is linear lighting topology with 0.114W. Minimum energy consumption has been observed in tree lighting topology with 0.0743W. In a lighting system with 25LN+CLN, in WSN tree lighting topolo-

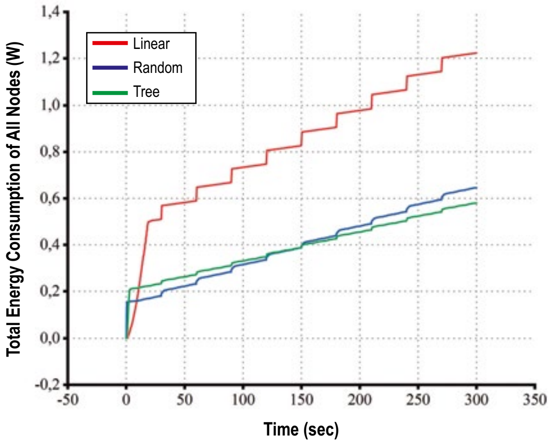

Fig. 5. Consumed total energy by 100LN+CLN

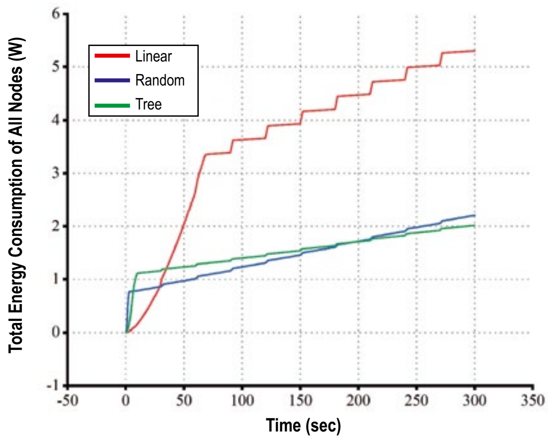

Fig. 6. Consumed total energy by 200LN+CLN

gy consumes 35 % less energy when compared with linear lighting topology. Random topology has consumed 27 % less energy when compared with linear topology. In Fig. 4, total energy consumed by 50LN+CLN is seen.

It can be seen in Fig. 4 that total energy consumptions of 50LN+CLN in simulation environment are 0.3293, 0.2287 and 0.20W respectively for linear, random, and tree topologies. Accordingly, in an electrical grid having 50 lighting devices, topology consuming most energy is linear lighting topology with 0.3293W. Maximum energy consumption has been observed in tree lighting topology with 0.20W. In a lighting system with 50LN+CLN, in WSNs tree lighting topology has consumed 40 % less energy when compared with linear lighting topology. When the number of lamps or fixtures in network gets increase, difference in energy consumption between linear and tree topologies is increasing too. While difference of total energy consumed for linear and tree topologies in WSN with 25LN+CLN is 35 %, in a system with 50LN+CLN total energy difference is 40 %. That is meaning each lighting device included in the system increases energy difference between most appropriate topology and other topologies. In Fig. 5, total energy consumed by 100LN+CLN can be seen.

It can be seen in Fig. 5 that total energy consumptions of 100LN+CLN in simulation are 1.223W, 0.6458W, and 0.58W respectively for linear, random, and tree topologies. Accordingly, in an electrical grid having 100 lighting devices, topology consuming most energy is linear lighting topology with 1.223W. Minimum energy consumption is seen in tree lighting topology with 0.58W. In a lighting system with 100LN+CLN in WSN, tree lighting topology consumes 53 % less energy when compared with linear lighting topology in average. In Fig. 6, total energy consumed by 200LN+CLN can be seen.

It is seen in simulation that total energy consumptions of 200LN+CLN are nearly 5.301W, 2.205 W, and 2.016 W respectively for linear, random and tree topologies. According to this, in an electrical grid having 200 pieces of lighting devices, most energy consuming topology is linear lighting topology with 5.301W. Minimum energy consumption is seen in tree lighting topology with 2.016 W. In a lighting system with 200LN+CLN in WSN, tree lighting topology consumes nearly 62 % less energy when compared with linear lighting topology. For different lighting systems, energy consumptions in WSN and hop-counts can be seen in Table 6.

