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Multi-Objective Planning and Optimization for WiMAX Multi-Hop Site Placement: Case Study in Nakhon Ratchasima City, Thailand

Chitapong Wechtaisong#1, Chutima Prommak*2, Ekkaluk Eaksook@3

#*Faculty of Industrial Technology, Nakhon Ratchasima Rajabhat University*
340 Suranarhai Rd., Naimuang, Muang, Nakhon Ratchasima, 30000, Thailand
[1]chitapong@nrru.ac.th

**Institute of Engineering, Suranaree University of Technology*
111 University Rd., Suranaree, Muang, Nakhon Ratchasima, 30000, Thailand
[2]cprommak@g.sut.ac.th

@*Advanced Info Service PLC. (Regional Operation North-East)*
399 Moo 3, Mittraphap Rd., Bankoh, Muang, Nakhon Ratchasima, 30000, Thailand
[3]ekkaluke@ais.co.th

***Abstract*— Wireless Interoperability for Microwave Access (WiMAX) is the interesting wireless broadband technology which has not ever been commercially operated in Thailand. This paper presents a simulation of planning and optimization for WiMAX multi-hop access network which deploys relay station (RS) to extend the coverage area of base station (BS) in a real area. Site placement is an important process for designing wireless access networks in order to optimize the investment cost and quality of services. The proposed multi-objective planning and optimization model aims to assign the optimal number and location of base stations and relay stations considering co-location sites with existing GSM mobile site. The city area of Nakhon Ratchasima, Thailand is chosen for being study area. Integer Linear Programming is used for formulating the planning and optimization model which aims to minimize the BSes and RSes installation cost and maximize the service coverage under signal strength guarantee constraints simultaneously. Numerical network planning results demonstrate that the proposed model can achieve overall service area with economical implementation cost. In addition, it can efficiently serve users in the target service area under the specified budget limitation.**

***Keywords*— WiMAX, multi-objective optimization, multi-hop access network, site placement**

I. INTRODUCTION

WiMAX (Wireless Interoperability for Microwave Access) network technology has become potential solutions to bring broadband internet access to people in the remote area where a wired network infrastructure cannot reach. With the support of the IEEE 802.16j standard, one can deploy the network topology using multi-hop relay station (RS) to enhance services of the base station (BS). As illustrated in Figure 1, RSes can provide coverage extension to the cell boundary area, the shadowing area and the coverage-hole area. To enable network operators to provide low-cost coverage with the quality of services guarantee, there is a need for an efficient network design.

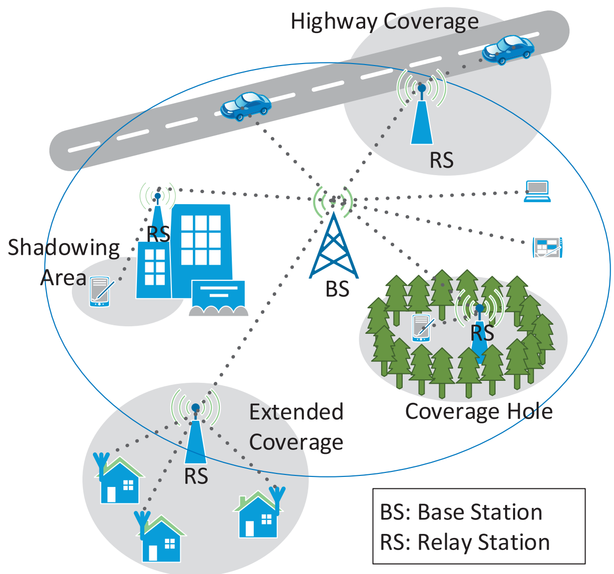

Fig. 1 Relay station deployment

In WiMAX network planning, base station and relay station placement is an important process to optimize investment cost and quality of services. If the objective of the planning is to increase the network coverage and the signal strength [1], many sites would be placed close to each other. This can improve the quality of services. However, it is not good in terms of investment cost. In contrast, the economical objective can be attained by restricting distances between sites [2, 3] but signal strength problem can occur. Hence, there is a tradeoff between investment cost and the quality of services in which many research groups are interested.

