Spatial Distribution of Wireless Sensor Nodes in the Urban Environment

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Abstract: Wireless sensor nodes are an important part of every wireless sensor network. If wireless sensor nodes have implemented or connected sensors, then they can be used for different types of measurements. These measurements can be carried out either in internal or external environment. Spatial distribution of sensor nodes in the urban environment is a crucial decision because on its basis the selected elements will be measured in the suggested places. It is necessary to choose localities where these measurements have the long term significance. Distribution of sensor nodes in the urban environment is determined by a lot of factors. These factors are related to technical parameters of nodes, terrain characteristics and parameters of measured elements. Distribution of sensor nodes is made on the basis of distribution algorithms or the sensor nodes are randomly spread to the area of interest. The graph theory is usually the background of distribution algorithms. This theory primarily does not take into account the characteristics of terrain and measured elements. This paper describes factors that influence the distribution of sensor nodes. The graphs that are used in the wireless sensor networks are described and the most suitable solution for implementing terrain characteristics is selected.

1 INTRODUCTION

Spatial distribution of wireless sensor nodes in the urban environment is a crucial decision because on its basis the selected elements will be measured in the suggested places. Measurements of chosen elements will be realized in the long term so that it is necessary to choose the localities where the measurements of selected elements will have long-term significance. Distribution methods are used to solve this task but these methods can be effectively used only in the indoor conditions because it takes into account only technical parameters and possibilities of the sensor nodes. The background of these algorithms is in the most cases based on the graph theory. A lot of factors influence the distribution of wireless sensor nodes in the urban environment so that the effective distribution of nodes is more complicated. Till now nobody paid the attention to the terrain characteristics which play an important role in the distribution process. These characteristics are very important in the case that the sensor nodes are situated in the urban environment so that they should be included in the distribution methods.

The author solves the problem of distribution of wireless sensor nodes in the urban environment on the basis of suggested factors. These factors contain not only technical requirements for nodes but they also include terrain factors and parameters of measured elements. The main objective of this paper is to analyze graphs which are used in the wireless sensor networks and select the most suitable one. The spatial distribution of sensor nodes in the urban environment could be carried out on the basis of the selected graph. The crucial requirement for the graph is to involve technical and terrain factors to its construction. If terrain factors were included in the distribution problem then the deployment of wireless sensor nodes in the outdoor environment could be effectively solved.

2 STAGE OF RESEARCH

This research has been ending its theoretical part. The literature, the articles and the distribution algorithms were studied in this part. The reasearch is now starting its practical part. The parameters which influence the distribution of sensor nodes in the urban environment were defined. The graph which is the most suitable for implementing of terrain parameters was scouted out. The method which will take into account not only technical parameters but it will solve the problem of distribution of sensor nodes more complex will be proposed in the future work.

3 OUTLINE OF OBJECTIVES

The objectives of this paper are to:

- define factors that influence the distribution of sensor nodes in the urban environment,
- scouted out graphs that can be used in the wireless sensor networks,
- select the most suitable graph for implementing terrain factors,
- suggest the way how the terrain factors can be implemented to the graph.

Till now no attention has been paid to the implementation of terrain factors into the distribution methods. These factors are very important in the case that the sensor nodes are distributed in the urban environment so that their inclusion in the distribution methods is necessary.

4 RESEARCH PROBLEM

The first problem of this research is to situate sensor nodes in the urban environment. Nodes placed in external conditions have to be protected against external influences. Their localization is influenced by other factors like technical characteristics of the node, terrain characteristics of the area of interest and parameters of measured elements. It is important to suggest method which will involve all factors that influence the distribution of sensor nodes in the external environment.

4.1 Factors that Influence the Distribution of Sensor Nodes

Basic factors influencing distribution of sensor nodes that have to be determined at the beginning are:

- area covered by nodes (size, type),
- count of nodes that will be situated in this area,
- density - factor which deals with the number of nodes and the size of selected area (there have to be situated enough nodes but not to many of them because the redundant data could be obtained).

Other factors influencing the distribution of nodes can be divided into two groups – technical and terrain. Terrain factors include demands on characteristics of measured elements (Table 1).

