

IOT Sensor Node Placement Model and Algorithm for Water-Efficient Irrigation

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Abstract

The increasing water scarcity has led to the rational use of water resources in agricultural fields and the automation of irrigation processes. This problem is being solved by using IoT technologies and wireless sensor networks to monitor land areas and irrigate only those areas that need water. This, in turn, is directly related to the correct placement of these sensor nodes in the fields to increase their efficiency. With the correct placement of sensor nodes, the monitoring accuracy increases, the coverage area is fully ensured, and energy consumption is reduced, and the number of sensors is controlled. This study models the placement of IoT sensor nodes for water-saving irrigation systems and develops an algorithm that is aimed at determining the location of sensor nodes, taking into account the geometric characteristics of the field, the coverage radius of the sensors, and the communication capabilities. The proposed approach allows for real-time monitoring of the irrigation process, reliable control of soil moisture, efficient use of water resources, and increased coverage and energy efficiency of the wireless sensor network.

Keywords: Water-efficient irrigation systems, wireless sensor network (WSN), sensor placement, IoT technology, coverage radius, number of sensors, field shape, soil type, crop type.

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1. Introduction

In the world, many studies are being conducted on the implementation and digitization of digital technologies for remote monitoring of water-saving irrigation systems based on IoT. Also, special attention is paid to the development of models, algorithms, hardware and

software complexes, as well as technical and software for implementing remote monitoring systems in irrigation processes. Based on IoT sensors, cloud platforms, mobile applications, artificial intelligence algorithms and remotely controlled irrigation devices, soil moisture, air temperature, humidity level, water consumption, pressure and agro-climatic indicators are monitored in

real time. Increasing the reliability of monitoring data transmission and reception, developing the structure and architecture of a wireless sensor network, node schemes, models and algorithms, and organizing a monitoring system are among the current trends.

To this end, the effective deployment of IoT sensor nodes is considered the main problem, which determines the reliability and economic efficiency of the IoT network. Excessive soil moisture or irrigation time between irrigations can lead to soil and plant dehydration. By creating automated monitoring and irrigation systems in wireless sensor networks, water, energy, and labor can be saved. When nodes are scientifically placed in the field, the system coverage increases, energy consumption decreases, and real-time monitoring is performed with high accuracy.

2. Methods

Solar-powered drip irrigation systems allow for increased application potential and cost-effective resource utilization. The power ratings of solar panels, batteries, and pump motors are determined by the amount of water required for the crop. Adequate and efficient irrigation processes are essential in agricultural fields. In current practice, irrigation is applied evenly to the soil based on the farmer's previous experience. However, the following factors affect the amount of irrigation: Crop type and physiology, soil physical, chemical, and biological parameters, and spatial variability of the soil, which affect crop water requirements, not only eliminates excess water consumption, but also reduces the amount of equipment required to operate the irrigation system [1]. This increases the potential for solar-powered irrigation systems. In addition, sufficient irrigation and increased product yield [2].

Soil moisture sensors are used in research to determine the water demand of agricultural land [3]. The data obtained from these sensors are used in the right areas based on the water demand of the crop area, thus reducing water consumption. The problem here is to determine how many sensors or sensor nodes should be used and where the sensors should be located. These two parameters affect the efficiency and cost of a sensor-based irrigation system. The connection of a sensor node to another sensor node or to a central node is called a sensor network. A wireless sensor network usually consists of many wireless devices placed at the desired coordinates of the land area, each of which is capable of

collecting, processing and communicating with neighboring devices [4]. Sensor networks are usually chosen for applications that require quantitative measurement. Numbers and location are the most important issues for indoor/outdoor applications. This problem has been solved by researchers using a decision support system based on evolutionary optimization algorithms [5]. Many studies on WSNs have focused on certain parameters such as continuous data transmission/reception, increasing system uptime, optimizing arrival time, and reducing the number of sensor nodes. Sensor placement and number of sensors are important issues that need to be addressed to achieve the main goal of studying WSNs [6]. In this study, sensors are placed in a uniform irrigation perspective to identify the same parts of the land with real moisture data. The irrigation amount is affected by various parameters (e.g., moisture, temperature, soil properties, and tree) that are considered to obtain uniform irrigation [7].

The analysis shows that the location of IoT sensor nodes in water-saving irrigation systems has not been studied depending on the location of the crop area, its geometric shape, crop type, and the selected wireless communication technology. In order to effectively use resources and increase irrigation efficiency, it is necessary to take into account their uniform distribution across the crop area, soil type and moisture, crop water requirements, irrigation needs, the location of the water distribution system, and communication parameters at the network nodes. For this purpose, taking into account the fact that soil moisture, crop type, and environmental factors affect the monitoring accuracy, there is a need to develop a model and algorithm for placing sensor nodes at strategic points that allow reliable measurements taking into account these crop areas and network parameters[8].