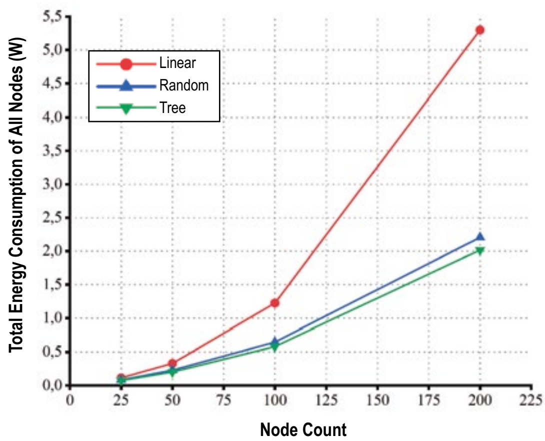

Fig. 7. Total energy consumption due to the increase in LN number for Linear, Random, and Tree topologies

Table 6. Total Energy Consumption in WSNs for Different Lighting Systems

Scenario	Topology	Energy consumption (W)	Advantageous topology (Best / Worst) (%)	Mean hop-count	Max hop-count
25LN+CLN	Linear	0,1140		13	25
	Random	0,0827		1,72	3
	Tree	0,0743	35	1,6	4
50LN+CLN	Linear	0,3293		25,5	50
	Random	0,2287		1,54	4
	Tree	0,2003	40	2,88	7
100LN+CLN	Linear	1,2234		50,5	100
	Random	0,6458		4,19	6
	Tree	0,5801	53	3,49	9
200LN+CLN	Linear	5,3012		100,5	200
	Random	2,2046		7,35	15
	Tree	2,0160	62	4,78	11

Changes in total energy quantities being consumed for the topologies being evaluated in this study are shown in Fig. 7.

As it can be seen in Fig. 7, minimum energy consumption takes place in Tree topology and maximum energy consumption takes place in linear topology. With increasing of the LNs number in network, total energy amount increases exponentially. In the graphic, while very serious differences are not seen between random and tree topologies, in linear topology it is seen that as number of nodes increase, there is very serious level of energy consumption. It is apparent that average hop counts have first degree effect on this outcome. For this reason in simulation studies, besides total energy being consumed, hop counts that are used by LNs to reach CLN for joining network and data transmission have also been investigated. In Table 6, maximum and minimum hop counts have been given for all scenarios and topologies which are used in simulation. As it can be seen in the table, in linear and tree topologies having equal distances between nodes and proper node distribution, energy consumption increases together with hop counts. On the other hand, as there is no proper distribution in random topology, it cannot be stated that average hop counts increase in parallel with increase in node numbers. As being parallel to the increases in node numbers, maximum hop counts also increase and this situation is observed more clearly in linear topology. A LN also transmits data of other LNs to which it serves for relaying besides its own data. Therefore, more number of relaying done by a LN means as much data transmission being made. When each relaying process is considered as a hop for linear topology, hop counts increase, and energy consumed by LNs for data transmission increase in relative degree. To give an example, a LN that is directly connected with CLN can send its own data directly. When the LN, which is connected with CLN through a different node, sends its data, it has to transmit the same data package on the node that functions as relay for it. In transmission of a package with 10 hops, 10 nodes have to transmit the same packet and this requires 10 times the energy that is consumed per packet.

8. CONCLUSIONS

In this study, energy consumptions of lighting system topologies with different scenarios having same number of nodes under same conditions in WSNs have been evaluated. For this purpose, in a scenario being adopted to RES lighting systems, simulation of which has been made, as having linear, random and tree topologies, having no grid connection, energy amounts being consumed during joining network in WSNs and then during data exchange have been measured. According to the being obtained findings, energy consumptions of nodes show variations when topology changes, even if the number of nodes is the same in lighting.

