Energy Efficiency of LoRa based Wireless Sensor Networks for Environmental Monitoring and Precision Agriculture

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***Abstract*—Sensor networks as a special subtype of wireless networks consist of a set of wirelessly connected sensor nodes. As sensor nodes have their own power sources, the network must be energy efficient, i.e., it is necessary to achieve minimal energy consumption. Therefore, energy efficiency of wireless sensor networks used for monitoring of environmental parameters is extremely important in remote networking scenarios. In this paper, an analysis of the energy consumption of sensor nodes in Long Range (LoRa) based wireless sensor networks, which are used in agriculture to observe environmental parameters, is performed. Network configuration is analyzed with regard to optimization of energy consumption in terms of selection of adequate network topologies, nodes layouts, data collection and routing processes, as well as settings of network radio parameters.**

Keywords- LoRa; Wireless Sensor Network, Environmental Monitoring; Precision Agriculture.

I. INTRODUCTION

Sensor networks as a special subtype of wireless networks consist of a set of wirelessly connected sensor nodes. The connected sensor nodes form networks used for gathering and exchanging information, and for forwarding data via gateways to public or private servers [1]. Data is then collected on storage servers for easier access and data processing [2].

Considering the fact that the sensor nodes can be equipped with different types of sensors, the field of application of wireless sensor networks is very wide. One of many possible areas of application of wireless sensor networks under Internet of Things (IoT) paradigm includes their application in agriculture and monitoring of environmental parameters [3-8]. In this case, the test environment consists of agricultural crops for which environmental and other parameters important for yield prediction are observed under different conditions. Wireless systems based on usage of sensor nodes make agricultural processes more intelligent, since they become more precise, data-oriented and highly automated [9].

The source of energy required for the operation of the sensor node is mainly a battery, which is sometimes connected to an additional system for its charging, for example with a solar collector. Replacing the battery is often impossible or impractical.

Therefore, the power supply capacity of the battery of the sensor node is one of the most severely limited resources in the wireless sensor network. Moreover, for implementation of the wireless sensor network, it is important to take into account the optimization of energy consumption and to achieve maximum possible energy savings [10].

Therefore, in this paper, an analysis of configurations of wireless sensor networks is carried out with regard to optimization of energy consumption. Optimization is analyzed in terms of selection of adequate topologies, node layouts, data collection and routing processes, as well as settings of network radio parameters. In Section II, selection of network technology used in further analysis is explained. In Section III, a comparative overview of energy consumption for different topologies of wireless sensor networks is presented. In Section IV, an analysis of adequate methods for data collection is performed. In Section V, additional analysis of configurations of radio parameters is conducted to select solutions that have appropriate range and energy efficiency.

II. SELECTION OF NETWORK TECHNOLOGY

Sensor nodes are characterized by small dimensions, low energy consumption, the ability to collect data via appropriate sensors, the ability to process data, and to support wireless communication within appropriate range. This concept enables the collection of data very close to the observed area, local aggregation of data and easy transfer of data to remote central locations intended for data collection and processing. Wireless sensor networks may contain a number of nodes located at relatively short distances from each other. Communication between nodes, as well as communication of nodes with the gateway can take place directly or through multiple nodes, within the so-called multi-hop topology, topology which extends the communication range [11].

Analyses of various aspects of wireless sensor networks implemented in rural environment are conducted hereafter to optimize operating parameters from the communications point of view. Optimization of wireless communication parameters is carried out with an aim of achieving fast and reliable communication with minimal energy consumption. Optimization is important for processes of directing the collected sensor data to a remote distant destination.

For use in agriculture and monitoring of environmental parameters, sensor networks are placed in remote locations, i.e., test fields. Therefore, it is necessary to use networking technologies that can achieve connectivity over long distances up to several tens of kilometers. For this reason, the application of short-range communication technologies (e.g., WiFi and ZigBee) is not suitable due to installation barriers of additional gateways, lack of suitable locations or inadequate electricity connectivity [12]. Although the deployment of communication via mobile networks meets the requirements on range and reliability, it is energy demanding and incurs additional costs in terms of a permanent subscriptions to the service provider. Hence, it is also not an optimal solution [13]. In addition to long range, the next important criterion in the selection of appropriate technologies is low energy consumption, so that the battery-powered nodes achieve a sufficiently long autonomy and multi-year life expectancy. Therefore, technologies from the group of Low Power Wide Area Network (LPWAN) technologies are suitable for application in precision agriculture scenarios [14]. LPWAN is the name for high-range, low-power wireless technologies. The specifics of LPWAN technologies are low power consumption and long communication range for sending information over greater distances. These features make LPWAN technologies very practical for open area IoT implementations. There are many LPWAN technologies and new ones are constantly emerging and improving, but currently LoRa, Sigfox and Narrowband IoT (NB-IoT) are leaders in this field [15,16]. The advantage of application of these technologies in networking relates to the fact that the end devices working with these technologies are designed to consume energy efficiently and minimally [17]. Low power and narrow bandwidth allow very low power consumption when sending messages [18]. Due to the simplicity of LoRa deployment in the fields, this paper analyzes the application of LoRa in agriculture for monitoring environmental parameters and optimization of its energy consumption in related scenarios. Considering the range of communication, LoRa has sufficient range required for its application in rural areas [9].