In water-efficient irrigation systems, the placement of IoT sensor nodes (monitoring devices) in the field takes into account the field parameters, crop type, soil properties, and coverage indicators of the selected communication technology. This process is important for reliable collection of monitoring data, ensuring communication continuity, and effective management of irrigation processes. Nodes should be located close to energy sources or equipped with solar panels, and the nodes should have sufficient signal strength to transmit and receive data. The communication network is an important factor in determining the location of sensor

nodes, and the nodes should be placed in protected areas. Taking the above factors into account for the placement of nodes, crop areas are analyzed in detail and the location is planned. For this purpose, the stages of application development and descriptions of its

capabilities are presented in Table 1, which sequentially shows the stages of data entry, calculation of the coverage radius, placement of sensor nodes, and generation of results.

Table 1. Functional architecture of sensor node deployment software

Module Name	Task	Incoming data	Output
Data Entry	Formulation and input of farm parameters into the program	Field coordinates, soil type, crop type, technology type	Set of initial parameters
Choose Communication Technology	Provide communication between nodes based on environmental and crop type characteristics	LoRaWAN, ZigBee, Wi-Fi, Bluetooth, GPRS, etc.	Communication technology parameters
Radius of Coverage	Determine effective coverage radius	Communication technology radius, soil and crop type characteristics	Calculated coverage radius
Obstacle Avoidance	Consideration of field constraints	Obstacle coordinates and radii	Permitted location areas
Sensor Placement	Determine node coordinates	Field shape, coverage radius	Set of node coordinates
Visualization	Graphical representation of fields and nodes	Sensor coordinates, field boundaries	Layout scheme
Result Formulation	Prepare final report	Calculation results	Number of nodes, coverage area, Report

To automate the process of placing sensor nodes for irrigation systems and selecting IoT technology, the program enters the name of the farm, field coordinates, soil and crop type, and communication technology used. Based on this data, the program calculates the effective coverage radius, forms the coordinates of the sensor node locations, and displays the results in a graphical format. It also takes into account obstacles in the field, visually displays the placement scheme, and provides a final report. A mobile device with the Android operating

system is required. Technically, the system serves to reduce the number of sensors, increase the level of coverage, and ensure continuity of communication. Economically, it allows you to reduce the number of redundant devices, reduce design time, and optimize the costs of implementing an irrigation system. The functional capabilities of this system are shown in Figure 1. As a result, the user will have the optimal sensor location and technology selection for the field area.

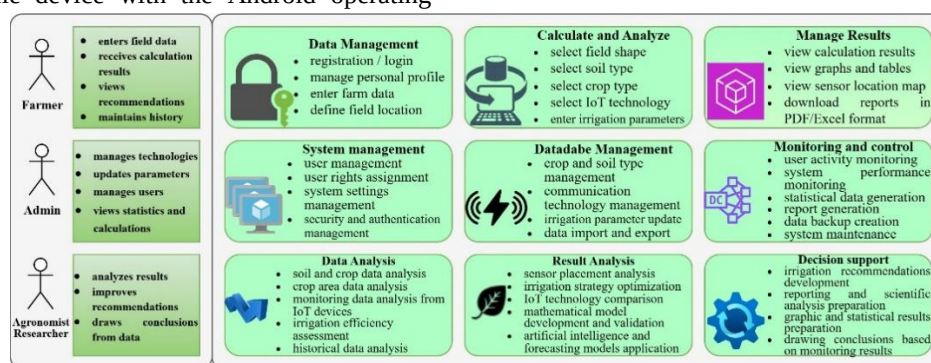


Figure 1. Conceptual model of the system for node placement and communication technology selection in cropland monitoring

The accuracy and efficiency of the node placement process largely depends on the correct formation of the initial data. Therefore, at the first stage of the system operation, information about the geometric parameters of the field, soil and crop types, communication technology, and existing obstacles is entered. This data allows you to

determine the coverage area of the sensors, calculate their optimal coordinates, and fully monitor the field area. As a result, a database of initial information is formed, necessary for subsequent calculation and visualization stages, and an important basis is created to ensure the efficiency of the system.

Table 2. Initial data entry parameters.

Parameter name	Description
Farm name	Project or farm identifier
Field shape	Field type in the form of a triangle, rectangle or hexagon
Field coordinates	Coordinates of points defining the boundaries of the field
Communication technology	LoRaWAN, ZigBee, Wi-Fi, Bluetooth, GPRS, Sigfox and other technologies
Soil type	Soil type: sandy, silty or mixed clay
Crop type	Wheat, cotton, rice, corn, vegetables and other crops
Hedge coordinates	Location of trees, buildings or other obstacles in the field
Hedge radius	Size of the area occupied by the obstacle

The initial data input stage considers the sensor node placement problem mathematically as a set of parameters: crop area (F), selected communication technology (T), soil type (S), crop type (C), and obstacles in the field (O). The sensor placement problem is expressed as follows

$$M=\{F,T,S,C,O\} \quad (1)$$

The set of input data required for the placement of the nodes. Based on the entered parameters, the effective coverage radius of the sensors is determined and the location coordinates of the nodes are calculated. Thus, the initial data serve as input parameters of the mathematical model for subsequent calculations and ensure the accuracy of the placement results.