Our existing paper presents the multi-objective planning and optimization problem for BSes placement in a simulated study area [4]. For more economical investment of the access network installation cost, the multi-hop relay station topology should be incorporated into the network structure. Therefore, the multi-objective planning and optimization model that includes both BSes and RSes placement is needed.

In this study, we examined the planning of WiMAX access network in Nakhon Ratchasima city area in which the site placement for BSes and RSes are considered. The proposed optimization model was formulated as an integer linear programming (ILP) problem which is usually adopted by other existing research works when dealing with the facility location problems. Specifically, the weighted sum method (WSM) was proposed here to solve the multi-objective optimization problem by combining two objectives and transforming them to one function to simplify the solution of searching process.

The rest of paper is organized as follows. We review existing research works in Section II. Section III presents the problem definition and mathematical formulation. We present the numerical experiment in Section IV and conclude the paper in Section V.

II. RELATED WORKS

There are many existing studies on the network planning and performance improvement for wireless networks. In [5], focus on adaptive cross-layer bandwidth scheduling strategy for hierarchical cellular networks. In addition, WiMAX baseband transceiver was implemented on multi-core software define radio platform [6]. Furthermore, there are several research works paid attention to wireless network planning schemes. For example, the studies on the wireless network planning for mobile cellular networks are presented in [7] and [8]. The practical network planning and implementation of WiMAX along with performance evaluation and analysis are presented in [9-11]. However, these research studies interested in real network performances. The network planning was done manually and lack of mathematical formulation to optimize the network configuration.

Recent research works formulated mathematical equations for optimizing WiMAX access network planning. In [2] and [3] presented network design and optimization model for WiMAX access networks which effectively minimize investment cost by reducing the number of BS and relay station while guarantied quality of receive signal strength for user's equipment. Moreover, [1] presented planning and optimization in WiMAX access network that can enhance network service coverage under budget limitation. Although, each of these literature works considered one side of network optimization problem and cannot support whole network planning problem. Therefore, multi-objective planning and optimization problem is needed.

Our previous research work focused on multi-objective planning and optimization problem for only BSes placement [12]. Besides BSes installation, implementing RSes is the significant option which can increase the quality of service in the planning area with optimal cost. This research considers both BSes and RSes implementation in WiMAX access network. Our multi-objective mathematical model is developed from the existing mathematical model for support both BSes and RSes installation.

III. MULTI-OBJECTIVE-OBJECTIVE OPTIMIZATION

A. *Problem Definition*

This research presents the method for considering locations for BSes and RSes placement from candidate sites along with the effect of weighted value with optimization result from two opposite objectives. The first objective was minimizing investment cost that considers from [2, 3] and another one was enhancing network service coverage from [1]. ILP was applied to formulate network planning problem. We used WSM to combine two opposite ILP objective function for easier calculation.

In the network design model, we considered that every BSes have the same infrastructure and transmitting power. In addition, every RSes are considered same as each other too. Demand points (DPs) were represented demand of users in the study area. The DPs can connect with the network through BS directly or via only one RS that mean maximum hop from DPs to BSes is not more than two. We guarantee the quality of service in terms of receive signal strength by threshold (Pt).

B. *Problem Formulation*

The WiMAX network planning problem in this research was formulated as an ILP model which consisted of three necessary parts. There were decision variables, objective functions and constraints. This model is popular to use as optimization tools for many research works. Table I describes the notation used in the proposed model.

There were five binary decision variables in our study. Installation of BS and RS sites were represented by β_j and γ_i respectively. They equal 1 if BS or RS was installed at candidate position j or i. In contrast, they equal 0 if candidate position j or i were not chosen to install site. In addition, connection of DPs to BSes, DPs to RSes and RSes to BSes were represented by u_{hj}, v_{hi} and w_{ij} respectively. They equal 1 if connections between their pairs were established and equal 0 if there were no connection.

