Optimal Relays Deployment for 802.16j Networks

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Abstract. In this paper, we consider optimal relay station deployment for the IEEE 802.16j networks. IEEE 802.16j is an emerging wireless broadband networking standard that integrates infrastructure base stations with multihop relay technology. The proposed relay deployment mechanism allows us to maximize network capacity for every user or to maximize total network capacity, and, therefore, to reach greater network capacity values while employing smaller number of relay stations. With the proposed approach, the necessary number of relays for a region can be found.

Keywords: WiMAX, 802.16j, Relay Stations, Deployment, Capacity.

1 Introduction

Broadband wireless networks are designed to be able to provide high data transmission rates for mobile applications. IEEE 802.16e/Mobile WiMAX is one of the technologies which provide access for mobile subscribers to multimedia services [1], [2]. WiMAX is a cellular network to which subscriber stations (SSs) are connected through base stations (BSs), located in the centre of every cell. Due to the fact that channel quality of user depends on many factors (e.g. slow and fast fading, path loss, antenna direction), the users located in different points of the cell have different level of signal-to-noise plus interference ratio (SINR) and, thus, have different values of reachable data transmission rates.

Subscribers at the edge of a cell and subscribers shadowed by big obstacles often have to put up with a low level of SINR, which does not satisfy the required level. The most intuitive way to improve the situation is to shrink the cell size.

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But it leads to two drawbacks. First, due to the reduction in the cell size, more BSs are needed for the coverage of the same area. This in turn leads to increasing costs: provider must pay for digital and radio equipment and the wired backhaul to the network for each BS. Second, shrinking the size of the cell leads to an increasing interference level for all subscribers, because the distance to BSs which do not service a subscriber is decreased.

Instead of shrinking the cell size, a more advanced approach was proposed. This approach provides deployment of fixed relay stations (RSs) inside the cell [3], [4]. The purpose of these RSs is to aid the communication from BSs to SSs and vice versa. Relay stations do not need any connection to the network wired backhaul and, thus, they can be deployed in places where it is too difficult and expensive or impossible to install a wired connection. In addition, deploying RS is simpler and faster, because simpler equipment is used in it.

Networks which use RS are called multi-hop networks. While IEEE 802.16j (an amendment to IEEE 802.16e which describes multi-hop networks) defines the physical and the MAC layer specifications, the issues related to deployment of relays for these networks are kept open for innovations by the network service providers. Because the allowable number of relays is often determined by costs, the problem of a deployment of relays that ensures a high level of SINR and reachable data transmission rate becomes very important.

In [5], a relay deployment mechanism, when there is one BS in the considered region and a fixed number of relay stations must be deployed to satisfy the bandwidth requirement of MSs. The proposed mechanism takes into account both the frame structure constraint and bandwidth constraint. The problem of determing optimal node location for BSs and RSs in relay-based 802.16 networks is formulated as an integer programming problem in [6]. The objective of this problem is to find the candidate sites for deploying the base stations and relay stations with minimal deployment cost. Standard branch and bound techniques are used to solve the problem. Study [7] investigates the optimal placement of wireless RSs which minimizes the operational cost of a wireless mesh network. The problem is formulated as a mixed integer program and solved by Benders decomposition. In [9], the realistic scenario using data from topology information and raytracing for the case of one BS only and that of one BS and several RSs is considered. The data is analyzed numerically, and the results for the gains in coverage and capacity are presented.

While the approach to find optimal RS positions by formulating the problem as an integer programming is not novel, existing researches lose sight of increasing interference caused by relay stations deployed in the region considered, or assume that RSs transmit a signal in different time frames and therefore do not interfere each other. But such scheme of the signal transmission can lead to not rational usage of bandwidth resource.

In this research, we formulate the problem for optimal positions of relays in some region which already contains several base stations taking into account the interference increase caused RSs deployment. Furthermore, the proposed algorithm allows to find the optimal number of RSs which should be placed in the region to maximize the network capacity and satisfy user throughput requirements. The problem is formulated as non-linear, non-convex, non-separable integer programming problem and solved by using an evolutionary algorithm. In addition, numerical calculations and network performance simulations using ns-2 WiMAX extension WINSE [10] are carried out to verify the optimal RSs positions found.

The rest of the paper is organized as follows. In Section 2 we describe the system model considered in this paper and formulate the basic problem. In Section 3 we introduce an evolutionary algorithm, which is used for solving the problem. Our computational results and Winse simulations are given in Section 4. In Section 5, the necessary number of relay stations for a region is determined. Finally, we conclude in Section 6.

2 Problem Formulation

We consider a region Ω containing N_{BS} BSs and N_{SS} SSs and focus on the deployment of N_{RS} RSs which will help to increase the value of network capacity in this region. Each SS is serviced by one BS, directly or through RS.