To enter the parameters of the crop fields, the geometric shape of the sensor nodes when placing them can be given in the form that is available in practice: triangle, rectangle and hexagon. The user first enters the shape of the field, then the parameters corresponding to the selected shape, coordinates or side lengths representing the boundaries of the field are entered. Trees, buildings, water bodies or other obstacles present in the field can also be entered. Based on this data, the program forms the field boundary and in the next stages places the sensor nodes precisely within this area. This data is used to determine the area where the sensor nodes can be placed.

The area of the land is designated by (F).

$$F_n = \{P_1, P_2, \dots P_n\} \quad (2)$$

where F_n - is the shape of the terrain, P_i - is the point defining the boundary of the terrain, $n \in \{3, 4, 6\}$ is the number of corners corresponding to the terrain shape.

Sensors cannot be placed in areas where obstacles are located on the terrain, and to bypass them, it is necessary to determine the values of their main indicators, and the set of obstacles is denoted by O:

$$O_n = \{O_1, O_2, \dots O_m\} \quad (3)$$

where $O_i(x_i, y_i, r_i)$ are the obstacle parameters, x_i and y_i are the center point of the obstacle, r_i is the obstacle radius, and m is the number of obstacles.

Based on this, the useful area where nodes can be placed is subtracted from the total area occupied by obstacles.

$$F_{eff} = F - O \quad (4)$$

The number of nodes depends on the coverage radius of the chosen communication technology. If the effective coverage radius of the technology is R_{eff} , the area covered by one node is:

$$S_{tugun} = \pi R_{eff}^2 \quad (5)$$

The number of nodes that can be placed within the area, the shape of the area, its dimensions, and the obstacles in the area determine the area where the nodes can be placed. The coverage radius of the selected IoT

technology determines how many nodes can be placed in this area. For this purpose, it is necessary to develop an algorithm for placing nodes. The input parameters of the algorithm and their description are given in Table 3.

Table 3. Parameters used in the node placement algorithm and their description

Parameter	Designation	Description
Land area	F_n	Total area where sensors can be deployed
Obstacles	O	Areas where sensors cannot be deployed
Useful area	F_{eff}	Area after obstacles are removed
Sensor coverage radius	R_{eff}	Effective radius of selected technology
Sensor coverage area	S_{sensor}	Area covered by one sensor
Number of sensors	N	Number of nodes that can be deployed

After determining the terrain parameters and existing obstacles, the process of placing nodes by selecting a communication technology in the program becomes important, since the coverage radius, data transmission distance and network capabilities of the selected technology form the basis for further calculations. The algorithm provides the ability to choose one of the following technologies: LoRaWAN, ZigBee, Wi-Fi, Bluetooth, GPRS, Sigfox, Z-Wave, MQTT and 5G. Predefined coverage radius and transmission parameters are used for each technology. The selected technology participates in forming the placement scheme of sensor nodes in accordance with the size, shape and monitoring requirements of the field area. Therefore, the decision made at this stage directly affects the subsequent performance of the system.

Communication technologies determine the coverage parameters and adapt them to the placement process. This takes into account the nominal coverage radius of the technology, data transmission capabilities and characteristics of the field area. As a result, the initial parameters necessary to determine the distance between sensor nodes, the number of nodes that can be placed and their coordinates are formed. The data generated at this stage is then used to calculate the coverage area, determine the location of sensor nodes, and monitor the

crop area to the maximum. Thus, the stage of selecting a communication technology is a key stage that determines the technical capabilities of the sensor network and ensures the effective operation of the entire system.

When selecting a communication technology and determining the coverage parameters, an algorithm can select one of the technologies. The selected technology determines the distance of information exchange between sensor nodes, coverage area, energy consumption, and overall network efficiency. Therefore, the choice of technology is one of the main parameters of subsequent calculations. The available technologies are represented by the following set:

$$T = \{T_1, T_2, \dots, T_k\} \quad (2.6)$$

The algorithm does not have a single fixed standard radius for communication technologies, the values obtained are taken relative, and the coverage distance based on the coverage radius given in the standard of all technologies varies depending on the antenna type, transmission power, frequency range, obstacles, terrain and environment. For this purpose, nominal values have been taken. The nominal coverage radii of the IoT technologies used in the algorithm are 45, as shown in Table 4 below.

Table 4. Comparison of wireless network technologies by coverage area

Table 4. Initial data entry parameters.

