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TopoSWiM – Simulation Tool for Topology Design and Accessibility Provision in Large Scale Wireless Mesh Networks

User Guide
V0.1

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1 Introduction

This manual is for users who have some basic knowledge in the field of wireless communication networks and network topology design. Is intended to help getting a better understanding of how the simulation tool works, what it can be used for and what its features are.

For any questions or comments feel free to contact me at maria.porcius@ijs.si or send an email at sensorlab@ijs.si.

1.1 Steps

The main steps you need to make are:
1. Download *TopoSWiM.zip*
2. Unzip the archive keeping the provided **.dll* files in the same folder with *TopoSWiM.exe*
3. Run *TopoSWiM.exe* application

2 Inside the Online Package

The simulation tool and the files it uses can be found at http://sensorlab.ijs.si/software.html. It does not require any previous installation; only download and run *TopoSWiM.exe* file found in the zip file. The tool is designed for Windows operating system; it was developed and used under Windows 7 Professional, and also tested on Windows XP.

The *TopoSWiM.zip* archive contains also few files that are needed by the tool and that have to be in the same folder with the executable file of the application:
- *Microsoft.NodeXL.Control.Wpf.dll*
- *Microsoft.NodeXL.Core.dll*
- *Microsoft.NodeXL.Layouts.dll*
- *Microsoft.NodeXL.Util.dll*
- *Microsoft.NodeXL.Visualization.Wpf.dll*

These files are part of *NodeXL* library used by the tool for visualization purposes. In addition, the archive contains few files that can be used for testing, as input data – it is important to adopt the same format when using your own test files (check the documentation for a more detailed explanation of their expected content):
- *Network.kml* –the GPS coordinates of the nodes
- *LjDEM.txt* – the DEM (including buildings) of Ljubljana
- *LjClutter.txt* –the clutter data for Ljubljana
- *PredefinedPositions.kml* –7 predefined gateways positions for the considered network

3 TopoSWiM menus

Below it is shown how the tool can be used for designing topologies for large scale wireless mesh networks.

When running *TopoSWiM.exe*, a GUI window appears with a menu bar from where the user

can choose different operations to perform. The menu bar contains: *Simulation, Network Settings, Topology Design, Help, About* and *Exit* items.

3.1 *Simulation* **Menu**

From the *Simulation's* drop down menu the user can choose *New, Load Coordinates* and *Suggestions* options, as in Figure 1:
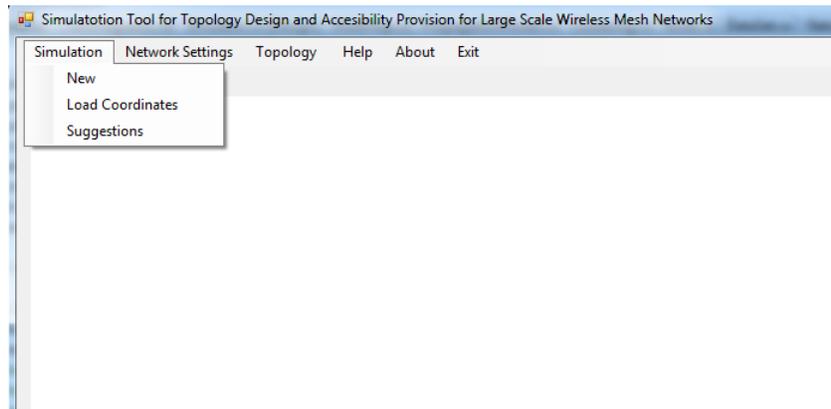

