Location and Strengthening of Cellular Network Sites in order to Maximize the Net Revenue and Coverage Space in Critical Situation

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Abstract: Mobile phone sites location and coverage in critical situation are one of the most important issues in set covering location. This paper discusses location and strengthening of cell phone sites so as to maximize service coverage and maximize the net revenue generated by each customer for each sites by considering emergency coverage. In addition, the proposed method provides efficient solution as compared to customary method. The model is applied to region in Iran; this numerical experiment demonstrates the significance and applicability of the proposed method as well as customary method.
Keywords: Strengthen; cell – phone sites; critical situation; coverage

1 INTRODUCTION

Location problem analyses capability of one area such as having suitable and enough land, and optimizes special objectives by considering constraint for choosing suitable areas. These objectives maximize the number of customer who is coverage after destruction of site, minimize loss communication after natural disaster, provide equitable services to customers, taking the largest market, etc. the severity of indecorous location damage is obvious to everyone. Sometimes compensation of damage is impossible.

Natural disasters such as earthquakes, hurricanes, flooding, landslides and volcanic eruptions have a strong impact on roads and bridges, communication systems, The supply of electricity and the availability of other utilities. In such crisis situation, it is difficult to supply emergency helicopters. Fire brigades, police, or army units are not able to reach the location of the emergency rapidly enough, especially in rural areas. Furthermore, due to the disruption of communication, people cannot contact or help each other [1].

Network planning and optimization play a key role in reducing the capital expenditure (CAPPLEX) and operational expenditure (OPEX) for deploying and expending cellular system. Typically radio network planning begins with a definition and dimensioning stage which includes traffic estimation, service definition, coverage and capacity requirements, etc. it is traditionally considered a static process. Some of the main tasks are site selection for base station location, location area and routing area planning, and radio resource management (RRM) strategies besides fulfilling the initial requirements such as coverage and capacity

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radio resource has to be acquired in a way that the cost is minimized. Optimization is long-term process before and after the launch of a network. The process applies various methods to maximize the system performance by optimally configuring the network and utilizing its resources. Traditionally, a large amount of manual tuning has been used in the optimization process. Nowadays, advanced optimization tools have been developed to automatically optimize the parameters for maximizing system performance making the optimization process and more efficient [2].

Research on cell phone towers and their properties and problems is far from new. An optimization problem that could be used to locate cell phone towers was formulated by Lee [3], whose communications Design Problem was primarily designed for the location of radio and television transmitters. Mather and Niessen [4] formulate a variety of models that include transmitter location and fixed and dynamic channel assignments. Anderson and McGeehan [1] also employ heuristic methods to solve small instances of microcell covering problem. Other algorithmic contributions in the area are those by Karaata [5], who discusses p-center and p-median problems in the context of mobile computing, as well as Butten et al. [6], whose software contains a two –step procedure that sites transmission towers in step 1 and determines the power of the tower (and with it its reach) in step 2. Dutta and Hsu [7], who select cell phone tower sites, power levels and antennas tilts, and Melachrinoudis and Rosydi [8], who present the model seeking the best locations, power levels and antenna heights of radio base stations in cellular network.

Our contribution is similar to Mather and Niessen [4] in that we also formulate a number of problems as mixed integer programming problems and solve them. the main different between previous contributions and our paper is our focus on strengthening part of the network and the potential loss of single signal, issues that has been studied separately by Chu and Lin [9] from the point of view of probability that destruction of a transmitters blocks some of calls. Finally, Church and Scaparra [10], investigate the possibility of what call "facility hardening". Note that we do not address power allocation, since under emergency situations, the transmitters are supposed to use their maximum power, so to increase coverage.