Technology	Nominal coverage radius (m)
Bluetooth LE [1]	100
Z-Wave [2]	30

Wi-Fi [3]	100
ZigBee [4]	100
5G [5]	500
LoRaWAN [6]	5000
GPRS (2G) [7]	3000
Sigfox [8]	10000

The coverage characteristics of various IoT technologies are used in the process of placing sensor nodes. However, the coverage distance for technologies does not have a single fixed value, since it varies depending on the transmission power, antenna type, operating frequency range, terrain, weather conditions, and obstacles in the area. For this purpose, nominal coverage radii have been adopted for each technology for use in practical calculations. These values are used as initial parameters for placing sensor nodes, assessing the coverage level, and performing preliminary design calculations. The algorithm assumes a coverage radius of 100 m for Bluetooth LE and Wi-Fi technologies, 100 m for ZigBee, 30 m for Z-Wave, and 500 m for 5G technology. Of the long-range communication technologies designed for monitoring large areas, nominal coverage radii of 5000 m for LoRaWAN, 3000 m for GPRS, and 10000 m for Sigfox were selected. These values are based on the practical ranges given in the scientific and technical literature on relevant standards and technologies [1–8]. In the calculation process, these coverage radii are analyzed together with the field size, obstacles, soil and crop types and are used to determine the required number of sensor nodes and their location coordinates. As a result, the program allows you to assess the field coverage level and deployment efficiency.

After selecting a communication technology, the program evaluates the capabilities of this technology based on the conditions of the crop field. The coverage range specified by the manufacturer for communication technologies is usually given for an open and ideal environment, and in practical agricultural fields, the signal propagation is affected by the type of soil, soil moisture, height and density of crops, and obstacles in the field. As a result, the actual coverage range of the technology may differ from the value indicated in the passport.

The algorithm adapts the nominal coverage radius of the

given technology to real conditions. The nominal coverage radius R_{tech} , soil type coefficient α and crop type coefficient β are used. The soil coefficient represents the degree to which the radio signal is attenuated by soil properties, while the crop coefficient represents the effect of vegetation on the signal absorption and propagation. The effective coverage radius is determined using the following equation:

$$R_{eff} = \frac{R_{tech}}{\alpha \cdot \beta} \quad (2.8)$$

where: R_{tech} - is the nominal coverage radius of the selected technology in m; α is the soil type coefficient, β is the crop type coefficient, R_{eff} - is the effective coverage radius in real conditions.

Based on this equation, α and β are used to determine the number of nodes and their placement across the field area, taking into account the impossibility of obtaining them directly from the standard. The more the soil and crops affect the signal, the smaller the coverage distance. The α and β coefficients are used to determine the coverage capabilities of the selected communication technology in real field conditions and to calculate the effective coverage distance, which serves as the basis for the placement of sensor nodes. These coefficients were introduced to take into account the attenuation of the radio signal under the influence of soil and vegetation, and the values of the α and β coefficients were determined based on the expert assessment method, experimental results and analyses conducted by specialists (Exhibit 1, 2, 3). Here, the α coefficient represents the effect of soil type on radio signal propagation, and the β coefficient represents the effect of crop cover density and height on signal propagation. The use of these coefficients allows for a more accurate assessment of the practical coverage distance of communication technology and increases the efficiency of sensor node placement.

Table 5. Coefficients for soil and crop type.

Soil type	α
Sandy	1.0
Loamy	1.1
Silly	1.2
Clay mix	1.3
Crop type	β
Low growth	1.0
Medium growth	1.1
High growth	1.2
Very dense crop	1.3

The coverage area is then compared to the useful surface area of the field. If the coverage radius is large, fewer sensor nodes are required to cover the area. Conversely, if the coverage radius is small, more sensor nodes need to be deployed to fully cover the field. Thus, the main task of this stage is to determine the coverage capabilities of the selected IoT technology in real field conditions. The resulting effective coverage radius and coverage

area are used in the next stage to calculate the number of nodes and determine their location coordinates.

Thus, the main task of this stage is to determine the practical coverage capabilities of the selected IoT technology, taking into account real field conditions. As a result, the Reff parameter is formed, which is used in sensor placement calculations.

Table 6. Input and output data

Input data	Output data
IoT technology R_{tech}	Effective coverage radius R_{eff}
Soil type α	Corrected coverage parameter
Crop type β	Base for further calculations
Input data	Output data

After determining the effective coverage radius R , i.e. the coverage radius used to place nodes based on technology, soil and crop data, the area F , obstacles O and radii R are used together to determine the number of nodes and calculate their coordinates. Using the calculated coverage radius, the coordinates of the sensors are determined.

Sensor node placement. At this stage, the algorithm determines the location coordinates of the sensor nodes based on the geometric shape of the field area, obstacles in the field, and the calculated effective coverage radius. The main goal of placement is to maximize the coverage of the field area and reduce the use of redundant sensors.

Once the field area F , obstacles O , and effective coverage radius R_{eff} are known, the area where the nodes should

be placed is formed. The nodes are placed within this area in such a way that the coverage areas complement each other. The set of nodes is represented in the form of the set shown below.

$$N = \{N_1, N_2, \dots, N_k\} \quad (2.9)$$

where: $N_i = (x_i, y_i)$ - coordinate of the i -node, k - number of sensors placed.

