

An Automated Planning Model for RoF Heterogeneous Wireless Networks

Ahmed Sherif Shawky, Hans Rune Bergheim, Olafur Petur Ragnarsson, Tahir M. Riaz and Jens Myrup Pedersen
Aalborg University, Dept. of Electronic Engineering
Email: {asms, bergheim, olafur, tahir, jens}@es.aau.dk

Abstract—The number of users in wireless WANs increasing like never before, at the same time as the bandwidth demands by users increase. The structure of the third generation Wireless WANs makes it expensive for Wireless ISPs to meet these demands. The FUTON architecture is an RoF heterogeneous wireless network architecture under development, that will be cheaper to deploy and operate. This paper shows a method to plan an implementation of this architecture. The planning is done as automatic as possible, covering radio planning, fiber planning and network dimensioning.

The outcome of the paper is a planning process that uses GIS-data to automate planning for the entire architecture. The automated model uses a collection of scripts that can easily be modified for planning a FUTON architecture anywhere. The scripts are made using functions for the different tasks, in order to make them easy to extend and modify.

I. INTRODUCTION

Towards the goal of deploying more wireless and mobile networks, Wireless Internet Service Providers (WISPs) are facing two main challenges. The first is a continuous increase in the number of wireless network users which leads to a growth in the bandwidth demands. The second is the increased complexity of wireless technologies which results in more complex and expensive equipment for the ISPs. This problem has been addressed by the FUTON project [1] which envisions a hybrid fiber-radio architecture, aiming at reducing the complexity and cost of wireless technology equipment by using simplified and less expensive equipment. The Futon architecture aims to replace expensive Base Stations (BSs) with simplified multi-frequency Remote Antenna Units (RAUs). The wireless signals from the RAUs are forwarded via Radio over Fiber (RoF) to a Central Unit (CU) as shown in Figure ??.

The CU will do a joint processing of the radio signals and Internet Protocol (IP) packets correctly. This architecture can also make use of legacy systems such as 3G, WiMAX and WiFi, and it enables the use of MIMO technology to enhance these systems as shown in Figure ?. The architecture aims to be cheap to both develop and operate, while allowing 4G services and always-on-access. The FUTON architecture requires radio planning to find the optimal locations of the RAUs and CUs as well as fiber planning to connect the RAUs and CUs which makes the planning task quite challenging and vast.

In this paper we solve this problem with a novel approach for integrated and automated planning of the different wired

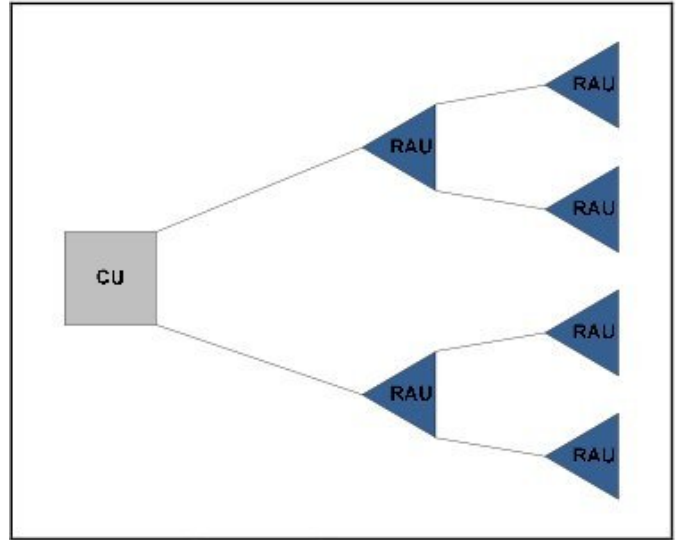


Fig. 1. CU to RAU connection

and wireless networks. It will demonstrate an automated planning method for essential aspects of planning and design of RoF wireless network. The feasibility of the method is shown by providing a case study: a network is designed which would cover the Danish municipality of Aalborg. The paper however does not target a fully optimal planning solution but rather solve problems by heuristic algorithms.

The remainder of the paper is organized as follows. Section II gives an overview of the proposed planning model, followed by a more detailed explanation of the different phases in Section III. In section IV we explain the case study and the results hereof. In Section V we provide the conclusion and suggestions for further work.

