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

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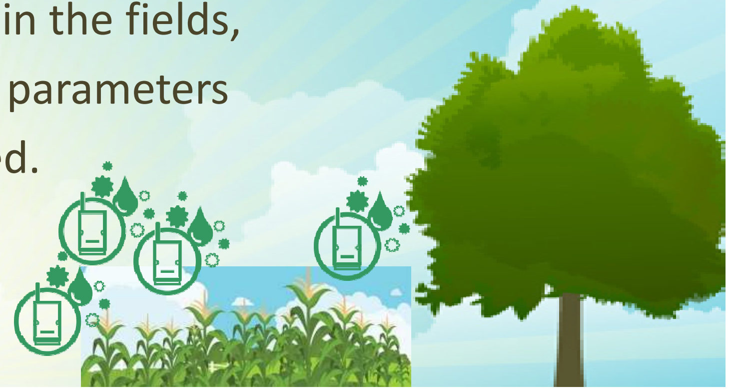
Introduction

- Sensor networks as a special subtype of wireless networks consist of a set of wirelessly connected sensor nodes. **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.
- As sensor nodes have their own power sources, 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 the paper, analyzes of energy consumption of sensor nodes in Long Range (**LoRa**) based wireless sensor network, which is used in **agriculture** to observe environmental parameters, are 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**.

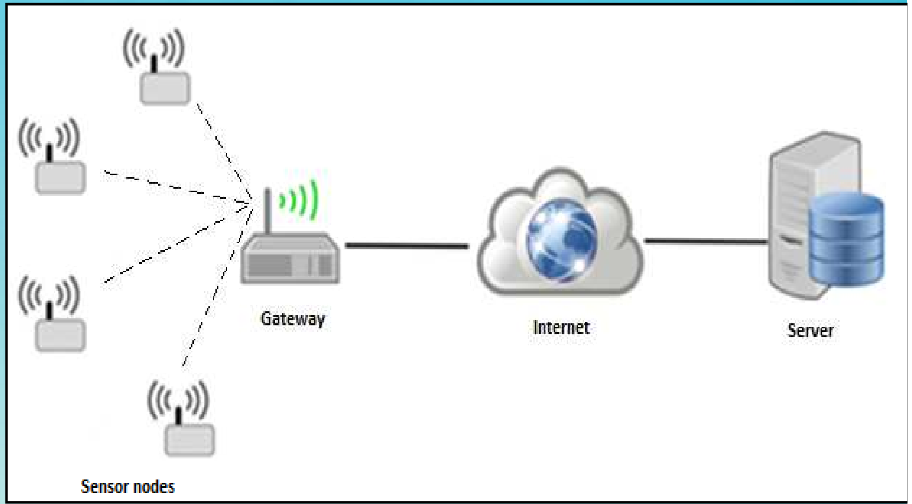
LoRa based Wireless Sensor Networks Used for Environmental Monitoring and Precision Agriculture

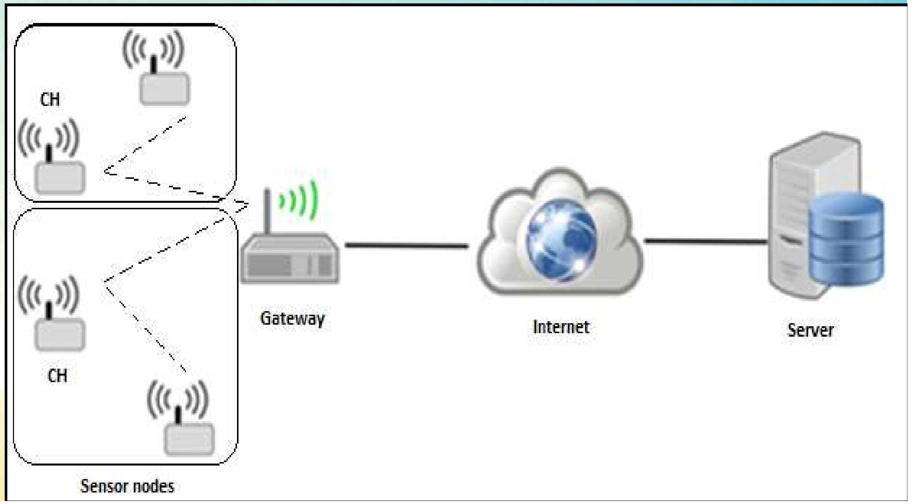
- Considering the fact that the sensor nodes can be equipped with different types of sensors, the field of **application of wireless sensor networks** is very wide.
- One of many possible areas of application of wireless sensor networks under Internet of Things (**IoT**) paradigm includes their application in agriculture and **monitoring of environmental parameters**.
- In this case, the **test environment** consists of **agricultural crops** for which environmental and other parameters important for **yield prediction** are observed.
- Wireless systems based on usage of sensor nodes make agricultural processes more intelligent, since they become more precise, data-oriented and highly automated.
- 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**.
- Due to the simplicity of LoRa technology deployment in the fields, the application of LoRa for monitoring environmental parameters and optimization of its energy consumption is analyzed. LoRa has sufficient range required in **rural scenarios**.