The paper is organized as follows: Section 2 contains definition of model, section 3 presents a real application with data from a region in Iran, and section 4 discusses conclusions

2 DEFINITION OF MODEL

As in each location model, we must choose the appropriate space. Since radio coverage depends largely on Euclidean distances between transmitters and receiver (except where there is obstruction). We have chosen to employ the Euclidean plane. Due to the fact that in practice, transmitters need electricity and adequate access, we may locate these base stations only at a finite number of points where these utilities can be made available at reasonable cost, making this a discrete location problem in the Euclidean plane. In addition to aforementioned practical considerations, there are also theoretical difficult related to locating base stations at arbitrary locations in the continuous plane. To demonstrate, consider that on perfectly flat plane, the reach of each transmitter would be circle, so that the task would be to locate a given number of circles, In order to capture the largest possible number of customers.

Note that there is no need to assume that customers are located in fixed places. There are, however, places where there are high densities of cell phones. These are models as demands nodes.

The strengthened transmitters will be equipped with the technology that allows them to transmit at less than full power. In a normal situation, they can transmit at less than full power. In contrast, in an emergency situation, the strengthened base station use maximum power, and there is no need of dealing with power allocation. The effect of this is that the coverage radius is not variable.

Consider now the objective of model, in the absence of losses due to destruction of facilities based on natural causes and those that are caused deliberately, it stands to reason to maximize coverage.

Guarding against system failures is an attempt to achieve network reliability. We can either attempt to protect the system against some worst-case losses, or try to cover the system against some average or expected loss. In this paper we investigate objectives that maximize the number of customers who still have cell phone coverage after the incident given the worst-case and average loss of single (fortified) facility. once a facility fails, customers who were only covered by destroyed facility will no longer be connected, while those customers who were covered at least one other facility in addition to the failed facility will have their call passed onto other radio base station. We have another objective in this paper which maximizes the net revenue of strengthen site by considering cost restriction.

In order to illustrate the difference between the aforementioned double coverage and minimization of the worst case lost that we propose in this paper, consider the following situation. Assume that we locate facilities on the plane, with customers uniformly distributed. Then each facility covers all customers in a circle, with the facility at its center. In the case of double coverage, the assumption is that any demand that is not double-covered is potentially lost. (Eiselt.H.A, Veladimir Marinove 2012) [1].

Not that in the case of loss of single transmitter. Only one of the areas that have single coverage will be lost. If we were to maximize the survival in case of worst-case lost, the only demand that is lost when a single facility fails are the customers that are only covered by this facility.

Naturally, in the case of large-scale disasters such as earthquakes, more than one base station can be destroyed. In order to reduce the likelihood of more than one strengthened cell being destroyed simultaneously. Consider the following since disasters are always local or at worst regional, the damage caused by the disasters is inversely related to the distance from its center. In other words, the farther away we are from the center of the problem destruction we can expect [11].

An obvious conclusion is that a cell phone network will be more robust if its transmitters are far apart from each other. This general idea can be realized in various ways. It may be possible to set up an objective function that maximizes the expected survival; including the probability that site survives. Given that another is destroyed. The problem with this approach is that it requires the knowledge of a joint probability distribution regarding the destruction of sites. Another approach is to maximize the shortest distance between any two sites (An objective reminiscent that of p-dispersion [12].

This technique requires that the decision maker defines a minimum spatial separation between any two sites. Computations of the size of destruction areas for different magnitudes of earthquake are available in the literature. Bollinger et al. [13] compare the damage areas and equivalent circular radius for earthquakes of different magnitudes. Using Mercalli levels VI ("strong " slight general damage) and VII("very strong" negligible damage in well-built structures and some damage in ordinary structures) as an estimation of damage, for the American east and west coast, the level VII average radius for earthquakes of magnitude 5,6 and 7 is 5.92, 16.8 and 48 kilometers, respectively. This means that if cell phone network is designed for surviving magnitude 5 earthquakes, the antennas could be required to be separated by a distance of 5.92 kilometers at least, so there are no two antennas that have to withstand level VII.

In order to formalize, consider the following conventions. Throughout our discussion, the subscript i and the set I refer to the customers sites j and l along with the set j denote the potential locations of transmission sites that we may strengthen.