Let us assume that SSs are distributed in the region Ω more or less uniformly. We divide this region by N_{SS} small sectors and assume that there is only one SS located in each sector. After introducing a coordinate system every sector can be denoted by a pair of coordinates corresponding to this sector centre. For example, if we use the Cartesian coordinate system OXY, the considered region Ω can be divided into sectors by lines parallel to X-axis and lines parallel to Y-axis. Hereafter, we concentrate on increasing the network capacity for the sectors obtained.

In the coordinate system introduced, we denote the coordinates of i-th BS as (x_{BS_i}, y_{BS_i}) and the coordinates of j-th RS as (x_{RS_j}, y_{RS_j}). The connection of an sector to one or another BS or RS is fixed and depends on the power of the received signal. Each sector is connected to base or relay station only if the power of the received signal from this station is maximal among signals from other BSs and all RSs.

When calculating the received signal power we focus on the path losses and antenna gains and lose sight of shadowing and fast fading assuming that its influence is not strong. Thus, the power of the signal P_{rcv,BS_i} received at the point (x, y) from the i-th base station can be calculated as following:

$$P_{rcv,BS_i}((x,y)) = 10^{\frac{1}{10}\left(P_{tr,BS_i}/B - L(x,y) + A_i(x,y)\right)},$$

where P_{tr,BS_i} is the transmitted signal power, B is bandwidth, $L(x, y)$ is path-loss on the distance between the transmitting base station and receiver at the point (x, y), $A_i(x, y)$ is antenna gain and an exponential function with base 10 is used to move from dB to watts. Path-loss of the transmitted signal basically depends on the distance between the transmitter and the receiver. Let us assume that an BS has directional antenna and its antenna gain is determined by this antenna direction. Transmitting power, positions and antenna directions of base stations are assumed to be fixed.

Similarly, the power of the signal P_{rcv,RS_j} received at the point (x, y) from the j-th relay station located at the point (x_{RS_j}, y_{RS_j}) is defined as

$$P_{rcv,RS_j}((x,y),(x_{RS_j},y_{RS_j})) = 10^{\frac{1}{10}\left(P_{tr,RS_j}/B - L((x,y),(x_{RS_j},y_{RS_j})) + A_{od}\right)},$$

and the power of the signal $P_{rcv,SS_{(p,q)}}$ received at the point (x, y) from the subscriber station located at the point (p, q) is

$$P_{rcv,SS_{(p,q)}}((x,y),(p,q)) = 10^{\frac{1}{10}\left(P_{tr,SS_{(p,q)}}/B - L((x,y),(p,q))\right)},$$

It is pointed out that transmitting power of an RS (P_{tr,RS_j}) and SS ($P_{tr,SS_{(p,q)}}$) are fixed, RSs have omni-directional antennas with fixed antenna gain A_{od} and SSs do not have any antenna gains.

Let us denote the set of relay stations coordinates as $R = \{(x_{RS_1}, y_{RS_1}), \ldots, (x_{RS_{N_{RS}}}, y_{RS_{N_{RS}}})\}$. Therefore, the sets of sectors S_{BS_i} and S_{RS_j} serviced by i-th BS and j-th RS respectively can be denoted as follows:

$$S_{BS_i} = S_{BS_i}(R) = \text{ set of } (x,y) \in \Omega \text{ such as:}$$
$$\begin{cases} P_{rcv,BS_i}(x,y) \geq P_{rcv,BS_l}(x,y),\ l = 1,\ldots,N_{BS},\ l \neq i, \\ P_{rcv,BS_i}(x,y) \geq P_{rcv,RS_j}((x,y),(x_{RS_j},y_{RS_j})),\ j = 1,\ldots,N_{RS}, \end{cases} \tag{1}$$

where the first $N_{BS} - 1$ constraints are associated with the location of other BSs and next N_{RS} constraints are associated with deployment of RSs, and

$$S_{RS_j} = S_{RS_j}(R) = \text{ set of } (x,y) \in \Omega \text{ such as:}$$
$$\begin{cases} P_{rcv,RS_j}((x,y),(x_{RS_j},y_{RS_j})) \geq P_{rcv,BS_i}(x,y),\ i = 1,\ldots,N_{BS}, \\ P_{rcv,RS_j}((x,y),(x_{RS_j},y_{RS_j})) \geq P_{rcv,RS_l}((x,y),(x_{RS_l},y_{RS_l})), \\ l = 1,\ldots,N_{RS},\ l \neq j, \end{cases} \tag{2}$$

where the first N_{BS} constraints are associated with the location of BSs and next $N_{RS} - 1$ constraints are associated with deployment of other RSs.