Table. 1: Factors that influence the distribution of nodes.

Number of group	Technical factors	Terrain factors
1	Battery life	Landcover (type)
2	Communication range	Obstacles (visibility, quality of signal)
3	Balanced number of node neighbours	Characteristics of measured elements (recording interval)
4	Back up communication paths	Security
5		Property conditions

4.1.1 Technical Factors

Technical factors influencing spatial distribution of sensor nodes in the area of interest are related to the technical equipment and technical possibilities of sensor nodes.

Battery life is the most important technical parameter. Battery is not used equally in all nodes because some nodes are used more for communication than the others so that their battery is more depleted. It is important to ensure that the battery consumption in all nodes is as equal as possible. There could be a power cut in overloaded nodes and measured data could be lost. Routers are usually more loaded with the communication so that they should be charged up with better type of batteries or equipped by the solar panel. Battery is discharged with the second power of communication distance. The better solution is if the nodes communicate for shorter distances than the longer ones.

Communication distance shows the maximal distance that enables the communication among nodes. Communication distance depends on the used protocol and terrain characteristics.

Every node should have balanced number of neighbours. One sensor node should not be overloaded with communication and the other sensor nodes should not be used only rarely. Balanced communication deals with energy consumption of nodes which are participating in the wireless sensor network.

Back up communication paths in the graph are necessary in the case of the power cut of one sensor node. Data that are sent through this node can not be directed to the gateway so that they can be lost.

4.1.2 Terrain Factors

Terrain factors include the demands on measured elements. The major terrain factors that influence spatial distribution of sensor nodes are composited of landcover, characteristics of measured elements and property conditions.

Landcover shows the different types of the land surface. A lot of types of landcover that influence values of measured elements are situated in the urban environment. Nodes have to cover all types of landcover in the area of interest. Every type of landcover has different characteristics which depend on heat absorption and reflection. It is necessary to involve these facts to obtain comparable data from different types of landcover. All types of landcover have to be covered by at least one node. Another aim of spatial distribution of sensor nodes in the urban environment is to locate nodes to more and less polluted parts of the area of interest (depend on the distance from the source of air pollutants). The comparison of data obtained in the different parts of area with different level of air pollutants is useful for predicting and modelling of different types of pollutants dispersion scenarios.

Terrain obstacle is an object in the communication path which can affect communication among two nodes. Obstacles can be natural or human made. Different kinds of obstacles can influence signal transmission in the various ways. It depends on their structure and angle of arrival of the transmitting wave. It is suggested to avoid any obstacles that are situated between two nodes which are communicating with each other. Demand on direct visibility between two communicating nodes comes from terrain obstacles. Quality of signal depends on the degree of visibility between nodes which communicate with each other. If these nodes are located in the area without obstacles, signal is only slightly influenced by dispersion and noise. Quality of signal can be influenced by another device which transmits in the same range as the sensor nodes.

Every measured element has defined the standardized height above surface, degree of shading and time of recording of measurement. Interval of recording is a parameter which points out the time step of data recording and it depends on the measured elements. Basic meteorological elements are recorded in the climatologic determined times. Three basic climatologic terms are defined (7 am, 2 pm, 9 pm). Detailed measurements can be recorded in more detailed climatologic terms. Own intervals for measurement can be determined but they have to be the same for all nodes to obtain comparable data. It is appropriate to select an interval which does not yield redundant data. The interval does not have to be too large because some differences in values of selected elements can appear in short time periods.

Security is a demand which is very complicated to fulfil. It is necessary to situate nodes into "safe" area to protect them against vandals. It can be used some tricks which can increase the probability that the nodes will not be stolen. These arrangements can involve the placement of nodes in:

- higher positions
- less visible places
- places with low human movement
- hardly accessible places
- fenced places

Property conditions are important factor if the nodes are situated in the private properties because the owner has to agree with their placement on his property.

