"Mesh Optimizer" is an application that can help with the problem of placing optimally a given set of Radio-Nodes (RNs) in an indoor 2D environment. The term optimal could be subject to different interpretations and definitions and thus, depending on the goals, there can also be different optimization approaches. Yet, in each case, what we are ultimately interested in adjusting, is the signal Radiomap (according to the respected definition).

In this case, the implemented method aims to find the Node-Setup that offers the maximum overall indoor coverage, after simulating various radio-map scenarios based on an enhanced free-space path loss signal model. The degree to which such an optimization can be successful for a 2D indoor environment is the leading research question that drives the development of this software prototype.

Running the Application

The "Mesh Optimizer" application has been designed and developed from scratch using Java 12 and JavaFX 12 and is delivered as an executable for Windows operating systems. To ensure that the application can run on the host machine, the latest Java Engine for windows (OpenJDK12) is also provided. Since Java language highly supports cross-platform software development, this tool is expected to be easily deployable for Linux and Mac environments too after only minor coding adjustments. Nevertheless, all tests have so far been conducted for Windows only. It should also be noted that "Mesh Optimizer" is not officially signed for windows and so, the user will have to accept the corresponding alert suggesting that it is not safe to execute this Application. Lastly, the test dataset "test project.mop" is offered to help users explore quicker the capabilities of the software.

Basic actions

After having launched the application, double left-clicks inside the window result in enabling and disabling the window maximization mode. To resize the window, the bottom-right anchor can also be used by dragging it. Zooming in or out is performed with the scroll button and panning can be done by dragging the mouse while having the left-click pressed. Finally, right clicks are used for selecting and editing features.

Initiating the Application

The first action that users need to do is either create a "New" project or "Open" an existing one using the corresponding buttons at the "Top menu bar".

Figure 1: Top menu bar

When creating a new project, the user is prompt to select an image of a floorplan which will be used as a base-map for the digitization process. Likewise, for opening an existing project, the user needs to select a file with ".mop" extension (same as the provided test dataset).

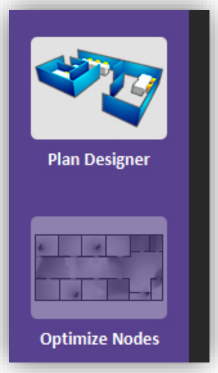

Figure 2: Left menu bar

The workflow is divided into two processing sections; the "Plan Designer" and the "Optimize Nodes" panels. One can navigate between them (when a base-map is available) using the left menu bar.

When a project has been created or opened, the corresponding base-map will become available within the "Plan Designer" panel (as shown in Figure 3) and the user will be able to digitize it using the editing Toolbox that is available on the right.