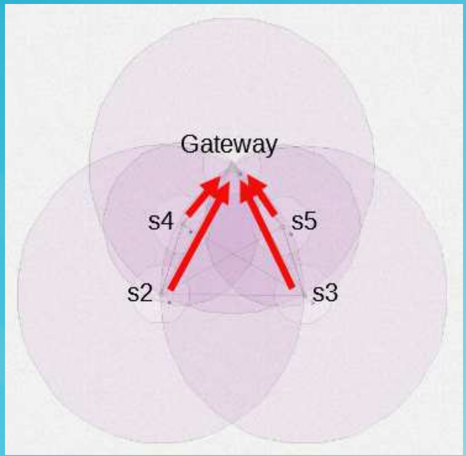
Selection of LoRa Network Topologies for Analyzes and Representation of Gathered Results

- The connected sensor nodes form LoRa sensor networks used for **gathering and exchanging information**, and for **forwarding data** via gateways to public or private servers. **Data is** then **collected** on storage servers **for** its easier access and **processing**.
- For comparing and selecting appropriate network topologies, a star topology is suitable for diverse IoT applications. However, in a number of scenarios, a more flexible network topology like decentralized multi-hop topology is needed.
- 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 topologies**, are selected.
- In order to see the total consumption per node, in the following graphs presenting **energy consumption**, the **residual energy** of the nodes is shown when **solar power** is excluded. However, with solar power **the life of the sensor nodes** is **extended**.





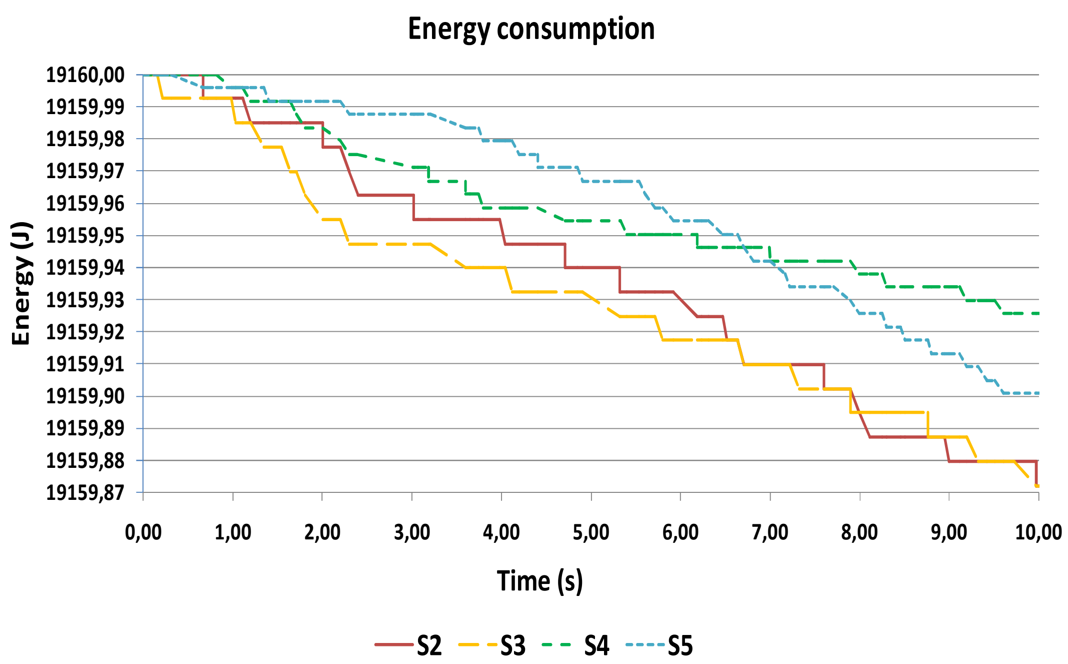
Star topology



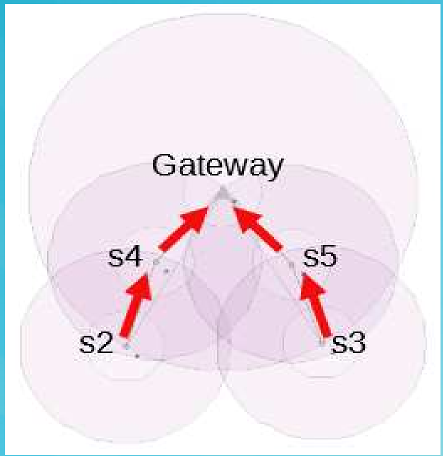
- In the star topology **every sensor node**, marked as *s2* to *s5*, is connected to the gateway and **sends data directly to the gateway**.
- The radii of area coverage with signal for individual nodes depends on the range which nodes need to cover area with signal.
- The ranges of area coverage with 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. When the specified parameter is not defined for the node, it is considered that the node covers the maximum area with its signal that it can.

