Paper

A Method of Mobile Base Station Placement for High Altitude Platform Based Network with Geographical Clustering of Mobile Ground Nodes

Ha Yoon Song

Abstract—High altitude platforms (HAPs) such as unmanned aerial vehicles (UAVs) which can be deployed as stratospheric infrastructures enable a sort of new configurations of wireless networks. Ground nodes must be clustered in multiple sets and one dedicated UAV is assigned to each set and act as an mobile base station (MBS). For the intra-set nodes, UAVs must communicate each other in order to establish network links among intra-set nodes. Here we find a geographical clustering problem of networking nodes and a placement problem of MBSs. The clustering technique of mobile ground nodes can identify the geographical location of MBSs as well as the coverage of MBSs. In this paper we proposed a clustering mechanism to build such a configuration and the effectiveness of this solution is demonstrated by simulation. For a selected region with a relatively big island, we modeled mobile ground nodes and showed the result of dynamic placement of MBSs by our clustering algorithm. The final results will be shown graphically with the mobility of ground nodes as well as the placement of MBSs.

Keywords— clustering geographical, clustering of mobile ground nodes, HAP based network, high altitude platforms, MBS placement, mobile base stations.

1. Introduction

The recent development of unmanned aerial vehicles (UAV) leads to interests in high altitude platforms (HAPs) as mobile base stations (MBSs) of wireless wide area networks. UAVs usually carry wireless network equipments and require less management and thus have been regarded as one of the best method to deploy wireless network over wide area without typical ground network equipments. This new sort of network configuration requires a lot of unsolved research topics from the physical layer to transportation layer as well as the ideal configuration of network. Many researches have been concentrated on the communication between stratospheric UAVs and mobile ground nodes. These topics include establishments of communication links among UAVs as well.

The goal of HAP based network is to cover as wide area as possible with deployment of multiple UAVs, i.e., ultimate goal of HAP network is to deploy as many MBSs to cover dedicated area in order to construct a network structure. In this configuration, UAVs can act as mobile base stations for the network. This sort of network configuration raises a new configuration problem of UAVs and mobile ground nodes.

Here we suggest an idea. Mobile ground nodes consist a number of clusters in order to be served by MBSs and each MBS covers a dedicated cluster of mobile ground nodes. MBSs cooperate each other in order to support communication of mobile ground nodes in the whole area. The HAP based wireless network usually regarded as a viable solution for the networks with minimal ground infrastructures or countries under development and so on.

In this paper, we will show a method to deploy MBSs for a dedicated area with possible number of MBSs and to cover dedicated area efficiently. By adopting a clustering mechanism for mobile ground nodes, we can solve a placement problem of MBSs as well as the coverage of each MBS. For an island area we set mobility model and simulated the dynamic clustering of mobile ground nodes and find proper locations for MBSs and coverage.

This paper is structured as follows. In Section 2 we will discuss research basis for this paper. In Section 3 we will see the basic configuration concept of HAP based network assumed in this paper. In the following Section 4 we will explain our clustering algorithm for mobile ground nodes and MBS placement. Then we will show simulation experiment and results in Section 5. The final Section 6 will conclude this paper and will discuss the future research direction.

2. Related Works

The basis of this research is usually categorized into two basic parts. The first one is HAP based networks. The second one is clustering algorithms. We will discuss about this two topics simply.

2.1. HAP Based Network

The HAP based network is one of the most recent research topics while there have been a long idea about stratospheric platforms as a media of networking. With the development of network technologies as well as aerial industries, HAP can be actual one and the idea of HAP based network spawns into real world. Nowadays, most of countries research on this topic. Some of them regard this sort of network as national project while others act as an individual company bases. The Republic of Korea researches on this topic as a national project as shown in [1] with the fruitful research at Electronics and Telecommunication Research Institute (ETRI).

For EU nations or EU companies, there are projects such as HeliNet and CAPANINA. England was one of the early starter in this topic and most of EU nations are participated in those projects [2]. Japan has the similar situation. Japanese Aerospace Exploration Agency [3] has an ongoing effort with HAP based network, named as SkyNet project. Also in the US, projects such as Sky Station, High Altitude Long Operation, SkyTower, Staratellite, Weather Balloon HAPs are undergoing ones [4].

The characteristics of this project are that they are still assuming a single HAP platform and are mostly concentrated on communication links establishment.

For example, World Radiocommunication Conference (WRC) of ITU started the first specification of frequency allocation for HAP network since the year 1997 and several bandwidth frequencies are allotted for specific nations [5]. The most recent decision made by WRC 2007 can be found in [6].

There have been several researches on the communication link establishment between mobile ground nodes and HAP base station [7], [8]. Also a protocol standard such as 802.16 can be a possible candidate for HAP networks [9]. For the inter-HAP links, there also have been researches such as [10].

Apart from these researches, this paper assumes an environment of multiple heterogeneous HAPs. We regard each HAP as a MBS of mobile ground nodes and tried to cluster mobile ground nodes in order to solve the placement problem of MBS. As far as we know, no such topic has been dealt until the first submission of this paper. The most similar one is in [11] but it is on a positioning control for HAP station.