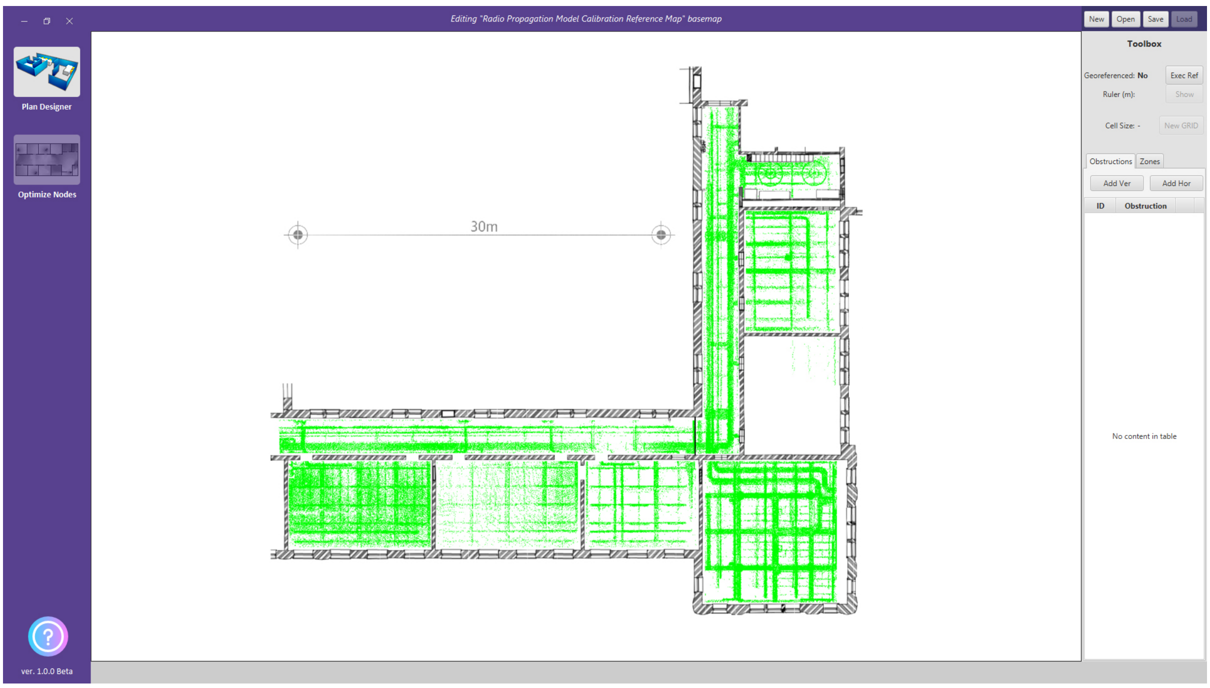

Figure 3: A new base-map being ready for digitization

Using the "Plan Designer" Panel

While searching for the optimal Node-Setup scenario in an indoor environment, Mesh Optimizer considers two things. 1) the **Obstructions** affecting the propagation of the radio signals that are emitted from the nodes and 2) the **Zones** of interest which are the areas (a) where these nodes could be placed and (at the same time) the areas (b) within which the signal has to become optimal. Although Mesh Optimizer at the moment considers those areas to be the same, a future update could distinguish them. That would allow for the possibility of installing nodes at areas within which the radio coverage has no importance. For example, a cellar between two room areas could still be the best place to install a Node for best covering those two rooms (even though coverage within the cellar itself is not needed). Both the Obstructions and the Zones need to be modelled (digitized) using the corresponding tabular sections at the bottom of the Toolbox. At any point, project's current state can be saved using the "Save" button at the "Top menu bar".

Editing an Obstruction

The orientation of the obstructions can either be vertical or horizontal which is sufficient for modelling most indoor environments. Other custom orientations are currently not supported since that introduces significant computational complexity.

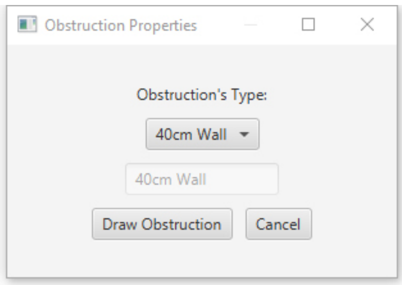

Figure 4: Dialog box for selecting the obstruction's type

After clicking to add a new obstruction, a Dialog box (Figure 4) will appear for the user to select an obstruction's type. Mesh Optimizer offers 3 different types of obstructions depending on their thickness (i.e. 10cm, 40cm and 70cm). The way these obstructions affect the propagation of the signals differs within the integrated simulator.

Every added obstruction will appear in the obstructions list (Figure 5). Selecting an obstruction (to resize or move it) can either be done via this list or by right-clicking directly on the feature itself. To move an obstruction, the user has to drag the mouse while having right-clicked the obstruction itself. Also, after selecting an obstruction, the resizer anchors will appear. These can be dragged using right-click to resize the corresponding obstruction.

Figure 5: Obstructions list

Without doubt, by reducing the 3-dimensional complex reality into a simplistic 2-dimensional indoor model, a lot of information is lost. Yet, while placing obstructions on the base-map, it is recommended that their connectivity is as adjusted as possible (like the right case in Figure 6). Future updates could introduce automatic point snapping.