We can then define the parameters of model as follows:

p : The total number of facilities be strengthen

w_i : The number of customers at site i

$-j$: The cost of strengthening a tower at site

ψ_1 : The probability of failure of fortified facility at site

r : Annual revenue generated by each person for each site

In addition, define the variables:

$$y_j = \begin{Bmatrix} 1 \rightarrow \text{if the base station at site } j \text{ strengthem} \\ 0 \rightarrow otherwise \end{Bmatrix}$$

$$z_{il} = \begin{Bmatrix} 1 \rightarrow \text{if the site } i \text{ is still covered even after a facility at } l \text{ is destroyed} \\ 0 \rightarrow otherwise \end{Bmatrix}$$

$$y_{ij} = \begin{Bmatrix} 1 \rightarrow \text{if the site } j \text{ covered the uncover demand } i \text{ in emergency situation} \\ 0 \rightarrow otherwise \end{Bmatrix}$$

$$\mathrm{v}_1 = \text{Total loss of customer if the facility at site l is destroyed}$$

$$\mathrm{x}_{ij} = \text{Denotes maximum number of customers at i can be serviced by the site at j}$$

In this paper, we will consider four objectives:

(1) The first objective is traditional covering objective;

$$Maxz_1 = \sum_i \sum_{j \in N_i} x_{ij}$$

(2)The second objective deals with the worst-case loss. The worst-case loss can be expressed as such that the number of customers who are still covered after destruction of facility that results in the largest possible loss is,

$$Maxz_2 = \sum_i \sum_{j \in N_i} x_{ij} - \max\{v_l\}$$

Which we attempt to maximize. The maximization function is piecewise linear in nature and it can be rewritten as, (Mather and Niessen (2000)) [4]

$$Maxz_2 = \sum_i \sum_{j \in N_i} x_{ij} - v, \; v \geq v_l$$

(3) The third objective considers the average case, in which we assume that the single failure occurs randomly. If the probability of the failure of the radio base station at site l is known in advance, the objective is

$$Maxz_3 = \sum_i \sum_{j \in N_i} x_{ij} - ql \sum_1 v_l$$

In the application below, we assume that the probability of a failure of transmission tower at any specific site is unknown, and we may use Laplace's argument that assumes them to be equal, i.e.

$$q_l = \frac{1}{p}$$

See Eiselt and Sandblom [14]. The expected loss can then be minimized or, equivalently, we can maximize the expected number of customers who are still covered after the loss of one facility. This number is defined as the difference between the numbers of customers who are covered only once. The expected loss is then $\frac{1}{p}\sum_1 v_l$, hence the objective is $Maxz3 = \sum_i \sum_{j \in N_i} x_{ij} - \frac{1}{p}\sum_1 v_l$

(4) The forth objective maximize the annual revenue generated by each site, the objective is

$$Maxz4 = r\sum_i \sum_{j \in N_i} x_{ij} - \sum_j c_j y_j$$

The model can then be formulated as follows:

$$Maxz_1 = \sum_i \sum_{j \in N_i} x_{ij}$$

$$Maxz_2 = \sum_i \sum_{j \in N_i} x_{ij} - \; v$$

$$Maxz_3 = \sum_i \sum_{j \in N_i} x_{ij} - \frac{1}{p}\sum_1 v_l$$

$$Maxz_4 = \sum_i \sum_{j \in N_i} x_{ij} - \sum_j c_j y_j$$

s.t

(1) $\sum_j y_j = p$

(2) $x_{ij} \leq w_i y_j$, $\forall i? \; j \in N_i$

(3a) $z_{il} \leq 1 - 2y_l + \sum_{j \in N_i} y_j \quad \forall i? \; l \in N_l$

(3b) $z_{il} = 1 \quad \forall i, \; l \in ?N_i$

(4) $v_l = \sum_{i: l \notin N_i} w_i \, (1 - z_{il}) \forall l$

(5) $v \geq v_l \quad \forall l$

(6) $y_k + y_j \leq 1 \quad \forall j, ?j \notin N_i, \; k \in M_j$

(7) $y_{ij} \leq y_j \quad \forall i, ?j \notin N_i$

(8) $\sum_i w_i y_{ij} + \sum_i x_{ij} \leq cap_j \quad \forall j$

(9) $y_{ij} \leq (1 - z_{il})? \quad \forall i \;\; l \in N_i \;\; j \notin N_i$

(10) $\sum_j c_j y_j \leq B$

(11) $\sum_i x_{ij} \leq w_i \quad \forall i$

(12) $x_{ij} \leq y_{ij} w_i \quad \forall i, l \in N_i, \; j \notin N_i$

(13) $y_j \, z_{il}, y_{ij}, \in \{0,1\} \quad \forall i, \; j, l, x_{ij} \geq 0$

The four objectives have already been discussed. Constraint (1) is the constraint that sets the total number of facilities to strengthen. Constraint (2) ensures that customers can be serviced only if there are towers that cover demand area. Consider now constraint (3a). We consider all pairs of sites I and l as the potential site of a facility. The first sum on the right –hand side of constraint (3a) denotes the number of times that node I is covered from node l (which is either zero or one). While the second sum on the right hand side of constraint (3a) measures the number of times that node I is covered from anywhere.

In summary, the variable will be only if node loses coverage in case node l is destroyed which is desired result.

Constraint (3b) simply expresses the fact that if node does not cover customer i . Then its destruction is not affected.

Constraint (4) defines the loss in case node l is destroyed. Recall that site I is associated with variable z_{il} that equals one, only if destruction of node l make it lose coverage. The actual loss is then the number of customers who are no longer connected. The loss of these losses then denotes the loss in case node l is destroyed. Constraint (6) enforces minimum separation between the antennas. Constraint (7) defines that is not necessary.

Demand of node i . Constraint (9) defines. Constraint (10) defines the budget for strengthen the base station at site. Constraint (11) ensures that one cannot serve more customers in a location than there is demand for service. Constraint (12) provides the specification of variables in this problem.

3 THE APPLICATION AND RESULT

The application in this paper considers the area in the M j azandaran in the north of Iran. Mazandaran has 1300 coverage sites and includes 1104 kilometers road, 192 cities, towns and village whose population is at least 3,037,336 people.

Fig. 1 shows current location of the sites in Mazandaran with TEMS program.

Fig. 2 shows the coverage in the Babol in the Mazandaran with ASSET program, the region with red color has ideal coverage situation, and the sites don't need strengthen in this area.