Figure 1:"Simulation" options in the menu

- *New* starts a new simulation, releasing all the resources it used in the previous one.
- *Load Coordinates* allows the user to import the positions of the network nodes into the simulation environment. When choosing this option a dialog box appears on the screen asking the user to select file with the GPS coordinates of the nodes (see *Network.kml*)
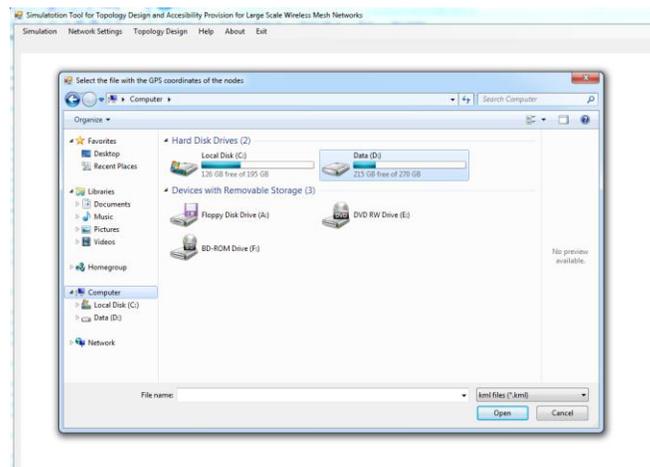

Figure 2: Window for loading file with nodes' GPS coordinates

- *Suggestions* item will give some indications referring to the isolated nodes and the way they can be integrated within the topology design. Suggestions are provided in the form of a message in a new window which tells the minimum number of hops that are needed to reach a gateway and the corresponding gateway (see Figure 9 as an example); there can be also nodes which are qualified as totally isolated. This

approach is supposed to guide the users in deciding about some new settings for the network which could increase the coverage and accessibility of the nodes in case one wants to further optimize the solution.

3.2   *Network Settings* **Menu**

By choosing *Network Settings* from the menu, the user can make customized configurations for the network by assigning different values to the wireless signal distance (or transmission range), number of gateways (when the number of gateways is not specified, its minimum value will be provided through the clustering algorithm), gateways separation, maximum path loss, maximum allowed number of hops or to the gateway selection mode. All these settings cannot be performed if a concrete network (i.e. the coordinates of the nodes) was not previously loaded – if this is the case a message is displayed to the user.

   For each of the first four options of *Network Settings* drop down menu, a new window opens where the user has the possibility to introduce a new value for the corresponding parameter. For instance, when selecting the first option of the menu for setting the wireless signal distance a new window appears, as depicted in Figure 3, where the user can either set the same value for all the nodes in the network – in this case one needs to check "*Set for the whole network*" box and then introduce the value in the *Transmission Range* text box; or set a different value from each node – in this case the *Set for the whole network* box needs to be unchecked and the user needs to choose each node from the *Nodes List* combo box and introduce the value of the transmission range for the corresponding node.
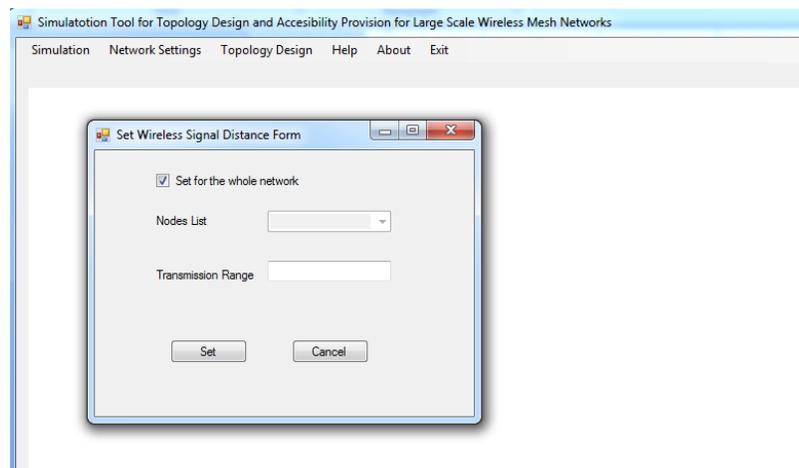