III. SELECTION OF NETWORK TOPOLOGIES

Through simulation procedures, networking scenarios using LoRa technology are analyzed. In these scenarios, sensor nodes communicate via a gateway with the rest of the network. The *CupCarbon* IoT simulator [19] is used for simulation and analysis of energy consumption during communication processes. For comparing topologies and selecting appropriate network topologies, a star topology is suitable for many and diverse IoT applications. However, in a number of scenarios, a more flexible network topology like decentralized multi-hop solution is needed [11]. Therefore, in order to compare the network topologies from the aspect of energy consumption, the star topology, i.e., one-hop topology, and topology in which linear structures are formed in clusters, i.e., multi-hop linear topologies, are selected, as shown in Figures 1 and 2. The terminal devices in the access network are sensor nodes.

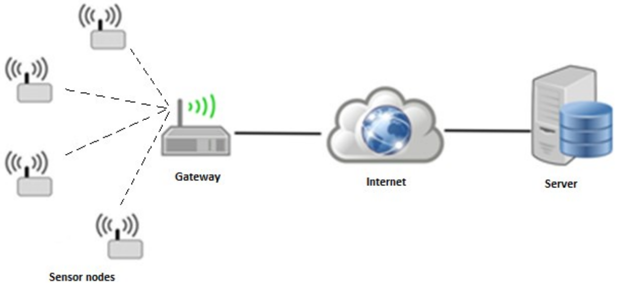

Figure 1. Star topology (one-hop).

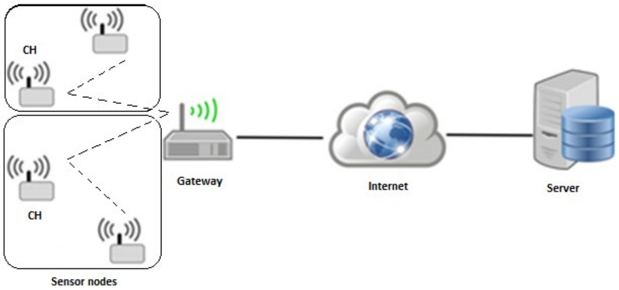

Figure 2. Line topology within individual clusters (multi-hop).

As presented in Figures 1 and 2, sensors measure data sent to the rest of the network via a gateway. Terminal devices, i.e. sensor nodes, rely on the gateway to transmit information from the access network to the network server.

A. Star topology

To start the analysis of energy consumption in different access network topologies, the star topology, topology in which each sensor node sends data directly to the gateway is chosen. The star topology is convenient for its ease of deployment.

Figure 3 shows the access part of the network created in the *CupCarbon* IoT simulator which includes the sensor nodes, marked as *s2* to *s5*, connected to the gateway. Figure 3 also shows the radii of area coverage with signal for individual nodes, which depend on the area range each node needs to cover with its signal. Thus, for example, node *s4* needs a smaller signal coverage radius for covering the area up to the gateway, while node *s2* needs a larger signal coverage radius so that the gateway can be reached, as presented in Figure 3. The ranges of area coverage with signal can be defined through an *atpl* parameter, which defines the percentage of signal coverage for each node in relation to the maximum possible coverage area, as defined in Table I for nodes *s4* and *s5*. In the case when the specified parameter is not defined for the node, it is considered that the node covers the maximum possible area it can cover with its signal. As presented in Table I, the gateway waits for the data to be sent from the sensor nodes according to the randomly selected (*randb*) moment for data sending that has a certain time delay.

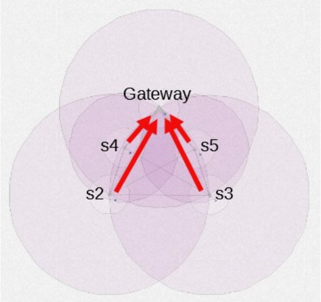

Figure 3. Representation of communication between nodes in scenario with star topology.