Let us determine the sector (x, y) capacity as the value of the capacity for the SS located in the sector (x, y) and denote this capacity as $C_{xy}(R)$. Consider two approaches, which will slightly differ in the objective function, for finding optimal relays locations. In the first approach the criteria of optimality for any decision of the deployment of relays is supposed to be the maximization of the total network capacity for the area considered: $\max_R \sum_{(x,y)\in\Omega} C_{xy}(R)$, and in the second one this criteria would be the maximization of the minimal sector capacity: $\max_R \min_{(x,y)\in\Omega} C_{xy}(R)$. We have to take into account both downlink (DL) and uplink (UL) communication.

For the uplink connection we assume that subscribers cannot create powerful interference amongst themselves. Thus, we will not consider interference caused by users in the uplink connection.

Using (1) and (2), the sector (x, y) capacity can be given as the sum of the downlink ($C_{xy}^{DL}(R)$) and uplink ($C_{xy}^{UL}(R)$) capacities for a user connected to a base station directly or through RS:

$$C_{xy}(R) = C_{xy}^{DL}(R) + C_{xy}^{UP}(R),$$

where

$$C_{xy}^{DL}(R) = \begin{cases} C_{BS_i - SS_{(x,y)}}((x,y),R), \text{ if } (x,y) \in S_{BS_i}(R), \\ \min\{C_{BS_{l(j)} - RS_j}(x_{RS_j}, y_{RS_j}), C_{RS_j - SS_{(x,y)}}((x,y),R)\}, \\ \text{if } (x,y) \in S_{RS_j}(R), \end{cases}$$

$$C_{xy}^{UL}(R) = \begin{cases} C_{SS_{(x,y)} - BS_i}(x,y), \text{ if } (x,y) \in S_{BS_i}(R), \\ \min\{C_{SS_{(x,y)} - RS_j}((x,y),(x_{RS_j}, y_{RS_j})), C_{RS_j - BS_{l(j)}}(x_{RS_j}, y_{RS_j})\}, \\ \text{if } (x,y) \in S_{RS_j}(R), \end{cases}$$

Here $C_{BS_i - SS_{(x,y)}}((x,y),R)$ is the downlink capacity of the link between i-th BS and the SS located at (x,y), $C_{BS_{l(j)} - RS_j}((x_{RS_j}, y_{RS_j}))$ is the downlink capacity of the link between j-th RS and the $l(j)$-th BS with which the j-th RS is logically connected, $C_{RS_j - SS_{(x,y)}}((x,y),R)$ is the downlink capacity of the link between j-th RS and the SS located at (x,y), $C_{SS_{(x,y)} - BS_i}(x,y)$ is the uplink capacity of the link between SS located at (x,y) and i-th BS, $C_{SS_{(x,y)},RS_j}((x,y),(x_{RS_j}, y_{RS_j}))$ is the uplink capacity of the link between j-th RS and the SS located at (x,y), $C_{RS_j - BS_{l(j)}}(x_{RS_j}, y_{RS_j})$ is the uplink capacity of the link between j-th RS and the $l(j)$-th BS with which the j-th RS is logically connected, which can be found as follows:

$$\begin{aligned}
&C_{BS_i - SS_{(x,y)}}((x,y),R) = B\log_2\left(1 + \frac{P_{rcv,BS_i}(x,y)}{N_0 + I_{BS_i}((x,y),R)}\right), \\
&C_{BS_{l(j)} - RS_j}(x_{RS_j}, y_{RS_j}) = B\log_2\left(1 + \frac{P_{rcv,BS_i}((x_{RS_j}, y_{RS_j}))}{N_0}\right), \\
&C_{RS_j - SS_{(x,y)}}((x,y),R) = B\log_2\left(1 + \frac{P_{rcv,RS_j}((x,y),(x_{RS_j}, y_{RS_j}))}{N_0 + I_{RS_j}((x,y),R)}\right), \\
&C_{SS_{(x,y)} - BS_i}(x,y) = B\log_2\left(1 + \frac{P_{rcv,SS_{(x,y)}}((x_{BS_i}, y_{BS_i}),(x,y))}{N_0}\right), \\
&C_{SS_{(x,y)} - RS_j}((x,y),(x_{RS_j}, y_{RS_j})) = \\
&= B\log_2\left(1 + \frac{P_{rcv,SS_{(x,y)}}((x_{RS_j}, y_{RS_j}),(x,y))}{N_0}\right), \\
&C_{RS_j - BS_{l(j)}}(x_{RS_j}, y_{RS_j}) = \\
&= B\log_2\left(1 + \frac{P_{rcv,RS_j}((x_{BS_i}, y_{BS_i}),(x_{RS_j}, y_{RS_j}))}{N_0}\right),
\end{aligned} \quad (3)$$