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*

- According to the level of energy consumption, it can be seen that the **sensor nodes closer to the gateway**, *s4* and s5, **consume less energy than the more distant nodes**, *s2* and *s3*.



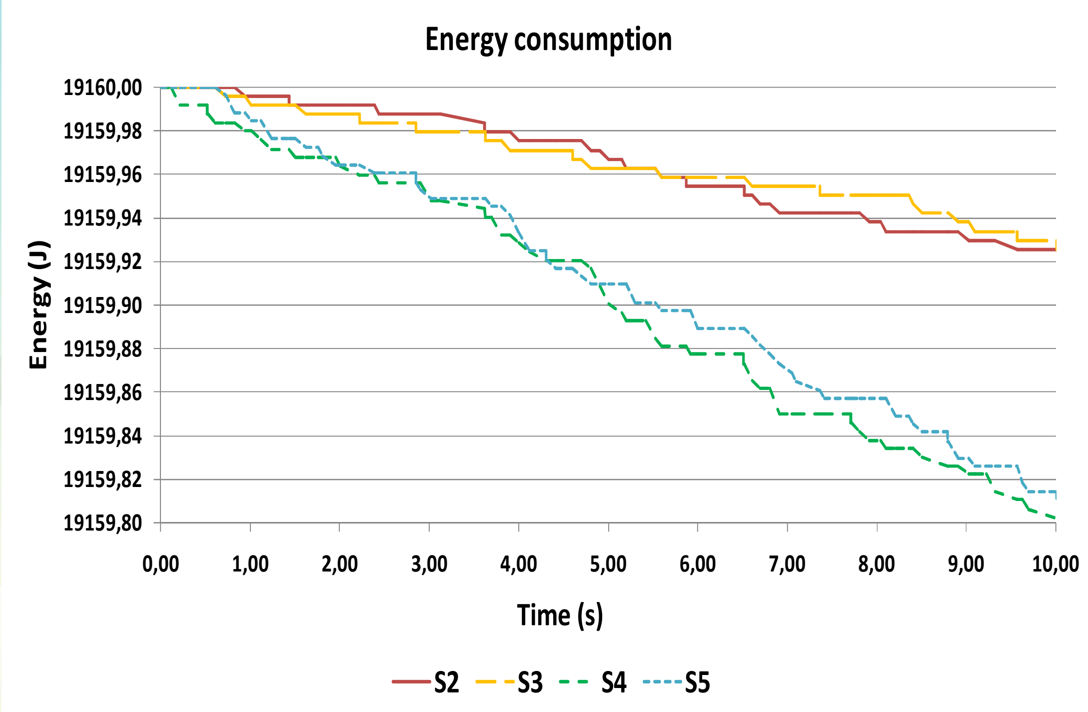
Multi-hop Linear Topology: CH Nodes Closest to Gateway



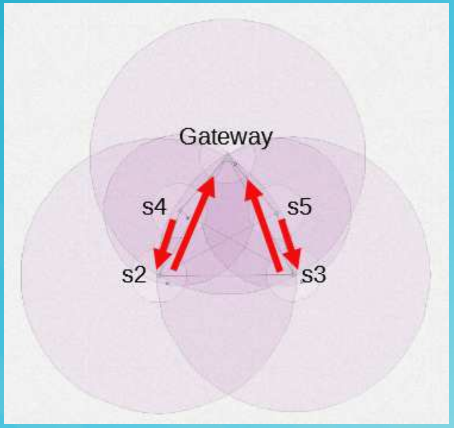
- The topologies in which **linear structures are formed in individual clusters**, i.e., multi-hop linear topologies, are analyzed. Unlike in mesh, in these topologies network data collision issues could be mitigated.
- Some **sensor nodes within individual clusters can communicate with each other**, e.g., *s2* and *s4*, as well as *s3* and *s5*. The *Claster Head* (**CH**) **nodes**, *s4* and *s5*, **communicate directly with gateway**. 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.

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*

- **CH nodes**, although the closest to the gateway, **consume more energy than the more distant nodes**. CH nodes receive data from nodes *s2* and *s3*, and send them to the gateway along with their own data. **The total energy consumption is higher than in the star topology**.