The main condition for sensor placement is as follows:

$$N_i \in F \quad (2.10)$$

In addition: the condition must also be met.

$$N_i \notin O \quad (2.11)$$

This means that the nodes are not placed in areas with obstacles.

The nodes are placed sequentially across the field and the following requirements are checked for each new node. The sensor must be within the field, the sensor must not fall into the obstacle area, the sensor coverage must fill the existing coverage, and the maximum part of the field area must be covered.

The resulting coverage area at the end of the placement is determined as follows:

$$S_{cov} = \bigcup_i^k S_i \quad (2.12)$$

where: S_{cov} - total area covered by all sensors, S_i - coverage area of the i -sensor. If, the field area is considered to be almost completely covered.

Table 7. Input and output data

Input data	Output data
Field area F	Number of sensors k
Obstacles O	Sensor coordinates N_i
Effective radius R_{eff}	Coverage map
IoT technology	Layout scheme

As a result, the program generates node coordinates for the field area and prepares them for graphical representation.

This algorithm is designed to automate the process of placing sensor nodes in triangular, rectangular, and hexagonal field areas in smart irrigation systems.

$$C = \frac{N \cdot \pi R_{eff}^2}{S_{field}} \times 100\% \quad (2.13)$$

The algorithm takes into account the field boundaries, the coverage radius of the communication technology, soil and crop coefficients, and the location of obstacles. As a result, the coordinates of the sensor nodes are determined, achieving maximum coverage of the field area.