II. THE PLANNING MODEL

The planning tasks can be divided into a number of steps as follows, where the output of one step is being used as an input for the next. The overall input to the model is Geographical Information Systems (GIS) data of the area together with a number of potential RAUs and the final output is a fully planned and dimensioned network. The planning task is divided into the following steps:

- Radio planning
- CU placement

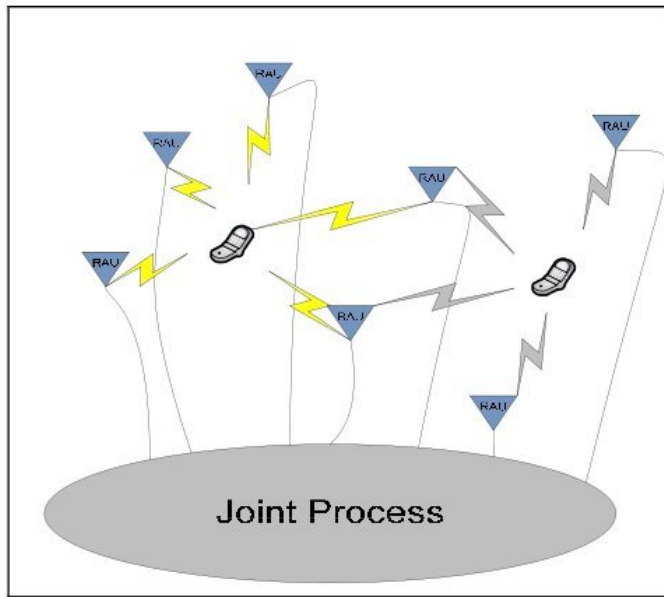


Fig. 2. CU joint processing and MIMO

- Fiber planning
- Traffic estimation and capacity dimensioning

A. Radio Planning

The first step of planning a deployment of the FUTON architecture is planning the coverage of the wireless networks that will provide a service to the end users. For this project, the problem was simplified by not considering real life factors such as backbone-connectivity, accessibility, power-supply, physical firewalls and security and lease conditions, due to lack of available data about these. Three types of networks were planned and used for implementation of the FUTON architecture: 3G, WiMAX and LTE-Advanced.

In Radio planning, the number of potential users and their location were estimated from GIS-data, by distributing potential wireless users around existing Network Terminations (NTs). Possible locations for the RAUs were assumed to be distributed around the municipality, and associated with a cost. The objective was to select a solution with the lowest cost, but still providing indoor coverage to 97% of the users. The coverage area of each RAU-location was found by calculating the range of wireless cells from sample radio budgets and a propagation model. The minimum number of RAUs needed was calculated using greedy and genetic algorithms for a modified set-cover-problem. The algorithm starts by selecting the BS that provides the best coverage at the lowest cost (users/cost). It then removes the MTs covered by this BS from the list of MTs that needs to be covered. When the coverage is larger than the coverage constraint, the algorithm terminates. The flow of the algorithm is illustrated in Figure ???. To find what MTs are covered by an RAU, coverage sets was made for all RAUs. The coverage sets simply contains the identification numbers of the MTs in range. When planning radio networks,

small cells are preferred. To achieve this, the cost function has to prioritize small cells. The urban BS covers 32% of the area of a suburban BS, and 10.5% of the area of a rural BS. If the cost of an urban BS is set to 10, it means that in order to prioritize smaller BSs, the suburban must cost more than 3.125 times as much, and the rural more than 9.5 times as much. Because of this, the costs are set to 10 for an urban, 32 for a suburban and 96 for a rural BS. These costs can be changed to the planners liking, depending on what cell size is wanted.