2.2. Clustering Algorithms

In a field of data mining, there have been researches regarding clustering of data in a large database [12], and multiprocessor versions can be found in [13]. They are usually concentrated on the patterns of related data while we need a geographical clustering based on the ground node coordinates. Thus we screened out several candidates and tried combinations of those clustering algorithms.

The most prominent candidates of clustering algorithms are K-mean, BIRCH, EM, PROCLUS, and SUBCLUS drawn from [12]. The K-mean is one of the most popular algorithm in the clustering world. Since we are dealing with mobile ground nodes, we cannot identify the exact coordinates but we only assume the probability of node coordination. In this aspect, we concentrated on expectation maximization (EM) with a probability of node coordinates.

Considering the limitations of number of nodes in a cluster, that is actually a bandwidth limitation of wireless routers equipped on HAP MBS, we need to split a cluster or merge clusters in order to balance the number of nodes in a cluster. The BIRCH and their successors can cope with such a requirement, thus we choose it as a possible candidate.

Even though EM and BIRCH are nice candidates for our application, these two cannot deal ideal initial clustering and the results are usually not a geographical one. Thus we need a multiphase clustering algorithm. Usually initial clusters can be drawn by K-mean algorithm and then the core cluster algorithm such as BIRCH or EM can work. For geographical consistency, a postprocessing of merging or splitting must be done. Two algorithms of SUBCLUS and PROCLUS are typical examples of multiphase clustering algorithms that attracts our interest.

However, apart from this existing algorithms, we will study the most appropriate clustering algorithms for HAP MBS placement. In this paper, we will show a basic result based on K-mean algorithm [14].

3. Basic Concept of HAP Based Network Configuration

The concept of HAP networking is similar to that of satellite communication. Characteristics such as broadness, simultaneousness, flexible configuration, and broadbandwidthness of HAP based network are similar to that of satellite network, however, on-time supplements, ease of management, short communication distance, low power mini handset, low round trip time are typical characteristics of HAP network that cannot be found in satellite network. The key point here is low communication delay and flexible network configuration. In this paper, we spotted on flexible network configuration and will start the discussion from the basic configuration of HAP network. Figure 1 shows a basic configuration of HAP based network. HAP usually resides on stratospheric area, about 21 km altitude with very low speed of winds as reported by NASA, USA.

Even though Fig. 1 presents only one HAP device, however there could be a lot of plans for multiple HAPs. Figure 2 shows the configuration of HAP based network with multiple HAPs deployed on more wide area.

This configuration with multiple HAPs will cause a interplatform link study and reapplication of traditional frequency reuse problem. It has been assumed that a radio or a optical communication for interplatform link and it is another research area. Several research regarding optical links, including the CAPANINA projects, issued results regarding optical communication links for inter-HAP links as well as downlinks [15], [16], [17]. One of the interesting aporoach includes downlinks of satellite as well [18].

Also a routing problem can be arisen while there are a lot of prepared routing protocol such as OLSR, TBRPF, DSDV, CGSR, WR, AODV, DSR, LMR, TORA, ABR, SSR, and ZRP.