where $I_{BS_i}((x,y),R)$ is level of interference for receiving SS located at the point (x,y) if transmitting station is the i-th BS, and $I_{RS_j}((x,y),R)$ is level of interference for the receiving SS located at point (x,y) if the transmitting station is j-th RS. These interference values can be calculated as the sum of power of signals from all other BSs and RSs except the serving station:

$$I_{BS_i}((x,y),R) = \sum_{l=1,l\neq i}^{N_{BS}} P_{rcv,BS_l}(x,y) + \sum_{j=1}^{N_{RS}} P_{rcv,RS_j}((x,y),(x_{RS_j},y_{RS_j})),$$

$$I_{RS_j}((x,y),R) = \sum_{l=1,l\neq j}^{N_{RS}} P_{rcv,RS_l}((x,y),(x_{RS_l},y_{RS_l})) + \sum_{i=1}^{N_{BS}} P_{rcv,BS_i}(x,y)),$$

In the expressions (3), N_0 denotes background noise. We assume that transmissions between base and relay stations are separated in time. On the other hand, BSs and RSs transmit data to SSs in one time frame and therefore they interfere each other.

Thus, the formulation of the problem in the first approach is given by the following optimization problem:

$$\max_{R} \sum_{(x,y)\in\Omega} C_{xy}(R),$$
$$\text{subject to } (x_{RS_j}, y_{RS_j}) \in \Omega,\ j = 1,\ldots,N_{RS}.$$

and, if we use the second approach, it is given by the following optimization problem:

$$\max_{R} \min_{(x,y)\in\Omega} C_{xy}(R),$$
$$\text{subject to } (x_{RS_j}, y_{RS_j}) \in \Omega,\ j = 1,\ldots,N_{RS}.$$

3 Solution

We will consider this problem as a problem of integer programming. Since the objective function is non-linear and non-convex, we can not use standard optimization methods. Also, since it is difficult to evaluate the objective function on some set, the usage of branch and bound method is not reasonable here. In this research we will use one of the evolutionary algorithms, namely the genetic algorithm. Evolutionary algorithms represent a class of stochastic optimization algorithms in which the principles of organic evolution are used as rules in optimization. They are often applied to optimization problems when specialized techniques are not available or standard methods fail to give satisfactory answers. A genetic algorithm allows to find the global optimum of a problem even for the case of complicated objective function. Another advantage of an genetic algorithm is that they are well suited to parallelizing [18].

Genetic algorithm is a powerful optimization algorithm. It starts with an initial set of feasible solutions (called population) and tends to an optimal solution using processes similar to evolution: crossover and recombination. These processes contribute new solutions to the population. During each iteration of the algorithm (called generation) all members of the current population are evaluated: better solutions have a higher probability to be selected for the new population. The algorithm stops when some stopping criterion is fulfilled (maximal number of generations has been reached, maximal number of function evaluations has been made, etc.).

In [11], the convergence properties of the canonical genetic algorithm (CGA) are analyzed. Using homogeneous finite Markov chain analysis, it was proved that a CGA will never converge to the global optimum, but variants of CGAs that operate with best solutions in the population are shown to converge to the global optimum.

Genetic algorithms where the best individuals survive with the probability of one are usually known as elitist genetic algorithms (or genetic algorithms with elitism). Elitism guarantees survival of the best element of the population, which, in turn, guarantees that at least the fitness of the population (measured as the fitness of the best individual) does not decrease after the next iteration. Study [12] considers several versions of genetic algorithms (in particular, elitist algorithm) and obtains theoretical estimates for their convergence.

Consider the use of a genetic algorithm for our case in more detail.

Initialization. After determining population size N_{ppltn} which we will use in the algorithm, we randomly (with uniform distribution) choose sets of relay coordinates R^k, where $k \in \{1, 2, \ldots, N_{ppltn}\}$:

$$R^k = \{(x^k_{RS_1}, y^k_{RS_1}), \ldots, (x^k_{RS_{N_{RS}}}, y^k_{RS_{N_{RS}}})\}.$$

When generating the population, it satisfies the following conditions:

$$(x^k_{RS_j}, y^k_{RS_j}) \in \Omega, \ \forall j \in \{1, 2, \ldots, n\}. \tag{4}$$

In addition, we set the value of recombination probability $P_{rcmbntn} \in (0, 1)$ and maximal number of generations $g_{max} > 0$.

Crossover. Crossover is a genetic operator that combines two solutions (parents) to produce a new solution (offspring). The idea behind crossover is that the new solution may be better than any of the parents if it takes the best characteristics from each of the parents. For example, a one-point crossover operator randomly selects a crossover point within a solution and then interchanges the two parent solutions at this point to produce two new offspring.

