Maximziation of Internet Coverage in Developing Nations

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Abstract

Internet poverty is a new type of societal problem that has emerged in the 21st Century. The day-to-day function of a developed country is ultra-reliant on internet access, while many in developing countries have either no access to internet services or the cost of procuring these services is too high. Thus this study focuses its discussion on internet access in model countries, such as those in some regions of Africa with low internet access. These areas often lack budget and locations where internet towers can be built. This fact can lead to two inference results: the first is that you have to determine where the base will actually be among the possible locations. The other is that there is a high probability that you will not be able to supply coverage to the whole region. These problems may be resolved using a maximum coverage location program (MCLP). However, from the perspective of the real world, different locales require the internet more than others, i.e., a school vs. a farm. In this paper, we define WMCLP, where we give a weight to each object in MCLP, and propose pruning and heuristic techniques to complete query processing within an allowable time. Furthermore, we propose a method that returns the minimum value of the budget required to achieve the target cover rate. The evaluation section proves that the time complexity of the proposed techniques is reasonable and efficient.

Introduction

Many residents in populated cities such as Seoul often take internet access as a guaranteed asset everywhere. The overwhelming majority of restaurants, cafes, and shops supply access to the internet for their customers. Before the internet, completed tasks were in person, from shopping for food to school to attending class. Since the introduction of the world wide web in 1993, the internet for day-to-day activities has exploded.

Now internet use in developed nations is ubiquitous. The COVID-19 epidemic has highlighted how dependent citizens in these countries have become regarding the internet, and the pandemic has also accentuated internet reliance, particularly in the work and education sectors. As schools and stores closed down and resorted to delivery systems and online classes to follow social distancing measures, access to the internet became necessary. Unlucky students could not participate in class because they had no internet available in or near their homes. In a society where more and more citizens are increasingly reliant on the internet, it is urgent to reduce internet poverty.

There are countries in Africa with relatively high internet coverage. For example, around 50% of people in Nigeria have access to the internet. However, only 12% of the population in Togo has access to the internet. When considering a model for optimal coverage in non-developed countries, it is vital to consider existing internet coverage. Others prioritize and concentrate facilities (e.g., schools, government, private offices, libraries, etc.) in areas to decide the most optimal places to install the Internet cost-efficiently while providing the most coverage.

Discussion about internet poverty

What this means, what it implies, why people need it, what does it mean not to have it, how does this negatively affect people

- 1 → In developed countries'
- 2 → In non-developed countries (Focus on Africa)

Internet poverty has been existing but has recently risen to the surface due to the COVID-19 pandemic. Internet poverty is defined as the inability of people to work digitally, often due to the lack of internet access. Those suffering from internet poverty would experience the inability to work from home or take classes from home (Morden, 2021).

In developed countries, people residing in remote areas cannot connect with society and become socially isolated. Other implications of internet poverty may be barriers to studying and knowledge acquisition. Some teachers may lack access to the internet or limit their technology capabilities, or students cannot participate in class because they lack the skills or equipment to do so. Students who do not have a strong Internet connection within their homestead have low chances of going to higher institutions. Students having Network connectivity, on the other side, have much greater digital abilities, which is a reliable indicator of standardized test scores. Finally, it accentuates social differences. Due to a lack of internet access, finding a new job and accessing quality employment becomes impossible primarily. (Iberdrola, 2021)

In non-developed countries, internet coverage is increasing as the primary basis for rapid development: financial inclusion, social inclusion, health, and education. *The economy is increasingly trading and interacting with other countries*. Increased internet coverage also increases communication within the nation. Therefore, society is better organized because the different parts of society are more informed of each other. However, the recent pandemic may prevent parts of the country from developing any further. Those areas without internet coverage force the people to stay inside their homes doing nothing, whereas regions with internet access can have meetings online and develop further. Students can also have a broader education online and not be limited to their school teachers through online resources. (Guerriero, 2015)

Discussion about internet poverty in Africa and implications

Africa is the place people look to when someone mentions the word 'poverty. It is often the central place where large charities assist residents with water, food, and health issues. Though it varies depending on individual countries, it is not surprising that internet coverage is minimal throughout the continent. A few elements of Africa can be blamed for this. Internet connection is more common in homes with higher incomes, according to the World Bank. Unfortunately, in a country where 422 million people or approximately one in every three live in extreme poverty, electricity is a luxury, and internet access for most households is financially unattainable. The continent itself also falls behind in internet infrastructure compared to its developed counterparts. A mobile broadband network does not cover almost a quarter of Africa's population, and around three-quarters of the people simply do not use the internet. Due to the rapid globalization of the internet, it has become increasingly important for African states to close the gap to the rest of the world. Failure to do so risks exacerbating existing inequities.