Figure 3: Setting the Wireless Signal Distance

   For the gateway selection mode a popup menu will appear with four available options*: First Found, Last Found, Closest/Minimum Number of Hops* and *Load Balancing* - see Figure 4.
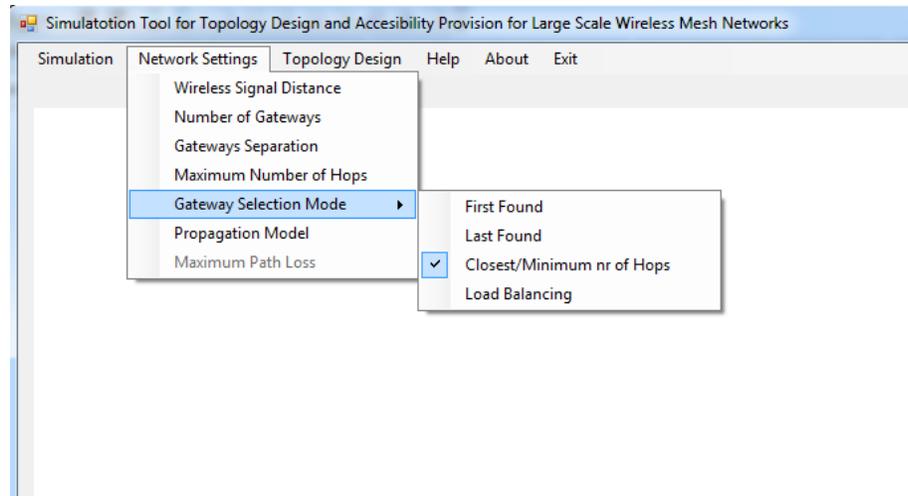
Figure 4:"Network Settings'" options in the menu

The *Propagation Model* is a separate option in the menu, allowing the user to take the decision of including it or not into the simulation. When selecting it, two open file dialog boxes appear, through which the files storing the DEM and clutter data can be loaded (in the zip archive the corresponding files we provided for test are *LjDEM.txt* and *LjClutter.txt*). If these operations succeed, the last option of the *Network Settings* drop down menu, i.e. *Maximum Path Loss* will be also enabled (if Radio Propagation Model is not included this option is not enabled) allowing the user to set the value of maximum allowed signal attenuation. At the moment, the implementation of the radio propagation model is based on the COST231-Walfish-Ikegami model.

If the user does not set these network parameters, their default values are:
- *Transmission Range = 200m (for all nodes)*
- *Number of Gateways = Undefined (minimum will be generated)*
- *Gateway Separation = 1.5*
- *Maximum Number of Hops = 1*
- *Gateway Selection Mode = Closest/Minimum Number of Hops*
- *Maximum Allowed Signal Attenuation = 110dB* (when *Radio Propagation Model* included)

3.3   *Topology Design* **Menu**

The next item in the menu bar of the tool, i.e. *Topology Design*, opens a new drop-down menu with the following options*: SingleHop - Undefined Positions, SingleHop - Fixed Positions, SingleHop - Partially Defined Positions, MultiHop - Undefined Positions, MultiHop - Fixed Positions, MultiHop Partially Defined Positions* and *Export,* as illustrated in Figure *5*.
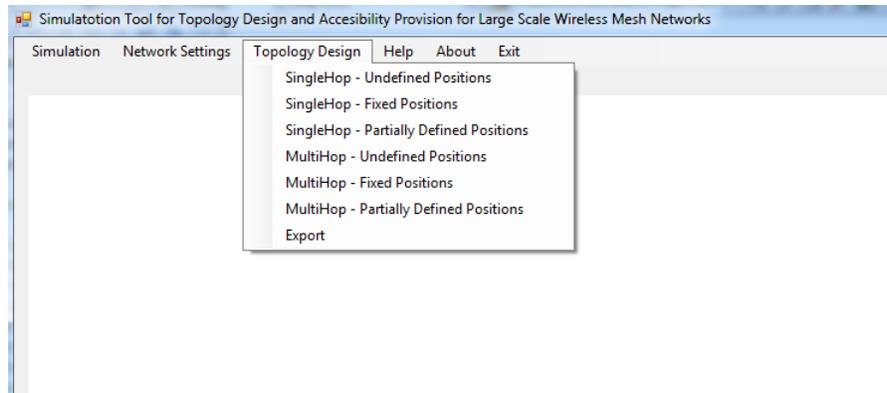
Figure 5: "Topology Design" options in the menu