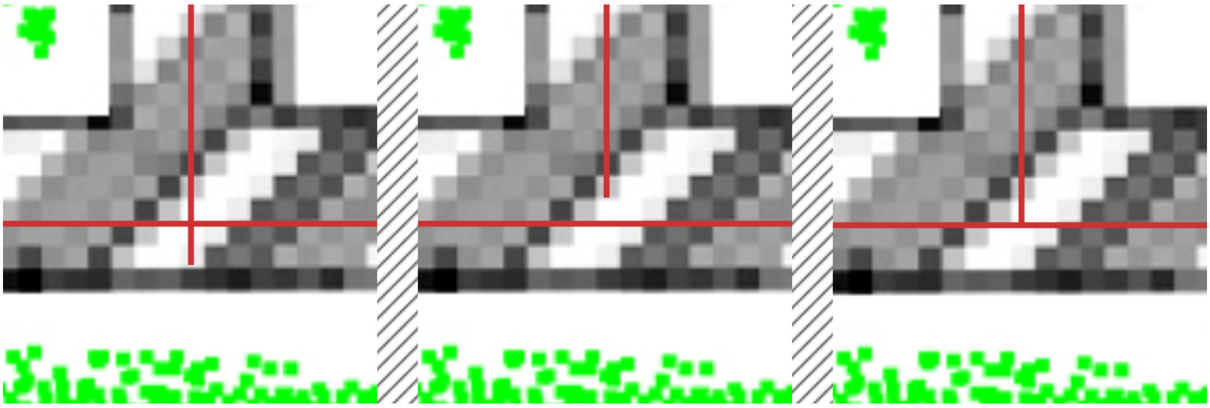

Figure 6: Obstructions connectivity of different qualities

An example of how a completed model of obstructions could be is shown in Figure 7 which is taken from the provided test dataset.

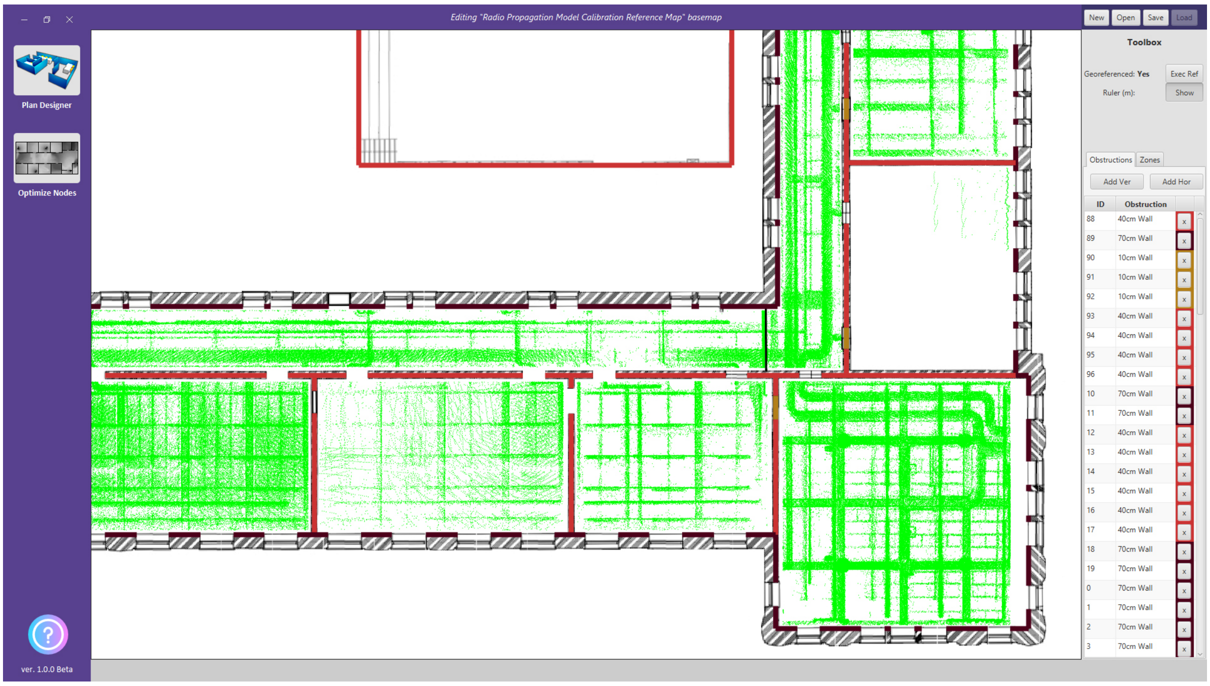

Figure 7: The obstructions of the provided test base-map

Editing a Zone

After modelling the indoor obstructions, the next step is to draw the Zones within which the overall signal coverage needs to be maximized. For that, one can use a similar workflow as in the previous case (obstructions editing). The main difference is that now the user can create and re-use different zone types, having distinct names and colouring. Drawing different zone types enables Mesh Optimizer to also offer additional optimization approaches in the future (e.g. for localization purposes). Zones of the same type need to be continuous, which can be achieved by drawing them having intersections. Contrariwise, zones of different types should not intersect since the simulator will automatically crop them, giving priority to the zone that was drawn first. An example illustrating the aforementioned practice is shown in Figure 8.