Because of the fast globalization of the internet, it is becoming increasingly important for African nations to reach the other nations' level. Failure to do so risks exacerbating existing inequities. This isn't the only issue, though. Households with higher per capita use have reliable electricity but not to the internet, according to reports. Computer illiteracy and high internet service costs may be hurdles to internet use for these households, most likely the result of limited competition and inadequate regulation. African individuals spend every month an average of 8.8% of their salary for 1GB of data, according to the Alliance for Affordable Internet (A4AI), compared to 3.6 percent and 1.5 percent in Latin America and Asia, respectively.

People spend as much as 20% of their salary on data in certain African nations, while South African data is the most expensive among Africa's leading economies. Cost is not the only problem. Internet lines are connected through optic cables underground and the ocean. This is the very reason people can visit websites from all around the world. Due to this reason, countries must be connected to these optic cables to be provided with the internet. To this end, some countries have to negotiate with other neighbouring countries if they have no border that lines the ocean. This may be a significant issue for some African countries because civil wars and national relations are not necessarily on good terms between neighbouring countries, which may provide an obstacle for certain African governments.

There are innumerous benefits to be obtained if widespread internet coverage in Africa were to become a reality. According to research conducted by the World Bank, a year of mobile broadband coverage can raise consumption by roughly 6% and around 8% after two years. T This indicates that after a year of broadband service, the proportion of households below the poverty line ($1.90 per day, as defined in the study) declines by 4% and around 7% after two more years. In terms of raw figures, this lifts nearly 2.5 million people out of poverty. Some entrepreneurs have access to the internet, which allows them to launch new firms. Startups in Africa face difficulties that startups in developed nations do not. For example, a recent investment report shows that African startups often have to invest in local infrastructures, such as distribution networks or internet access, to meet their goals. Thus these businesses must focus on infrastructures such as fintech platforms and education so that the rest of Africa, who were not given this opportunity, c lift Africa out of poverty. ("Chasing Outliers", 2021)

WORLD BANK

Landlocked countries have lower Internet usage because the basic infrastructure required to deliver infrastructure is more expensive, and connectivity is more reliant on neighbouring countries. Several African countries (Kenya, Namibia, Rwanda, Uganda, Mauritius and Benin) have recently made headlines (2016). These are developing countries which are all located in Sub-Saharan Africa. In all six countries, access to the internet is much higher among better-off households with higher per capita consumption. Internet connectivity is much higher for more excellent families with higher per capita expenditure in all the countries.

Power is an essential determinant of internet accessibility within a place. Several well-abled families from the six countries are connected to electricity, yet they have no internet. In this area, Uganda has a proportion of the top 60% of the population, of 21%, whereas Namibia has nearly 50%. Factors affecting internet connection for these families comprise lack of skills on operating a computer and costly internet sustainability, resulting from inefficient market policies, regulation, or the residents' geographic location. On average, rural residents, who are poorer in all six nations, have less access to the internet. Because of their geographical location, rural areas have low internet access rates in many countries, and the requisite technology is less viable for network operators. Just the nation's capital enjoys high-speed internet, with the rest of the country falling behind.

GSMA

With nearly 4 billion mobile broadband subscribers worldwide, mobile technology is the most used source of internet connectivity for individuals worldwide. It is especially important in Africa, where most people use mobile phones instead of fixed broadband to access the internet. Africa, on the other hand, is lagging in terms of mobile broadband infrastructure deployment. About 25% of the African population is not covered by cellular internet infrastructure. Almost three-quarters of the population doesn't access cellular internet, which means they cannot enjoy browsing the internet that dominates the globe (Bahia et al., 2020). This is becoming more significant as indicators of expanding digital disparities in internet access among countries and along demographic and socioeconomic lines have emerged, exacerbating existing inequalities.