Figure 3 shows the star topology and communication among nodes in the access network. The illustration shows that the sensor nodes (*s2*, *s3*, *s4* and *s5*) send data directly to the gateway. This is defined through a *send* parameter that defines which node sends data to which one. Thus, for example, the label *send 1 1* in Table I defines that nodes *s2*, *s3*, *s4* and *s5* send one data packet to node 1, i.e., the gateway. The *randb* parameter is used to send data with a random delay variable *x*. In order to compare the topologies that can be used in communication between sensor nodes and the gateway, power consumption in the example of a star network topology is presented in Fig 4. According to the level of energy consumption shown in Figure 4, it can be seen that the sensor nodes closer to the gateway, i.e., *s4* and *s5*, consume less energy than the more distant nodes, i.e., *s2* and *s3*. Further comparison of the results obtained should be possible when the results for different topologies are taken into account within a similar time period as indicated on the abscissa.

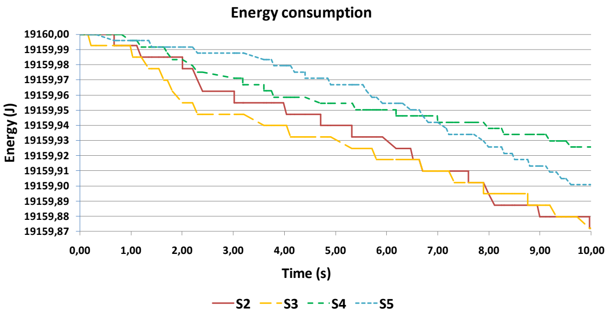

Figure 4. Energy consumption of LoRa technology in scenario with star topology.

TABLE I. PARAMETERS CONFIGURATION FOR STAR TOPOLOGY

Nodes	**Nodes marking:**		
	Gateway:	*s2* and *s3*:	*s4* and *s5*:
Instruct.:	*loop* *wait* *read x*	*loop* *randb x 10 1000* *delay $x* *send 1 1* *delay 50*	*loop* *atpl 55* *randb x 10 1000* *delay $x* *send 1 1* *delay 50*

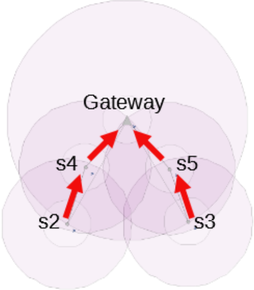

Figure 5. Representation of communication between nodes in scenario with line topology within clusters and with CH nodes closest to the gateway

B. *Multi-hop linear topology*

Next, the topologies in which linear structures are formed in individual clusters, i.e., multi-hop linear topologies, are analyzed. Unlike in mesh, in these topologies network data collision issues could be mitigated so they are selected for the analysis of reliable network data transmission.

1) *Line topology within clusters with CH nodes closest to the gateway*

In the combination of line network topologies presented in Figure 5, some sensor nodes within individual clusters can communicate with each other, e.g., *s2* and *s4*, as well as *s3* and *s5*. The so-called *Claster Head* (CH) nodes, nodes *s4* and *s5*, communicate directly with the gateway. They rely on the gateway to transmit information to the network server, as shown in Figure 5. The other nodes, *s2* and *s3*, forward data in the direction of CH nodes. Devices are synchronized and wake up at specific moments in time to receive data packets from their neighbors, which they can combine with their own data packets and send further along the line. This scenario is created considering the conclusion given for the star topology that the distance of the nodes affects the energy consumption. Therefore, for the CH node within each cluster, the node closest to the gateway within the cluster is selected and its choice is fixed throughout the simulation process of network data transmission.

Figure 5 illustrates the determined signal coverage radii for individual nodes. They depend on the range each sensor node needs to have to cover the area with its signal. In this scenario, it is assumed that, in order to cover the area up to the gateway, node *s4* needs the same signal coverage radius as node *s2* in order to reach node *s4*. The reason is a comparison of the impact of different frequencies of data transmission of nodes on energy consumption. From Figure 5 it can be seen that sensor nodes *s2* and *s3* send data to nodes *s4* and *s5*. The nodes *s4* and *s5* then send their data, as well as data received from nodes *s2* and *s3*, directly to the gateway. The two clusters with line communication within nodes are created, one with *s2* and *s4*, and one with *s3* and *s5*, in which the CH nodes are nodes *s4* and *s5*. According to the configuration of the parameters of nodes, it can be seen that the specified ranges of signal coverage are also defined through the *atpl* parameter.

