# MULTI-OBJECTIVE PLANNING AND OPTIMIZATION FOR WIMAX SITE PLACEMENT: CASE STUDY IN NAKHON RATCHASIMA CITY, THAILAND

**Chitapong Wechtaigsong[1,2], Chutima Prommak[3] and Ekkaluk Eksook[4]**
**[1]Faculty of Industrial Technology, Nakhon Ratchasima Rajabhat University**
**[2]Graduate School of Engineering and Science, Shibaura Institute of Technology**
**[3]Institute of Engineering, Suranaree University of Technology**
**[4]Regional Operation (Northeast), Advanced Info Service PLC.**
**chitapong@nrru.ac.th, cprommak@sut.ac.th, 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 access network in a realistic area. The proposed multi-objective planning and optimization model aims to assign the optimal number and location of base stations mainly considering co-location sites with existing GSM mobile base stations and considering new sites installation for only necessary case. 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 installation cost and maximize the service coverage under signal strength guarantee constrains 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.

## 1. INTRODUCTION

In WiMAX network planning, base station (BS) 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 (Prommak and Wechtaison, 2011), 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, economical objective can be attained by restricting distances between sites (Prommak and Wechtaison, 2010a; Prommak and Wechtaison, 2010b), 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 previous paper presents the multi-objective planning and optimization problem for BSes placement in a simulated study area where position of sites and users are uniformly spread (Wechtaisong, et al., 2014). In the other hand, there are limited conditions for practical site installation. Network planners usually consider co-location with existing operated sites for installing the more modern technology equipment to refrain new facility investment such as land rental fee, tower, electrical system and transmission link. Candidate positions for installing sites and positions of users in the realistic area may be different from random positions in the simulated area. Therefore, the multi-objective planning and optimization model for BSes placement which considers candidate sites from both co-location sites and new sites 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 is considered. The proposed optimization model was formulated as an Integer linear programming (ILP) problem which is usually adopted by other existing research works when deal 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 searching process.

The rest of paper is organized as follows. Section 2 presents the problem definition and mathematical formulation. We present the numerical experiment in Section 3 and conclude the paper in Section 4.

## 2. MULTI-OBJECTIVE OPTIMIZATION

### 2.1 PROBLEM DEFINITION

In this research presents the method for considering location for placement BSes from two types of candidate sites along with effect of weighted value with optimization result from two opposite objectives. The first objective was to minimize investment cost that considers from (Prommak and Wechtaison, 2010a; Prommak and Wechtaison, 2010b) and another one was to enhance network service coverage from (Prommak and Wechtaison, 2011). ILP was applied to formulate network planning problem. We used WSM to combine two opposite ILP objective functions for easier calculation.

In the network design model, we consider candidate positions for installing BSes by using co-location with existing GSM sites or installing new sites. In addition, demand points (DPs) were represented demand of users in the study area. We guarantee quality of service in terms of received signal strength by threshold (*Pt*) and SNR.

## 2.2 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 be used as optimization tools for many research works. Table 1 describes the notation used in the proposed model.

Table 1 Definition of Notation Used in Proposed Model

| Notations | Definitions |
|---|---|
| **Sets:** | |
| $B_c$ | A set of candidate positions from co-location sites to install base stations (BSes); $(1,2,3,..,b_c) \subset B_c$ |
| $B_n$ | A set of candidate positions from new sites to install base stations (BSes); $(1,2,3,..,b_n) \subset B_n$ |
| $T$ | A set of demand points (DPs); $(1,2,3,..,t) \subset T$ |
| **Decision variables:** | |
| $\beta_j$ | A binary {0, 1} variable that equals 1 if the BS is installed at co-location site $j$, $j \in B$; 0 otherwise |
| $\gamma_i$ | A binary {0, 1} variable that equals 1 if the BS is installed at new site $i$, $i \in R$; 0 otherwise |
| $u_{hj}$ | A binary {0, 1} variable that equals 1 if the DP $h$ is assigned to co-location 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 new site BS $i$, $h \in T$ and $i \in R$; 0 otherwise |
| **Constant parameters:** | |
| $C_n$ | Cost to install base station by using new site |
| $C_c$ | Cost to install base station by using co-location site |
| $P_{hj}$ | The signal strength that a DP $h$ receives from co-location site BS $j$, $h \in T$ and $j \in B$ |
| $P_{hi}$ | The signal strength that a DP $h$ receives from new site BS $i$, $h \in T$ and $i \in R$ |
| $Pt$ | The received signal strength threshold for DPs |
| $Pn$ | The signal strength of thermal noise |
| $SNR$ | The signal to noise ratio threshold |