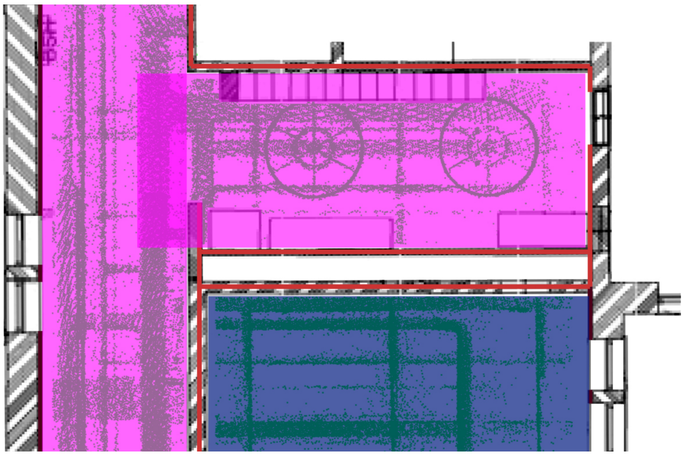

Figure 8: Zones of different and same (purple) types

Georeferencing the Base-Map

The last action of the user is to geo-reference the indoor model. This is required since Mesh Optimizer simulates the radio propagation respecting real-life physics. For that, one can press the execution button on the top of the toolbox. Then, a line will appear in the middle of the base-map and the user will have to resize it according to some ground control points (GCPs) of known distance. Finally, the user needs to enter this distance (in millimeters) within the Georeference toolbox and then press the confirmation button. After having successfully geo-referenced the indoor model, the line can be used as a ruler.

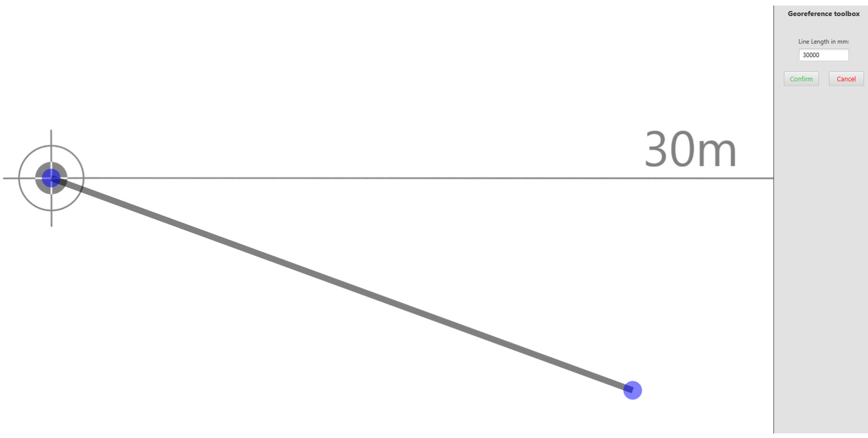

Figure 9: Placing the georeference ruler to a ground control point

Using the "Optimize Nodes" Panel

When the modelling process is ready, the next step is to switch to the "Node Optimize" panel and from there load the model by using the corresponding button.