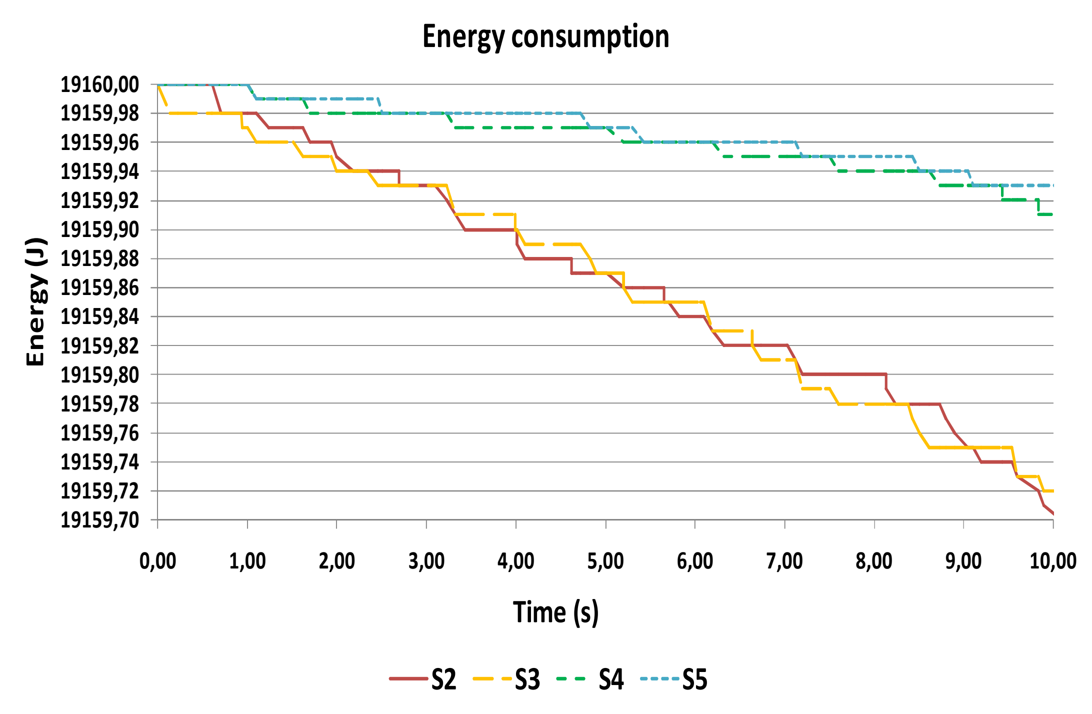


Multi-hop Linear Topology: CH Nodes Furthest from Gateway



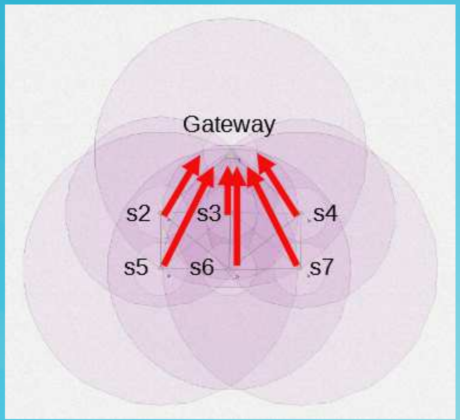
- This scenario gives analysis of energy consumption if **randomly selecting CH nodes, and not fixly** as in previous example. For the CH node within each cluster at one point, as well as the nearest, the nodes furthest from the gateway can be selected, i.e., nodes *s2* and *s3*.
- A **much higher energy consumption of CH nodes** can be noted in this scenario.
- Moreover, the comparison of the results 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**.

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*



- The **random choice of CH nodes** was selected in this scenario to analyze the possibility of **reducing the energy depletion of certain fixly selected CH nodes**.
- **The total amount of energy consumed in this scenario is the highest.**

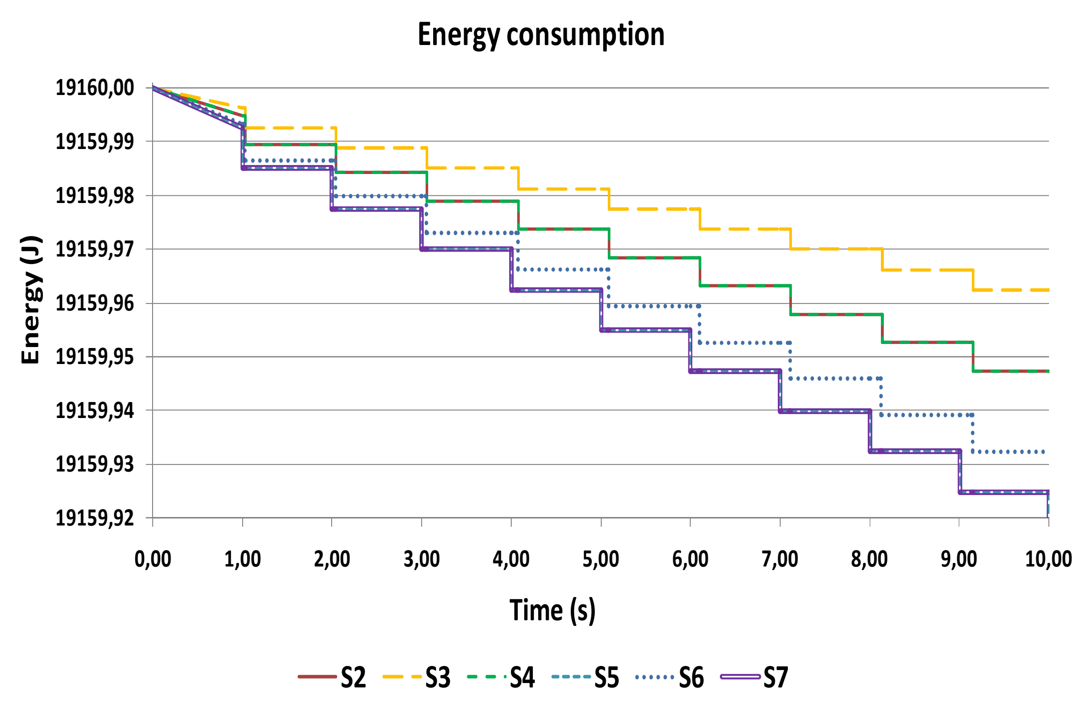
Selection of Adequate Volume of Network Traffic - Sending an Equal Amount of Traffic from Nodes Equally Distant from Gateway



