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A Base Station Placement Of An Wireless Network With Linear Topology And A Network Performance Evaluation With NS-3

A. A. Mukhtarov[*], **A. M. Sokolov**[*]

[*] *V.A. Trapeznikov Institute of Control Sciences of Russian Academy of Sciences*
65 Profsoyuznaya street, Moscow 117997, Russia

Email: `mukhtarov.amir.a@gmail.com`, `aleksandr.sokolov@phystech.edu`

The paper is dedicated to the design problem of a wireless communication network. The problem of base stations optimal placement along a linear section is formulated. The goal is to maximize the coverage area under the control of multiple deployed base stations while respecting budget constraints. In the paper, the features of the technological statement are analyzed. The formulation of the problem in the form of integer linear programming (ILP) is proposed.

Based on the results of the placement algorithm (points of placed stations) to enforce conditions of technological restrictions, we evaluated network performance by NS-3 simulator. The optimal placement and also all obtained integer solutions in solving the problem were used to estimate the network performance.

The ILP problem and NS-3 simulation were computed via software for parallel tasks computation. All calculations are produced in cloud servers. The comparison results of network performance are given in the paper.

Key words and phrases: wireless network, optimization problem, NS-3.

1. Introduction

Base station optimal placement is one of the most important design stages of wireless networks. A similar problem has been proposed and discussed in several works [1–3]. This work is a continuation of the researches [4–6], where the particular case of the problem is considered when the controlled area is a linear section, for example, the area along highways. In the above papers, the formulation was given in the form of an integer linear programming model. This paper proposes network performance estimates with NS-3 for all obtained feasible integer solutions since the optimal solution does not always satisfy all design constraints.

2. Problem statement

Given a line segment of length L with the end points a_0 and a_{n+1} and a finite set of placement points $A = \{a_i\}, i = 1, ..., n$ inside.

Given a set of base stations $S = \{s_j\}$ is given. Each station has characteristics $s_j = \{r_j, \{R_{jq}\}, c_j\}$, $j = 1, ..., m; q = 1, ..., m; q \neq j$. Here r_j is a coverage radius of a station, R_{jq} is a link distance between stations s_j and s_q, and c_j is a station cost.

Coverage radius r_j and link distance R_{jq} can be calculated by link budget equation (1) and Friis transmission equation (2):

$$P_{tr} - L_{tr} + G_{tr} - L_{fs} + G_{recv} - L_{recv} = SOM + P_{recv}, \qquad (1)$$

where P_{tr} is a transmitter output power, dBm; L_{tr} is a ransmitter losses, dB; G_{tr} is a transmitter antenna gain, dBi; L_{fs} is a free space path loss, dB; G_{recv} is a receiver antenna gain, dBi; L_{recv} is a receiver losses, dB; SOM is a system operating margin, dB; P_{recv} is a receiver sensitivity, dBm.

$$L_{fs} = 20 \lg F + 20 \lg D + K, \qquad (2)$$

Then

$$D = 10^{\left(\frac{L_{fs} - 20 \lg F - K}{20}\right)},$$

where D is a coverage radius r_j of a station or a link distance R_{jq} between stations.

Special stations s_{m+1} (gateways) are already placed at the endpoints a_0 and a_{n+1}. For these stations r_{m+1} is equal 0. A link distance and a cost are not set.

3. ILP Model

Objective function will be presented as:

$$f = \sum_{i=1}^{n} (y_i^- + y_i^+) \to max,$$

where y_i^+ and y_i^- $\forall a_i, i = \overline{0, n+1}$ are non-negative integer values determined as the right and left sides from point a_i, covered by the placed stations. $y_0^+, y_0^-, y_{n+1}^+, y_{n+1}^-$ are equal to 0 for gateways.

Let's introduce binary variables x_{ij}, e_i and z_{ijkq}.

- $x_{ij}, i = \overline{0, n}$, $j = \overline{1, m}$. Variable x_{ij} is equal to 1 if station s_j is placed at point a_i and x_{ij} is equal 0 otherwise.
- $e_i, i = \overline{0, n+1}$. Variable e_i is equal to 1 if any station is placed at point a_i and e_i is equal to 0 otherwise. For gateways placement points $e_0 = 1$ and $e_{n+1} = 1$.
- $z_{ijkq}, i = \overline{1, n}$, $j = \overline{1, m}$, $k = \overline{1, n}, k \neq i$, $q = \overline{1, m}, q \neq j$. The variable z_{ijkq} is equal to 1, if there is a station s_j at point a_i and it is connected with a station s_q placed at the point a_k; and z_{ijkq} is equal to 0 otherwise.

Let us formulate the following system of the problem constraints (3) – (19).