5 STATE OF ART

A lot of studies deal with the application of graph theory in wireless sensor networks because the communication among nodes can be easily described by this theory. Wireless sensor nodes are represented by nodes in the graph and communication paths are depicted with edges. The aim of lower number of studies is to search the most suitable localization for wireless sensor nodes. These studies do not involve terrain characteristics and parameters of measured elements in the proposed algorithms. The obstacles which influence signal transmitting are included only in the elementary basis because graph theory does not primarily count with the usage of nodes in the external conditions. The most frequently solved factors which influence distribution of wireless sensor nodes are battery life and communication distance.

Mizera (2011) dealt with the proposition of wireless sensor network which was applied to the monitoring of potential forest fires in the selected area which was situated in the eastern part of the Czech Republic. Mesh topology was used for this kind of monitoring. This type of topology allows to use more communication paths among nodes. The nodes were situated in squares. The distance between two neighbour nodes was 200 meters. Terrain obstacles were only mentioned and they were not involved in the calculation but they could be expressed as weights in the graph. Sarioz (2012) aimed his dissertation thesis at data transmitting in wireless sensor networks. The communication among nodes was described by graph theory. His attention was concentrated on obstacles and their distribution in the communication paths. He tested which deployment of obstacles influences more the transmitting wave and which modifies the wave only subtly. Kawagashi (2005) presented a model which uses percolation, a kind of random graph where the edges are formed and the communication is performed only among the nearest nodes. He has commented that the jump effect of the phase transition appears sharply by synergistic effect with radio wave attenuation as the distance between the transmitter and the receiver increases. The distance between the nodes should be in effective range. Yan (2008) has dealt with multilevel clustering as a mechanism for prolonging the lifetime of wireless sensor network node. Root tree with the performances of the minimal relay set and the maximal weight according to graph theory was declared. Energy-aware multilevel algorithm was proposed. This algorithm is able to reduce the number of relays used for data transmission and it enables to load energy evenly among all sensors in the network. Jorio (2013) proposed a new algorithm which concentrates on the energy issue in the wireless sensor nodes. K-Way Special Clustering Algorithm in wireless sensor network was proposed. This algorithm is based on spectral classification. The aim of this algorithm is to find the ideal distribution of wireless sensor nodes and their cluster heads in the area of interests. Classification method determines similar nodes before identifying cluster heads. Residual energy is taken into account when the cluster head is scouted out. Nodes and communication links are represented by the graph theory. Results show that this method ensures lower energy consumption in nodes. Ding (2008) aimed the attention at limited energy source in wireless sensor nodes. He proposed a new two dimensional model with percolations using random graph which connects only neighbour nodes. Connectivity and energy consumption was investigated. The energy consumption was analyzed by Markov process and all the results were investigated in the simulation process. The energy consumption in nodes is solved in the other studies like the one from Lu (2005). This study deals with the question of providing periodic energy-efficient radio sleep cycles while minimize the end to end communication delays. He aimed his attention at communication latency because every sensor node has a duty to be awake for given time slots and data do not have to be obtained in this given time. He formulated a graph theoretical abstraction of the problem. The data transmitting which is displayed with graph theory is described in the study from Baranidharan (2012). This study deals with a design of energy efficient protocol for clustered wireless sensor networks. First of all the cluster head is selected. Data are collected in all clusters and they are sent to the head of their cluster. The algorithm which is based on the graph theory is proposed. The shortest path from the selected node to the cluster head is searched. Silva (2009) proposed a model that protects against the overflow of communication channel. This overflow can cause the lost of transmitted packets. Two types of congestion can appear in the wireless sensor networks – node level (caused by buffer overflow) or link level (caused by sharing wireless channels). Link overflows are studied in this paper. The measurement of congestion is the inverse value of the greatest eigenvalue of the adjacency matrix in the random graph. This measure gives an approximation of the average quantity of wireless links of a certain length in the network. The congestion number is linked to the number of connected paths of given length. Haghpanahi (2012) solved the problem of connectivity in large scale wireless sensor networks. The desired path of traffic flow is displayed with the flow vector. The known count of flows from one node leads to the known number of edges which originate in every sensor node. The existence of enough paths connecting the source and the destination node is guaranteed. The density of wireless sensor network is known. Kar (2008) aimed his work at design of wireless sensor network topology. This paper studies the problem of designing the topology assigning the probabilities of communication among nodes to maximalize the rate of convergence of average consensus. The failtures that can appear in wireless communication among nodes are taken into account. The network is modelled as a Bernoulli random topology. It is shown that the topology design with random link failtures, link communications costs and communication constraint is a convex optimization problem that can be solved by semidefinite programming techniques.