The first six of them will start a simulation process for the chosen scenario: single or multi hop communication with fixed, undefined or partially defined positions for the gateways. For the fixed and partially defined positions scenarios, the user will be asked to select a file with the corresponding positions before starting a simulation – one example of such a file is *PredefinedPositions.kml* included in *TopoSWiM.zip* archive file. For all the scenarios, if the user did not already load the coordinates of the nodes, he will be asked to do this first. The user does not have to use *Simulation->New* if wants to simulate a new scenario for the same network – just select the scenario and a new simulation will run.

The generated topology design will be displayed in the GUI along with a message announcing the simulation time, the number of isolated nodes from the total number of nodes and the average size of clusters. One example displaying a topology design is given in Figure 6 where each small colored circle represents a network node while bigger black circles are the gateways positioned within the simulation process. The red nodes represent the inaccessible or isolated nodes while the nodes with other colours are the nodes that are attached to a gateway – all the nodes attached to a specific gateway have the same color of their corresponding gateway.
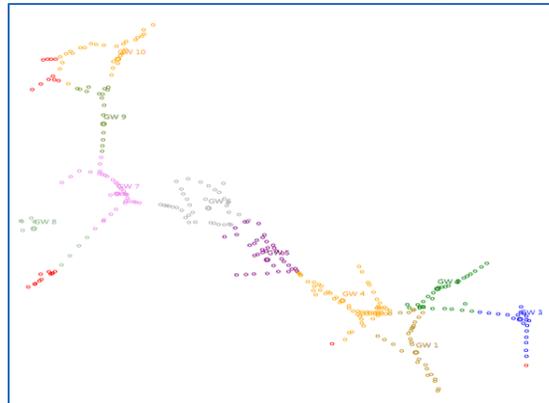

Figure 6: An example of a topology design displayed in the GUI

Finally, *Export* option of the same drop down menu allows saving the generated solution in a *kml* file that can be after that opened inside Google Earth for a different visualization of the clustered topology. The destination file is chosen by the user in a similar way the nodes coordinates are loaded, except that in this case if the file does not exist it is automatically created.

3.4   *Help, About and Exit* **Menu**

Next two items of the menu bar are *Help* and *About.* The first one indicates what you should do in case you have some questions and you need help, while the second one shortly describes the context in which the simulation tool was designed, what problem it solves and how it solves it.

The last option available to the user is *Exit,* which finishes all the running processes and closes the application.

4 Use Cases

In general, for a use case you need to perform the next sequence of steps:
1. Run *TopoSWiM.exe*
2. Choose *Simulation -> Load Coordinates*
3. Either
   a. Use the default network settings or
   b. Make all or some of the next settings
      i.   *Network Settings -> Wireless Signal Distance*
      ii. *Network Settings -> Number of Gateways*
      iii. *Network Settings -> Gateways Separation*
      iv. *Network Settings -> Number of Hops (*for multi-hop based scenarios*)*
      v.   *Network Settings -> Gateway Selection Mode*
      vi. *Network Settings -> Propagation Model*
      vii. *Network Settings -> Maximum Path Loss*
4. Choose scenario to simulate from *Topology Design*
5. Visualize the generated topology design in the GUI window of the tool
6. Analyze the displayed result and ask for *Simulation -> Suggestions* (optional)
7. *Topology Design -> Export* the result (optional)
8. Change network settings and rerun the simulation if the solution needs adapting (optional

In the following, we show several results obtained when using the input files included in *TopoSWiM.zip* and different network settings. These results are also analysed in order to understand the impact of the settings on the topology design.