There were four binary decision variables in our study. Installation of BS in co-location and new sites were represented by $\beta_j$ and $\gamma_i$ respectively. It equals 1 if BS was installed at candidate position *j* or *i.* In contrast, it equals 0 if candidate position *j* or *i* was not chosen to install site. In addition, Connection of DPs to co-location site and new site BSes were represented by $u_{hj}$ and $v_{hi}$ 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 different side of network design problem. The first objective function aimed to minimize the network cost in terms of BS installation cost which can be written as objective function (1). The second objective function aimed to maximize service coverage in terms of number of DPs as show in objective function (2). These objective functions would be collaborated with each other by WSM that would be explained in the next topic.

We defined the network design requirement to a set of constraints. There were mathematical equations which represent purpose of radio network planning. Equation (3) and (4) are constraints that ensure DPs connect with only installed co-location site BSes or new site BSes. The guarantee of received signal strength from installed co-location site and or new site BSes for each DPs defined in equation (5) and (6) respectively. The guarantee of signal to noise ratio for each DPs defines in equation (7) and (8).

Objective functions:

$$minimize \sum_{j=1}^{b_c} C_c \times \beta_j + \sum_{i=1}^{b_n} C_n \times \gamma_i \tag{1}$$

$$maximize \sum_{j=1}^{b_c} u_{hj} + \sum_{i=1}^{b_n} v_{hi} \qquad , \forall h \epsilon\, T \tag{2}$$

Subject to:

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

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

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

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

$$u_{hj}(P_{hj} - Pn) \ge SNR \qquad , \forall h \epsilon T, j \epsilon B \tag{7}$$

$$v_{hi}(P_{hi} - Pn) \ge SNR \qquad , \forall h \epsilon T, i\, \epsilon R \tag{8}$$

## 2.3 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 a necessary tool for study tradeoff between two difference objective functions. We explained details of combination two objective functions by WSM method in our existing paper (Wechtaisong, et al., 2014).

To divisibly combine two different objectives, the maximization objective of equation (2) was reversed to minimization objective in equation (9) which *t* was an amount of total DPs in service area however it still was the same as original meaning. The final equation of multi -objective optimization by WSM is shown in (10).

Reverse form of equation (2):

$$minimize\ \ t - (\sum_{j=1}^{b_c} u_{hj} + \sum_{i=1}^{b_n} v_{hi}) \qquad , \forall h \epsilon T \tag{9}$$

Final WSM multi-objective function:

$$minimize\ W_1 \left[ \frac{\left(\sum_{j=1}^{b_c} C_c \times \beta_j + \sum_{i=1}^{b_n} C_n \times \gamma_j\right) - f_1^{\,min}}{f_1^{\,max} - f_1^{\,min}} \right] + W_2 \left[ \frac{\left(t - \left(\sum_{j=1}^{b_c} u_{hj} + \sum_{i=1}^{b_n} v_{hj}\right)\right) - f_2^{\,min}}{f_2^{max} - f_2^{min}} \right] \qquad , \forall h \epsilon T \tag{10}$$

## 3. NUMERICAL EXPERIMENTS

### 3.1 PARAMETER SETUP

In numerical experiments, we considered 8.7km x 5.3km area of Nakhon Ratchasima city as shown in Figure 1. There are 53 and 40 candidate positions from co-location site and new site respectively. 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 (Erceg, et al., 2001). Received signal threshold at DPs was set at -91 dBm and SNR was set at 9 dB(Eira, J. P., & Rodrigues, A. J. ,2009). Table 2 shows the parameters used in numerical experiments (WiMAX Forum, 2010). We considered existing GSM site for co-location site. In addition, positions of candidate new sites were defined in grid pattern over service area.

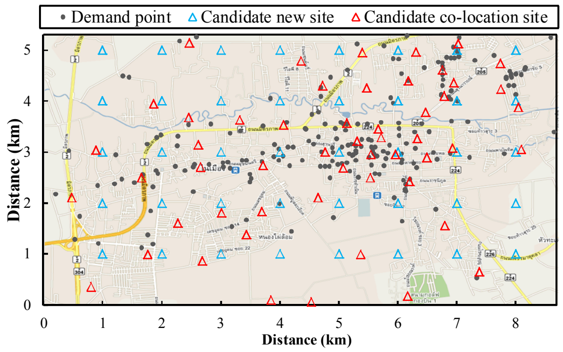


Fig. 1. Candidate sites and demand points on Nakhon Ratchasima city map.