The articles about distribution algorithms, implementation of graphs in the wireless sensor networks or application of wireless sensor networks can be found. Only a few studies implement distribution algorithms to the distribution process. The sensor nodes are in the most cases distributed randomly in the selected area. Nobody tried to include terrain characteristics in the distribution process.

6 METHODOLOGY

The suggested methodology for the distribution of wireless sensor nodes in the area of interest is graph theory because the wireless sensor network communication can be easily described by graph. Nodes of wireless sensor network are represented by nodes in graph and communication paths are depicted with edges.

6.1 Graph Theory in Wireless Sensor Networks

Graph theory is very commonly used in wireless sensor networks for solving problems with communication paths among nodes. The usage of graph theory in wireless sensor networks can decrease energy consumption and increase the effectiveness of the system. Following graphs are considered to be localized structures for topology construction and they are used in wireless sensor networks:

- Unit Disk Graph,
- Minimum Spanning Tree, Localized Spanning Tree
- Gabriel Graph,
- Yao Graph,
- Relative Neighbourhood Graph,
- Delaunay Triangulation (this triangulation is a basis for Thiesson Polygons) (Stojmenović, 2005).

6.1.1 Unit Disk Graph

The wireless sensor network is consisted of known number of sensors and known communication distance which is the same for all nodes. It is possible to determine the broadcast area for all the nodes and to determine the nodes which communicate with each other. If the position of nodes is unknown it is necessary to select possible localities of their occurrence. Nodes which communicate with each other are neighbours (Stojmenović, 2005). This graph enables to suppress the communication range and reduce the energy consumption. If the position of nodes is known it is necessary to choose the unit which will be the same for all nodes. This unit is either communication range or average count of nodes for one node. Figure 1 shows the spatial distribution of nodes in the Unit Disk Graph without the basemap and with the basemap which gives the spatial base to the sensor nodes distribution. The unit is the communication range.

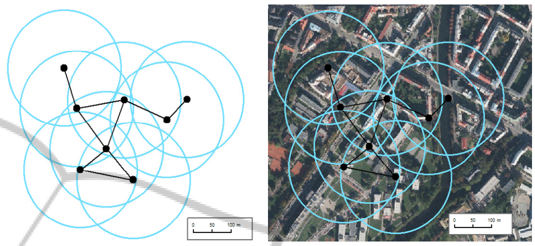

Figure 1: Unit graph for 8 nodes.

This type of graph can be used only with limits in the distribution process of sensor nodes in the urban environment. The highest attention is paid to the communication range. This graph solves from the above mentioned factors all technical ones. Terrain factors can be expressed indirectly by using weight values but the weights can be primarily used only for one factor and not for all of them. The average weight for all factors could be determined. The property conditions, type of landcover and security can be easily expressed manually.

6.1.2 Minimum Spanning Tree and Localized Tree

Minimum spanning tree is a subgraph of Unit Disk Graph which is continuous, contains all nodes and the sum of all lengths in graph is minimal. This graph is edge-weight depend (Stojmenović, 2005). Minimum spanning tree can be localized – it means that every node collects positions of its single-hop neighbours.

This type of graph can be used for observing the length of edges and their weight evaluations which determine edge preferences. Obstacles can be displayed by edge preferences. This type of graph can not primarily include types of landcover, security and property conditions. The localized type of this graph is more appropriate for analyzes of spatial distribution because the positions of nodes in the graph are known as well as the count of node neighbours.

6.1.3 Gabriel Graph

Edge *e* is in the Gabriel Graph if and only if the circle with edge *e* as the diameter contains no other node inside it. The Gabriel graph partitions the graph into faces that are bound by polygons and make up the edges of the graph (Matula, 2010, Stojmenović, 2003).