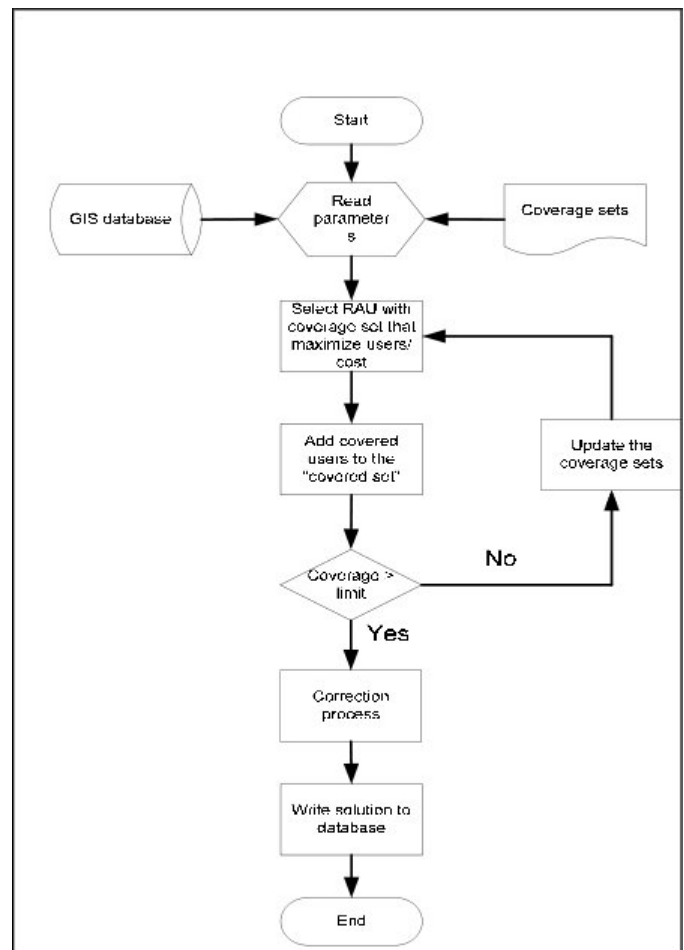


Fig. 3. The greedy algorithm for solving the set-cover problem

B. CU-Placement

It was also necessary to plan the best locations for the CUs, that will handle radio signal processing. For this project it was assumed that CUs could be placed at the RAU-locations if needed. The objectives here were to have multiple CUs, for redundancy and availability. It was also an objective to have an evenly distributed number of RAUs per CU, in order to achieve an even traffic load in the network. The maximum distance from CUs to the RAUs is limited by the RoF-technology. This way it could be formulated as a set-cover-problem solvable by the genetic and greedy algorithms. After the CUs have been

placed, each RAU is then assigned to the closest CU using a path-finding algorithm to find best path from CU to RAU using the segment information in the GIS-database. In order to make the path-finding as fast as possible, it was necessary to reduce the complexity of the available GIS-data by removing redundant information. The GIS database contains information on segments (small pieces of road), and segment points, which are the points where the segments interconnect. The segment database contains many segment points that have a degree of 2. All these segment points are there to make the GIS-data geographically correct, but for the purpose of network planning, it is redundant information. These points can therefore be removed without loss of information. The SPs with degree 2 is removed, and the new segment has a length equal to the sum of the replaced segments. This procedure is illustrated in Figure ??.

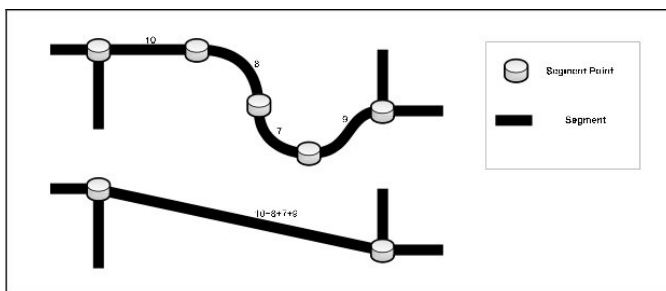


Fig. 4. Segment table reduction

The shortest path algorithm used to join the CU to RAU is the A* algorithm. The A* search uses two cost functions in order to find the shortest path: cost of getting to current location, and estimated cost of getting from current location to the goal. In this project, the cost of getting to the location is the length of the segments travelled, and the estimated cost to goal is the Euclidian distance [3].

C. Fiber Planning

Fiber Planning was done to connect the RAUs to CUs, and also to interconnect CUs. The objective was to minimize fiber and trench length needed for this, since digging trenches and laying fiber are the most expensive parts of network deployment. The segment information in the GIS-data was utilized for deciding the placement of fibers and trenches. Both Dijkstra [2] and the A*-algorithm [3] was implemented for pathfinding.

The solutions for connecting the RAUs to the CUs with shortest trench length was found by implementing algorithms for spanning trees, and a genetic algorithm minimized the fiber length needed for that solution. The algorithm can be seen in Figure ??.

The CUs were interconnected in a ring-topology, which enabled simplifying the problem of interconnection to a traveling salesman problem [2], and solved by a genetic algorithm. The flow of the algorithm is shown in Figure ??.