Table 2 Parameters Used in Numerical Experiments

| Parameters | Value |
|---|---|
| Height of BSes | 40 m |
| Height of DPs | 1.5 m |
| Transmitted Power (BS) | 43 dBm |
| Transceived antenna gain (BS) | 15dBi |
| Transceived antenna gain (DP) | 0 dBi |
| Frequency | 3.5 GHz |
| Terrain type | A |
| Bandwidth | 10 MHz |
| Cost of co-location site base station | 120,000 $ |
| Cost of new site base station | 170,000 $ |

### 3.2 NUMERICAL RESULTS

The numerical experiments were implemented with the ILOG-OPL development studio likewise in (Wechtaisong, et al., 2014). The ILP problems were solved with CPLEX 5.2 optimization solver. The computation was run on an Intel Centrino Core2 Duo Processor 2.0 GHz and 2.0 GB of RAM.

$W_1$ 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 3. In addition, Figure 2 shows 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 service area.

### 3.3 ANALYSIS AND DISCUSSION

In table 3, from 53 and 40 candidate co-location and new sites respectively for installing BSes, our purposed scheme with weighted value of scenario 1 uses only 13 BSes (10 co-location and 3 new sites) to serve WiMAX signal for overall DPs in service area. Installation cost and percent coverage of STPs are related with $W_2$. In the other hand, they are inversely related with $W_1$.

Table 3 Results of Network Planning Experiment

| Scenario | $W_1$ | $W_2$ | Co-location Site | New Site | Coverage DPs (%) | Cost (M$) |
|---|---|---|---|---|---|---|
| 0 | 0.00 | 1.00 | 55 | 40 | 100.00 | 13.40 |
| 1 | 0.05 | 0.95 | 10 | 3 | 100.00 | 1.71 |
| 2 | 0.10 | 0.90 | 9 | 2 | 98.55 | 1.54 |
| 3 | 0.15 | 0.85 | 8 | 2 | 97.58 | 1.42 |
| 4 | 0.20 | 0.80 | 8 | 1 | 95.65 | 1.30 |
| 5 | 0.25 | 0.75 | 6 | 1 | 91.30 | 1.13 |
| 6 | 0.30 | 0.70 | 6 | 0 | 86.96 | 0.72 |
| 7 | 0.35 | 0.65 | 6 | 0 | 86.96 | 0.72 |
| 8 | 0.40 | 0.60 | 5 | 0 | 82.61 | 0.72 |
| 9 | 0.45 | 0.55 | 4 | 0 | 76.81 | 0.48 |
| 10 | 0.50 | 0.50 | 4 | 0 | 76.81 | 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 | 2 | 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 |

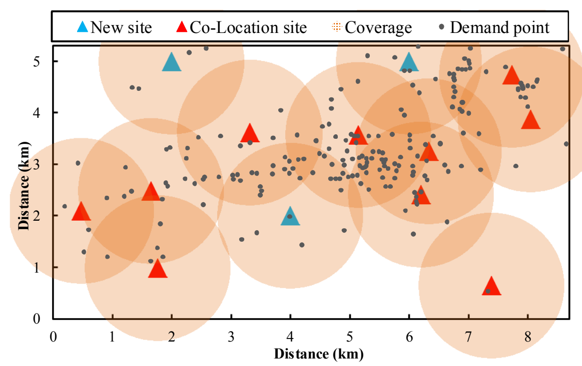


Fig. 2. 100% coverage of DPs from installed sites.

Figure 3 shows percent coverage of DPs versus investment cost in each scenario. Trend of percent coverage is decreasing related to decrease of installation cost. When consider scenario 5, service coverage can support 91.3% of DPs by saving 34% of investment cost when comparing with scenario 1. For this reason, this can be an option for a network planner who has limitation in terms of capital budget.

Figure 4 shows cumulative distribution functions(CDF) graph of received signal strength at DPs. We select scenario 1, 5, 10 and 15 which $W_1$,$W_2$ were set at (0.05,0.95), (0.25,0.75), (0.5,0.5) and (0.75,0.25) to compare effect of weighted to result of network planning. Scenario 1 can serve the highest received signal strength to DPs in service area. 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.

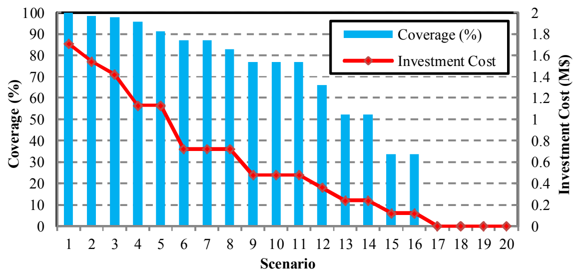


Fig. 3. Coverage and investment cost of each weighted scenario.