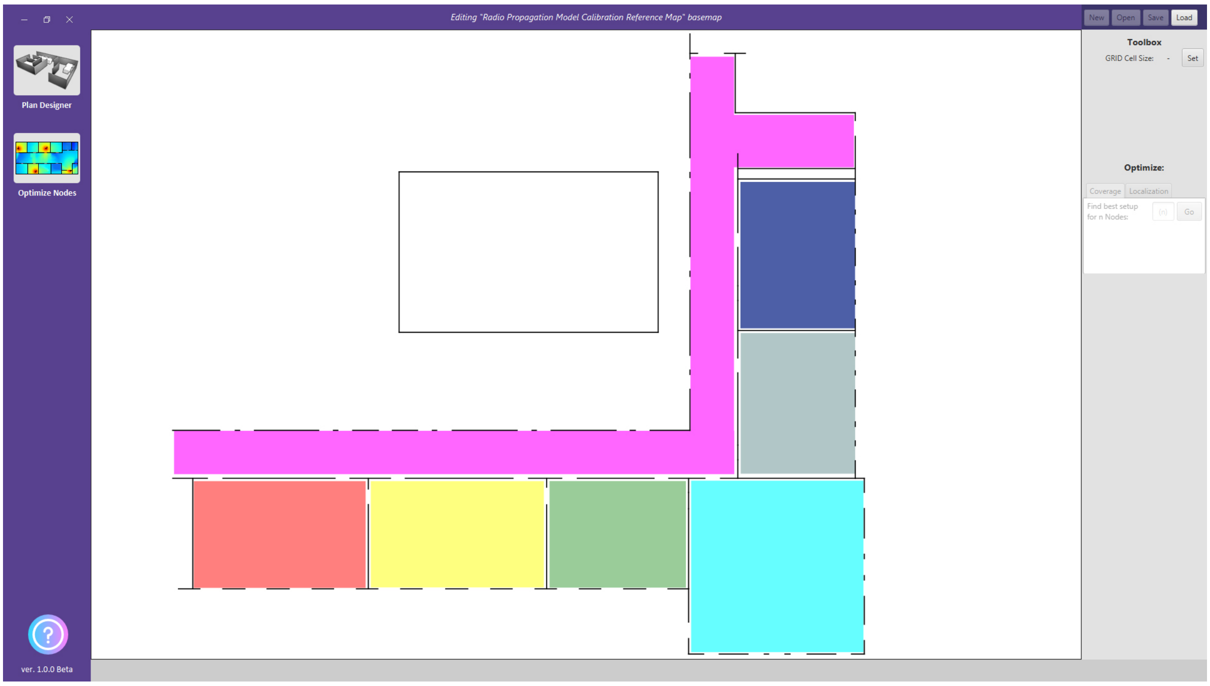

Figure 10: After having loaded the provided test dataset

Here, the user has several configuration options regarding the optimization implementation. These affect the optimization's accuracy (value) and the optimization's speed (cost) in a highly nonlinear way, which means that a small change of a value (e.g. of the Cell size) could lead to a great change of calculation costs. Therefore, some hands-on may be required before the user can intuitively select configurations that can lead to an optimization of good value/cost ratio. After having researched different configuration scenarios, some good practices by example shall be discussed below (using the provided test dataset) for the user to quickly gain some valuable experience.

To gain speed, the optimization is designed to run in parallel and asynchronously and utilize the entire CPU. This might be challenging for processors of previous generations and so, future updates could let the user choose how many threads to initiate. Still, to avoid executing optimizations that may require too much time, a safety mechanism has been implemented that forbids optimizations that are predicted to take to many computations.

There are 3 different values that the user has to configure:

1) the Cell Size of the GRID,

2) the percentage of possible Node positions to be checked, and

3) the Node setup size (i.e. number of Nodes that need to be optimized).

GRID Cell Size
The optimization process requires that the continuous space within the zones is converted into a discrete one with the use of a Grid of cells. For that, one needs to press the "Set" button and select a cell size in centimeters. This will affect the Grid's resolution (i.e. how many cells can fit within the zones). Smaller cell sizes will tend to result in Grids of higher resolution, able to offer more precise (but also slower) optimization outcomes. It is important that the user selects a cell size which can cover as much of the zone areas as possible. For example, in Figure 11, although the cell size of the left case is bigger, it might still be a better choice compared to the right case, since it covers more zone areas.