By definition (3):

$$e_i = \sum_{j=1}^{m} x_{ij}, i = \overline{1, n}. \tag{3}$$

Each station is placed in only one coordinate (4):

$$\sum_{j=1}^{n} x_{ij} \leq 1, j = \overline{1, m}. \tag{4}$$

The values of coverage are no more than the coverage radius of the station placed at a_i, and equal to 0 if there is no station at a_i (5) – (6):

$$y_i^+ \leq \sum_{j=1}^{m} x_{ij} r_j, i = \overline{1, n}. \tag{5}$$

$$y_i^- \leq \sum_{j=1}^{m} x_{ij} r_j, i = \overline{1, n}. \tag{6}$$

The total coverage area between any two points a_i and a_k, can't exceed the distance between these points (7) – (8).

$$y_i^+ + y_k^- \leq \frac{l_k - l_i}{2}(e_i + e_k) + (2 - e_i - e_k)L,\ k = \overline{i+1, n+1},\ i = \overline{1, n}; \tag{7}$$

$$y_i^- + y_k^+ \leq \frac{l_i - l_k}{2}(e_i + e_k) + (2 - e_i - e_k)L,\ k = \overline{0, i-1}\ i = \overline{1,n}, \tag{8}$$

where l_k and l_i are the coordinates of the points a_i and a_k, respectively.

The station located at a_i must be connected with at least one station on the left and one station on the right, including stations at the end points a_0 and a_{n+1}.

For $i = \overline{1,n}$ and $j = \overline{1,m}$:

$$z_{ijkq} \leq e_i, \quad i = \overline{1,n}, \quad j = \overline{1,m}, \quad k = \overline{1,n}, k \neq i, \quad q = \overline{1,m}, q \neq j; \tag{9}$$

$$z_{ijkq} \leq e_k, \quad k = \overline{1,n}, \quad j = \overline{1,m}, \quad i = \overline{1,n}, i \neq k, \quad q = \overline{1,m}, q \neq j. \tag{10}$$

Station s_j at point a_i is connected to any one station located at point a_k, to the right of a_i $(k > i)$ or to the right gateway s_{m+1} (11) – (12).

$$\sum_{k=i+1}^{n} \sum_{\substack{q=1 \\ q \neq j}}^{m} z_{ijkq} + z_{ij(n+1)(m+1)} = x_{ij}, \quad i = \overline{1,n}, \quad j = \overline{1,m}. \tag{11}$$

Station s_j placed at a_n has only gateway s_{m+1} from the right at place a_{n+1} (12).

$$z_{nj(n+1)(m+1)} = x_{nj} \quad j = \overline{1,m}. \tag{12}$$

Also, at least, it is connected with any one station located at point a_k to the left of point a_i $(k < i)$ or with the left gateway s_{m+1} (13) – (14).

$$z_{1j0(m+1)} = x_{ij}, \quad j = \overline{1,m}; \tag{13}$$

Station s_j placed at a_1 has only gateway s_{m+1} from the left at place a_0 (13).

$$z_{ij0(m+1)} + \sum_{k=1}^{i-1} \sum_{\substack{q=1 \\ q \neq j}} z_{ijkq} = x_{ij}, \quad i = \overline{2,n}, \quad j = \overline{1,m}. \tag{14}$$

Station s_q at point a_k is connected to another station to the right located at point a_i (15).

$$\sum_{i=k+1}^{n} \sum_{\substack{j=1 \\ j \neq q}}^{m} z_{ijkq} = x_{kq}, \quad k = \overline{1, n-1}, \quad q = \overline{1,m}; \tag{15}$$

Also, station s_q at point a_k is connected to another station to the left located at point a_i (16).

$$\sum_{i=1}^{k} \sum_{\substack{j=1 \\ j \neq q}}^{m} z_{ijkq} = x_{kq}, \quad k = \overline{2,n}, \quad q = \overline{1,m}; \tag{16}$$

Inequalities (9) - (10) and equalities (11) - (16) provide a condition for symmetry of communication between base stations located at points a_i and a_k for all i, k.

If station s_j and s_q are connected the maximal communication link distance of these placed stations must be no less than the distance between a_i and a_k, where s_i and s_q are located (17) – (18).

For $i = \overline{1,n}$:

$$z_{ijkq}(R_{jq} - (a_i - a_k)) \geq 0, \quad k = \overline{0, i-1}; \quad j = \overline{1,m}; \quad q = \overline{1,m}, q \neq j; \tag{17}$$

$$z_{ijkq}(R_{jq} - (a_k - a_i)) \geq 0, \quad k = \overline{i+1, n+1}; \quad j = \overline{1, m}; \quad q = \overline{1, m}, q \neq j. \tag{18}$$

And for cost limit C there is the following condition (19):

$$\sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} \cdot c_j \leq C. \tag{19}$$

4. NS-3 model

For checking network performance for optimal placement we build a simulation model in network simulator NS-3. In this case network has linear topology with stations with characteristics given above. Based on the results of ILP, a linear topology was designed for each solution. For traffic generation, 802.11n standard is used. Traffic is generated on each station with intensity is equal to 50 packets per second by Poisson distribution. The packet size is equal to 1500 bytes. The packet's count for simulation is 100000. The physical characteristics of stations are shown in Table 1. We measured base network characteristics: throughput, end-to-end delay, and packet loss.