[WORLD BANK + GSMA ANALYSIS OF NIGERIA]

According to the findings, a year with internet connectivity boosts the final spending by roughly 6%. After two years of coverage, this projection rises to 8%. Similarly, after the first year of phone internet service, most households suffering from poverty ($1.90 per day) declined by around 4%. After two or more years of coverage, it drops by about seven percentage points. This equates to nearly 2.5 million individuals being lifted out of abject poverty (Bahia et al., 2020). Nevertheless, there is limited research on how access to mobile broadband affects a person and household's well-being at the micro-level, especially among the severely poor.

Moreover, the advantages of the internet would not be distributed evenly among humans; there are considerable disparities in who benefits. For example, some data indicate that social media may help particularly educated people who are better equipped to appreciate the full potential of digital innovations (this could lead to one of your implications → to reap the most benefits from the introduction of the internet higher levels of education must exist in the country). This might worsen digital differences while also increasing inequality in other social metrics like schooling.

Cost is, predictably, the reason for Africa's lack of internet access. Africa does have the world's most expensive broadband. As per the Alliance for Affordable Internet, the African continent spends 8.8% of their monthly income for 1GB of data, compared to 3,6% in Latin America and 1,5 per cent in Asia. In certain circumstances, Chad and the DRC used t spend one-fifth of their salary to cater for 1GB. Among Africa's world's major economies, South Africa has the highest data costs. As in many other regions of the world, certain socioeconomic and demographic groups in Nigeria may encounter major barriers to accessing mobile internet, preventing them from realizing the benefits of broadband service. In Nigeria, for example, the gender gap in mobile internet usage was 29% in 2019 (meaning 71% more men were likely to use cellular internet than women), while communities in the rural areas were 47% less likely than urban residents to use the internet using mobile devices.

To reap the full benefits of digital technology, Efforts to bridge the consumption gap among those with accessibility chances but fails to utilize it will continue to be essential policy objectives. Of fact, offering mobile broadband connection does not in and of itself eliminate poverty or enhance people's lives well-functioning industries, institutional arrangements, and supporting developments such as road infrastructure, competitiveness in input and output businesses.

Also, more significant public utilities all promote operational function in remote and distant locations, which must interact with mobile internet connectivity to maximize its possible future welfare implications. There is a need for the government to improve the infrastructure that will boost economic growth. Integration of these implementations and improved internet access will help improve the lives of people.

AFRICAN STARTUPS

According to Adegoke (2021), startup owners worldwide frequently discuss "scaling up" as their businesses develop. It's a slang term for obtaining economies of scale using internet connectivity, in which the amount used in producing a site is reduced through creating more sites. However, in many African markets, it does not always work out that way. Bad infrastructure, ranging from inadequate internet access to poor road networks and insufficient financial inclusion, could result in scale diseconomies. As a result, many African startup founders concentrate on "trying to solve large, foundational problems that could improve the lives of countless people," as well as making infrastructures like distribution channels and fintech areas, hoping for huge markets all over Africa while leveraging rural understanding (Hofer, Hamel & Tong, 2021).

In several African nations with big consumer bases, the constraints of poor financial inclusion and obsolete banking technology and payment methods have resulted in significant investment in startups tackling these issues. Stripe bought Nigeria's Paystack. Visa invested in Lagos-based Flutterwave, Goldman Sachs led investment rounds in Jumo, a South African fintech startup, and Kobo360, a Lagos-based logistics startup. For long years, fintech has dominated African startup investment. Suppose there is one takeaway from the research. In that case, Africa's startup ecosystems must adopt norms, structures, and processes that match the realities of doing business across the continent. This is very important in venture capital and other investor funding structures. The study argues that general partners of funds require more flexible arrangements to better deal with markets that are changing at the same rate as most African ecosystems. Alternative instruments and structures, such as debt or perpetual capital vehicles (PCVs) that work by providing an endless timeline for recouping gains are among them. (Hofer, Hamel & Tong, 2021)

Another option is to take a more targeted investment approach, such as B2B investments or investing in more mature companies. Investors must evaluate their preconceptions and biases in the end. The authors add, "What is obvious now is the necessity to recognize the context in which funds and startups operate and use it as a foundation for developing acceptable fund and business building principles." (Hofer, Hamel & Tong, 2021)

Why coverage optimization is an important issue and how it can be done

Internet coverage must be provided for the vast majority of the population to provide equal education opportunities. However, installing internet cables everywhere possible is not ideal. There may be locations that are relatively inefficient because the area is unpopulated or only has individual homes.