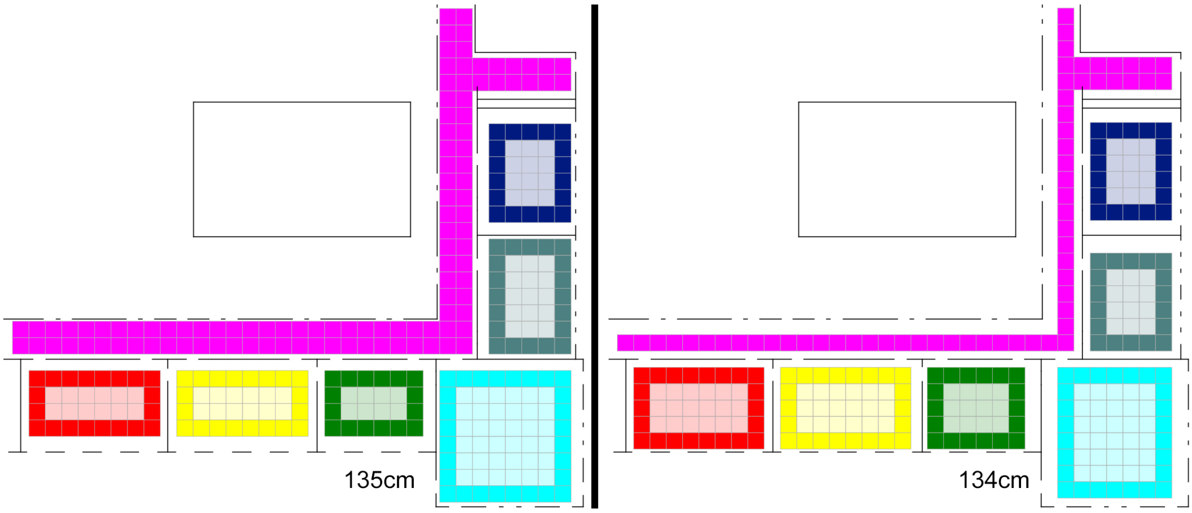

Figure 11: Selecting proper cell sizes

Possible Node positions to be checked
While searching for the optimal deployment, Mesh Optimizer does not evaluate by default all positions in the Grid. This is set by the user via the related button. For example, if the Grid has generated 1000 cells and the user chooses to check 50% of all possible positions, then only 500 cells shall be considered as candidates for nodes placement. After their generation, these positions can be viewed using the "Inspect" button. Here, the user can also inspect the simulated radio coverage from each node, by clicking on it (Figure 12).

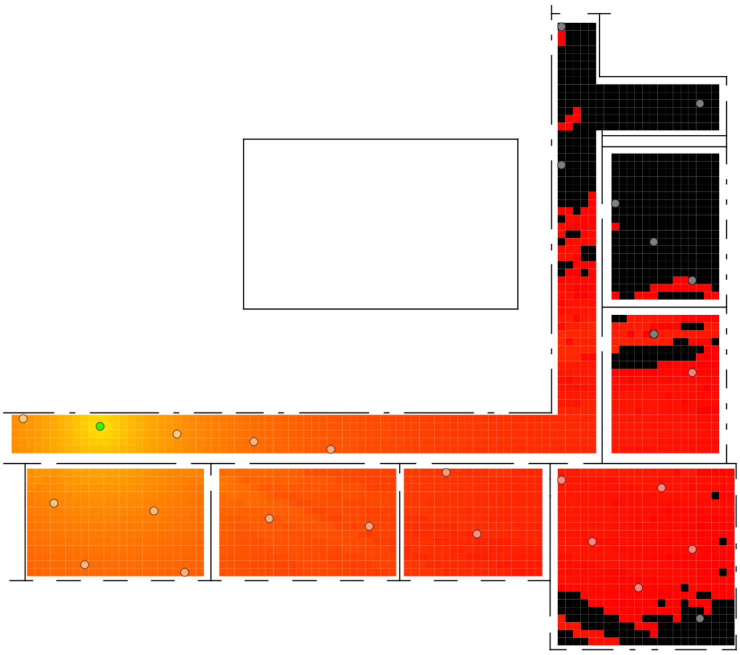

Figure 12: Inspecting the Radio Coverage from a node. (Cell size: 50cm, 1% Candidates)

The way these candidates are selected, is based on simple space division, which (depending on the Grid's shape) may lead to distributions that are not uniform. For that reason, it is highly suggested that the user selects a value that will lead to sparse node distributions (left case in Figure 13).