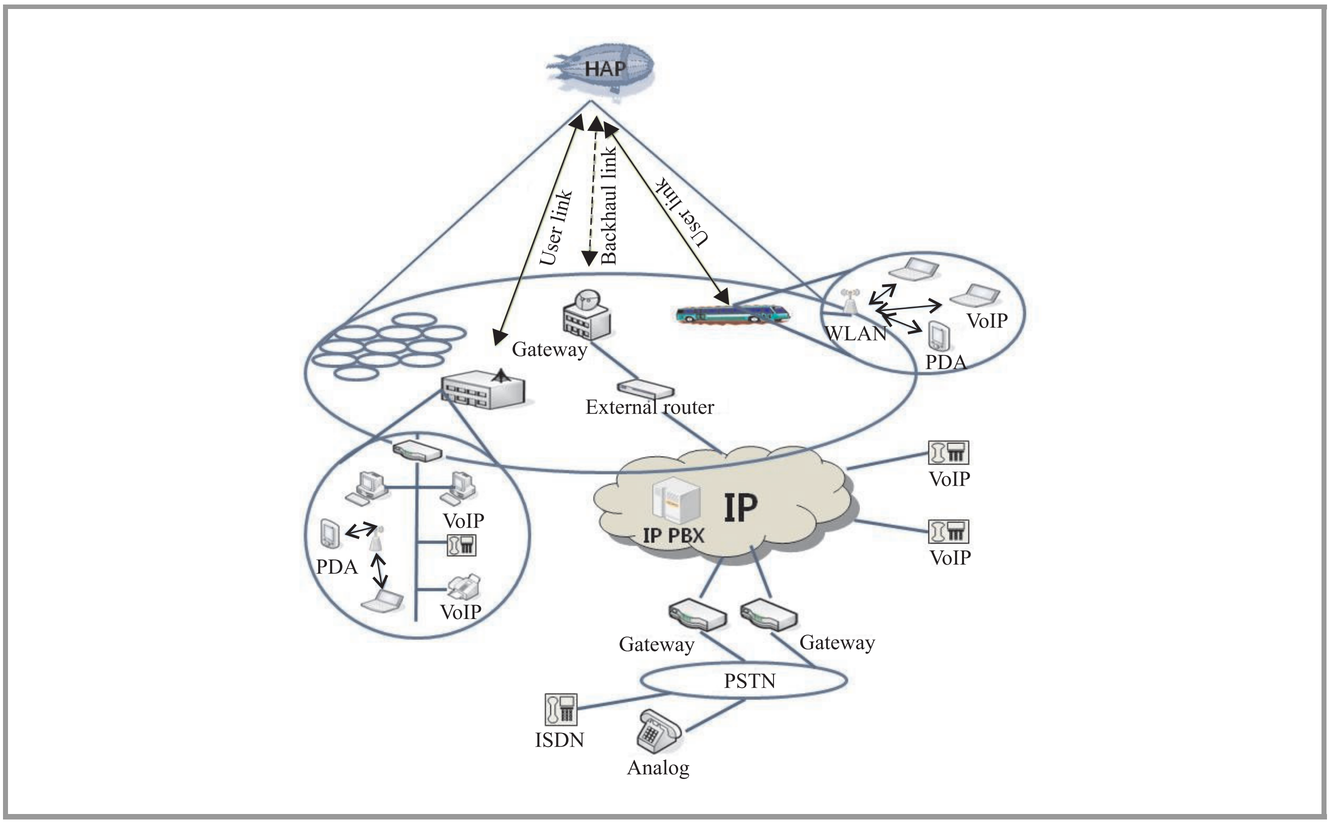

Fig. 1. Basic configuration of HAP based network: singular HAP case. Explanations: IP PBX – Internet protocol private branch exchange, ISDN – integrated services digital network, PDA – personal digital assistant, PSTN – public switched telephone network, VoIP – voice over Internet protocol, WLAN – wireless local area network.

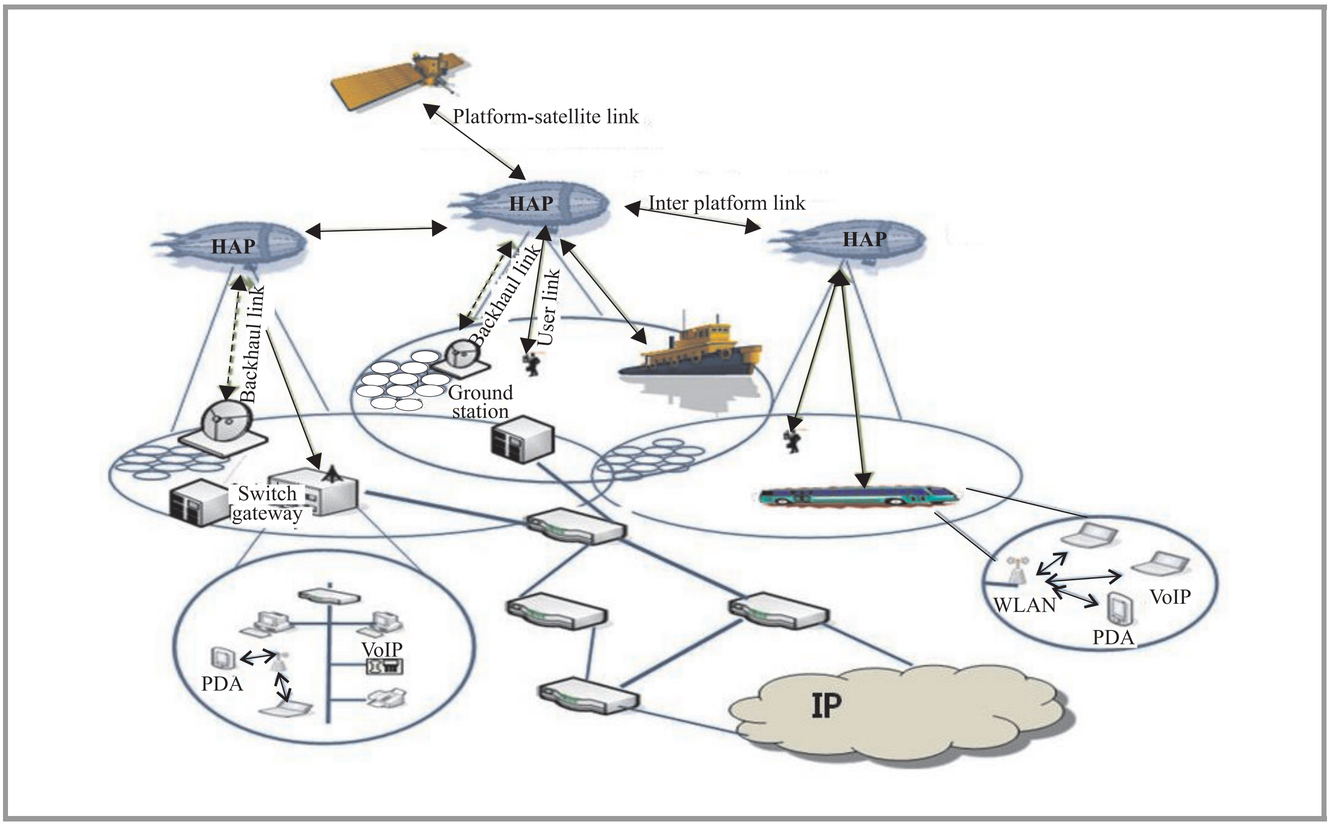

Fig. 2. Basic configuration of HAP based network: multiple HAP case.