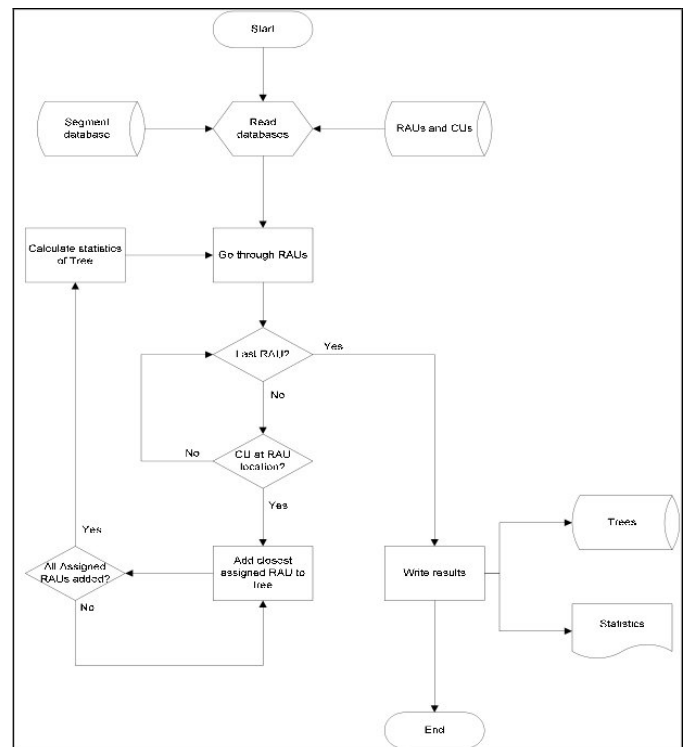


Fig. 5. Flow of algorithm for planning CU-RAU trees

D. Traffic Estimation and Capacity Dimensioning

Traffic estimation is important for anticipating the traffic in both the wireless and fiber-parts of the network. As network traffic, and especially traffic in wireless networks is increasing at high speed, it is important to take future usage into account, in order for the network not to become obsolete shortly after deployment.

Traffic estimation was done by researching application usage and bandwidth requirements. A forecast for 4G networks was made based on trends and future predictions, in order to future-proof the network. The wireless networks were then sectorized according to the expected number of users and their bandwidth demand. The number of fibers and wavelengths in the fiber-infrastructure was dimensioned according to the traffic generated in the wireless networks.

III. CASE STUDY

The case study of this project could be summarized as follows:

- Objectives and assumptions
- The municipality of Aalborg
- Results

A. Objectives and Assumptions

The main project objective is to design a planning model that is able to implement the proposed FUTON architecture, this planning model should be as automatic as possible in order to reduce the planning time and ease the job of the network planner. This automatic planning model is able