There are many ways to implement a crossover: from the simple single-point crossover, described above, to complicated crossovers: [13], [14] or [15]. In this research we use a multipoint crossover: we randomly (with uniform distribution) choose $N_{prnts} = N_{RS}$ solutions from the current population (we will call them "parents") and create a new solution by taking the coordinates of the first relay from the first "parent", the coordinates of the second relay from the second "parent" etc. The new solution has to satisfy conditions (4). If not, then we randomly choose a new set of "parents".

Recombination. Recombination produces spontaneous random changes in various solutions of the current population. For every solution k of the current population ("parents" and new solutions obtained as a result of a crossover) we change the coordinate of j-th RS ($x^k_{RS_j}$ or $y^k_{RS_j}$) with probability $P_{rcmbntn}$. A new value for coordinate is chosen randomly, with uniform distribution, in such a way that the obtained solution has to satisfy conditions (4).

Mutation probability (probability that a vector component in a solution vector will be changed from its original state) is the most important parameter for the recombination process. In [16] and [17] finding the optimal value of the mutation probability such that a genetic algorithm converges most rapidly is studied.

Selection. After crossover and recombination we need select some solutions for the next generation. In the simple genetic algorithm, selection is implemented by a linear search through a roulette wheel slots weighted in proportion to string fitness values. In this paper we use the elitist selection method. That means that we select N_{ppltn} solutions, that maximize the objective function. Thus, we obtain the next generation, for which the processes of crossover, recombination and selection should be applied again.

Stopping Criterium. The following three kinds of termination conditions are traditionally used for genetic algorithms: an upper limit on the number of generations is reached, an upper limit on the number of evaluations of the fitness function is reached, the chance of achieving significant changes in the next generations is excessively low.

In this research the process of forming new generations continues at least till the maximal number of generations g_{max} reached. After reaching the maximum number of generations, the process of forming new generations continues until the best solution does not change g_{after_max} times in a row.

4 Numerical Examples and Simulations

Consider some example of relays deployment. We will try to find the optimal locations for three relays in a cell, serviced by one BS. We do this by applying the two approaches mentioned: in the first case we will maximize the total network capacity for users located in this cell and, in the second one, the minimal sector capacity. We will take into account interference from two other BSs located the most close to the considered cell. In Table 1, the basic network characteristics are presented. For the genetic algorithm we will use the parameters declared in Table 2.

When solving this problem with the help of the genetic algorithm the following results were obtained. The optimal coordinates of RSs in the first case are $(600, 300)$, $(570, 750)$ and $(180, 990)$ as shown in Figure 1. In Figure 2 we can see the optimal deployment of relays for the second case: the coordinates of relays are, correspondingly, $(660, 270)$, $(600, 780)$ and $(150, 1080)$.

These two scenarios were simulated by using network simulator ns-2 and its extension, Winse. We consider the DL FTP- like continuous TCP transmission over 802.16 connections. Of course, there is also UL traffic caused by the TCP protocol functioning. We ran 40 different simulations to obtain statistically

Table 1. Network parameters

Parameter	Value
Distance between BSs	1.5 km
Center frequency	2.5 GHz
Bandwidth	10 MHz
PHY	OFDMa
Duplexing mode	TDD
OFDM symbols	47
DL / UL symbols	30 / 15
DL / UL relay zone size	4 / 3
BS / RS / SS Tx power	10 W / 5 W / 0.2 W
BS / RS / SS antena pattern	3GPP / omni / omni
BS / RS / SS antenna gain	17 / 5 / 0
Propagation model	sub-urban
Fading margin	9
Background noise	-160 dB

Table 2. Algorithm parameters

Parameter	Value
Maximal number of generations	200
Maximal number of additive generations	10
Number of solutions in every population	30
Probability of recombination	0.5

reliable results. Each simulation contained 25 SSs located in random places and lasted for 5 seconds.

Here the 3D surface with SS throughput-over-area distribution is shown for the case when total network capacity is maximized (Figure 1) and the case when minimal sector capacity is maximized (Figure 2). It can be seen that throughput distribution is more or less uniform in the second case, whereas, in the first case, there are areas where throughput is significantly greater than in other places of the considered region. In Figure 3 the minimal, maximal and mean values of throughput are presented for the two mentioned cases and for the case when only the BS serves the area considered. The use of RSs helped to increase the throughput significantly. Where the total network capacity is maximized, the mean value of the throughput is greater than for the scenario where the minimal capacity is maximized. In our case, however, there are some SSs for which the throughput will be quite small because of non-uniform throughput-over-area distribution. In Figure 4, the cumulative distribution function for the