We considered two different objective functions for effectively cover many perspectives of network design problem. The first objective function aimed to minimize the network cost in terms of BS and RS installation cost which can be written as objective function [1]. The second objective function aimed to maximize coverage in terms of number of DPs as show in the objective function [2]. These objective functions would be collaborated with each other by WSM that would be explained in next topic.

TABLE I : Definition of Notation Used in Proposed Model

Notations	***Definitions***
Sets:	
B	A set of candidate sites to install base stations (BSes); (1,2,3,..,b) □ B
R	A set of candidate sites to install relay stations (RSes); (1,2,3,..,r) □R
T	A set of demand points (DPs); (1,2,3,..,t) □ T

TABLE I : Definition of Notation Used in Proposed Model (continued)

Notations	Definitions
Decision variables:	
β_j	A binary {0, 1} variable that equals 1 if the BS is installed at site *j*, $j \in B$; 0 otherwise
γ_i	A binary {0, 1} variable that equals 1 if the RS is installed at site *i*, $i \in R$; 0 otherwise
u_{hj}	A binary {0, 1} variable that equals 1 if the DP *h* is assigned to BS *j*, $h \in T$ and $j \in B$; 0 otherwise
v_{hi}	A binary {0, 1} variable that equals 1 if the DP *h* is assigned to RS *i*, $h \in T$ and $i \in R$; 0 otherwise
w_{ij}	A binary {0, 1} variable that equals 1 if the RS *i* is assigned to BS *j*, $i \in R$ and $j \in B$; 0 otherwise
Constant parameters:	
C_b	Cost to install one base station
C_r	Cost to install one relay station
P_{hj}	The signal strength that a DP *h* receives from BS *j*, $h \in T$ and $j \in B$
P_{hi}	The signal strength that a DP *h* receives from RS *i*, $h \in T$ and $i \in R$
P_{ij}	The signal strength that a RS *i* receives from BS *j*, $i \in R$ and $j \in B$
Pt	The received signal strength threshold for DPs

We defined the network design requirement to a set of constraints. There were two groups of mathematical equations that represent the purpose of radio network planning. The first group is the constraints that guarantee network service coverage. Equation (3) and (4) are the constraints that ensure DPs connect with only installed BSes and RSes. The guarantee of receive signal strength from installed BSes and RSes for each DPs defined in equation (5) and (6) respectively. The second group was constraints that enforce connection between BSes and RSes. Equation (7) ensures RSes connect with only one parent BS. Equation (8) is the constraint that ensures RSes connect with only installed BSes. The guarantee of received signal strength for each RSes defined in equation (9).

Objective functions:

$$minimize \sum_{j=1}^{b} C_b \times \beta_j + \sum_{i=1}^{r} C_r \times \gamma_j \qquad (1)$$

$$maximize \sum_{j=1}^{b} u_{hj} + \sum_{i=1}^{r} v_{hi} \qquad , \forall h \epsilon\, T \qquad (2)$$

Subject to:

C1: Network service coverage

$$u_{hj} \le \beta_j \qquad , \forall h \epsilon T, j \epsilon B \qquad (3)$$

$$v_{hi} \le \gamma_i \qquad , \forall h \epsilon T, i \epsilon R \qquad (4)$$

$$u_{hj}(P_{hj} - Pt) \ge 0 \qquad , \forall h \epsilon T, j \epsilon B \qquad (5)$$

$$v_{hi}(P_{hi} - Pt) \ge 0 \qquad , \forall h \epsilon T, i\, \epsilon R \qquad (6)$$

C2: BS-RS connections

$$\sum_{j=1}^{b} w_{ij} = \gamma_i \qquad , \forall i \epsilon R \qquad (7)$$

$$w_{ij} \le \beta_j \qquad , \forall i \epsilon R, j \epsilon B \qquad (8)$$

$$v_{hi}(P_{hi} - Pt) \ge 0 \qquad , \forall i \epsilon R, j \epsilon B \qquad (9)$$

C. Combination of Objective Functions

In this topic, we developed multi-objective optimization mathematical equation for ILP. The tradeoff between two opposite objective function is considered. There were objectives that minimize network implementation cost and increase network coverage. The WSM is the necessary tool for study tradeoff between two different objective functions.