The NS-3 simulation takes a lot of time. For getting accurate results we should spend a few hours. So all computations were made on cloud servers via software for parallel computing.

5. Numerical experiments

This section shows one simple case of the problem.

Given the section of length L is equal to 300 with n is equal to 7. Total budget C is equal 130. Carrier frequency f is equal to 2437 MHz. As for physical characteristics, throughput is not less than 0.5 Mbt/s and e2e-delay is not more than 0.1 second. Placement points are given as $l_i = \{29, 40, 95, 139, 181, 230, 273\}$. There are $m = 8$ base stations with parameters given in table 1. Also table contains gateways and user

BS	P^R_{tr}	G^R_{tr}	P^R_{recv}	P^r_{recv}	G^r_{recv}	c
	dBm	dBi	dBm	dBm	dBi	c.u.
1	20	5	-69	-67	5	40
2	19	5	-67	-67	5	28
3	18	5	-69	-67	5	45
4	19	5	-69	-67	6	22
5	19	5	-67	-67	5	21
6	20	5	-69	-67	5	40
7	19	5	-67	-67	5	28
8	18	5	-69	-67	5	45

Gateway	G^R_{recv}	P^R_{recv}		User device	P^r_{tr}	G^r_{tr}
	dBi	dBm			dBm	dBi
	5	-69			15	2

Table 1

Parameters of base stations, gateways and user devices.

devices parameters. User devices parameters are required to calculate coverage radius of station.

ILP problem has been solved by Optimization Toolbox MatLab. Table 2 contains all feasible integer solutions.

a_i	a_1	a_2	a_3	a_4	a_5	a_6	a_7	Coverage	Cost
Point	29	40	95	139	181	230	273	m	c.u.
Feasible solution 1	s_1	s_2	s_6	–	–	–	s_4	286	130
Feasible solution 2	s_4	–	s_5	s_7	–	–	s_2	289	99
Optimal solution	s_4	s_2	–	–	s_1	–	s_5	300	111

Table 2

ILP solution.

In Table 3 networks characteristics are shown for all solutions of ILP. All solutions satisfy requirements. Based on results simulation model optimal solution gives the best result. As we can see in Table 3 feasible solution 2 and optimal solution are similar by physical characteristics. But feasible solution 2 gives more appropriate solution by cost, although it's total coverage is worse.

	Throughput, Mbt/s	E2E Delays, s	Packet loss, %
Feasible solution 1	0.561	0.08	6.84
Feasible solution 2	0.711	0.07	7.18
Optimal solution	0.715	0.07	6.38

Table 3

NS-3 solution.

6. Conclusion

The paper considers the problem of optimal placement of the given base stations set of wireless network on a set of possible placement points to maximize the coverage area while respecting budget constraints. To estimate network performance NS-3 simulation model is used. The ILP problem and NS-3 simulation were computed via software for parallel tasks computation. All calculations are produced in cloud servers. The comparison results are given in the paper. Our code is available at https://github.com/ipu69/bsp_ns3.

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Размещение базовых станций беспроводной сети с линейной топологией и оценка производительности сети с помощью симулятора NS-3

А. А. Мухтаров[*], **А. М. Соколов**[*]

[*] *Лаборатория 69,*
ИПУ РАН,
ул. Профсоюзная, д. 65, Москва, Россия, 117997

Email: `mukhtarov.amir.a@gmail.com`, `aleksandr.sokolov@phystech.edu`

Данная статья посвящена проблеме размещения базовых станций при проектировании беспроводной сети связи. Сформулирована задача оптимального размещения базовых станций на контролируемом участке с линейной топологией. Цель задачи - максимизация зоны покрытия, находящейся под контролем развернутых базовых станций, при соблюдении бюджетных ограничений. В статье анализируются особенности технологической постановки. Предлагается постановка задачи в виде целочисленного линейного программирования (ЦЛП).

По результатам расчета задачи оптимизации для отобранных базовых станций, а также полученных координат их размещения с целью соблюдения условий технологических ограничений проводится оценка производительности сети с помощью имитационной модели на симуляторе NS-3. Для оценки характеристик использовалось не только оптимальное размещение, но и все полученные целлочисленные решения в ходе движения по дереву поиска задачи.

Так как две последовательные задачи: ЦЛП и имитационное моделирование в NS-3 сами по себе ресурсоёмки по времени, комплексный расчет проводился с помощью программного комплекса для параллельного выполнения задач. Все вычисления производились с использованием облачных технологий. В работе приведены результаты сравнения комплексной задачи.

Ключевые слова: беспроводные сети, задача оптимизации, имитационная модель.