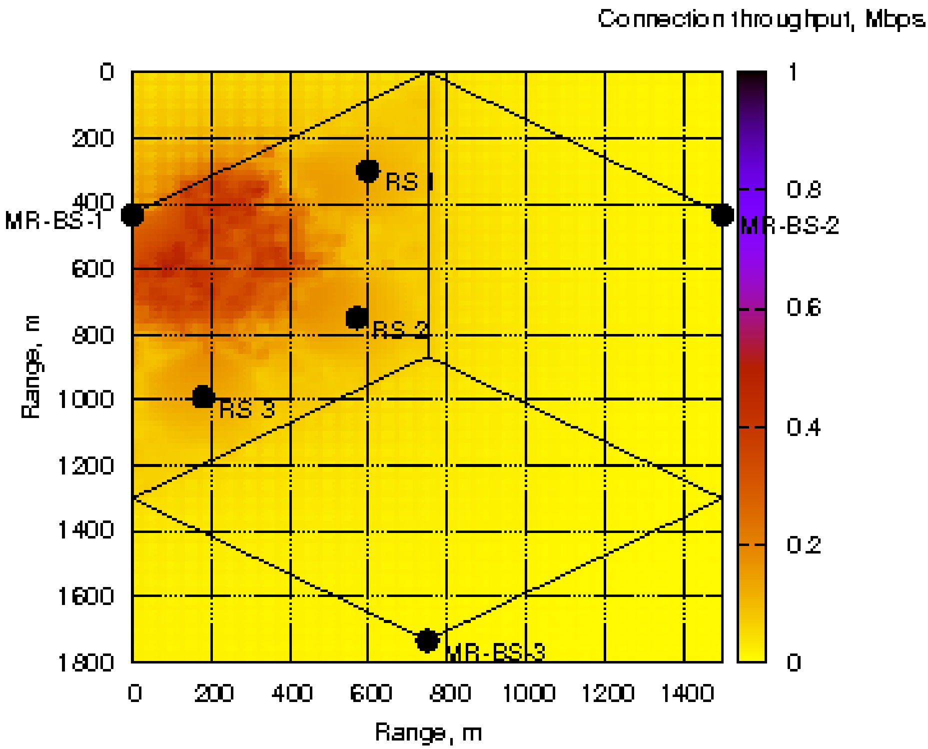

Fig. 1. Throughput-over-area distribution (Total capacity maximized)

mean DL connection throughput (CDF) is presented. The mean throughput is calculated individually for each connection. The figure shows that when we maximize the total network capacity more than 60% of SSs have a lower throughput when compared to the scenario when minimal sector capacity is maximized.

5 Finding Optimal Number of Relay Stations

To solve the problem of energy consumption and effective resources usage, minimal sufficient number of RSs should be found. Consider some area where several BSs are located. Imagine that the provider which uses these stations wants to attract new customers. For this reason, it is planning to deploy a number of relays to guarantee that the network capacity in the serviced area will be not less than some value.

Consider a situation where the provider is planning to deploy RSs in three adjacent cells with three BSs already located. To calculate how many relays have to be deployed, the maximal value of the minimal sector capacity is calculated for cases when different numbers of relays deployed. The network settings and