4.1   **Varying Gateways Separation and Maximum Path Loss**

We consider next the first scenario, i.e. single hop with undefined positions (and undefined number of gateways) and we start from:

- *Number of Gateways = undefined*
- *Maximum Number of Hops = 1*
- *Transmission Range = 200m*
- *Gateway Selection Mode = Closest/Minimum No. of Hops*
- *Radio Propagation Model* included

Since the goal is to provide a solution for topology design and accessibility provision as to reduce the cost of deployment by finding the most appropriate topology (i.e. the minimum number of gateways and their positions) for selected network settings, we consider the number of isolated nodes an appropriate metric to evaluate the performance and analyse the impact of network settings on a solution.

Table 1 shows the average number of isolated nodes which is obtained when varying the maximum allowed signal attenuation and gateways separation. The results of the six simulation runs are also illustrated in Figures 7(a), 7(b), 7(c), 7(d), 7(e) and 7(f). We can deduce from Table 1 that decreasing the threshold for the signal attenuation reduces the number of nodes able to communicate with a gateway (by decreasing the coverage area for the corresponding gateway) and thus increases the number of isolated nodes. Nevertheless, we can control this number and increase the accessibility by decreasing the value for gateway separation which in turn increases the number of required gateways.

Table 1: Average No. of Isolated Nodes for CAPG with Undefined Number of Gateways with Different values for Gateways Separation and Signal Attenuation

|	Signal Attenuation [db]	
Gateway Separation	**110**	**120**
1.2	22 [1]	18 [2]
1.5	25 [3]	23 [4]
2	113 [5]	93 [6]

(1) Figure 7(a)
(2) Figure 7(b)
(3) Figure 7(c)
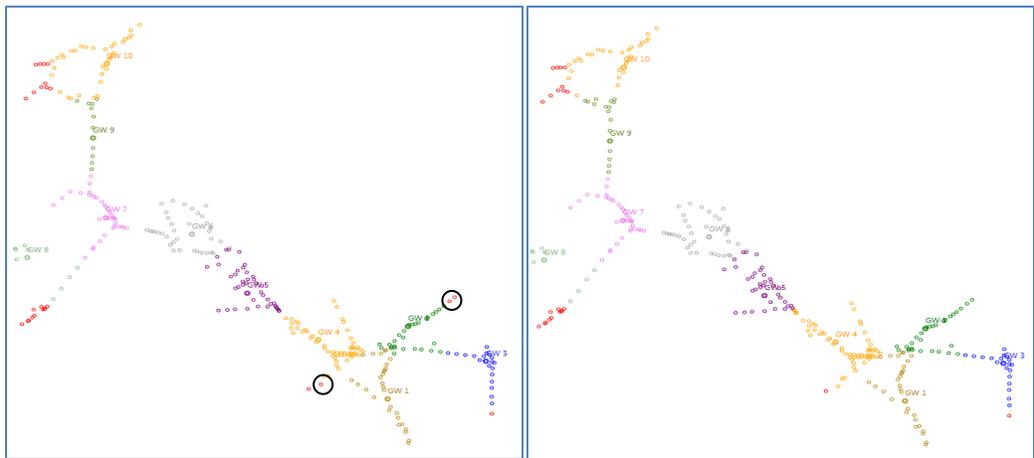(4) Figure 7(d)
(5) Figure 7(e)
(6) Figure 7(f)

Therefore, if we compare Figure 7(a) with 7(b), Figure 7(c) with 7(d) and Figure 7(e) with 7(f) we can see the influence of the maximum allowed signal attenuation. In Figure 7(a), 7(c) and 7(e) the signal attenuation threshold was set to 110dB, while in Figure 7(b), 7 (d) and 7 (f) it was set to 120dB. We observe that by allowing higher signal attenuation more nodes become accessible, i.e. nodes that were isolated before might be able to reach a gateway in this case (few of them are marked with black circles in Figure 7).