Energy consumption is more during the connection of nodes with network and the reason for this is because at the moment when system is energized, package traffic takes place which originates from timing, control and relay packages. After package installation is completed, package delivery (data) frequency of relevant lighting node (LN) gets reduced and, depending on this energy quantity being consumed, gets reduced with a fixed slope.

Increase in energy consumption especially attracts attention in an apparent way in linear scenarios. As number of lighting devices increase, energy consumption in WSN has also increased. The reason for this is maximum hop counts in WSN. Minimum energy consumption has occurred in random topology with scenario having 25 nodes and with respect to energy consumption, it is very close to tree lighting topology. It is seen that in general energy consumptions of tree and random topologies are very close to each other and that their energy efficiencies are high. However, with respect to energy consumption fundamental problem is observed in linear topology.

This study has shown that as hop counts in topological distributions increase (especially in networks having linear topologies), there is serious energy consumption during joining network processes. As LN numbers increase, total energy amount being consumed increases exponentially and energy consumption efficiency gets reduced. For this reason, it is required for network joining stages of LNs to be realized specially by using energy efficient methods (or MAC protocols). When the inevitability of Linear topologies in long distance road lighting systems are considered, importance of effective and efficient network joining techniques increases even more. By evaluating this particular in future studies, studies should be conducted on solution methods.

Finally, in the simulation work being done, it was seen that lighting systems having different topologies in WSN consumed energies at different levels.

REFERENCES:

1. Arı, D., Çıbuk, M., Ağgün, F., Effect of Relay Priority Mechanism on Multi hop Wireless Sensor Networks, Bitlis Eren University Journal of Science and Technology, 2017, V7, #2, pp. 145–153.

2. Çıbuk, M., Tek Atlamalı Kablosuz Algılayıcı Ağlarda Yeni Bir Hızlı Ağa Katılım Algoritması, Bitlis Eren Üniversitesi Fen Bilimleri Dergisi, 2018, V7, #1, pp. 72–83.

3. A. Shrestha, L., Xing, A., Performance Comparison of Different Topologies for Wireless Sensor Networks, 2007 IEEE Conf. Technol. Homel. Secur, 2007, pp. 280–285.

4. Q. Mamun, A Qualitative Comparison of Different Logical Topologies for Wireless Sensor Networks Sensors, 2012, V12, #12, pp. 14887–14913.

5. Karun R., Johny M., Street Light Commander System Using Zigbee Network of Devices. 2014, V4, #4, pp. 165–169.

6. Srinath V., Srinivas S., Street Light Automation Controller using Zigbee Network and Sensor with Accident Alert System. International Journal of Current Engineering and Technology, 2015, V5, #4, pp. 2819–2823.

7. Bhargavi, R., Pavitra, B., Development of Automatic Street Light Illumination and Vehicle Speed Controlling System on Arm7 for Roadways, Int J Res Adv Eng. Technol, 2016, V5, #3, pp. 16–22.

8. Journal I, Technology S, Dp T, Prof SOEP, Pune TDPSOE, Remotely Control High Energy Efficient Automatic Street Lighting System. 2015. V1, #11, pp. 43–46.

9. Caponetto, R., Dongola, G., Fortuna, L., Riscica, N., Zufacchi, D., Power consumption reduction in a remote controlled street lighting system. Int Symp Power Electron Electr Drives, Autom Motion, 2008. pp. 428–433.

10. Chen, Y., Liu, Z., Distributed intelligent city street lamp monitoring and control system based on wireless communication chip nRF401. Proc – Int Conf Networks Secur Wirel Commun Trust Comput, 2009. V2, pp. 278–281.

11. Lin J, Jin X, Mao Q, 2009. Wireless monitoring system of street lamps based on ZigBee. Proc – 5th Int Conf Wirel Commun Netw Mob Comput, 2009. pp. 2–4.

12. Jun, L., Cangxu, F., Xuesong, S., Aijun, Y., Street lamp control system based on power carrier wave. Proc-2nd 2008 Int Symp Intel Inf Tech Appl Work IITA 2008, pp. 184–188.