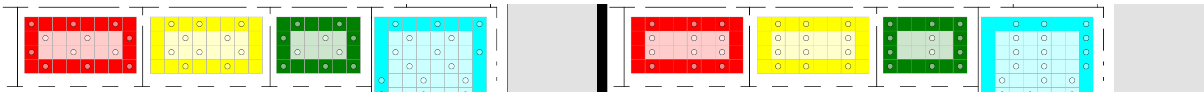

Figure 13: Different distribution scenarios of node candidates

Node setup size

Having generated the candidate positions for the nodes (cn), the next step is to choose our setup size (sz), which is the number of nodes that we would like to optimally deploy. The total number of combinations to evaluate can be calculated by the expression $cn!/sz!\,(cn-sz)!$, which suggests why the computational complexity is highly nonlinear. To find the optimal placement for a single node can be done even with Grids of very high resolution. However, to optimize more nodes, a reduction is required in the parameters of Cell-Size and/or Node-Candidates. A future update of great importance would be to introduce a heuristic approach for the evaluations based on Machine Learning methods (e.g. Genetic Algorithms) which could vastly reduce the search space.

Experimenting with various configuration parameters for the optimization, one might notice that the Grid's resolution does not have so much significant impact to the precision of the optimization. This is illustrated below.

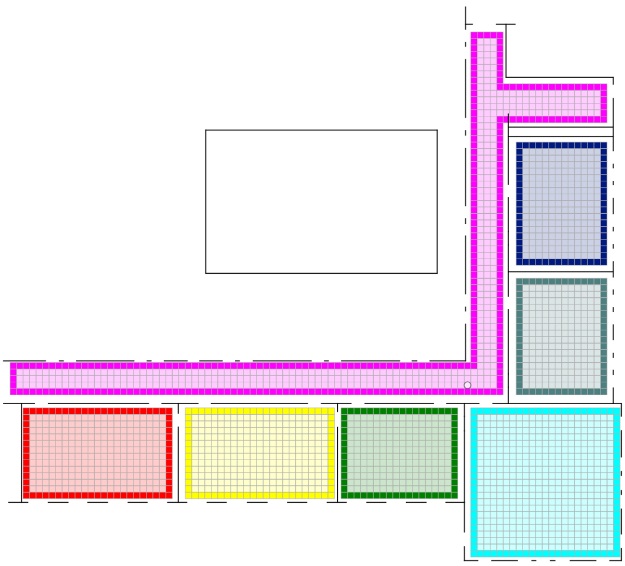

Figure 15: Optimal placement of 1 node
(Cell size: 50cm, 100% Candidates, Calculation time: 30 min)

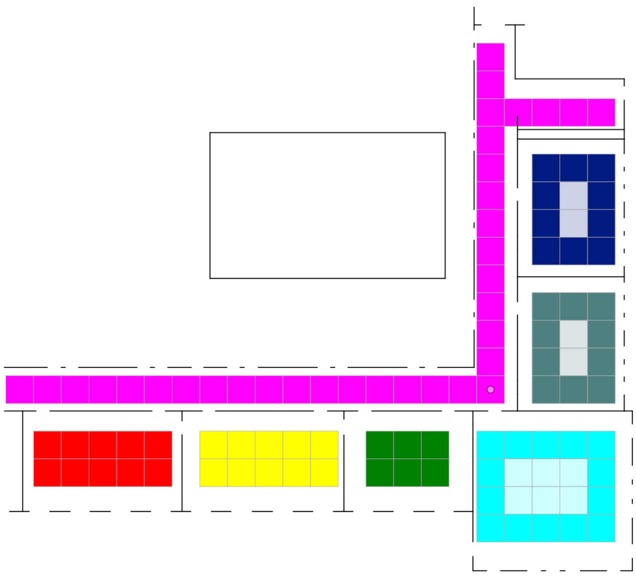

Figure 14: Optimal placement of 1 node
(Cell size: 210cm, 100% Candidates, Calculation time: 1 sec)

On the contrary, using different number of node candidates, may lead to quite different results. Yet, the optimization outcomes seem always to be intuitively correct, with the nodes being evenly dispersed around, away from the edges.