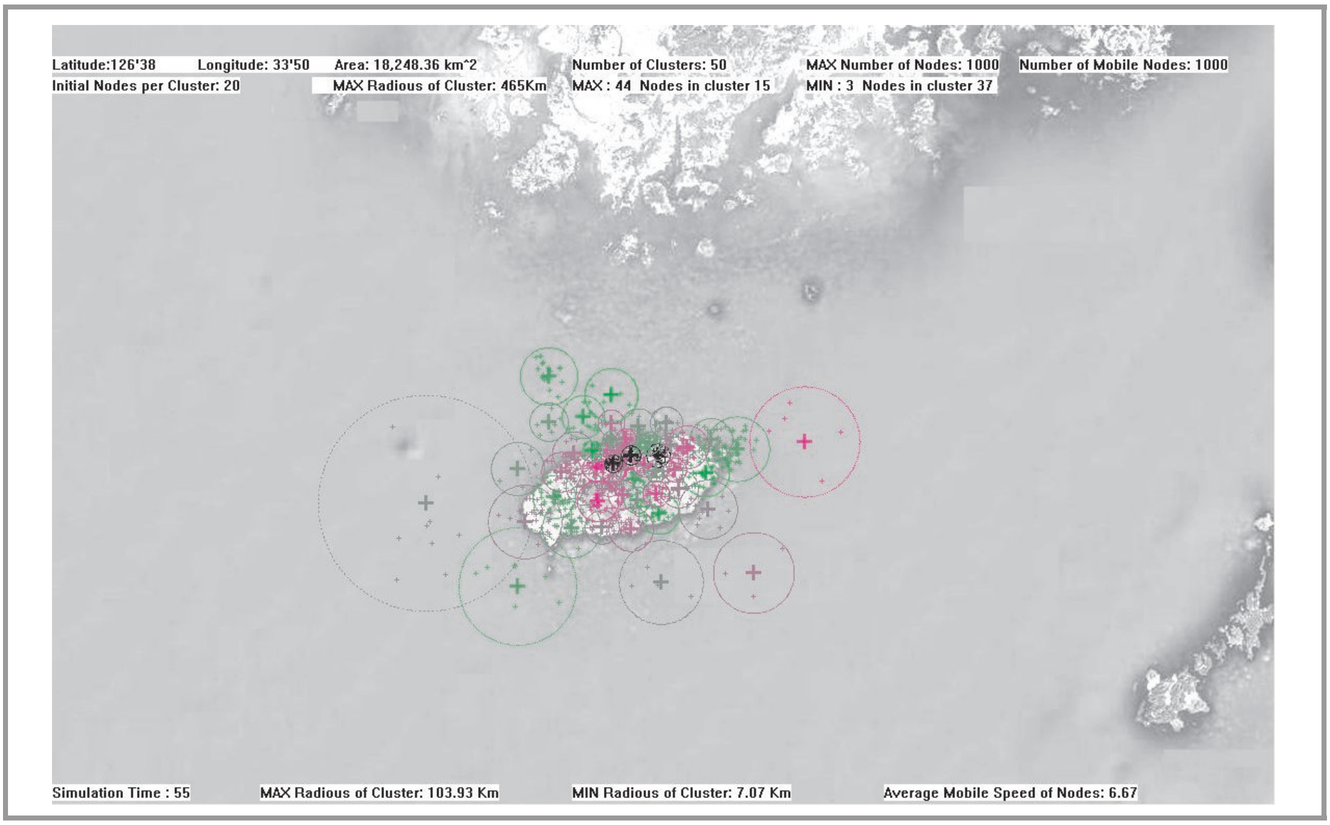

Fig. 3. Geographical simulation results mapped on Cheju Island and neighboring seas.

Therefore we will concentrate on the multiple HAPs network. The first problem of this multiple HAPs network is a clustering of mobile ground nodes and finds an optimal location for multiple HAPs as a clusterhead or mobile MBS. We expect the final result looks like in Fig. 3 where we can see 50 MBSs work as clusterhead and the coverage of each MBS are defined by the population density.

For the environment of this multiple HAPs network, we have similar problems in wireless network listed below:

– uncertainty of mobile ground node coordinates;

– link error rate, lower than satellite network;

– network topology variance, frequent;

– network security.

We can consider parameters below for network configuration:

– total number of mobile ground node, network size N;

– network connectivity;

– topological rate of change;

– link capacity;

– fraction of unidirectional links;

– mobility of ground nodes;

– fraction and frequency of sleeping nodes.

4. Clustering of Ground Nodes for MBS Placement

For multiple HAP network, mobile ground nodes are clustered into several clusters, and each HAP acts as MBS of a cluster or is regarded as clusterhead. Since the number of nodes in a cluster is a major parameter, another parameter of cluster coverage is a dependent variable. Each HAP has capability to adjust its coverage individually by adjusting its angle of elevation. These parameters can vary dynamically according to the mobility of ground nodes. We can assume the following scenarios of dynamic clustering.