TABLE II. PARAMETERS CONFIGURATION FOR LINE TOPOLOGY WITHIN CLUSTERS WITH CH NODES CLOSEST TO THE GATEWAY

Nodes	**Nodes marking:**			
	Gateway:	*s2*:	*s3*:	*s4* and *s5*:
Instructions:	*loop* *wait* *read x*	*loop* *atpl 55* *randb x 10 1000* *delay $x* *send 1 4* *delay 50*	*loop* *atpl 55* *randb x 10 1000* *delay $x* *send 1 5* *delay 50*	*loop* *atpl 55* *randb x 10 1000* *delay $x* *send 1 1* *delay 50* *send 1 1* *delay 50*

For each node, the percentage of coverage area in relation to the maximum possible coverage area of the node is defined as presented in Table II for nodes *s2*, *s3*, *s4* and *s5*. From Table II, it can be seen that nodes *s4* and *s5* need the same signal coverage radius for covering area up to the gateway, as radius of node *s2* to reach node *s4*, as well as radius of node *s3* to reach node *s5*. According to the level of energy consumption shown in Figure 6, it is evident that node *s2* sends data more often than node *s3*, so its energy consumption is higher. The CH nodes, i.e., nodes *s4* and *s5*, although the closest to the gateway, consume more energy than the more distant nodes, i.e., nodes *s2* and *s3*. The reason for this is the fact that CH nodes receive data from nodes *s2* and *s3*, and send them to the gateway along with their own data. The gateway waits for the data sent from the CH nodes according to the randomly selected moment for sending with a certain time delay. In this scenario, the total energy consumption is higher than in the star topology.

2) Line topology within clusters with CH nodes furthest from the gateway

To avoid fast energy depletion of CH nodes selected in a fixed manner, this scenario gives the analysis of energy consumption of randomly selecting CH nodes, and not fixed ones, as in the previous example. In the combination of line network topologies within individual clusters shown in Figure 7, sensor nodes can communicate with each other, e.g., *s2* and *s4*, as well as *s3* and *s5*. For CH nodes, the data transmission process relies on the gateway to transmit information to the network server. In this example, the CH nodes are selected at random.

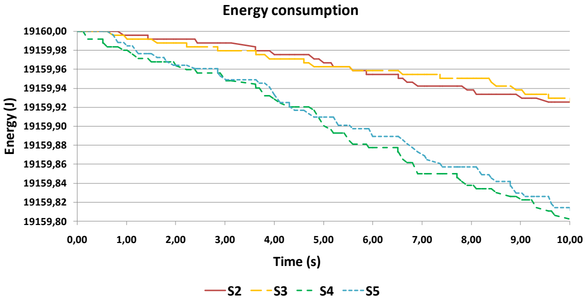

Figure 6. Energy consumption of LoRa technology in scenario with line topology within clusters and with CH nodes closest to the gateway.

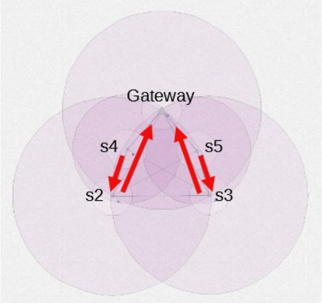

Figure 7. Representation of communication between nodes in scenario with line topology within clusters and with CH nodes furthest from the gateway.

For the CH node within each cluster at one point, as well as the nearest, the nodes furthest from the gateway can be selected, i.e., nodes *s2* and *s3*. In Figure 7, the signal coverage radii for individual nodes are shown, depending on the area ranges that the nodes need to cover with their signal. Thus, for example, node *s4* needs a smaller signal coverage radius covering the area up to node *s2*, compared to the necessary radius of node *s2* for reaching the gateway. The same is true for the radii of nodes *s3* and *s5*.

According to the level of energy consumption shown in Figure 8, it can be seen that the sensor CH nodes, i.e., nodes *s2* and *s3*, furthest from the gateway, consume more energy than nodes *s4* and *s5*. At one point, nodes *s4* and *s5* send their data to the CH nodes *s2* and *s3*, which then send these data to the gateway in addition to their own data.

For a comparison with the energy consumption in the example of a line topology within a cluster with CH nodes closest to the gateway, a much higher energy consumption of CH nodes can be noted in this scenario. Moreover, the comparison of the results from Figures 4, 6, and 8 shows that in a star topology, unlike multi-hop topologies, the optimal scaling strategy of LoRa radio parameters can be achieved to obtain the long range communication while enabling the lowest energy consumption.

As defined in Table III for nodes *s4* and *s5*, the specified ranges of signal coverage radii are also defined through the *atpl* parameter. There is also the case when the specified *atpl* parameter is not defined for the node. In this case, it is considered that the node covers the maximum possible area that it can with its signal. This is the case for nodes *s2* and *s3*. This allows for random selection of CH nodes as each node, from *s2* to *s5*, is able to cover the area to the gateway with its signal.

The random choice of CH nodes was selected in this scenario to analyze the possibility of reducing the energy depletion of certain CH nodes selected in a fixed manner, as it was the case in the previous scenario with the fastest energy depletion of CH nodes selected in a fixed manner, i.e., the ones closest to the gateway. However, the total amount of energy consumed within the observed time period in this scenario is the highest.