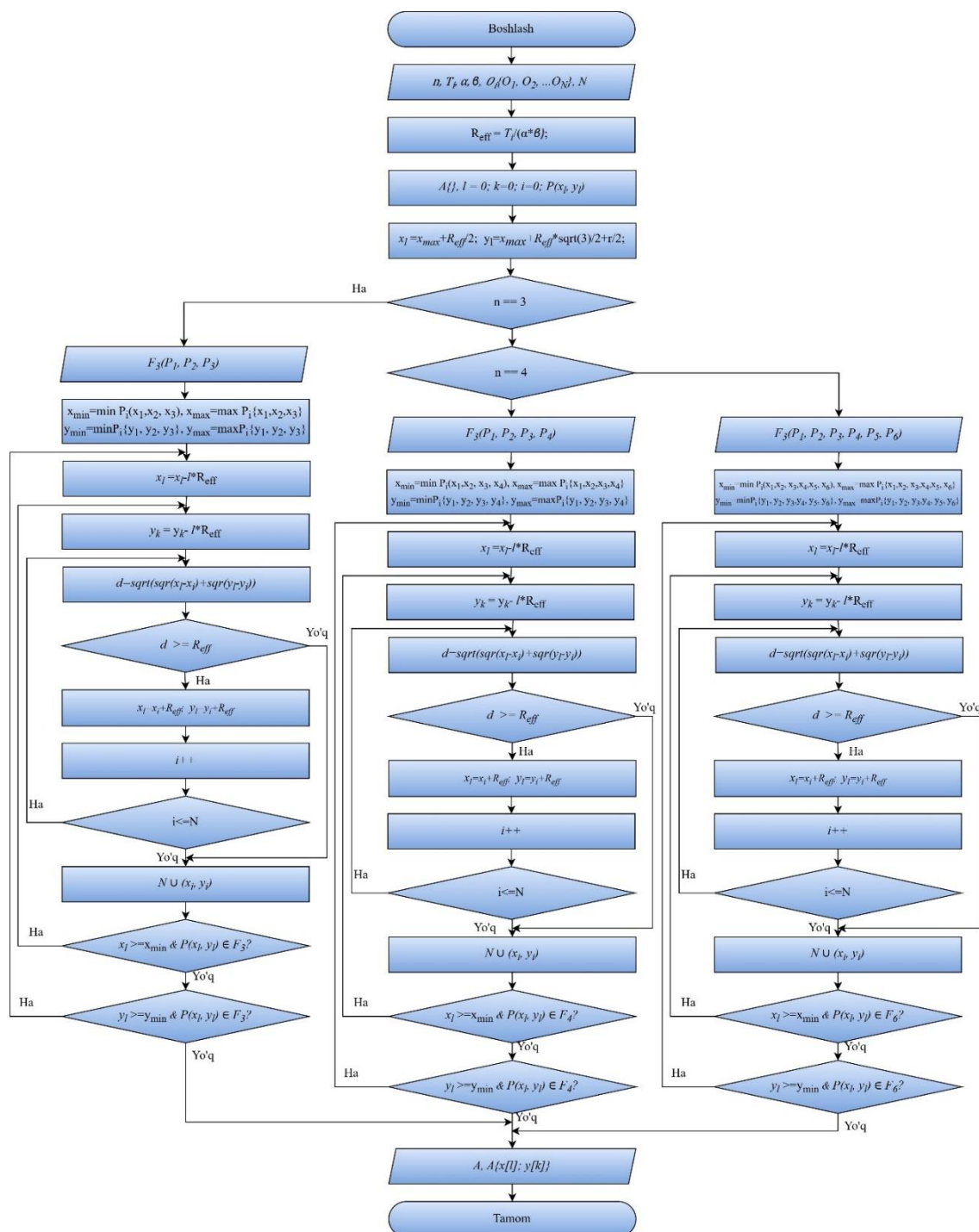


Figure 2. Node placement algorithm

The algorithm starts by accepting the initial parameters entered by the user. Initially, the field shape n , the selected IoT technology T_i , the soil type coefficient α , the crop type coefficient β , the set of obstacles $O=\{O_1, O_2, \dots, O_m\}$, and the set of sensor nodes N are accepted. Based on the entered data, the effective coverage radius of the selected technology is calculated.

For this, the nominal coverage radius of the technology is divided by the soil and crop coefficients, i.e. $R_{eff} = T_i / (\alpha \cdot \beta)$. This value is used to determine the distance between the sensors in the next steps. After that, the field shape is determined. If $n=3$, a triangular field $F_3=\{P_1, P_2, P_3\}$ is formed, if $n=4$, a rectangular field $F_4=\{P_1, P_2, P_3, P_4\}$, and if $n=6$, a hexagonal field

$F6=\{P1,P2,P3,P4,P5,P6\}$ is formed. Next, the smallest and largest coordinates of the area are determined. Where x_{min} is the smallest value among all x coordinates, and x_{max} is the largest value. In the same order, the values of y_{min} and y_{max} are also determined.

The sensor placement process starts from the starting point of the field. The starting coordinates are given as $x_k = x_{min} + Reff / 2$ and $y_k = y_{min} + Reff / 2$. This ensures that the sensor is not placed too close to the field boundary. For each generated point, it is first checked whether it is located inside the field. For this, the condition $P(x_k, y_k) \in F_n$ is checked. If the point is outside the field, it is rejected and the next point is checked. If the point is located inside the field, an obstacle check is performed. The distance between the point and the obstacle is determined using the center of each obstacle $O_j(x_j, y_j)$ and its radius r_j . Distance $d_j = \sqrt{(x_k - x_j)^2 + (y_k - y_j)^2}$ is calculated by the formula. If the calculated distance is less than or equal to the obstacle radius, i.e. $d_j \leq r_j$, the node is considered to be in the obstacle area and the sensor is not placed. If the condition $d_j > r_j$ is met for all obstacles, the node is considered suitable for placement.

The node that is found to be suitable is added to the set of nodes. Mathematically, this is expressed as $N = N \cup \{P(x_k, y_k)\}$. After that, the number of nodes is increased by one, i.e. $i = i + 1$. To move to the next point,

the value $x_k = x_k + Reff$ is calculated. If $x_k > x_{max}$, a new row is moved and the values $x_k = x_{min}$, $y_k = y_k + Reff$ are accepted. This process is repeated as long as the condition $y_k \leq y_{max}$ is met. At the end of the algorithm, the coordinates of all placed sensor nodes, their total number and coverage results are formed. The results are written to an array in the form $A = \{x[i], y[i]\}$ and presented to the user in the form of a graph and a report. Thus, an optimal scheme for placing sensor nodes is created, taking into account the shape of the field, IoT technology, soil and crop properties, and obstacles.

In order to analyze the relationship between the number of nodes and the effective coverage radius, the field area parameters, the coverage capabilities of communication technologies, and the effective coverage radius values used in the node placement algorithm were used. The calculations took into account the expansion of the area covered by one node with an increase in the coverage radius, resulting in a decrease in the number of sensors required. The number of sensors was selected as an independent variable in the graph, and the corresponding effective coverage radius for each value was determined. The results were plotted on the coordinate plane, and a correlation curve was generated. The graph allows us to assess the impact of the coverage radius on the network architecture and the number of devices during the node placement process, and is an important analytical tool for choosing the optimal technology.

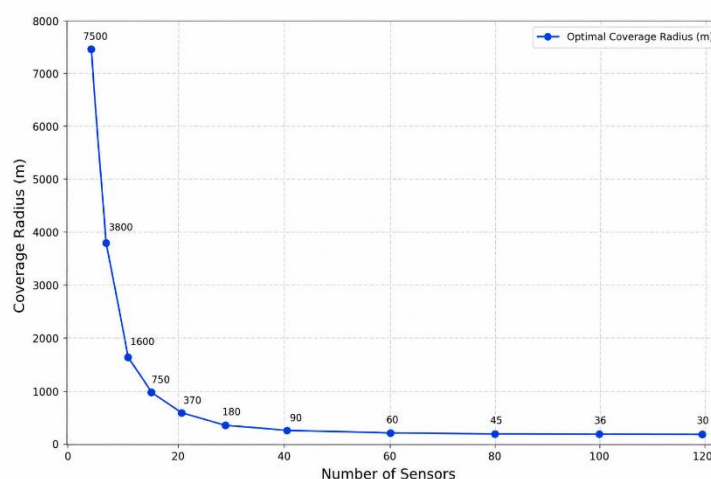


Figure 3. Relative graph of the change in the effective coverage radius depending on the number of sensors