Experts refer to this problem as the Maximal Covering Location Problem (MCLP). It aims to find the ideal location for a few facilities to maximize accessibility over a range of demand nodes. It is said that MCLP uses tools such as CPLEX, Gurobi, and Lingo. Often, several variables are considered when determining which areas should be provided with internet coverage. In simple terms, one would think of the population density in the area, the number of facilities in the area, and the importance of each facility. Areas with fewer people and fewer essential facilities, such as government offices, libraries, and schools, would move down in the rankings for importance. Some of the more professional variables used when assessing the MCLP are:

- i: the index of demand nodes
- j: the index of facility sites
- a_i: population nor demand of the node i
- d_{ij}: the shortest distance (or time) from node i to facility j
- P: number of facilities to be located
- S: coverage distance
- N_i: a set of potential facilities that can cover the demand generated in i
- X_j: a binary variable which equals is valid if the facility is placed at a node
- Y_i: binary variable that is true if demand node "i" is covered by one or more facilities located within the Distance of S

These variables are used to assign values to evaluated locations and determine whether it is necessary to provide internet coverage.

Problem definition

Objective function

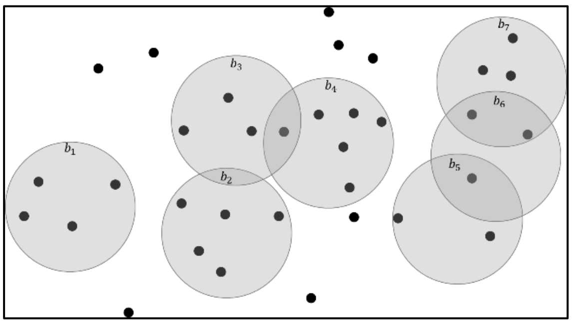
During dangers, service providence to all nodes that require it should be the essential thing. As a result, the objective function would be to maximize profit or efficiency. The problem has three types of constraints: restrictions on coverage, placement, and performance. The location considerations and module placements are binary. The variables for a continued range of the node; some variables are only defined by true and false (0 or 1), whereas others have intermediate levels as their value (0 through 9). Here, we can apply the coverage concept provided by the Set Covering Location Problem (SCLP). The model gives the lowest number of facilities required to cover all demand nodes.

A. Baseline

The two most important factors to consider in establishing a base station are, first, the range covered by the base station should be maximized, and second, it must meet the budget to select a base station. This problem can be solved with the Maximum Covering Location Problem (MCLP).

Definition 1. MCLP

Given selected basement set $B = \{b_1, b_2, b_3, \ldots, b_t\}$, budget e, demand node n_k, a set of nodes which are covered by b_i: $C(b_i)$. MCLP is to find a subset of B, where $|B| \leq e$ and maximize $f = \sum | \cup C(b_i) |$. Note that all $C(b_i)$ Have its capacity c which is represented as a circler region in spatial data.



<figure 1>

Example 1. Consider <figure 1>, suppose that $e = 3, c = gray\ circle$.

Basement set be $B = \{b_1, b_2, b_3, b_4, b_5, b_6, b_7\}$,

$$|C(b_1)| = 4, |C(b_2)| = 5, |C(b_3)| = 4, |C(b_4)| = 6, |C(b_5)| = 3, |C(b_6)| = 3, |C(b_7)| = 5$$

$f_{max} = \sum C(b_4 \cup b_2 \cup b_7) = 16$, which means we should select b_4, b_2, b_7 and the basements cover 16 demand nodes over 34 nodes.

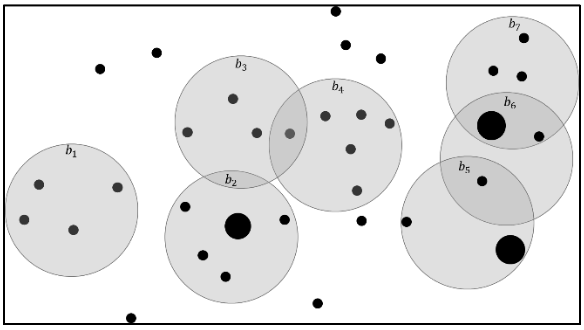
First, after calculating the number of demand nodes belonging to an area with a radius of c from the centre of b_i, find a combination in which the sum is maximized. When the number of Demand nodes is $|N|$, the time complexity of obtaining all $C(b_i)$ is $O(|N| * |B|)$. Since the number of cases of finding a combination of B is $\binom{|B|}{e}$, the total time complexity is $O(|N||B| + |B|^e)$. Since it is |N|>|B| in general, we are very sensitive to the number of demand nodes, but we guarantee a minor computation than $O(|N|^2)$ but if the value of |B| or e becomes unexpectedly large, time complexity becomes exponential.