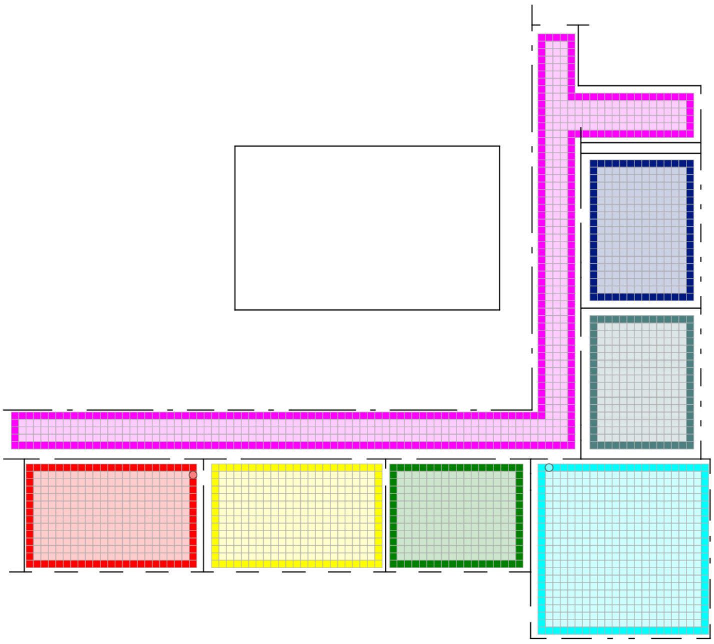

Figure 16: Optimal placement of 2 nodes.

Cell size: 50 cm
100 % Candidates
Calculation time: 1080 sec

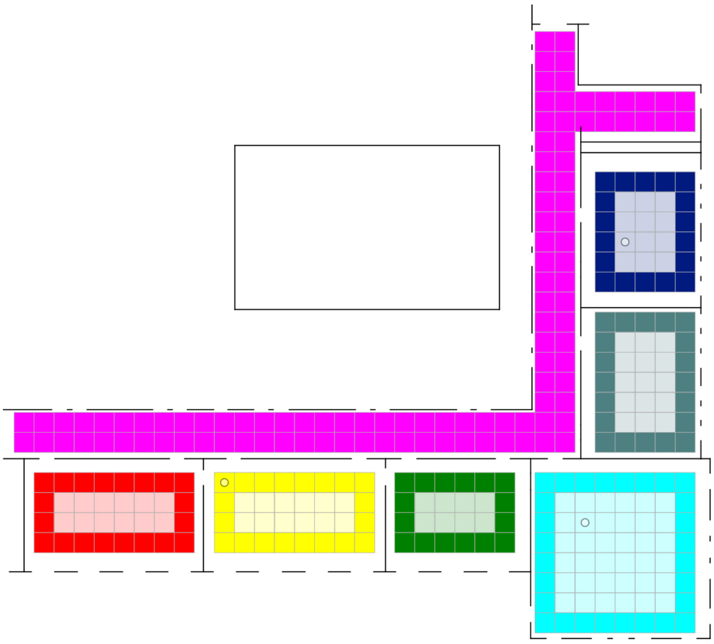

Figure 17: Optimal placement of 3 nodes.

Cell size: 135 cm
100 % Candidates
Time: 210 sec

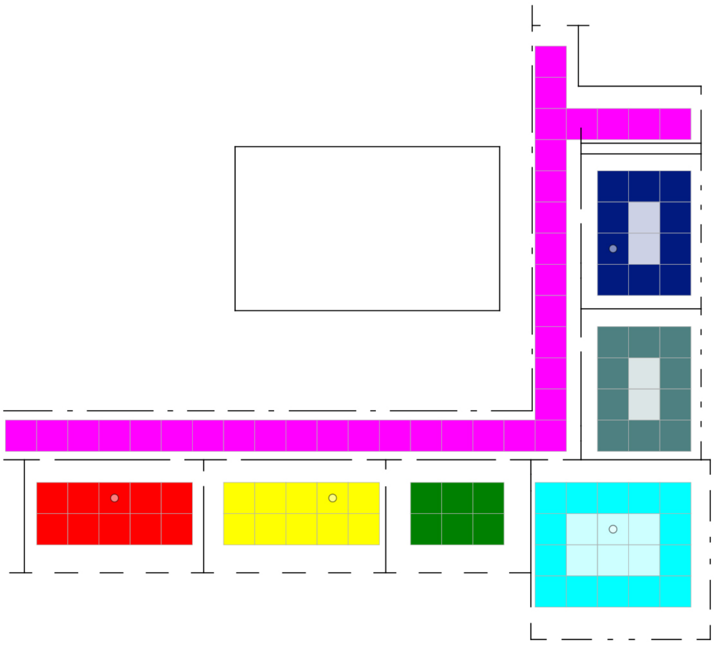

Figure 18: Optimal placement of 4 nodes.

Cell size: 210 cm
100 % Candidates
Time: 140 sec