The results obtained showed that there is an inverse relationship between the number of nodes and the effective coverage radius. As can be seen from the graph, the coverage radius takes on very large values when the number of nodes is small, and as the number of nodes

increases, the coverage radius decreases sharply. While the rate of change is high at the initial points, the graph stabilizes in the subsequent stages. This confirms that technologies with a large coverage radius require fewer sensors, while technologies with a small coverage radius

require more sensor nodes. The results show that it is important to optimize the number of nodes and choose an IoT technology suitable for the field area. The graph analysis showed that there is an inverse relationship between the number of nodes and the effective coverage radius. It is shown that communication technologies with a large coverage radius can cover large areas with a small number of nodes, while technologies with a small coverage radius require more nodes. As a result, the number of nodes determines the possibility of reducing network costs and increasing coverage efficiency by choosing the appropriate IoT network technology.

The scientific novelty of the proposed approach is that it develops a single mathematical model for areas of various geometric shapes and creates the possibility of placing sensors even when the number of obstacles is not known in advance. In addition, the coverage radius of IoT technologies is adjusted using soil and crop coefficients, bringing it closer to real field conditions. This approach allows optimizing the number of sensors, increasing coverage efficiency, and ensuring the reliability of the irrigation system.

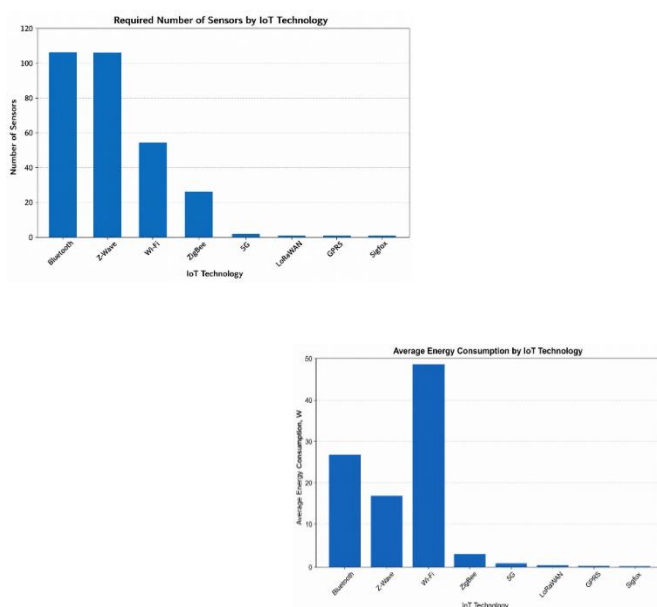


Figure 4. Key indicators of the number of nodes required for IoT technology

A method for placing sensor nodes based on a single mathematical model has been developed for fields of various geometric shapes (triangle, rectangle, and hexagon). The proposed model allows expressing field boundaries through a set of coordinates and using a single calculation mechanism. A mathematical approach is proposed that takes into account the geometric shape of the field, the location of obstacles, and the coverage radius of the communication technology when placing

nodes. This approach serves to increase the coverage level of nodes and reduce the number of redundant nodes. A model for adapting the nominal coverage radii of IoT technologies to soil type and crop characteristics has been developed. The model approximates the coverage capabilities of communication technologies to real field conditions. Based on this, the functional capabilities of the application have been developed, as shown in Figure 5.



Figure 5. Use case diagram of an IoT-based sensor placement and irrigation planning system for agriculture

This figure illustrates the use cases of the FarmCalculateProject software system. The system is designed to automate irrigation and node placement processes for farms, where the user enters field parameters, soil type, crop type, IoT technology, and environmental data. The program checks, calculates, and analyzes the entered data and determines the optimal technology and placement parameters.

The program allows you to generate irrigation plan recommendations, technology coverage maps, water consumption calculations, yield forecasts, and economic efficiency indicators based on the results. The system also supports the functions of technology management, parameter updating, and statistics viewing by the administrator.