- **Initial clustering**. The very first stage of network configuration. Almost a static clustering.
- **Service oriented reclustering**. New influx of mobile ground nodes to a specific cluster cause a overloaded router on a HAP and thus requires a reclustering. Maybe a new UAV can be added.
- **Geographical reclustering**. The mobility of ground nodes can cause more area to be covered by HAP based network. This situation causes reclustering.
- **Airship backup reclustering**. Failure of one or more UAV can cause a reclustering situation.
- **Shrinking clustering**. Decrement of the number of mobile ground nodes will cause a non-mandatory reclustering.

From the scenarios above, we assume a geographical reclustering situation in this paper. However, all of the above scenarios require reclustering algorithm according to the geographical network coverage or mobile ground node distribution. In order to provide such an algorithm, we can assume the following requirements for network parameters.

1. An UAV as a HAP can equip MBS facilities.
2. An UAV can identify number of ground nodes served.
3. An UAV can identify the location of mobile ground nodes.
4. An UAV can identify the location of itself.
5. An UAV can vary the geographical network coverage by adjusting the angle of elevation.
6. An UAV can communicate with ground base stations.

These assumptions can be realized with the help of aero engineering, electro engineering, antenna technology or other related modern technology. Under these assumptions, the following lists requirements for clustering algorithms of mobile ground nodes.

1. The sum of bandwidth requirement from mobile ground nodes in a cluster is equal to or smaller than the total bandwidth of an MBS for the cluster.
2. Each UAV can move in a limited speed. Thus the reclustering must consider the speed of UAVs.
3. Cluster algorithm requires realtimeness for continuous network service.

Here we can show a simple clustering algorithm based on K-mean clustering algorithm.

Algorithm 1: **Clustering and MBS placement**

Require: B : Router bandwidth capacity on a HAP
S : Total sum of required bandwidth by nodes in a cluster
C : A set of coordinates of mobile ground nodes
A : Total area size to be covered by network
M : Maximum area can be covered by a HAP

Ensure: L : List of clusters
P : List of cluster centroids

SpB = S/B //bandwidth requirement

ApM = A/M //geographical requirement

Calculate the number of cluster K = min(SpB,ApM)

L = result of K-mean clustering algorithm with input C

P = calculated centroid of each cluster.

The exact location of each MBS for a cluster is a centroid of the each cluster. The centroid of a cluster is median value of geographical coordinates of mobile ground nodes in the cluster. Instead of mean value, we use median value in order to guarantee the efficiency of MBS coverage. Thus we can use this algorithm for MBS placement.
Even though we use K-mean algorithm, this algorithm can be replaced any of proper clustering algorithm. We experienced several clustering algorithms produce inclusive clusters. To resolve such problem, we need postprocessing of clusters that merges inclusive clusters to including cluster. We regard this problem as a future topic and will discuss basically in the conclusions and future research section.
The time complexity of Algorithm 1 is $O(TN^2)$, where N is total number of mobile ground nodes and T is number of reclustering. Simply speaking, K-mean clustering takes time of $O(N^2)$ for N data entries and the reclustering happens, and the total count of reclustering is T. Whenever the constraints of HAP network clustering are violated, a reclustering is done by K-mean algorithm.

5. Simulation of HAP MBS Placement

We do simulation experiment based on assumptions and algorithms for HAP based network. Our aim is to show simulation results geographically in order to identify clustering result and HAP placement result graphically. The simulation is done first by NS-2 (network simulator 2) with mobility models for nodes. With the NS-2 trail output, we parse them in order to identify node mobility in time and the parsed results are used by clustering algorithms. Finally a clustering results are visualized.

5.1. Simulation Environments and Parameters

For the geographical environment for network simulation, we choose Cheju Island of the Republic of Korea and its neighboring seas. 1000 nodes are distributed according to population distribution on Cheju Island and several marine vehicles were also assumed. The reason why we choose this area is as follows.

- Two cities have denser population than other area.
- The other area has lower population.
- There is high mobility to or from two cities to other area.
- Almost all sort of mobility can be included. There are various type of mobility including human walk, ground vehicle, horse rider, and marine vehicle.
- There are frequent mobility between Cheju Island and its two neighboring small islands which have lower population.
- Lots of travelers show very high mobility.