TABLE II : Notation Used in weighted Sum Method

Notations	***Definitions***
W_1	Weighted value of objective function 1; $W_1 \in [0,1]$
W_2	Weighted value of objective function 2; $W_2 \in [0,1]$
$F_1(x)$	Normalized objective function 1
$F_2(x)$	Normalized objective function 2
f_1^{min}	Minimize value of objective function 1
f_1^{max}	Maximize value of objective function 1
f_2^{min}	Minimize value of objective function 2
f_2^{max}	Maximize value of objective function 2

Two objectives were transformed to one objective format as shown in equation (10). Normalization equation is represented by equation (11) and (12). We normalize both objective functions before collaborating each other because of releasing different units [13]. The weighted values were used for comparing the tradeoff results. To divisibly combine two different objectives, the maximization objective of equation (2) was reversed to minimization objective in equation (13) which *t* was the amount of total DPs in study area however it stilled be same as original meaning. The final equation of multi objective optimization by WSM is shown in (14).

Weighted sum method functions:

$$minimize\ Z = W_1 F_1(x) + W_2 F_2(x) \qquad (10)$$

Normalize functions:

$$F_1(x) = \frac{f_1(x) - f_1^{min}}{f_1^{max} - f_1^{min}} \qquad (11)$$

$$F_2(x) = \frac{f_2(x) - f_2^{min}}{f_2^{max} - f_2^{min}} \qquad (12)$$

Reverse form of equation (2):

$$minimize\ t - (\sum_{j=1}^{b} u_{hj} + \sum_{i=1}^{r} v_{hi}) \qquad , \forall h \epsilon T \qquad (13)$$

Final WSM multi-objective function:

$$minimize\ W_1\left[\frac{\left(\sum_{j=1}^{b} C_b \times \beta_j + \sum_{i=1}^{r} C_r \times \gamma_j\right) - f_1^{min}}{f_1^{max} - f_1^{min}}\right]$$
$$+W_2\left[\frac{\left(t - \left(\sum_{j=1}^{b} u_{hj} + \sum_{i=1}^{r} v_{hj}\right)\right) - f_2^{min}}{f_2^{max} - f_2^{min}}\right]$$
$$,\forall h \epsilon T \quad (14)$$

IV. NUMBERICAL EXPERIMENTS

A. Parameter Setup

TABLE III : Parameters Used in Numerical Experiments

Parameters	Value
Height of BSes	40 m
Height of RSes	12 m
Height of DPs	1.5 m
Transmitted Power (BS)	43 dBm
Transceived antenna gain (BS)	15 dBi
Transceived antenna gain (RS)	7 dBi
Transceived antenna gain (DP)	0 dBi
Frequency	3.5 GHz
Terrain type	A
Bandwidth	10 MHz
Cost of base station installation	120,000 $
Cost of relay station installation	48,000 $

In numerical experiments, we considered 8.7km × 5.3km area of Nakhon Ratchasima city as shown in Figure 2. There are 53 candidate positions represent by blue triangles. The number of DPs was 207 which located many users such as academic institutes, department stores, offices and temples. We used the Stanford University Interim (SUI) model which was recommended by the IEEE 802.16 to obtain the path loss in WiMAX networks [14]. Received signal threshold at DPs was set at -91 dBm [15]. Table III shows the parameters used in numerical experiments [16]. We considered existing GSM sites for being positions of candidate BS and RS sites over the service area. Using the existing infrastructures of GSM sites, it can save the investment cost such as radio tower, electricity system, transmission system and rental fee.