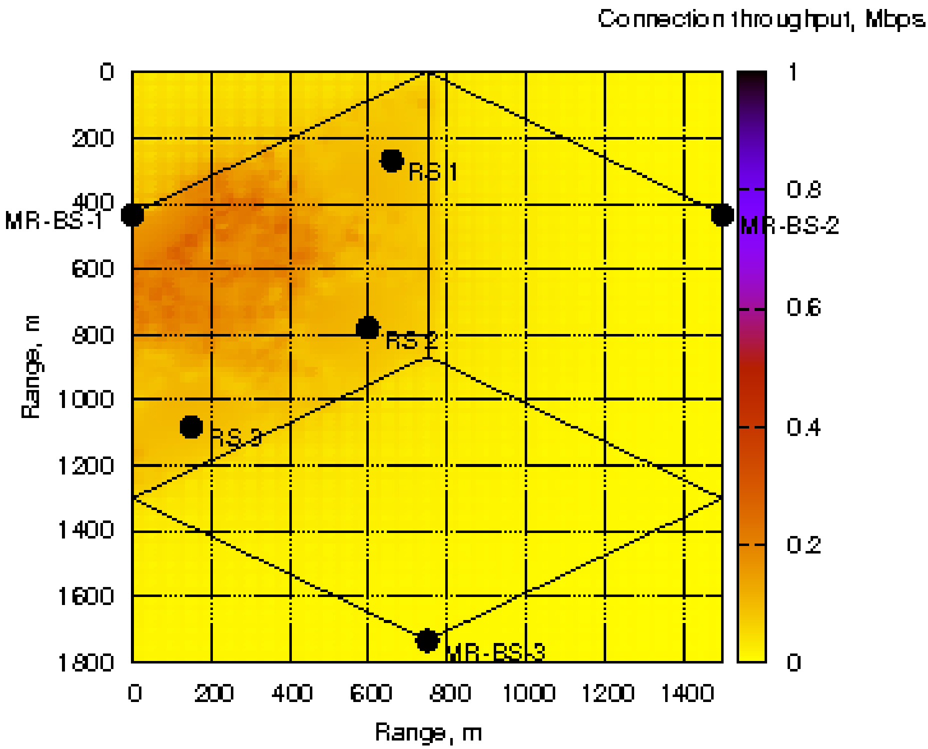

Fig. 2. Throughput-over-area distribution (Minimal capacity maximized)

genetic algorithm parameters are the same as those in the previous section. The base stations are located at coordinates $(0, 433)$, $(1500, 433)$ and $(750, 1732)$ and the angles of their antenna directions are located at coordinates 330, 210 and 90 respectively.

In Figure 5, the minimal sector capacity depending on the number of RSs is shown. For every case the optimal way of deploying the relays has been found and the corresponding value of the minimal sector capacity has been obtained. Thus, the provider can determine how many relays can be deployed to guarantee that the capacity in the cell will be greater than some given value. For example, to guarantee that the capacity will be greater than 4 Mbps the provider has to deploy at least 6 RSs.

We can see that the function which expresses the dependence of maximized value of the minimal sector capacity on number of relays is increasing at least for the range of relays from 0 to 10. The rapid growth of this function when the number of relays becomes greater than 3 can be explained as follows. There are three areas where the network capacity is much less than in other areas of the cell. These three areas are located in such vertexes of the hexagon where there are no BSs. The optimal way of deploying two RSs is to place relays in two of these areas, and the sector with the minimal capacity value in the remaining