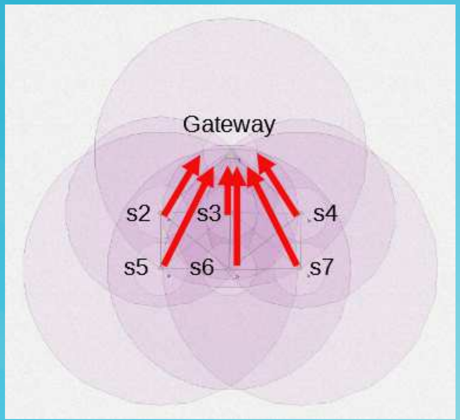
- These scenarios aim at analyzing **the impact of the amount of transmitted network traffic on the energy consumption** in the network.
- **In cluster topology the energy of CH nodes is depleted the fastest**. CH nodes are difficult to replace, which causes **the loss of functionality of the entire cluster**, while **in a star topology, the depletion of energy of an individual node does not cause such a loss in data delivery**.
- **The star topology** is used for communication between nodes as it is defined as **more appropriate in terms of total energy consumption compared to the line structure within clusters**.

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*

- The smallest radius of area coverage has the node closest to the gateway. The **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, adequate coverage of area with signal must be achieved**.



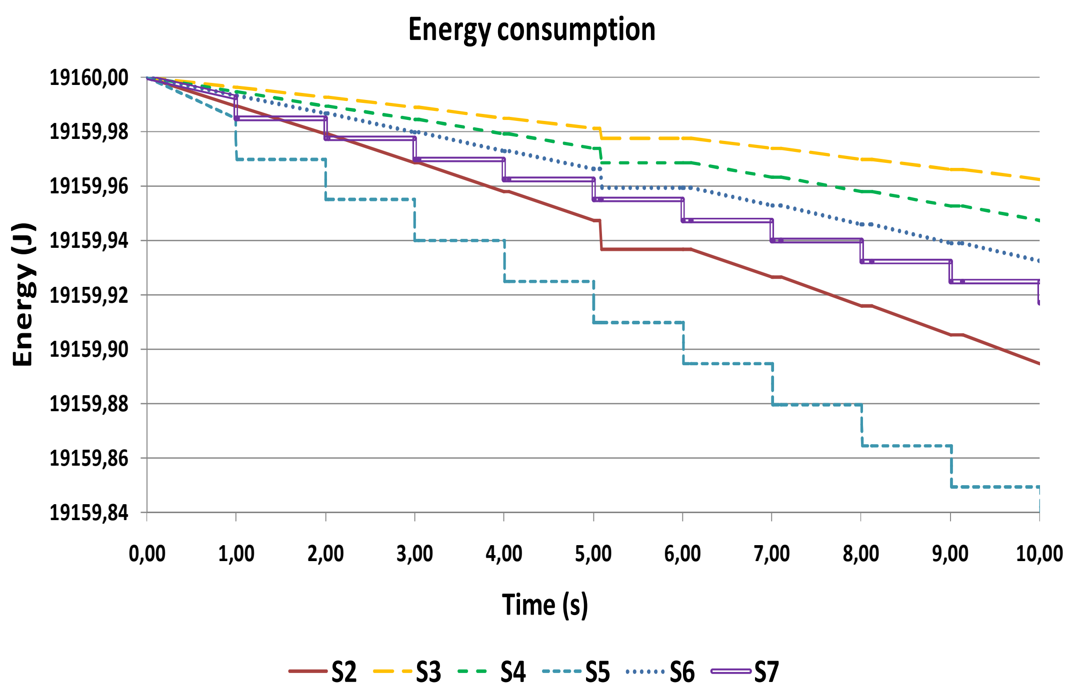
Selection of Adequate Volume of Network Traffic - Sending Different Amounts of Traffic from Nodes Equally Distant from Gateway