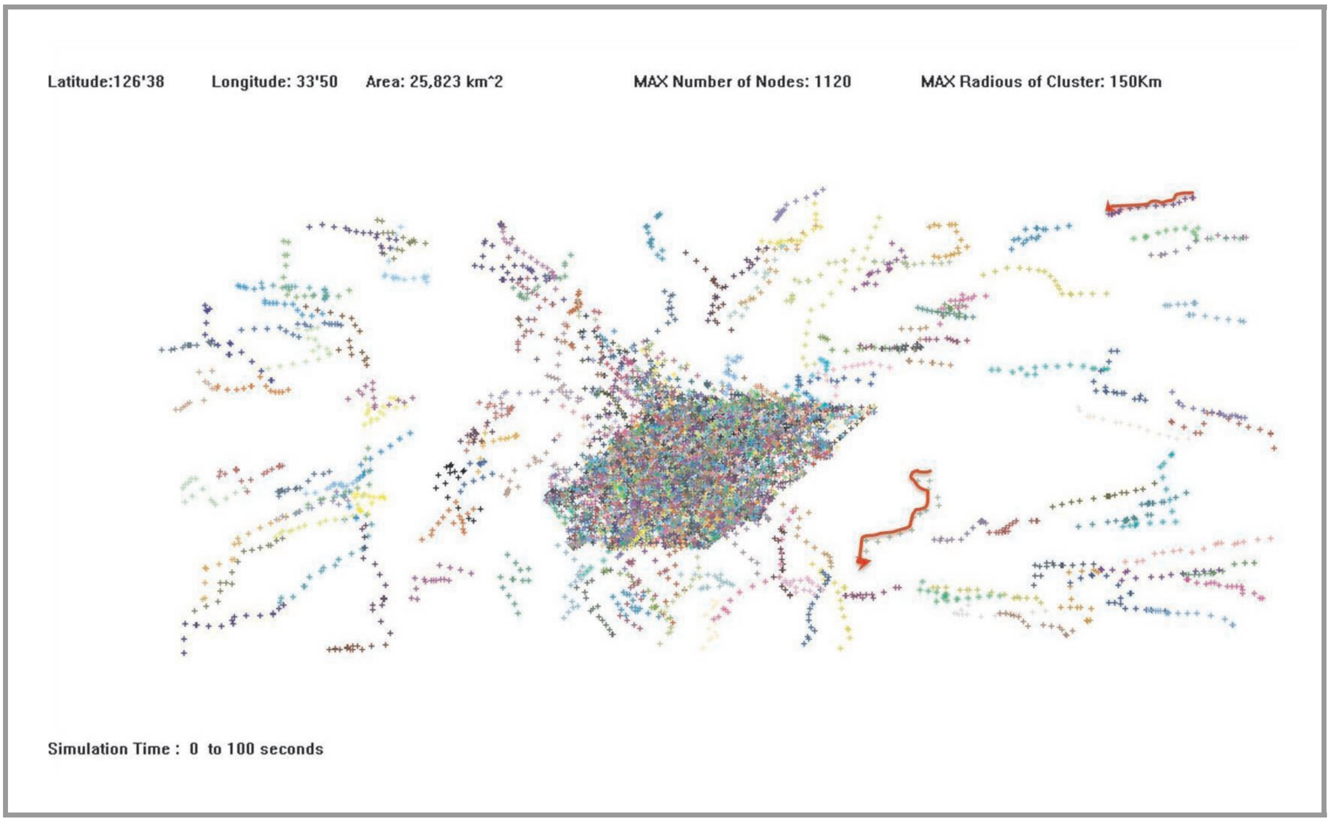

Fig. 4. Node mobility snapshot.

In addition we wanted to look at the phenomena that non-island areas are connected from island area by HAP MBS. The simulation parameters are as follows:

– 28,246 km^2 coverage area;

– total number of mobile ground node is 1000;

– number of initial clusters is 50;

– number of average nodes in a cluster is 20;

– random waypoint (RW) mobility model;

– speed of mobility is 4∼7 km/s;

– node population is proportional to actual population density;

– simulation time up to 60 min;

– maximum 465 km for inter-hap links;

– maximum 150 km for cluster radius as specified by ITU [19].

Figure 4 shows a cumulated snapshot of mobile nodes trajectory for these simulation experiments.

5.2. Simulation Results and Analysis

With this simulation parameters, simulation results are shown geographically in selected Figs. 5–13. Each figures stands for the result of simulation from 15 to 55 min after the start of simulation. In each figure, the radius of a cluster is magnified by the factor of 1.4 for visibility reason. The dots are mobile ground nodes while crosses are centroids of clusters and thus locations of HAP MBSs. Two cities with high population show a lot of clusters with small coverage. This is due to the restriction of network bandwidth provided by on HAP MBS. In order to guarantee minimum bandwidth for individual nodes, the maximum number of nodes per cluster is restricted since HAP MBS has limited bandwidth as a wireless router. The neighboring seas are covered by relatively larger clusters and smaller number of HAP MBS. The maximum number of nodes in a cluster is up to 47 while the minimum number is 2 for a cluster. The largest cluster has radius of 154 km in marine area while the smallest cluster has 6.5 km in city area. Note that 154 km of cluster radius slightly exceeds a maximum radius of HAP MBS coverage specified by ITU.

Even though some nodes look like multiple participant in a cluster, they are actually a member of specific single clusters. This sort of overlapping can be overcome by frequency allocation and reuse [20]. Some clusters with dedicated MBSs look like an orphan. However, the presumably orphan MBSs are within 930 km of other connected HAP MBS, i.e., orphans are within the range of inter-hap links.