Fermer xo'jaligi nomi
Guliston ravnaqi

1. Texnologiyani tanlang +
Texnologiyani tanlang
ZigBee (100 m)

2. Shakl turi +
Shaklini tanlang
To'rtburchak

3. Maydon koordinatalari
To'rtburchak uchun namuna:
50,50
450,50
450,300
50,300
50,50
450,50
450,300
50,300

4. To'siqlar (har qatorda x,y,radius)
x1,y1,r1
x2,y2,r2
x3,y3,r3
...

5. Tuproq turi +
Tuproq turini tanlang
Qumli (1.1)

6. Ekin turi +
Ekin turini tanlang
Makkajo'xori (0.15)

Maydonni chizish

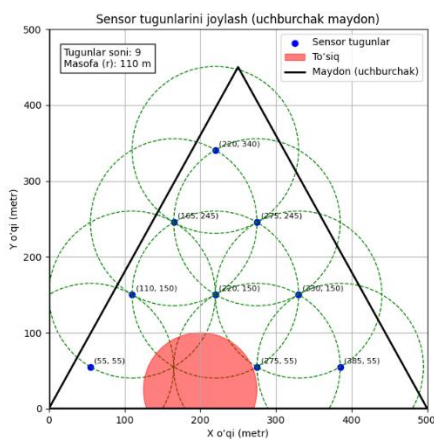
Shart	Kvadrat panjara	Heksagonal panjara	Farq	Tejamli ...
1000×1000 M · R = 100 M · CHEGARA = R/2 = 50 M				
To'siqsiz	100 ta	105 ta	Hex +5 ta	Kvadrat
To'siqli - (500, 500, r=150)	90 ta	87 ta	Hex -3 ta	Heksagonal
To'siqli - (500, 500, r=200)	88 ta	90 ta	Hex +2 ta	Kvadrat
1000×1000 M · R = 100 M · CHEGARA = 0 (OFFSETSIZ)				
To'siqsiz	100 ta	105 ta	Hex +5 ta	Kvadrat
To'siqli - (500, 500, r=150)	92 ta	90 ta	Hex -2 ta	Heksagonal
To'siqli - (500, 500, r=200)	88 ta	90 ta	Hex +2 ta	Kvadrat
PARAMETRLAR TAQQOSLASH — TO'SIQSIZ, CHEGARA = 50 M				
r = 100 m, 500×500 m	25 ta	24 ta	Hex -1 ta	Heksagonal
r = 100 m, 1000×1000 m	100 ta	105 ta	Hex +5 ta	Kvadrat
r = 100 m, 2000×1000 m	200 ta	209 ta	Hex +9 ta	Kvadrat
r = 150 m, 1000×1000 m	49 ta	48 ta	Hex -1 ta	Heksagonal

Eslatma: Heksagonal panjara nazariy jihatdan ~13.4% tejamkor, ammo to'siq maydoni markazida (500,500) joylashganda va radiusi katta (R>2r) bo'lganda to'q qatorlarni ko'proq kesib o'tishi tufayli kvadrata ustunlik qilishi mumkin.

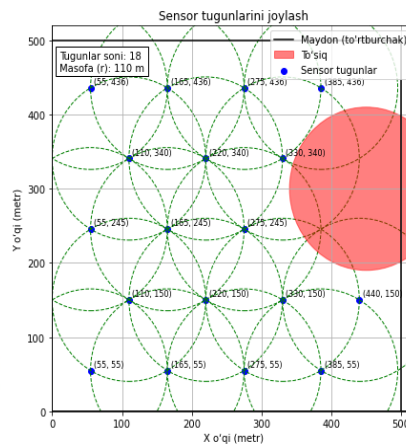
Panjara sxemasi: Kvadrat — $dx = dy = r$ · Heksagonal — $dx = r, dy = \sqrt{3}/2 \cdot r \approx 0.866r$

a)

b)

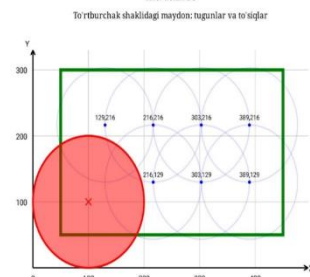


d)



e)

bobo oltin yong'og'lari fermer xo'jaligining tugunlarini joylashtirish ma'lumot



f)

Figure 6. Software package for positioning sensor nodes, estimating coverage area, and visualizing results based on field parameters, IoT technology, soil and crop type data

An integrated model, algorithm, and software for sensor node placement that takes into account the geometric shape of the field, obstacles, communication technology, soil type, and crop characteristics has been developed. The proposed approach allows for optimizing the number of nodes, increasing coverage, and improving monitoring efficiency in smart irrigation systems.

3. Conclusion

An algorithm for node placement has been developed in cases where the number of obstacles is not known in advance. The proposed algorithm checks the location of each potential point relative to all obstacles and forms optimal coordinates, avoiding obstacles. A method for automatically determining the boundaries of the area and

forming an area based on boundary coordinates is proposed for node placement. This method reduces the computational complexity and reduces the time for sensor placement.

An algorithm for automatically generating node coordinates based on the effective coverage radius has been developed. The algorithm ensures continuity of coverage by selecting the distance between nodes in accordance with the coverage radius. A complex mathematical model of node placement has been developed that combines the parameters of the field area, obstacles, and IoT technologies. The model allows determining the number of nodes, calculating coordinates, and assessing the level of coverage. A mechanism for graphical visualization of the results of node placement and automatic report generation has been developed. As a result, the user will be able to simultaneously analyze the coordinates of nodes, coverage areas, and the impact of obstacles.

A method for calculating the number of nodes based on the coverage radius for various communication technologies has been developed. This method allows for technology selection and optimization of the number of nodes in small and large areas.

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