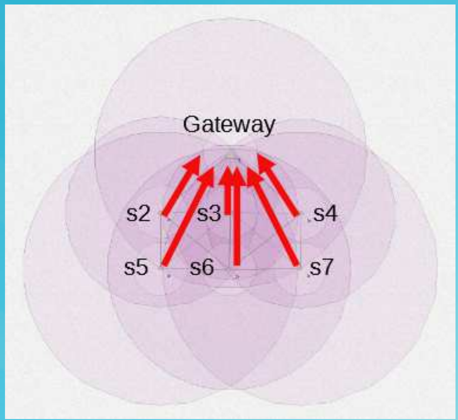
- **Data from some nodes are sent more frequently**. Despite the same distance of nodes *s2* and *s4* from gateway, more data is sent from node *s2* to gateway than from node *s4*. The same is true for data sending from node *s5*, from which **data is sent to gateway more often** than from node *s7*, although both nodes are equally distant from the gateway.
- The node closest to the gateway, node *s3* consumes the least energy. The most energy is consumed by the farthest node *s5*. The node *s5* consumes more energy than node *s7*, and the node *s2* consumes more energy than node *s4*.

Nodes	**Nodes marking:**						
	Gat.:	*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*

- 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**.

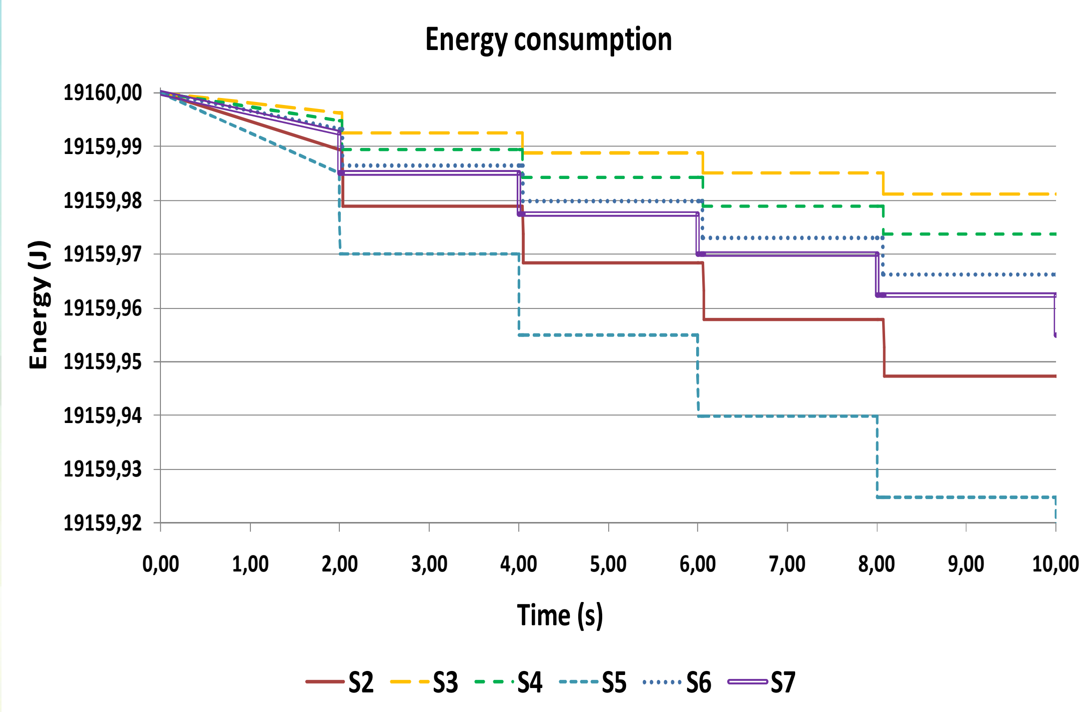


Selection of Adequate Volume of Network Traffic – Less Frequent Data Transmission



- The communication parameters are similar to the data from the previous scenario, except that **data from nodes are 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.
- From the comparison of presented results, **the significantly less energy consumption can be noted** within the same time interval **when sending data with higher delay**, i.e., less frequently.

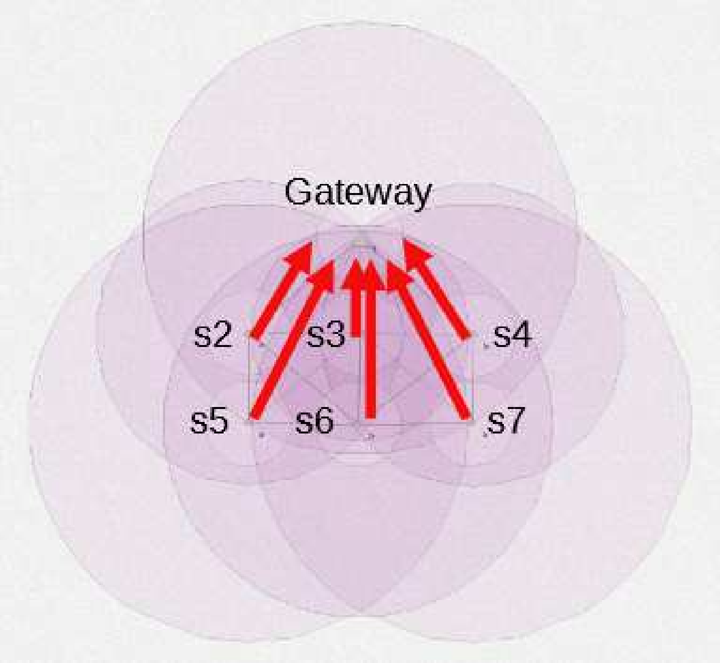
Nodes	Nodes marking:						
	Gat.:	*s2*:	*s3*:	*s4*:	*s5*:	*s6*:	*s7*:
Instruct.:	*loop wait read x*	*loop atpl 70 send 1 1 send 1 1 delay 2000*	*loop atpl 50 send 1 1 delay 2000*	*loop atpl 70 send 1 1 delay 2000*	*loop send 1 1 send 1 1 delay 2000*	*loop atpl 90 send 1 1 delay 2000*	*loop send 1 1 delay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