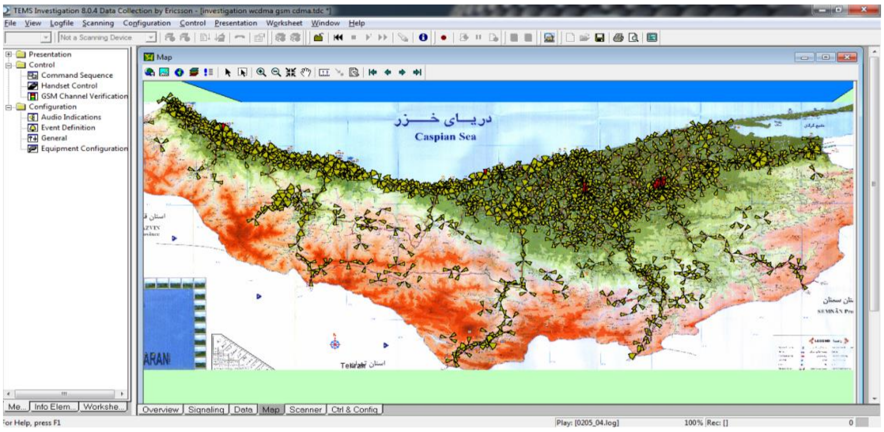

Fig. 1. Current sites location

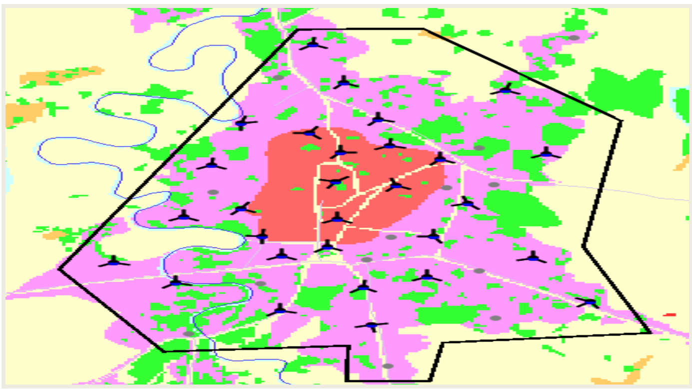

Fig. 2. The study area

For solving the proposed model, we used GAMS program with CPLEX solver, version 24.1.2. On average the computing time for each scenario was 1.716 seconds, and we consider the region in Babol which has poor coverage and the sites of this area need strengthen. This region includes four sites and three demand points. By considering the result which shows in Table 1, the first site can strengthen, this strengthen site covers these three demand points. if this strengthened site destroyed, we don't have emergency coverage from other sites because each demand points gets coverage just from first site, in other words they have single coverage, Also all of the sites covers 5 kilometers and fortified in region for expected demand. By destroying the first site, the customers in its coverage area lose the communication. Fig. 3 shows the current location of these four sites with yellow color in a Google earth by using MapInfo program information.

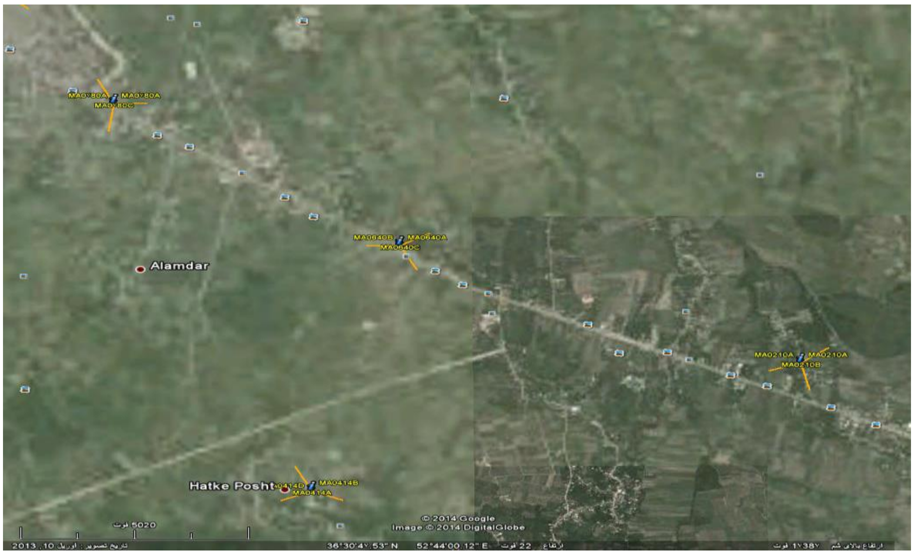

Fig. 3. Current location of these four sites

Table 1. The result of solving

Total objective	3660			
V	420			
x_{ij}	1	2	3	**4**
1	140	0	0	**0**
2	140	0	0	**0**
3	120	0	0	**0**
y_{ij}	1	2	3	**4**
1	0	0	0	**0**
2	0	0	0	**0**
3	0	0	0	**0**
z_{ij}	1	2	3	**4**
1	0	1	1	**1**
2	0	1	1	**1**
3	0	1	1	**1**
y_j	1	2	3	**4**
	1	0	0	**0**

4 CONCLUSIONS

This paper has discussed the location and strengthening of cell phone sites given that decision maker objective is to either maximize the coverage of demand or to maximize the net revenue generated by each customer for each site. The problems were solved with GAMS program and the resulting of model were then applied for the region in north of Iran.

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