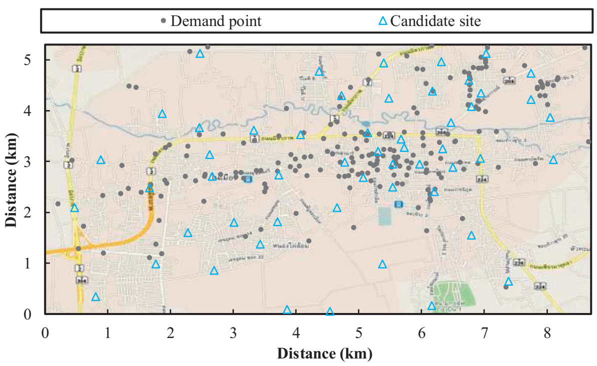

Fig. 2 Candidate sites and demand points on Nakhon Ratchasima city map. [12]

B. Numerical Results

The numerical experiments were implemented with the ILOG-OPL development studio. The ILP problems were solved with CPLEX 12.7 optimization solver. The computation was run on an Intel Core i5-6600 3.30 GHz and 16 GB of RAM.

TABLE IV : Results of Network Planning Experiments

Scenario	W_1	W_2	BS Site	RS Site	Coverage DPs (%)	Cost (M$)
0	0.00	1.00	11	5	100.00	1.56
1	0.05	0.95	11	5	100.00	1.56
2	0.10	0.90	9	5	98.55	1.32
3	0.15	0.85	8	4	96.62	1.15
4	0.20	0.80	8	2	92.27	1.06
5	0.25	0.75	6	2	90.34	0.81
6	0.30	0.70	5	3	86.96	0.74
7	0.35	0.65	5	1	85.51	0.65
8	0.40	0.60	4	1	80.68	0.53
9	0.45	0.55	4	1	74.40	0.53
10	0.50	0.50	4	0	74.88	0.48
11	0.55	0.45	4	0	76.81	0.48
12	0.60	0.40	3	0	66.18	0.36
13	0.65	0.35	2	0	52.17	0.24
14	0.70	0.30	1	0	52.17	0.24
15	0.75	0.25	1	0	33.82	0.12
16	0.80	0.20	1	0	33.82	0.12
17	0.85	0.15	0	0	0.00	0.00
18	0.90	0.10	0	0	0.00	0.00
19	0.95	0.05	0	0	0.00	0.00
20	1.00	0.00	0	0	0.00	0.00
[12]	0.05	0.95	15	-	100.00	1.80

W_1 and W_2 represent weighted values of objective function 1 and objective function 2 respectively. Weighted values were set to change 0.05 for each step, W_1 increases from 0.0 to 1.0 and W_2 decreases from 1.0 to 0.0, to consider the tradeoff results between conflict objectives. The numerical results of WiMAX network planning in terms of site placement by ILP and WSM are shown in Table IV. To compare with the existing work, we added the planning result of [12] at the last line of Table IV. In addition, Figure 3 shows the result of scenario 1 when set W_1 and W_2 at 0.05 and 0.95 respectively which can guarantee 100% received signal to DPs in the service area.

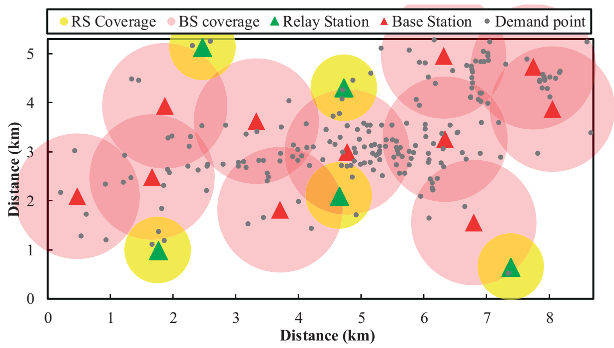

Fig. 3 100% coverage of DPs from installed sites.

C. Analysis and Discussion

In Table IV, from 53 candidate sites for installing BSes and RSes, our purposed scheme with weighted value of scenario 1 uses only 11 BSes and 5 RSes to serve WiMAX signal for overall DPs in service area. It can save 13.3% of installation budget comparing with the existing [12] scheme which install only BSes (15 BSes installed from co-location with existing GSM sites). Installation cost and percent coverage of DPs are related with W_2. In the other hand, they are inversely related with W_1.