The fulfilment (green, smaller one) and non-fulfilment (red, bigger one) of the Gabriel condition is shown on the left side of Figure 2. The example of distribution of nodes which fulfils the Gabriel condition is shown on the right side of Figure 2.

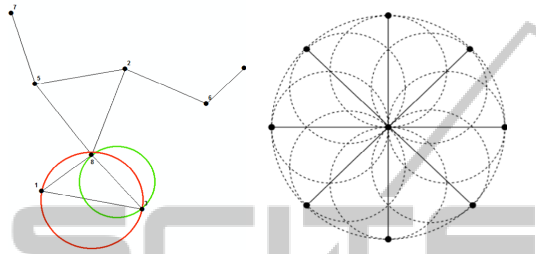

Figure 2: Communication possibilities in Gabriel Graph.

This type of graph is used for detection of distances where the nodes will be situated. No third node can be situated between them and disturb their communication. This communication is carried out among neighbours so that the communication range is as short as possible. All above-mentioned technical factors can be described by this type of graph. Terrain factors like obstacles can be expressed by weight values but the Gabriel condition has to be fulfilled. Different types of landcover, property conditions and security can be situated in the communication range but these factors are not directly expressed in this type of graph.

6.1.4 Yao Graph

The basic thought of Yao graph is the segmentation of the space into the sectors which have the same angle size. Every node communicates with the nearest node in every sector (Scheideler, 2004). Figure 3 shows the communication among nodes in quadrates.

This graph is used in oriented applications such as in the case when the azimuths are known. All technical factors can be solved in this type of graph. Communication range is determined by the distance of nodes in the sectors. This distance is not the same for all sectors. Battery life can be increased because the node communicates only with the nearest node in every sector. The number of neighbours of one node is influenced by the number of quadrants. Terrain factors like obstacles could be described by weights but in some cases the basic principal of this type of graph could be broken. Factors like security, property conditions and landcover can not be involved in the calculations in this type of graph.

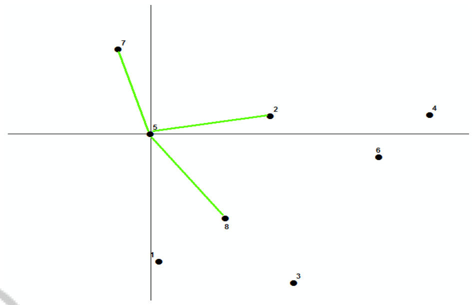

Figure 3: Communication in Yao Graph.

6.1.5 Relative Neighbourhood Graph

Edge is involved in the graph only in case that it is not the longest edge in the *uvw* triangle. If the suture of two nodes is situated in the middle of two nodes, then no other node must be situated in the intersection of circles (Stojmenović, 2005). Graph which can be called Relative Neighbourhood Graph is shown in Figure 4. It fulfils the demand on the nearest nodes connection in all its nodes.

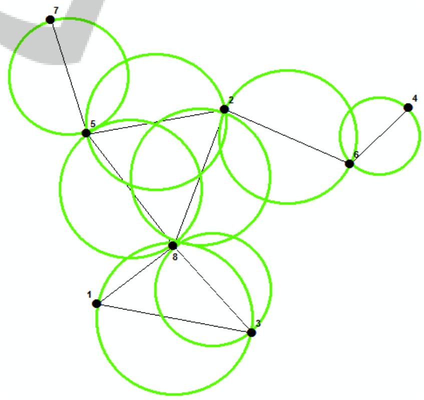

Figure 4: Relative Neighbourhood Graph for 8 nodes.

This type of graph deals with the problem of communication distance - the nearest node is scouted out. All technical factors can be complied in this type of graph. It will be complicated to include terrain factors to this graph because assigning weights to edges could lead to the contravention of the rules.

6.1.6 Delaunay Triangulation

Delaunay Triangulation is commonly used method for the representation of surface characteristics. The aim of this method is to create triangles which are as equilateral as possible. The circumscribing circle to every triangle must not contain any other node except for the vertices of the triangle (Stojmenović, 2005). Figure 5 shows the communication among 5 selected nodes. This communication is displayed in orange colour. All requirements for Delaunay Triangulation are fulfilled in this case.