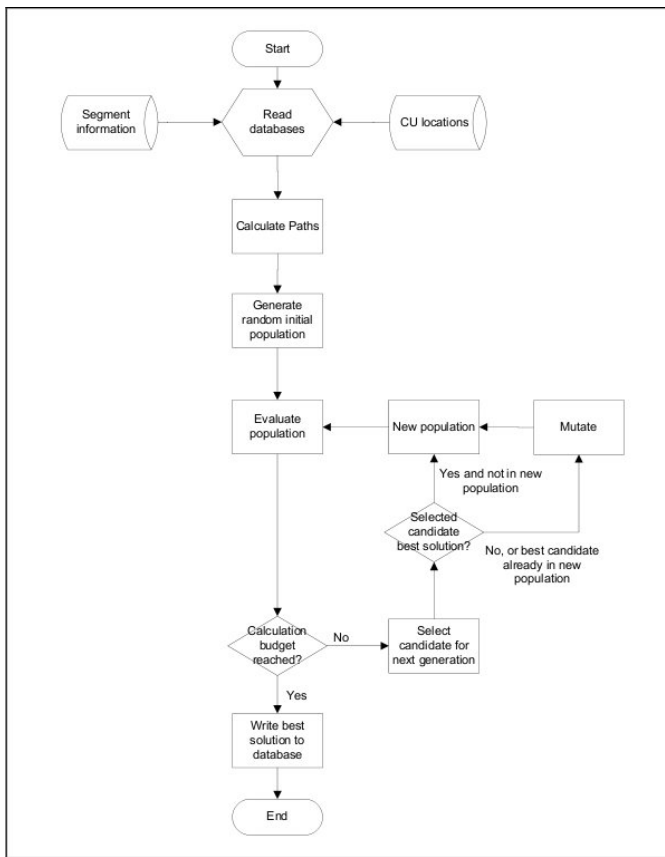


Fig. 6. Flow of algorithm for planning CU-CU ring

to perform all the planning tasks such as radio planning, CU placement and Fiber planning. It is assumed that the planning done in this project is for an organization that wants to deploy the FUTON architecture and lease it out to interested ISPs. The architecture can include any 3G or WiMAX Base Stations (BSs) the ISPs already have active. The FUTON project is scheduled to be finished in 2013, and for this reason the networks planned in this paper are assumed to be used by 2013. For that reason the networks need to be ready for the estimated number of MTs and traffic in 2013. As a base for comparison, estimations of current traffic (2009) will also be done. The wireless radio planning is done for three different wireless technologies: WiMAX, 3G and Distributed Broadband Wireless System (DBWS). Both WiMAX and 3G are expected to be technologies deployed by different WISPs in 2009. In 2013 DBWS will be deployed by an organization that allows the two WISPs to use the same infrastructure and deploys all three wireless technologies together using FUTON infrastructure.

B. The Municipality of Aalborg

It was necessary to choose a geographical area that could be suitable for implementing the FUTON architecture. Since the GIS data of the Danish Municipality of Aalborg was available, Aalborg was chosen as the geographical scenario of the project. Aalborg is located on both sides of Limfjorden in

the county of North Jutland. It is Denmark's fourth largest city, with 192 000 inhabitants in the whole municipality and 122 000 in the city area [4]. The landscape is typically Danish, with an urban town centre surrounded by flat farmland and a few hills. The geographical size of the municipality is 1 143, 99 square km [5]. Statistics show that 11 785 people commute out of Aalborg every work day, and 21 215 commute into Aalborg. This means that during the work-hours on weekdays, there are 201 430 people in the municipality [4]. The Figure ?? shows population density and road network for the municipality of Aalborg.

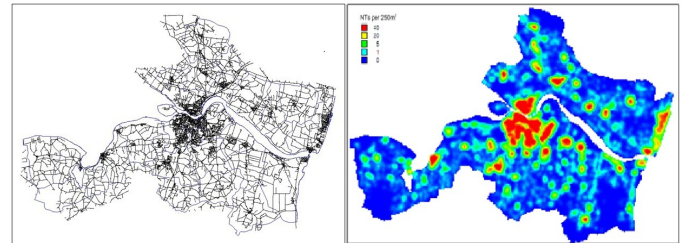


Fig. 7. Road networks And Population density in Aalborg

C. Results

1) *Radio Planning Results:* The Coverage plans for 3G, WiMAX and DBWS were made automatically for the hypothetical network of the Municipality of Aalborg. It was found that the total number of RAUs that are required to be connected in a FUTON architecture is 233, this number was found to be 40% less than if the three networks were deployed separately. Even though the indoor coverage was set to 97% of the MTs, the resulting outdoor coverage is 100% of the area. This means that the networks are able to provide mobility for outdoor users. The results from the radio planning are shown in Figure ??.

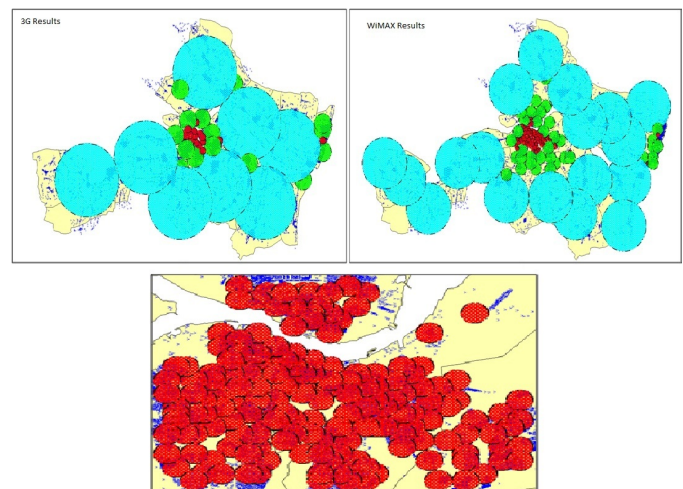


Fig. 8. Radio Planning results

2) *CU-placement*: The automatic CU placement was done using a combination of Greedy and GA for the set-cover problem. The RAU positions were used as potential CU locations, and cover the RAUs within a distance of the RAU. The required number of CUs was found to be 11 using this automatic approach. But due to some flaws in the CU assignment a manual solution was implemented that also required 11 CUs but with more evenly distributed attached RAUs.