Figure 4 shows percent coverage of DPs versus investment cost in each scenario. The trend of percent coverage is decreasing related to decreasing of installation cost. When considering scenario 5, service coverage can support 90.34% of DPs by saving 45% of investment cost when comparing with scenario 1. For this reason, this can be an option for a network planner who has the limitation in terms of investment budget.

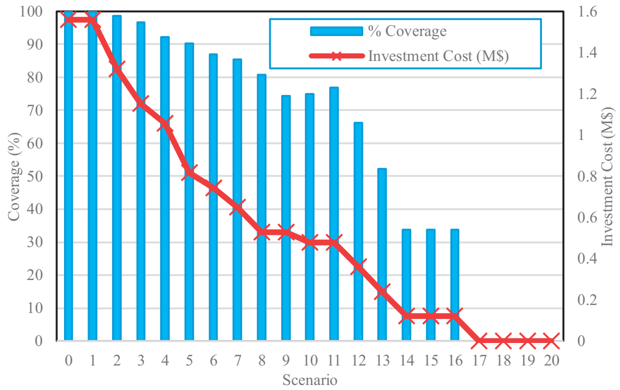

Fig. 4 Coverage and investment cost of each weighted scenario.

Figure 5 shows cumulative distribution functions (CDF) graph of received signal strength at DPs. We select scenario 1, 5, 10 and 15 and the existing single-hop access network [12] which W_1,W_2 were set at (0.05,0.95), (0.25,0.75), (0.5,0.5), (0.75,0.25) and (0.05,0.95) to compare effect of deploying multi-hop access network using RSes and weighted value with network planning result in terms of received signal strength. Scenario 1 can serve the highest received signal strength to DPs in service area which its signal level is similar to the existing single-hop network [12] under the same weighted value (0.05,0.95). Received signal strength of scenario 5, 10 and 15 are lower from that in scenario 1 respectively. As a result, we concluded that the weighted values can be chosen depending on desire of network planner which focuses on quality of service or limitation of installation budget.

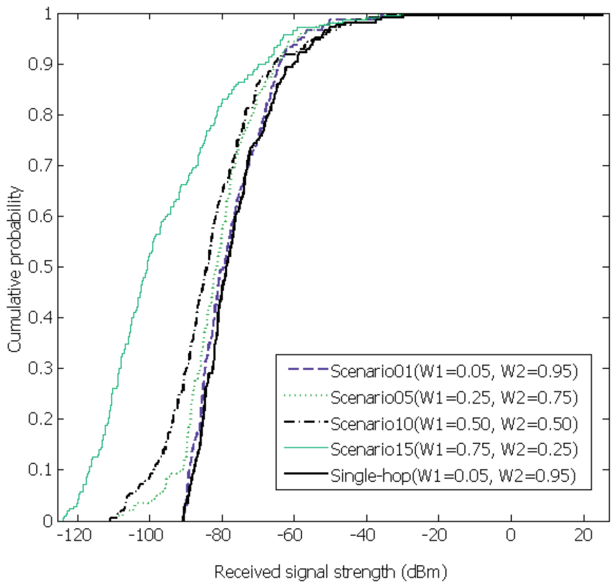

Fig. 5 CDF graph of received signal strength.

V. CONCLUSIONS

This study presents a novel mathematical model for an efficient optimization planning of WiMAX multi-hop access network site placement for the real area. We formulate the problem as integer linear programming problem with consideration of two opposite objectives which are to minimize the installation cost and maximize service coverage. In particular, we use weighted sum method to transform two objectives into single objective and compare the effect of weighting value in each one. We consider city area of Nakhon Ratchasima, Thailand, for doing the experiment. In addition, the proposed model can determine optimal numbers and locations for BSes and RSes installation. The numerical results illustrate that our WiMAX site placement planning model can achieve overall coverage in the study area and save 13.3% of installation budget compared to the existing research work. In case of limited budget, our model can produce optimized configuration which still achieves most of coverage. Our future research will consider the optimal position for site placement to increase average received signal for users in the study area.

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