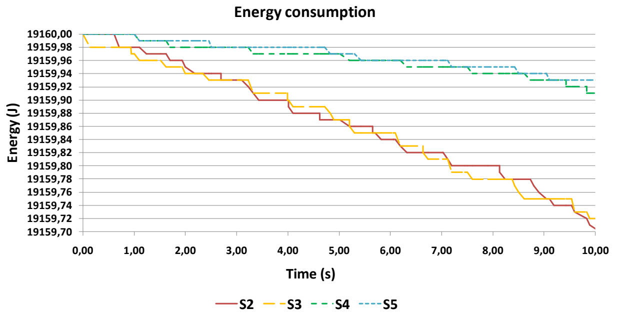

Figure 8. Energy consumption of LoRa technology in scenario with line topology within clusters and with CH nodes furthest from gateway.

TABLE III. PARAMETERS CONFIGURATION FOR LINE TOPOLOGY WITHIN CLUSTERS WITH CH NODES FURTHEST FROM THE GATEWAY

Nodes	**Nodes marking:**			
	Gateway:	*s2* and *s3*:	*s4*:	*s5*:
Instructions:	*loop* *wait* *read x*	*loop* *randb x 10 1000* *delay $x* *send 1 1* *delay 50* *send 1 1* *delay 50*	*loop* *atpl 55* *randb x 10 1000* *delay $x* *send 1 2* *delay 50*	*loop* *atpl 55* *randb x 10 1000* *delay $x* *send 1 3* *delay 50*

From the comparison of the results in Figures 4, 6, and 8 it can be concluded that the star network topology can be considered as the best option with regard to cumulative energy consumption.

IV. SELECTION OF ADEQUATE VOLUME OF NETWORK TRAFFIC

The following scenarios are created with the aim of analyzing the impact of the amount of transmitted network traffic within the network on the energy consumption in the network. These scenarios aim to reduce energy consumption with adequate traffic volume, and to improve the range. The energy consumption control is considered and the rate adaptation for one-hop scenarios presented in Figure 9 is analyzed. For this purpose, the network topology shown in Figure 9 was created, which consists of sensor nodes, marked *s2* to *s7*, and a remote gateway. Star topology is used for communication between nodes.

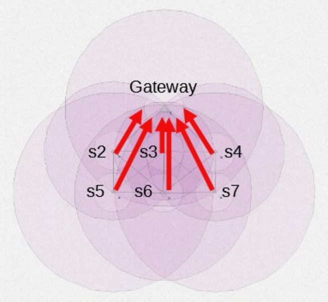

Figure 9. Communication between nodes for one-hop scenarios.

In previous examples, the star topology was defined as more appropriate in terms of total energy consumption compared to the line structure within clusters. The radii of area coverage with signal for individual nodes are shown in Figure 9, so the node closest to the gateway has the smallest radius, i.e., node s3, while the nodes furthest from the gateway, i.e., nodes s5 and s7, have the largest radii.

A. *Sending an equal amount of traffic from nodes equally distant from the gateway*

As shown in Table IV, in this scenario, the gateway waits for data to be sent from the sensor nodes *s2* to *s7* and then reads the sent data *x* and proceeds with data forwarding.

The largest radius for data transmission is used by nodes *s5* and *s7*, which can be seen according to the omitted parameter *atpl* in Table IV. This implies usage of the entire available coverage radii of the nodes *s5* and *s7*. This parameter is specified for nodes *s2*, *s3*, *s4* and *s6*. It can be seen that node *s3* uses the smallest radius (50% of the total largest possible radius). Data is sent continuously (*loop*), but a delay is made between sending individual data. This scenario corresponds to predefined data transmission moments in which all nodes send data at the same time intervals. This is a common case in rural scenarios for sending data collected from the field.

Figure 10 shows the energy consumption when applying LoRa technology in a star network topology with the same amount of data sent from nodes equally distant from the gateway. Therefore, the same amount of data is sent from nodes *s2* and *s4*, and the same amount of data from nodes *s5* and *s7*, so there are overlaps on the graph in energy consumption for these nodes. The node closest to the gateway, node *s3* consumes the least energy for sending, while the most energy is consumed by the farthest nodes, nodes *s5* and *s7*, whose energy will be depleted the fastest.

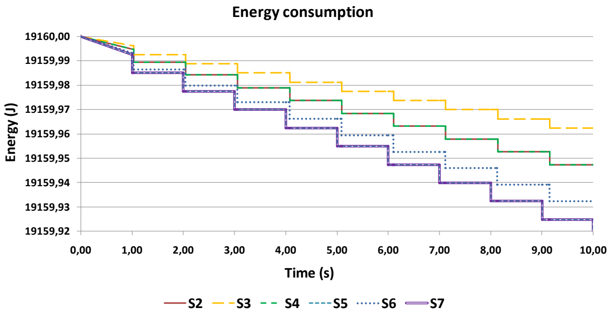

Figure 10. Energy consumption in a star topology with the same amount of data sent from nodes equally distant from the gateway.