B. Proposed method = WMCLP

Maximization does not guarantee a 100% cover rate. In other words, nodes that cannot be covered are generated. When we consider pragmatic, not all institutions/households expressed in the node have the same importance. For example, the average number of members of a home in Korea is 2.3. If the category of Demand node is a general family house, the importance can be viewed as 2.3. On the other hand, let's say that five devices can access the internet in a nearby library and a maximum of 20 connections per day considering the rotation rate. It can be said that it has about ten times greater importance than in the previous case.

Definition 2. WMCLP

We define w_k, the weight of the demand node n_k. Now we must consider $w_k * n_k$ as elements of $C_w(b_i)$. WMCLP(Weighted MCLP) is to find the subset of B, where $|B| \leq e$ and maximize $f = \sum | \cup C_w(b_i) |$



<figure 2>

Example 2. Consider <figure 2>, suppose that $e = 3, c = gray\ circle$.
Basement set be $B = \{b_1, b_2, b_3, b_4, b_5, b_6, b_7\}$, small dots represent weight one node, and bigger dots represent weight ten nodes.

$$|C(b_1)| = 4, |C(b_2)| = 14, |C(b_3)| = 4, |C(b_4)| = 6, |C(b_5)| = 12, |C(b_6)| = 12, |C(b_7)| = 14$$

$f_{max} = \sum |C(b_5) \cup C(b_2) \cup C(b_7)| = 40$.
Selected Basements set is $\{b_5, b_2, b_7\}$. Compared to the case where weight is not considered, when b_5 is selected instead of $b_4 6$ units of weight are less lost because a weight total of 6 is discarded, and a weight total of 12 is obtained.

The following section presents a way to improve the query time to find the correct answer by properly pruning the basements that cannot be the right answer and reducing damage to uncovered nodes from a realistic point of view.

C. WMCLP with Pruning

1. Reducing computation for $C(b_i)$

The process of obtaining $C(b_i)$ in Baseline is as follows:

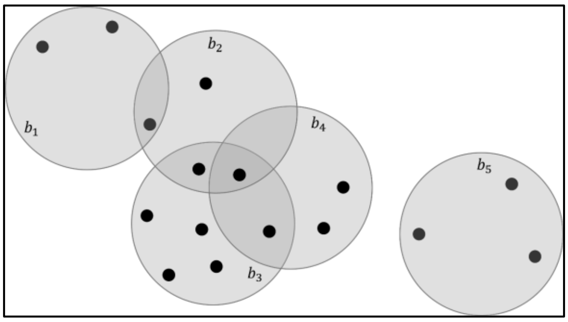
$for\ n_i\ in\ N$:
$\quad for\ b_i\ in\ B$:
$\quad\quad if\ dist(n_i, center\ of\ b_i) \le c$:
$\quad\quad\quad add\ n_i\ to\ C(b_i)$

Before calculating distance, if n_i exists outside when a straight line is drawn at a point c from top to bottom based on the centre of b_i, there is no need to calculate distance. Equations of straight lines have the effect of decreasing time complexity because they only need to be calculated once per b_i. When a square made of a straight line is called a boundary square, the algorithm to which Pruning is applied is as follows:

Algorithm: Pruning
$for\ n_i\ in\ N$:
$\quad for\ b_i\ in\ B$:
$\quad\quad if\ \left(n_{i_x}, n_{i_y}\right)\ is\ in\ bundary\ square \le c$:
$\quad\quad\quad if\ dist(n_i, center\ of\ b_i) \le c$:
$\quad\quad\quad\quad add\ n_i\ to\ C(b_i)$

2. Reducing computation for combination problem

This problem cannot be solved simply by sorting it in descending order because it is not just a sum, but size must be obtained after the sum operation.



Instead of calculating all combinations in this paper, you can translate it to 'net profit.' By newly defining '', the heuristic algorithm was applied with the correct answer for the combination whose value is the maximum.