- LoRa supports data transmission with lower requirements for high transfer speeds of large amounts of data. Thus, its application is adequate in precision agriculture, where additional **energy savings can be achieved by sending smaller amounts of data over longer periods of time between transmissions**.

Effect of SF and CR Parameters on Consumed Energy

- **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 **analyzed parameters**, 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 value of SF, the more capability the receiver has to move away the noise from the signal. Thus, **the greater value is taken**, the **more time is taken to send a packet**, but **a higher range will be achieved** because the sensitivity of the receiver is better. 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), while n is 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**.

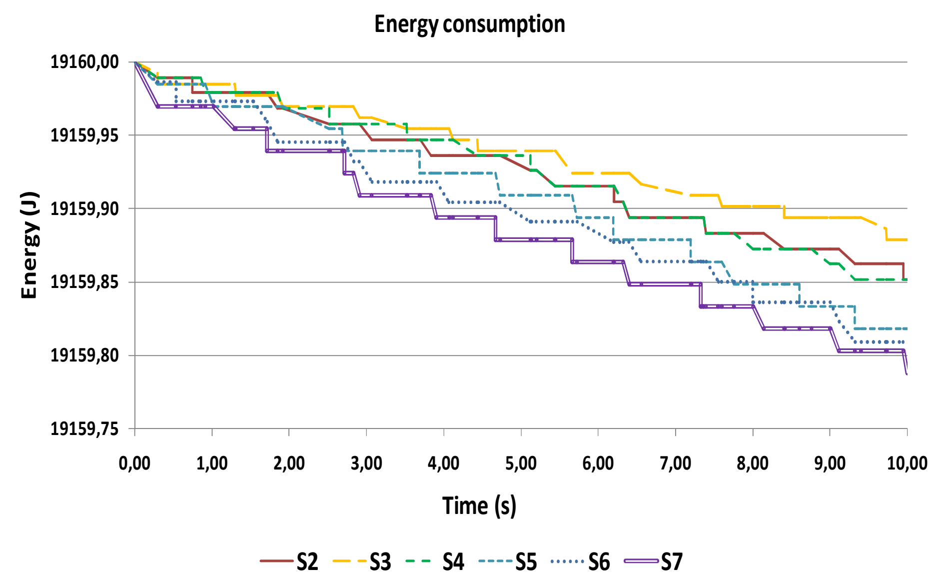


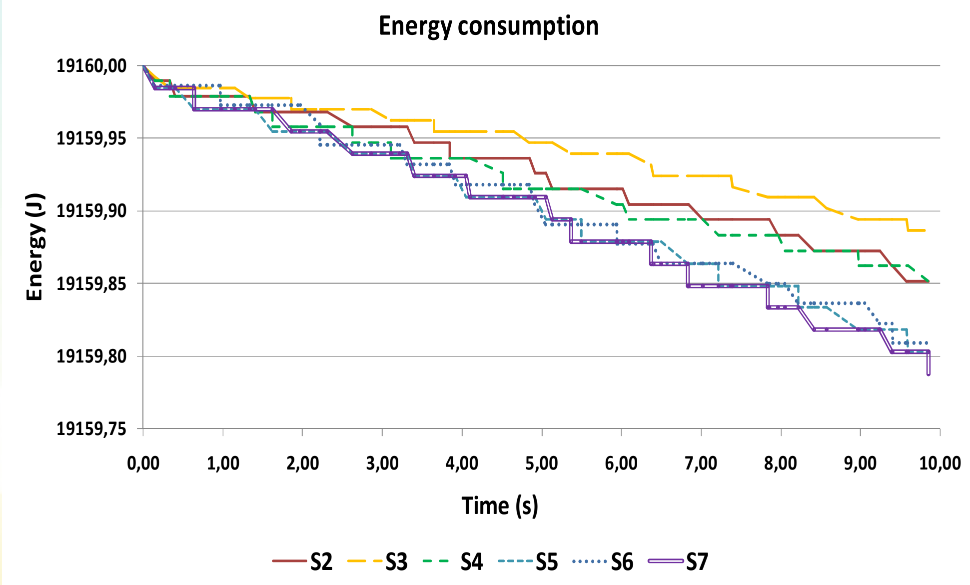
Effect of SF and CR Parameters on Consumed Energy

- The analysis of the effect of different values of SF and CR LoRa radio parameters on consumed energy and range is performed hereafter.
- **When 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 on the right, the SF expansion factor is set to a maximum value of 12, unlike in the case shown in Figure on the left where the SF is set to value 7. The reason for **setting high SF value** is **to maximize the transmission range** as one of the most important factors in the field deployments.