TABLE IV. INITIAL PARAMETERS CONFIGURATION FOR DATA TRANSMISSION

Nodes	**Nodes marking:**				
	Gateway:	*s2* and *s4*:	*s3*:	*s5* and *s7*:	*s6*:
Instr.:	*loop* *wait* *read x*	*loop* *atpl 70* *send 1 1* *delay 1000*	*loop* *atpl 50* *send 1 1* *delay 1000*	*loop* *send 1 1* *delay 1000*	*loop* *atpl 90* *send 1 1* *delay 1000*

TABLE V. PARAMETERS CONFIGURATION FOR MORE FREQUENT DATA TRANSMISSION

Nodes	**Nodes marking:**						
	Gateway:	*s2*:	*s3*:	*s4*:	*s5*:	*s6*:	*s7*:
Instruct:	*loop* *wait* *read x*	*loop* *atpl 70* *send 1 1* *send 1 1* *delay 1000*	*loop* *atpl 50* *send 1 1* *delay 1000*	*loop* *atpl 70* *send 1 1* *delay 1000*	*loop* *send 1 1* *send 1 1* *delay 1000*	*loop* *atpl 90* *send 1 1* *delay 1000*	*loop* *send 1 1* *delay 1000*

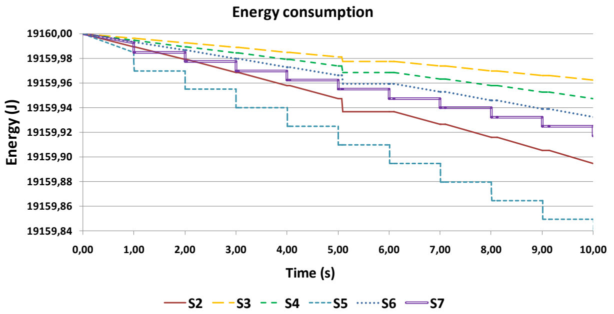

Figure 11. Energy consumption in a star topology with different amounts of data sent from nodes equally distant from the gateway.

It can be concluded that node placement in star topology presents an important determinant of sensor node life time. However, although the nodes should be as close as possible to the gateway to reduce energy consumption, at the same time, adequate coverage of area with the signal must be achieved. With regard to the energy depletion of individual nodes, the star topology is more suitable for application in sensor networks than a cluster topology

In cluster topology, the energy of CH nodes is depleted the fastest. CH nodes are difficult to replace, which causes the loss of functionality of the entire cluster, while in a star topology, the depletion of energy of an individual node does not cause such a loss in data delivery from the area which it covers with its signal.

B. *Sending different amounts of traffic from nodes equally distant from the gateway*

The parameters listed in Table V are similar to the data from the previous scenario, except that data from some nodes is sent more frequently. Despite the same distance of nodes *s2* and *s4* from gateway, more data is sent from node *s2* to the gateway than from node *s4*. Moreover, from node *s5* data is sent to the gateway more often than from node *s7*, although both nodes are equally distant from the gateway. Figure 11 shows the energy consumption when applying LoRa technology in a star network topology with different amounts of data sent from nodes equidistant from the gateway. Therefore, different amount of data is sent from nodes *s2* and *s4*, and different amount of data from nodes *s5* and *s7*, so there are no overlaps on the graph in energy consumption for these nodes. The node closest to the gateway, node *s3* consumes the least energy required for sending. The most energy is consumed by the farthest node *s5*. Moreover, it sends more data compared to node *s7*, which is at the same distance from the gateway as node *s5*.

TABLE VI. PARAMETERS CONFIGURATION FOR LESS FREQUENT DATA TRANSMISSION

Nodes	**Nodes marking:**						
	Gateway:	*s2*:	*s3*:	*s4*:	*s5*:	*s6*:	*s7*:
Instruct.:	*loop* *wait* *read x*	*loop* *atpl 70* *send 1 1* *send 1 1* *delay 2000*	*loop* *atpl 50* *send 1 1* *delay 2000*	*loop* *atpl 70* *send 1 1* *delay 2000*	*loop* *send 1 1* *send 1 1* *delay 2000*	*loop* *atpl 90* *send 1 1* *delay 2000*	*loop* *send 1 1* *delay 2000*

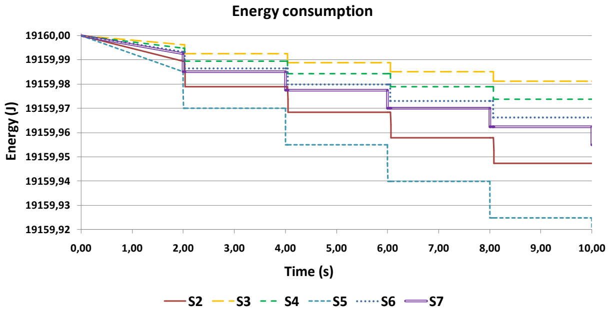

Figure 12. Energy consumption of LoRa technology in a star topology with the less frequent sending of data from sensor nodes to the gateway.