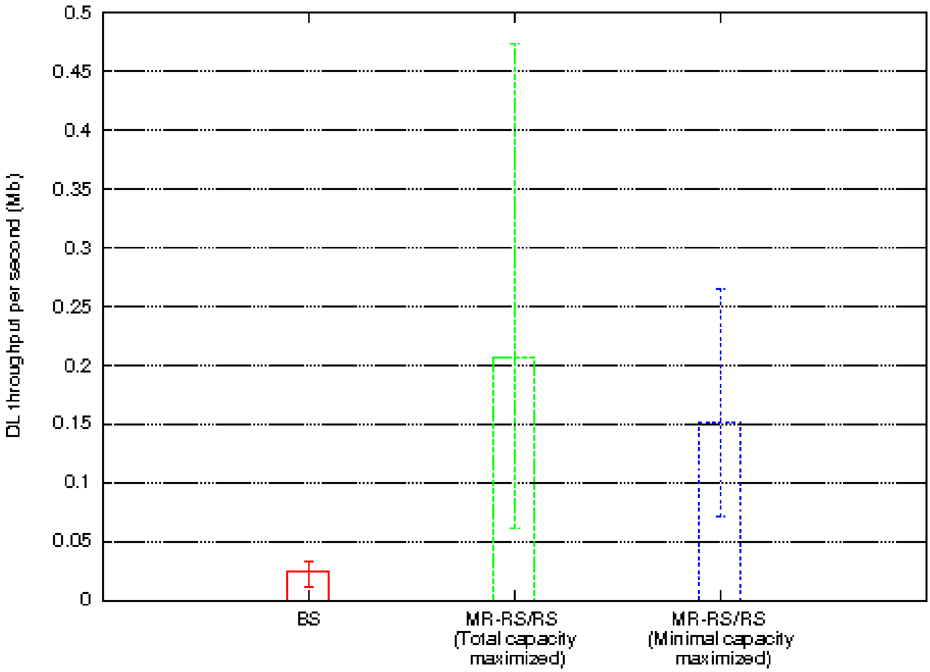

Fig. 3. Minimal, maximal and mean values of the throughput

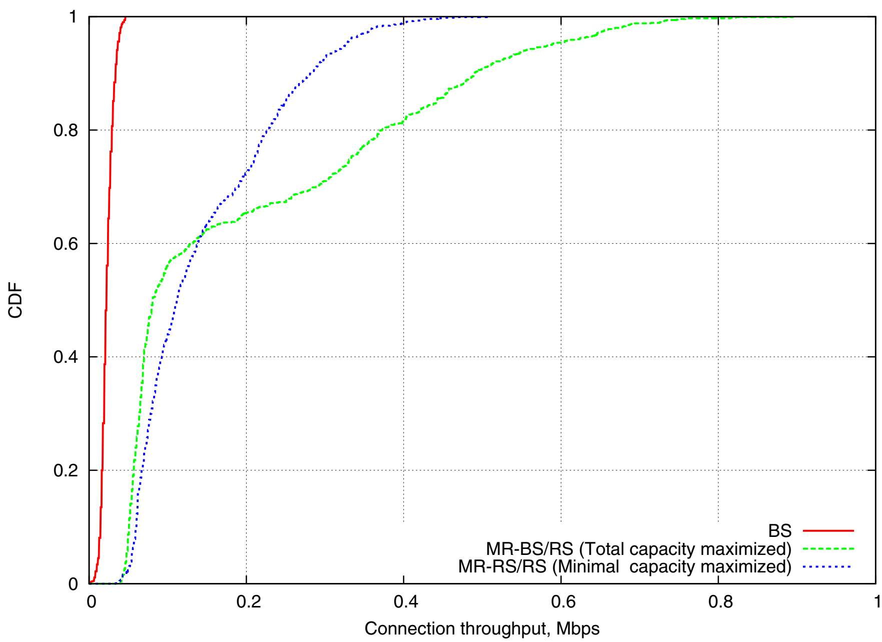

Fig. 4. DL connection throughput (cumulative distribution)

area. Obviously the capacity of that sector will almost equal the capacity when no relays, are located in the cell. After deploying three relays, the location of the sector with minimal capacity moves to the hexagon centre and the value of this minimal capacity will increase.

The technique proposed can be also extended to the case when subscribers are distributed non-uniformly or they have different capacity requirements. In this case the objective function is formulated as follows: if a sector capacity is greater than the value required for this sector, then the objective function is zero, otherwise the objective is equal to difference between the current sector capacity and its required value. This required value of the sector capacity can also take into account the likelihood that a user is located in the sector.

Despite the fact that the optimal number of RSs can be found in the situation considered, usually this number is limited by some fixed value, which is determined taking into account relay deployment costs and money which the provider is willing to pay for deploying the relays.

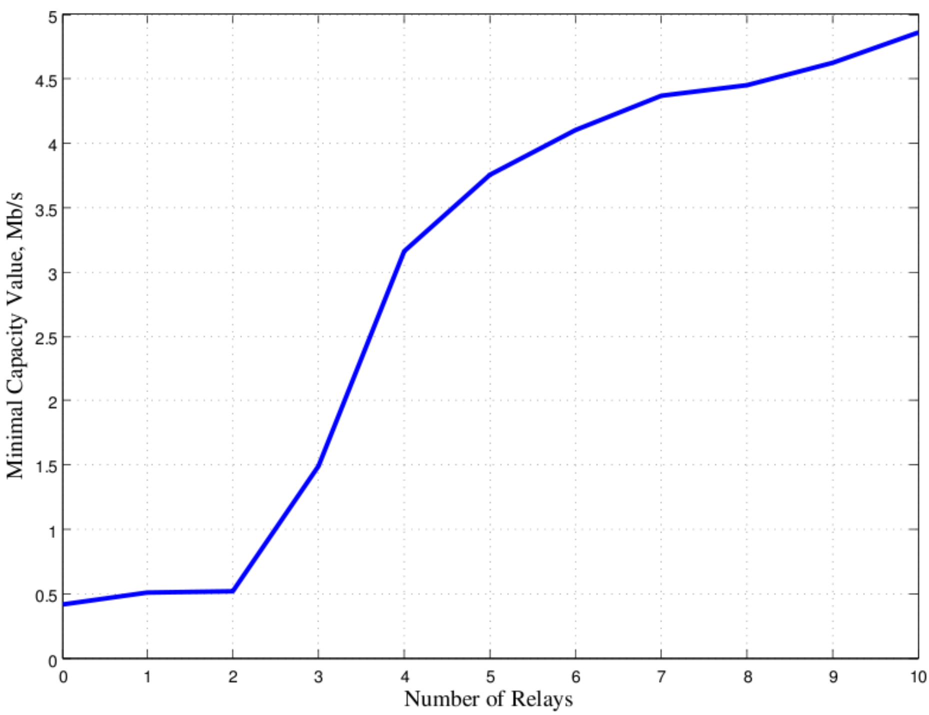

Fig. 5. Dependence of maximized value of minimal sector capacity on number of relays

6 Conclusion

Depending on the network implementation scenarios, relay stations could be an efficient solution for rolling out WiMAX networks. In this study, a deployment mechanism for relay stations, when there are several BSs located in the region considered, is proposed. The simulation results verify that this method is bandwidth-efficient and exhibits good fairness in relay networks. In addition, the problem of finding a required number of RSs for a region has been solved. We are planning to investigate the problem of cost-effective coverage area extension by using relays and consider novel resource management algorithms for multi-hop WiMAX networks.

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