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*

Nodes	Nodes marking:				
	Gat.:	*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*



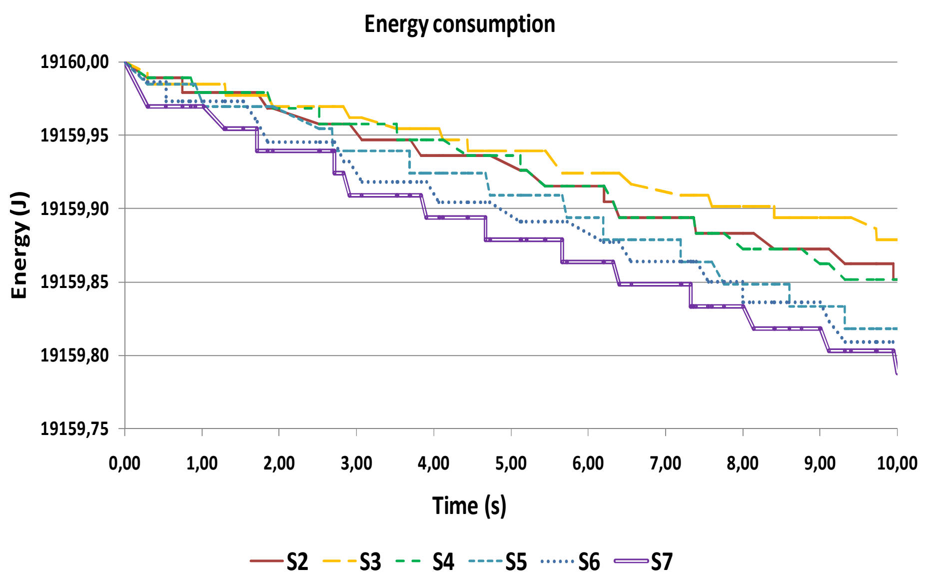


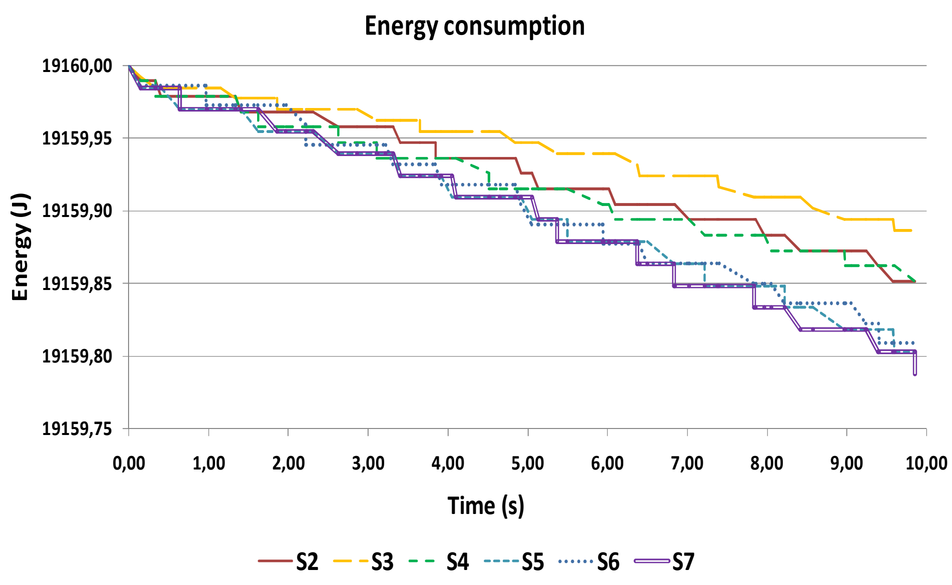
Effect of SF and CR Parameters on Consumed Energy

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

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*

Nodes	**Nodes marking:**				
	Gat.:	*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*





Conclusion

- **LoRa system aim at** pushing **optimization of energy consumption further while maintaining a long range**, hence the scenarios for **implementation of LoRa solutions in precision agriculture scenarios** have been analyzed.
- **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.
- The presented results show that **optimizing LoRa parameters**, such as **SF and CR**, **with regard to required long range communication is a key element to reduce the consumed energy by the sensor nodes**. Since **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 **CR should be as high as possible to reduce total energy consumption**.
- The presented findings of the effect of 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**.

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