The node *s5* consumes more energy than node *s7*. From the results, it can be concluded that in scenarios where sending a larger amount of data is not necessary, as in the case of monitoring the state of yield, energy savings should be achieved by sending an adequately determined smaller volume of data from sensors.

C. *Less frequent data transmission*

The parameters listed in Table VI are similar to the data from the previous scenario, except that data from nodes is sent less frequently, which is seen by a higher value of the delay parameter that defines the time delay between sending individual data. In this scenario, data is sent twice as rarely compared to the previous scenario.

Figure 12 shows the energy consumption using LoRa network access and star network topology. In this scenario, less frequent sending of data from sensor nodes to gateway is analyzed and compared with the scenario presented in Figure 11. From the comparison of the presented results, significantly less energy consumption can be noted within the same time interval when sending data with higher delay, i.e., less frequently. LoRa technology has adequate features for usage in wireless sensor networks if long-range communication with minimal power consumption should be achieved. LoRa supports data transmission with lower requirements for high transfer speeds and transfer of large amounts of data. Thus, as can be concluded from the presented results, the application of LoRa technology is an adequate solution in IoT scenarios where fast transmission of large amounts of data is not required, as in precision agriculture, where additional energy savings can be achieved by sending smaller amounts of data over longer periods of time between transmissions.

D. *Effect of SF and CR parameters on Consumed Energy*

The LoRa access based wireless sensor network implemented in the field serves to connect sensor nodes located in different remote locations to centrally located storage and advanced data processing servers. The communication should be achieved in an energy efficient way. It can be highlighted that the range of communication in the fields and open spaces presents one of the most important parameters because it is necessary to ensure the energy efficient transmission of data over relatively long distances. In that case, the high data transfer rate is not so significant. The parameters described hereafter, the spreading factor and the coding rate, affect transmission range and energy efficiency.

The Spreading Factor (SF) presents the number of chips per symbol. Its value is an integer number between 6 and 12. The greater the SF value, the more capability the receiver has to move away the noise from the signal. Thus, the greater the SF value, the more time is taken to send a packet, but a higher range will also be achieved because the sensitivity of the receiver is better. Thus, for example, if the expansion factor is minimal, i.e., SF = 6, a higher speed can be achieved, but with a reduction in the possible range.

The expression for Coding Rate (CR) is CR =4/(4+n), where n is a value from 1 to 4. It denotes that each four useful bits are encoded by 5, 6, 7 or 8 transmission bits. The smaller the coding rate is, the higher the time on air is to transmit data. Prolonged data transfer time will also affect battery consumption.

The analysis of the effect of different values of SF and CR LoRa radio parameters on consumed energy and range is performed hereafter.

TABLE VII. PARAMETERS CONFIGURATION FOR SF=7 AND CR=4/8

Nodes	**Nodes marking:**				
	Gateway:	*s2* and *s4*:	*s3*:	*s5* and *s7*:	*s6*:
Instructions:	*loop* *wait* *read x*	*loop* *atpl 70* *send 1 1 7 8* *randb x 10 1000* *delay $x* *send 1 1 7 8* *delay 1000*	*loop* *atpl 50* *send 1 1 7 8* *randb x 10 1000* *delay $x* *send 1 1 7 8* *delay 1000*	*loop* *send 1 1 7 8* *randb x 10 1000* *delay $x* *send 1 1 7 8* *delay 1000*	*loop* *atpl 90* *send 1 1 7 8* *randb x 10 1000* *delay $x* *send 1 1 7 8* *delay 1000*

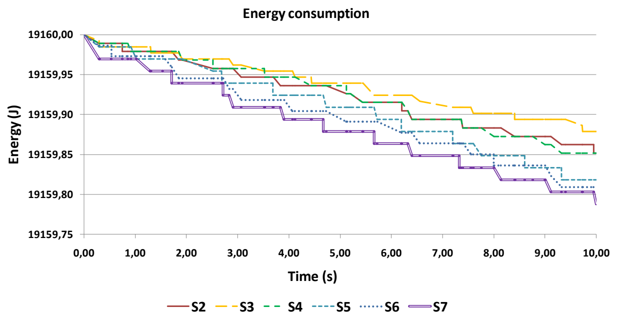

Figure 13. Energy consumption of LoRa technology in a star topology with SF=7, and CR=4/8.