Furthermore, by varying the gateways separation we can control the number of gateways and modify the number of isolated nodes. Thus, setting this parameter to 1.2 will generate a solution with 13 gateways and 18 uncovered nodes (Figure 7(b)). Adding another gateway would break the algorithm constraints and even though more nodes would become accessible, interference would be more probable to occur and costs would be increased. If we increase this value to 1.5 only 10 gateways will be positioned within the network and 23 nodes will remain isolated (Figure 7(d)). Moreover, if we set the value to 2, even less gateways (i.e. 7) will be allowed within the network and the number of isolated nodes will increase to 93 (Figure 7(f)). Nevertheless, the value used for gateways separation is a design choice; it depends on the network goals and network parameters the designer wants to optimize.
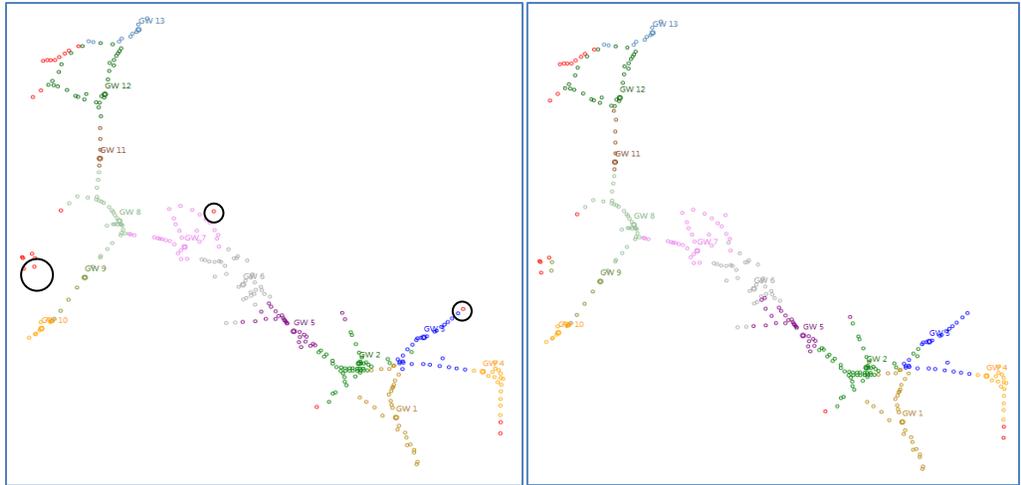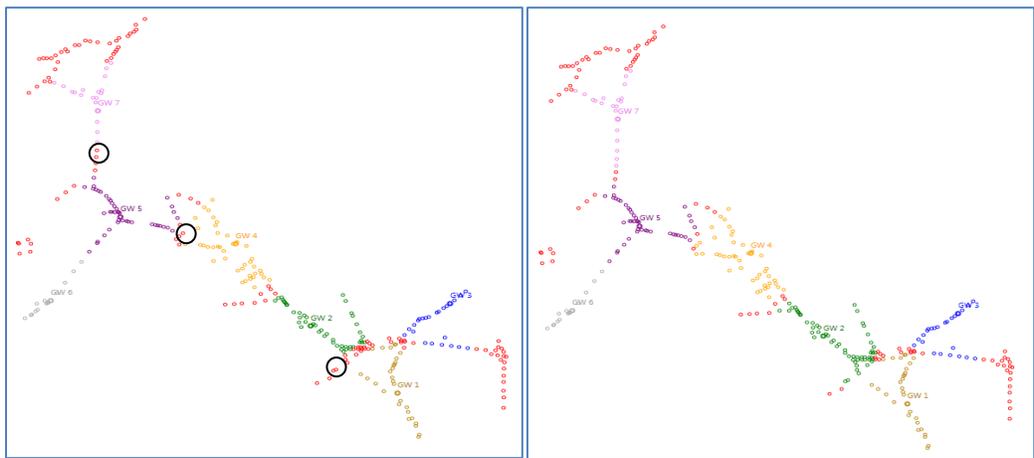
Separation=1.2; Attenuation=110dB   *(b) Separation=1.2; Attenuation=120dB*
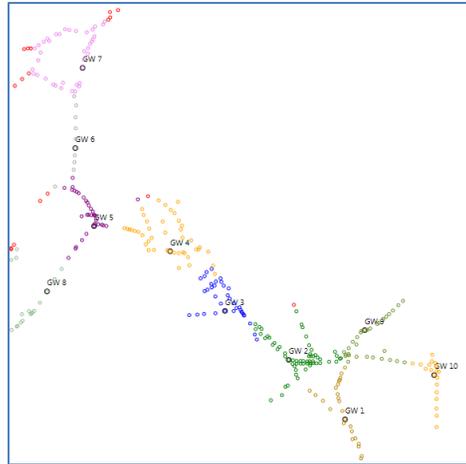
(c) Separation=1.5; Attenuation=110dB   *(d) Separation=1.5; Attenuation=120dB*
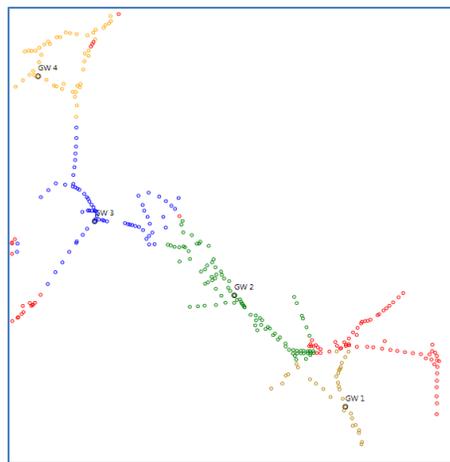
(e) Separation=2; Attenuation=110dB   *(f) Separation=2; Attenuation=120dB*
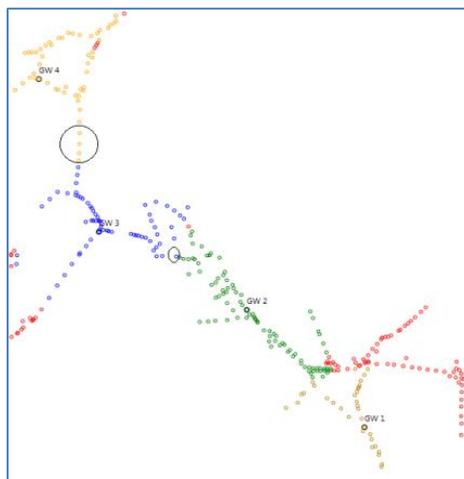
Figure 7: Results for Single Hop with Undefined No. of Gateways and Undefined Positions