Some postprocessing algorithms required in order to merge or to split clusters with abnormal number of nodes. Clusters with larger number of nodes must be split and clusters

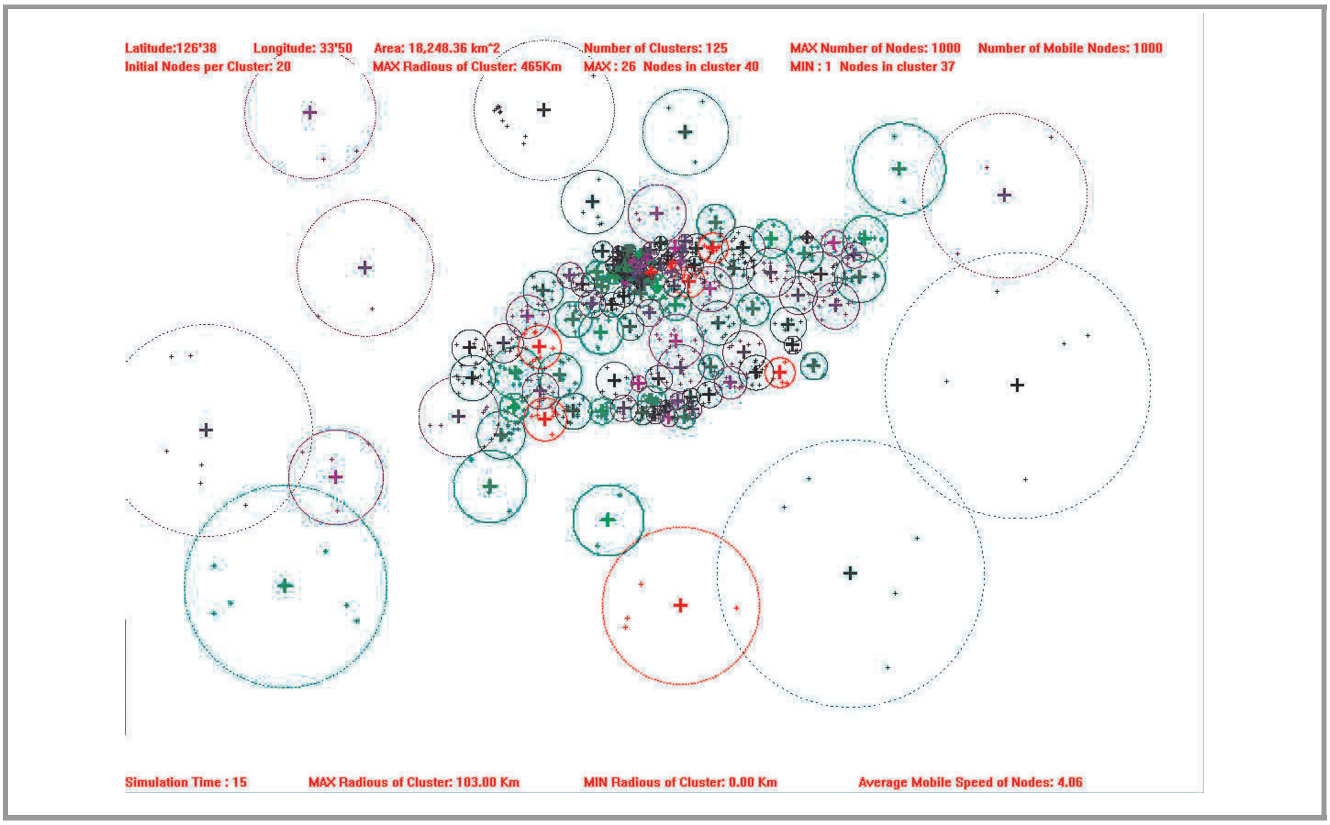

Fig. 5. Placement and coverage of MBSs after 15 min.