As already stated, when the SF value is high, the time for data transmission increases which means that the sensor node consumes more power to transmit data. As presented in Figure 14, the SF expansion factor is set to a maximum value of 12, unlike in the case shown in Figure 13 where the SF is set to a value of 7. The reason for setting a high SF value is to maximize the transmission range as one of the most important factors in the field deployments.

Furthermore, when the coding rate increases, the data transmission time and the consumed energy decrease. Therefore, in the case when a long range needs to be ensured, energy consumption can be regulated by the CR factor, as presented in Figures 13 and 14. The energy consumption shown in Figure 14 would have been higher if the same CR factor had been used as in the example shown in Figure 13. By increasing the CR value from 4/8 to 4/5, energy consumption can be reduced while maintaining the maximal range enabled by the high SF parameter value.

V. CONCLUSION

LoRa technology can be applied in agriculture to monitor environmental parameters. It is used for communication among remote sensor nodes located in test fields in order to achieve energy efficient communication. The LoRa system aims at pushing optimization of energy consumption further while maintaining a long range, hence the scenarios for implementation of LoRa solutions in precision agriculture have been analyzed in this paper. LoRa sensor network implementation for monitoring of environmental parameters in agriculture is analyzed.

The specifics of LoRa technology are low power consumption and long communication range used in sending information over large distances.

TABLE VIII. PARAMETERS CONFIGURATION FOR SF=12 AND CR=4/5

Nodes	**Nodes marking:**				
	Gateway:	*s2* and *s4*:	*s3*:	*s5* and *s7*:	*s6*:
Instructions:	*loop* *wait* *read x*	*loop* *atpl 70* *send 1 1 12 5* *randb x 10 1000* *delay $x* *send 1 1 12 5* *delay 1000*	*loop* *atpl 50* *send 1 1 12 5* *randb x 10 1000* *delay $x* *send 1 1 12 5* *delay 1000*	*loop* *send 1 1 12 5* *randb x 10 1000* *delay $x* *send 1 1 12 5* *delay 1000*	*loop* *atpl 90* *send 1 1 12 5* *randb x 10 1000* *delay $x* *send 1 1 12 5* *delay 1000*

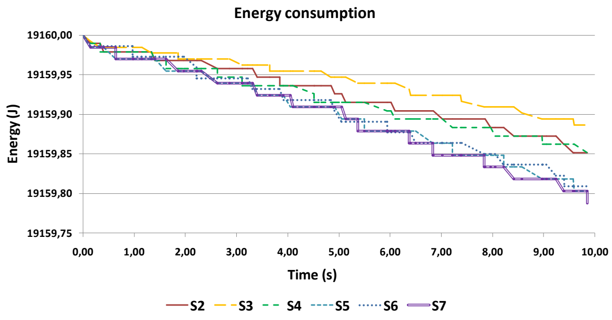

Figure 14. Energy consumption of LoRa technology in a star topology with SF=12, and CR=4/5.

The biggest drawback is the low speed of data transmission and the limited amount of data that can be sent. For LoRa based environmental monitoring, high throughput and high transfer rate are not of great importance since, generally, small amounts of data is transmitted. Basically, mainly numerical values representing readings of different types of sensors that monitor plant parameters and their close environment are sent. Therefore, it is important to achieve long-range communication with minimal energy consumption, with lower requirements for the amount and frequency of data transfer.

In this paper, LoRa star, i.e., one-hop, and multi-hop linear topologies have been compared. Considering cumulative energy consumption of sensor nodes in the network, the star topology is identified as the one which could better fit lower energy consumption in the presented scenarios. Moreover, the presented simulation results show that, for a star topology, optimal scaling strategy of LoRa radio parameters necessary for environmental monitoring can be achieved to obtain the long range while enabling low energy consumption. The presented results show that optimizing LoRa parameters, such as SF and CR, with regard to the required long range communication is a key element to reduce the consumed energy by the sensor nodes. Since the SF factor must have the highest possible value to achieve a greater range of communication necessary for precision agriculture, the presented results show that in that case the CR should be as high as possible to reduce total energy consumption. The presented findings of the effect of the studied network elements on the energy consumption collected through conducted simulations are important for further research activities in the field of LoRa based environmental monitoring and precision agriculture in rural areas.

For a multi-hop linear topologies, energy consumption can also be optimized by applying different radio configurations for different network layouts. In these topologies, the density of nodes plays a determinant role in coverage and number of hops. Therefore, future work will include analysis of optimization of energy consumption in multi-hop networks by exploiting various radio configurations and the network topologies (e.g., the number of hops, the network density, the coverage), and a strategy to take advantage of combination of both star and multi-hop topologies will be proposed.

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