13. Nordic Semiconductor: nRF905 Single chip 433/868/915MHz Transceiver, 2019. http://infocenter.nordicsemi.com/pdf/nRF905_PS_v1.5.pdf (02.02.2019)

14. Özkaya, M., 1994. Aydınlatma Tekniği, Birsen Yayınevi, İstanbul-1994, 91.

15. TSE standard: TS EN13201–2, Road lighting – Part 2: Performance requirements (Effective date: 09.12.2016).

16. Cengiz M.S., A Simulation and Design Study for Interior Zone Luminance in Tunnel Lighting, Light & Engineering. 2019, V27, #2, pp. 42–51.

17. Tetri, E., Chenani, S.B., Rasanen R.S., Advancement in Road Lighting, Light & Engineering, 2018, V26, #1, pp. 99–109.

18. Barua, P., Mazumdar, S., Chakraborty, S., Bhattacharjee, S. 2018. Road Classification Based Energy Efficient Design and its Validation for Indian Roads, Light & Engineering, 2018, V26, #2, pp. 110–121.

19. Cengiz M.S., Cengiz, Ç., Numerical Analysis of Tunnel LED Lighting Maintenance Factor, IIUM Engineering Journal. 2018, V19, #2, pp. 154–163.

20. Iacomussi, Rossi, G., Soardo, P., 2012. Energy Saving and Environmental Compatibility in Road Lighting, Light & Engineering, 2012, V20, #4, pp. 55–63.

21. Van Bommel, W., Van Den Beld, G.,. Van Ooyen M., 2003. Industrial Light and Productivity, Lighting & Engineering, 2003, V11, #1, pp. 14–21.

22. Cengiz M.S., The Relationship Between Maintenance Factor and Lighting Level in Tunnel Lighting, Light & Engineering. 2019, V27, #3.

23. Cengiz M.S., Cengiz, Ç., Numeric Analysis for the Efficiency of LED and Traditional Luminaries used in Tunnel Lighting, International GAP Renewable Energy and Energy Efficiency Congress, 10–12 May 2018, 347–348.

24. Cengiz M.S., Cengiz, Ç., Mamiş, M.S., Contribution of Reflector Design formed by Numeric Calculations to Energy Efficiency, International GAP Renewable Energy and Energy Efficiency Congress, 10–12 May 2018, 349–350.

25. Çıbuk, M., Arı, D., Ağgün, F., Relay Mechanism with Three way Handshake for Wireless Sensor Networks, presented at the 8th International Advanced Technologies Symposium, Elazığ, 2017.

26. Arı, D., Çıbuk, M., Ağgün, F., A New Proxy Based Network Joining Method for Linear Wireless Sensor Networks, presented at the International Engineering and Natural Sciences Conference (IENSC2018), Diyarbakır, 2018.

27. "Riverbed Models, 2018. Available at: https://www.riverbed.com/gb/products/steelcentral /steelcentral-riverbed-modeler.html. (Access date 28-Feb.-2019).

28. Hammoodi, I.S., Stewart, B.G., Kocian, A., McMeekin, S.G., A comprehensive performance study of OPNET modeler for ZigBee wireless sensor networks, 3rd Int. Conf. Next Gener. Mob. Appl. Serv. Technol. 2009, pp. 357–362.

Musa Çıbuk,
received his M. Sc. and Ph. D. degrees from Fırat University, Turkey in 2002 and 2009, respectively. His research interests include WSNs, MAC, Computer Networks, Digital Communication and Image Processing. He worked at the University of Fırat between 2000 and 2010. He is currently working at Bitlis Eren University, in position of Head of Department at Computer Engineering

Mehmet Sait Cengiz
Ph.D. He was Director of Research and Development in period of 2000–2010 years in Turkey Electricity Distribution Company. In 2011, he completed his master degree in the field of Electrical and Electronics Engineering. In 2016, he completed his doctorate degree in Inonu University, Institute of Science and Technology, Electrical and Electronics Engineering and works in the field of applied lighting. He is currently working at Bitlis Eren University