No. of Hops=1; Gateway Selection Mode=Closest/Minimum No. of Hops

No. of Hops=2; Gateway Selection Mode=Closest/Minimum No. of Hops

No. of Hops=2; Gateway Selection Mode=Load Balancing

Figure 8: Undefined No. of Gateways and Undefined Positions Scenario

4.2   Varying Number of Hops and Gateway Selection Mode

Installation and further maintenance costs can be reduced using a smaller number of gateways and this can be achieved also by increasing the maximum number of allowed hops. If we allow 2 hops within our test network, the design in Figure 8(a) changes to that in Figure 8(b) where only 4 gateways are needed and the average number of nodes assigned to a gateway increases. When increasing the number of allowed hops it is also possible in some cases that the number of isolated nodes increases due to the algorithm constraints regarding the separation between clusters.

When the gateways separation value is smaller than 2, the areas covered by two gateways are overlapping. Inside the overlapping area the nodes can be attached to more than one gateway. Since for all the above tests we used gateway selection mode set to Closest/Minimum Number of Hops, the closest gateway was chosen. If we want the topology design to evenly distribute the nodes to the gateways, we set Gateway Selection Mode to Load Balancing and we obtain the solution in Figure 8(c). The difference, compared to Figure 8(b) can be observed at the borders of the GW3: few nodes that were previously assigned to GW3 are now belonging to GW2 and one node is now attached to GW4 (all marked with black circles).

The solution can be further improved through the use of suggestions that the simulation tool provides for a topology design. For example, for the isolated nodes in Figure 8(c) we get the suggestions depicted in Figure 9 where some nodes are described as totally isolated, while for the others minimum number of hops is indicated so they can reach one of the already positioned gateways.
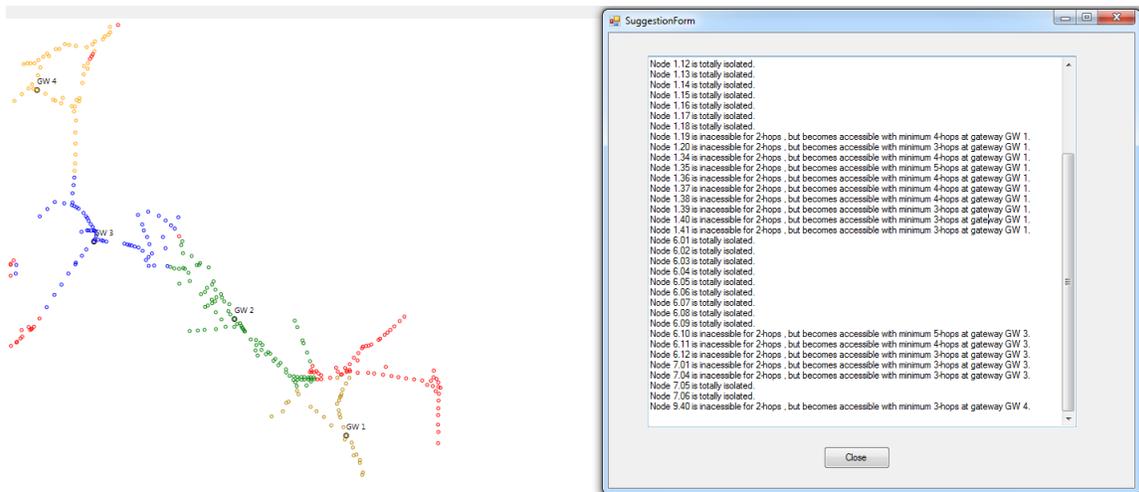

Figure 9: Suggestions for Isolated Nodes; Multi-hop (No. of Hops=2) with Undefined No. of Gateways and Undefined Positions

4.3 Other

Based on the discussions above, it can be deduced the importance of the network related parameters, such as gateway separation, maximum allowed number of hops and maximum allowed signal attenuation, on the topology design. Maximum allowed signal attenuation controls the accessibility of a node to the gateways, while gateways separation and number of hops can be used to control the number of gateways in the solution. The number of generated gateways in turn influences the number of isolated nodes, thus the topology design and accessibility of the network. The number of gateways generated with the clustering algorithm used within the simulation tool can be minimized by increasing the number of hops and/or increasing gateways separation. But, on the other hand, the issue of forcing the minimum distance between gateways and the maximum allowed number of hops is that it is possible that only few gateways are generated and many nodes might remain isolated. Nevertheless, we do not consider this an issue of the clustering algorithm, since the tool allows users to set these parameters, thus it is a design choice. If the designer makes the settings so as to generate only a small number of gateways, one has to be aware that it is possible to have a high number of isolated nodes. The gain in such designs is that it reduces the costs of the network and the level of interferences between transmissions, thus a more reliable communication is provided. But, if the designer's main goal is to increase the accessibility and to have the least number of isolated nodes, even at the cost of possible interferences, he will need to set the above mentioned parameters so as to generate the number of gateways that can fulfil his requirements.