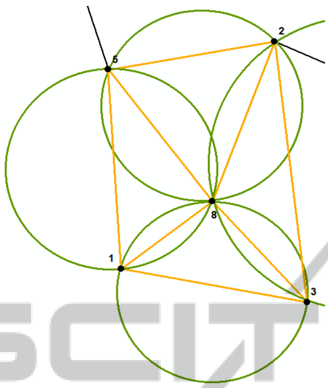

Figure 5: Delaunay Triangulation for 8 nodes.

Delaunay Triangulation can be used for distribution of sensor nodes in wireless sensor networks but in the case of its usage it is important to take into account that the energy consumption is higher because the communication has to be performed in triangles so that every node communicates with at least three other nodes. All technical factors can be expressed with this method. Terrain factors may be marginally included in the calculation.

Delaunay Triangulation is connected to the Thiesson Polygons Method. This method determines the catchment area of the node. Figure 6 shows the catchment area of every node in the wireless sensor network.

7 EXPECTED OUTCOME

The expected outcome of this paper is only one objective of dissertation thesis which is aimed at the distribution and following monitoring of air pollution in the city of Olomouc.

The outcome of this particular objective is aimed at the suggestion of technical and terrain factors that influence the distribution of sensor nodes in the urban environment. The selection of the most suitable graph for including terrain characteristics in the distribution process is necessary. These characteristics should be added to the existing methods and suggest one compact method or algorithm that will have universal usage for distribution of sensor nodes in the urban environment.

8 CONCLUSIONS

Factors that influence the spatial distribution of wireless sensor nodes in the urban environment were suggested in this paper. These factors were divided into two groups – technical and terrain. Terrain factors included parameters of measured elements. Graphs are usually used as a basis of distribution algorithms. Seven types of graphs are commonly used in the wireless sensor networks. The technical factors are included in the majority of graphs but the terrain factors have to be implemented to them. It is not possible to implement terrain factors in all types of graphs because of the basic rule for graph construction would be broken. The most suitable graph for the implementing of terrain factors was analyzed as the Unit Disk Graph.

The future work is aimed at the usage of the selected graph in the practical part of work. Firstly, the way how to implement the terrain factors to the selected graph will be practically certified. The suggested method will be verified in the real task which deals with the distribution of sensor nodes for monitoring of air pollutants in the urban environment.

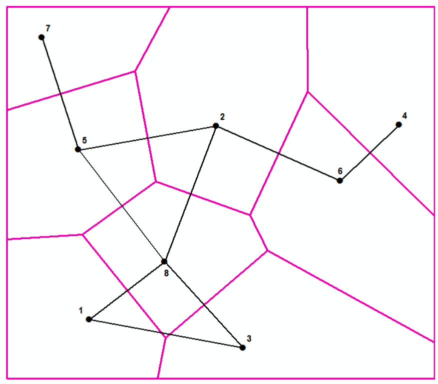

Figure 6: Catchment area of 8 nodes.

9 DISCUSSION

There are a lot of factors that influence the distribution of sensor nodes. The major factors that influence the distribution sensor nodes depend on the technical and software equipment of sensor nodes. This paper suggests technical and terrain factors that should be included in the distribution of sensor nodes in the urban environment. Are these factors enough for the effective distribution of sensor nodes in the urban environment or are there other significant influences? Some factors can be more important than the others in the different types of application. Should the suggested factors be evaluated by weights? The graph theory is a way how to express the communication in the wireless sensor network. Seven types of graphs are usually used in the wireless sensor networks. Would it be possible to use some other type of graph that is not primarily used in the wireless sensor networks or suggest the new one? The graph theory is not the only method that can solve the problem of distribution of wireless sensor nodes in the urban environment. There are other methods like chaos theory that can be used for the distribution of sensor nodes. Would this theory be more appropriate for implementing terrain characteristics in the calculation? The problem of implementing terrain factors into the distribution methods is crucial in the case that the sensor nodes are situated in the urban environment. The solution of this problem would make the distribution of sensor nodes more efficient.

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