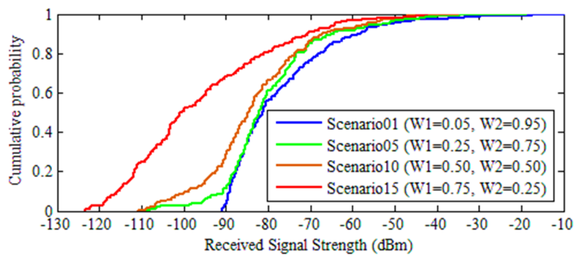


Fig. 4. Cumulative distribution function (CDF) graph of received signal strength which DPs receive from network.

## 4. CONCLUSION

This study presents a novel mathematical model for an efficient optimization planning of WiMAX site placement for realistic 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 effect of weighting value in each one. We consider city area of Nakhon Ratchasima, Thailand, for doing experiment. In addition, the proposed model can determine optimal numbers and locations for BSes installation. The numerical results illustrate that our WiMAX site placement planning model can achieve overall coverage in study area. In case of limited budget, our model can produce optimized configuration which still achieve almost coverage.

## REFERENCES

Eira, J. P., & Rodrigues, A. J. (2009)., Analysis of WiMAX data rate performance, *Lisbon Instituto de Telecomunicaçốes /Instituto Superior, Technical University of Lisbon*, 2009.

Erceg V., Hari K.V.S., Smith M.S., Baum D.S., Sheikh K.P., Tappenden C., Costa J.M., Bushue C., Sarajedini A., Schwartz R., Branlund D., Kaitz T., Trinkwon D., Channel Models for Fixed Wireless Applications, *IEEE 802.16 Broadband Wireless Access Working Group*, 2001

Prommak C. and Wechtaison C., WiMAX Network Design and Optimization Using Multi-hop Relay Stations, *the 10th International Conference on Applied Informatics and Communications (AIC)*, pp. 75-80, 2010a.

Prommak C. and Wechtaison C., WiMAX Network Design for Cost Minimization and Access Data Rate Guarantee Using Multi-hop Relay Stations. *International Journal of Communications, vol4*: pp.36-46, 2010b.

Prommak C. and Wechtaison C., On the quality of service optimization for WiMAX networks using multi-hop relay stations. *Communication in Computer and Information Science, Springer-Verlag Berlin Heidelberg,* pp.93-106, 2011.

Upase B., Hunukumbure M., Dimensioning and cost analysis of multihop-relay-enabled WiMAX networks. *Fujitsu Science Technology Journal,* vol.43, pp.303-307, 2008.

Wechtaisong C., Sutthitep T., Prommak C. Multi-objective planning and optimization for base station placement in WiMAX network, *the 11th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON2014),* pp. 1-4, 2014.

WiMAX Forum., Requirement and Recommendations for Multi-hop Relay profile of WiMAX networks, pp. 1-35, 2010.

## ACKNOWLEDGEMENT

The authors would like to thanks Assoc. Prof. Hiroaki Morino and Prof. Atsuko K. Yamazaki at Shibaura Institute of Technology for their useful advice. We also would like to extend our gratitude to the Wireless Communication Laboratory, Suranaree University of Technology for their support throughout this study.

**Chitapong Wechtaisong** received B.Eng (2006) and M.Eng (2011) in Telecommunication Engineering from Suranaree University of Technology, Thailand. Currently he is a teaching staff of Faculty of Industrial Technology, Nakhon Ratchasima Rajabhat University, Thailand.

**Chutima Prommak** received B.Eng (Hons) in Electrical Engineering from Khon Kaen University, Thailand in 1992. She received M.Sc. and Ph.D. in Telecommunications from University of Colorado at Boulder, CO, USA in 1998 and University of Pittsburgh, PA, USA in 2004, respectively. Currently she is an assistant professor in Suranaree University of Technology, Thailand.

**Ekkaluk Eksook** received B.Eng (2001) in Telecommunication Engineering from King Mongkut's Institute of Technology Ladkrabang, Thailand. He received M.Eng (2009) in Telecommunication Engineering from Suranaree University of Technology, Thailand. Currently he is an engineer specialist of Regional Operation (Northeast), Advanced Info Service PLC., one of the largest mobile phone network operators in Thailand.