Definition 3. Let's say S_x^- is the set of all nodes belonging to an intersection with other groups of nodes belonging to a set S_x, and S_x^+ is a set of nodes belonging only to S_x. The net profit $S_{x_{net}}$ of S_x is defined as follows:

$$S_{x_{net}} = |S_x^+| - |S_x^-|$$

Example 3. In <Figure 3>, each $\boldsymbol{S_{x_{net}}}$ be:

$\boldsymbol{S_x}$	$\boldsymbol{\lvert S_x^+ \rvert}$	$\boldsymbol{\lvert S_x^- \rvert}$	$\boldsymbol{S_{x_{net}}}$
b_1	2	1	1
b_2	1	3	-2
b_3	4	3	1
b_4	2	2	0
b_5	3	0	3

<figure 3>

The heuristic algorithm for finding the optimal combination proceeds as follows:

Step1) Net profit is calculated for all $C(b_x)$

Step 2) Sort based on net profit.

- If the net profit is the same, sort based on the value of $\boldsymbol{|S_x^+|}$

Step3) The sum from the first $C(b_x)$ to the e-th $C(b_x)$ is calculated.

Step4) Find and return all combinations that have the same sum as the sum of Step 2).

Algorithm1: Finding Combination with Heuristic
$for\ x\ in\ range\ (len(B)):$
$\quad Compute\ C(b_x)_{net}$
$Sort\ C(b_x)\ \ net\ profit\ value$
$Initialize\ max\_net\_profit, curIdx$
$While\ curr\_net\_profit < max\_net\_profit:$
$\quad answer.append(COMBINATION_{curIdx}$
$Return\ answer$

This algorithm has $O(|B|)$ from Step1 to time complexity, $(|B|log|B|)$ from Step2, and $O(log|B|\ )$ from Step4). Therefore, the total time complexity can be viewed as $O(|B|log|B|)$, which is very small compared to the solution time complexity of the combination probe in baseline algorithm being $O(|B|^e)$.

Example 4. In <Figure 3>, the sorted $\boldsymbol{S_{x_{net}}} = [b_5, b_3, b_1, b_4, b_2]$.

Given e=3, we select $\{b_5, b_1, b_3\}$ as the answer combination. The number of aggregates in this combination is 13, and the size of the aggregates is larger than that of the other three elements.

There is no other combination in which the number of sets is 13. At this time, it is "cover rate = 13/16 = 81%."

D. Estimating budget in WMCP

From the previous **Example 2**, $f_{max} = 29$ was obtained. Initially, the weighted sum of all nodes that could be covered was 53, so the cover rate is $\frac{40}{53} \approx 75.5\%$. If the target cover rate was more than 80%, how much should e be increased? In reality, the target cover rate is frequently given, and the minimum value of the budget must be estimated. This problem can be solved using the preceding Heuristic 1 algorithm. Since it is sorted based on net profit, after the aggregation operation, the number of nodes is greater than or equal to the number of target covered nodes, and the number of combination sets at that time is returned as a budget. In this case, the merge operation is performed by increasing the budget value from 1.

Algorithm2: Estimating budget
$for\ x\ in\ range\ (len(B))$:
$\quad Compute\ C(b_x)_{net}$
$Sort\ C(b_x)\ \ net\ profit\ value$
$Initialize\ cover\_cnt, goal\_cnt, curIdx$
$While\ true$:
$\quad answer.append(COMBINATION_{curIdx}$
$\quad if\ "\#\ of\ nodes\ in\ union\ of\ answer\ list$ $\geq\ goal\_cnt$:
$\qquad break$
$Return\ answer, len(answer)\ as\ budget$

Example 5. In <Figure 3>, assume that the user satisfying cover rate is 60%.

Sorted $\boldsymbol{S}_{x_{net}} = [b_5, b_3, b_1, b_4, b_2]$.

- $Iter\ 1 \rightarrow |\{b_5\}| = 3$, 18.8 cover rate
- $Iter\ 2 \rightarrow |\{b_3\}| = 7$, 43.8 cover rate
- $Iter\ 3 \rightarrow |\{b_1\}| = 3$, 18.8 cover rate
- $Iter\ 4 \rightarrow |\{b_4\}| = 4$, 25 cover rate
- $Iter\ 5 \rightarrow |\{b_2\}| = 4$, 25 cover rate
- $Iter\ 6 \rightarrow |\{\ b_5, b_3\}| = 10$, 62.5 cover rate

Since the Cover rate is 60% or more, the processing can be completed in the sixth iteration. At this time, the minimum budget $e_{min} = 2$ is obtained.