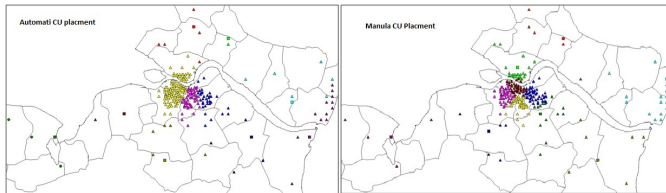


Fig. 9. CU placement Results

3) *Fiber Planning*: The RAUs are connected to the CUs using the tree topology. In order to minimize the digging needed, the Minimum Spanning Tree (MST)-algorithm was used. One MST was made for each CU. A solution was made both with and without splitters. If no splitters are used it adds significantly to the length of fiber, and number of fibers, but might still be a cheaper solution, depending on the price of the splitters and if amplification is needed as a result of the splitting. The fiber planning was made for both the automatic and the manual approaches of CU placements. The fiber lengths for the automatic approach was found to be 296976 meters and the trench lengths 147988 meters, for the manual approach the fiber lengths was found to be 290492 meters and the trench lengths 145246 meters.

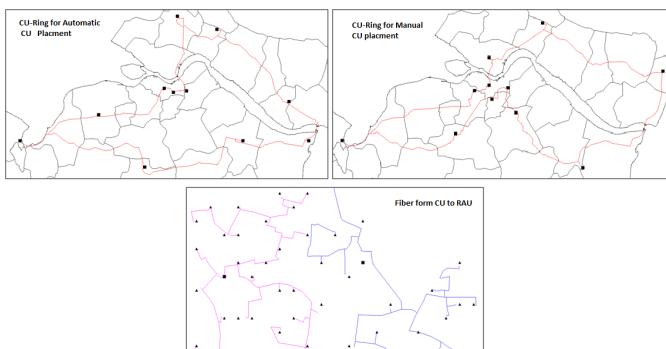


Fig. 10. Fiber Planning Results

4) *Traffic Estimation and Capacity Dimensioning*: The average bandwidth usage of each user is calculated for the three wireless technologies, both for the situation today, and the future situation predicted in 2013. The results for today show that 3G users use less average bandwidth than WiMAX users, which is due to many 3G users only using the phones for calls or light data-traffic, whilst WiMAX users have the same traffic amount as regular broadband users. By looking at what applications are assumed to be used in 2013, it was found

that the average bandwidth usage will increase by 78%. The number of users a sector can support is calculated by dividing the average capacity of a cell by the average bandwidth usage of the users. The results are that today's 3G networks can support more users than WiMAX, this was found to be due to the low average bandwidth usage of the 3G users. In the future prediction of 2013, the DBWS is predicted to support more users in a sector than WiMAX or 3G, due to the high capacity of the LTE-Advanced technology which is assumed to be used as a DBWS technology.

IV. CONCLUSION

The model presented in this paper is able to automatically plan RoF heterogeneous wireless networks based on the proposed FUTON architecture, which was demonstrated by a case study in the Municipality of Aalborg. This automated process is able to perform radio planning, CU placement and fiber planning as well as calculating traffic estimations and capacity dimensioning for the created network. This method makes use of different wireless systems which makes it more feasible and easier to implement on existing networks. However due to the inaccuracy of the propagation model used to obtain the radio coverage, the coverage area of each BS is imprecise. The results of the automated planning would therefore be more realistic if using more detailed propagation models to get more accurate information about the coverage area of each RAU. The CUs are placed using a genetic algorithm much like the one used in radio planning, with the objective of covering the RAUs by having a CU within range. The results show that it is able to provide coverage of all RAUs, but it does not place the CUs in positions where they even out the number of connected RAUs. A manual solution was therefore created in addition to the automatic, to see how they compared in fiber planning and traffic dimensioning. Due to the sub-optimal solution from the automatic CU-placement in this project, this area is suggested as an interesting area for further work. The interconnection of CUs was planned using a ring-topology, due to its widespread deployment, simplicity and low cost. The paths between the CUs were found using A*, and a GA finds the ring using the minimum amount of trenches. The results show that the two placements of CUs that has been done, does not differ in the length of the trenches. The standard deviation of traffic load on the CUs and the traffic between CU pairs are higher for the automatically placed CUs than for the manually placed CUs. This shows that the automatic method of placing CUs from chapter 5 does not provide optimal solutions with regards to even network load. In the future it would be interesting to create an expandable and easily configurable planning tool for planning this kind of architecture based on the scripts in this project. A GUI frontend could be made to enable fast configuration of the planning mechanisms. The splitting of tasks into functions means that if someone made an implementation of the SUI propagation model, the planner can simply choose whether to use the COST 231 Hata model or the SUI model as the propagation model in radio planning.

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