E. Evaluation

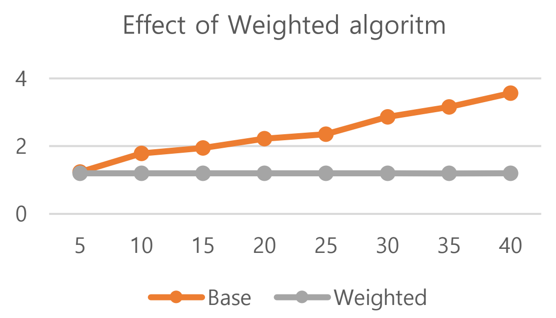
In this section, how efficient the previously proposed methods are and the efficiency is analyzed. The density of the query point was selected by generating a total of 10000 points in Gaussian distribution and sampling 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% in a uniform manner. POI was set to random points of 5, 10, 15, 20, 25, 30, 35, and 40% in the sampled query point data. At this time, weight was randomly distributed to 1, 3, 5, 7, and 9. The basements were set to 0.1, 1, 10, and 100% of the total query points and were generated uniformly.

Default value settings are as follows:

The density of query point	25
Density of POI	50

# of basement	0.1

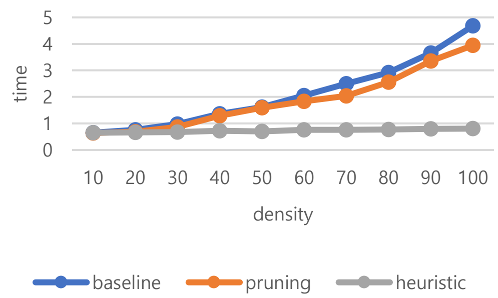
1. Effect of Weighted algorithm



<Figure 4>

In <Figure 4>, the orange line shows the execution time that compares the base capacity according to importance after reaching one by one when a specific POI is assumed to be more 'important than elsewhere in the baseline algorithm. The x-axis represents the ratio of POI to all-important query points. Although linear, the time increases as the ratio of POI increases. On the other hand, when weight is stored from the beginning, and only the basement capacity is compared, the time hardly increases even if the ratio of POI increases. The difference in speed increase is noticeable when the ratio of POI exceeds 25%. At this point, the speed of execution may be doubled.

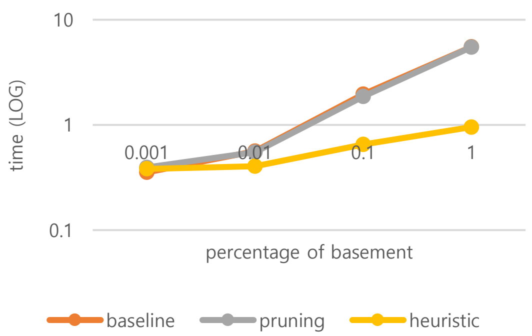
2. Time compare irt. The density of query points



<Figure 5>

It can be seen from the blue line and the orange line in <Figure 5 that the time complexity becomes exponential as the density of the query point increases. Application of Pruning seems to reduce time, but it is still extrinsic. The increase in efficiency of the Pruning technique corresponds to the case where the density is 60% or more. On the other hand, the time complexity following the query point denim has a linear form close to the constant when a heuristic algorithm is applied. Considering that even 10,000 pieces of data have a processing time of less than 1 second, the algorithm proposed in this paper is very efficient.

3. Time compare irt. Percentage of Basements



<Figure 6>

In <Figure 6>, the time scale is expressed as a log. The proposed algorithm cannot reduce the linear increase in time complexity in the number of basements. In the case of Pruning techniques, there is almost no time reduction in terms of the number of bases. In Heuristic, the time has been remarkably reduced.

F. Conclusion and future works

In this paper, we redefined it with WMCLP using MCLP to suit real-world situations and proposed pruning techniques and heuristic algorithms for efficiency in terms of time complexity. The evaluation section proved its efficiency. In addition, a method for efficiently offering a minimal budget was also introduced. The distribution of experimental data was limited to the Gaussian and uniform distributions, and there are more techniques for generating data to represent the distribution of points in the real world. In the subsequent study, we will experiment with the efficiency of various distributions based on them and improve them based on the results.

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