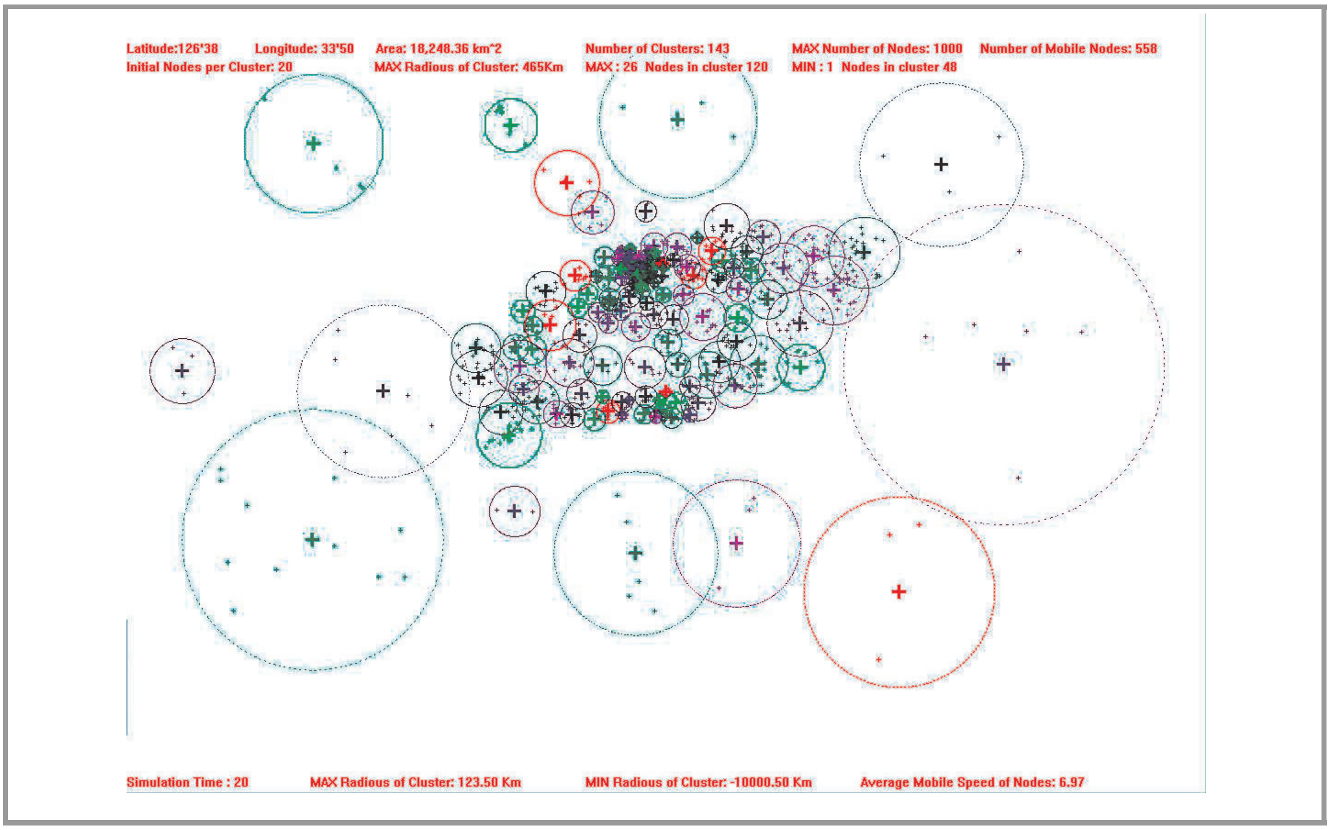

Fig. 6. Placement and coverage of MBSs after 20 min.

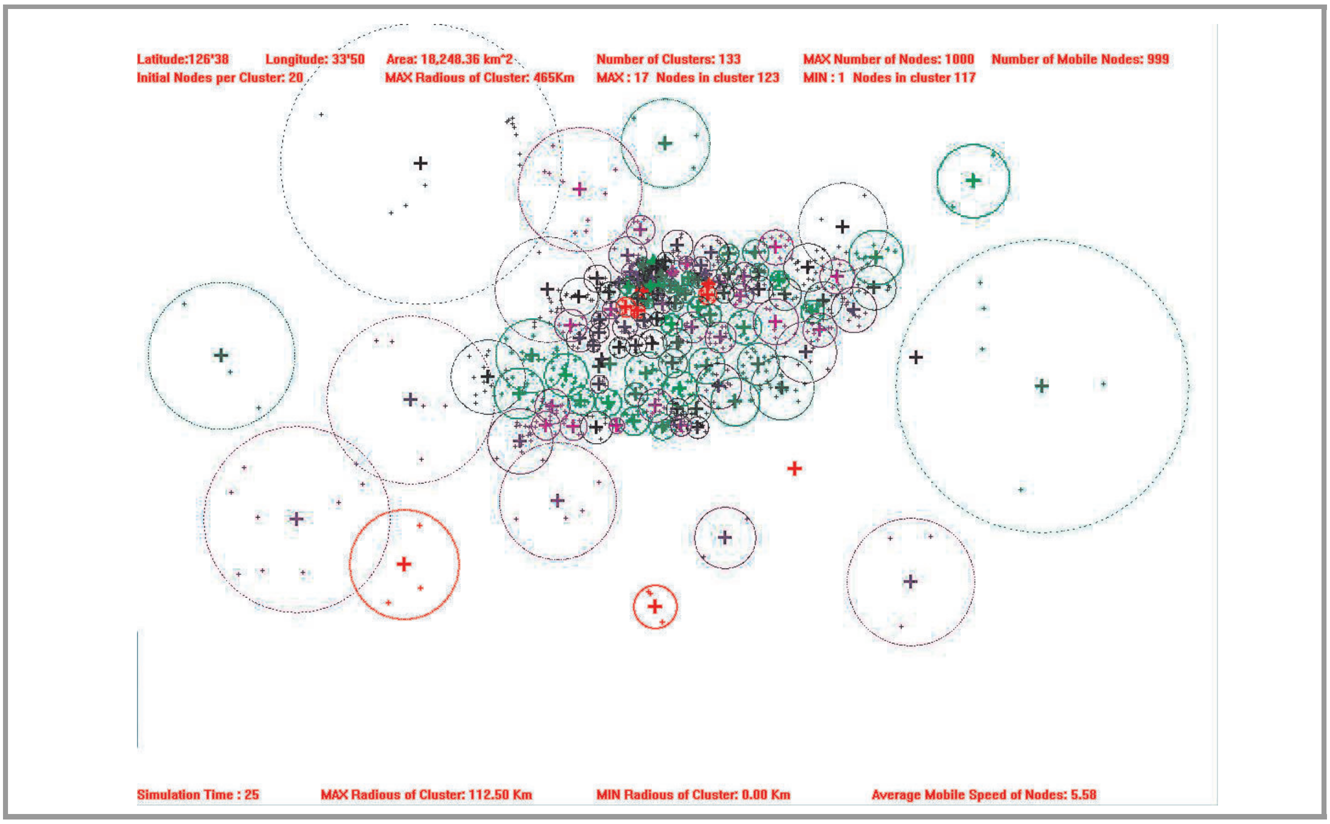

Fig. 7. Placement and coverage of MBSs after 25 min.

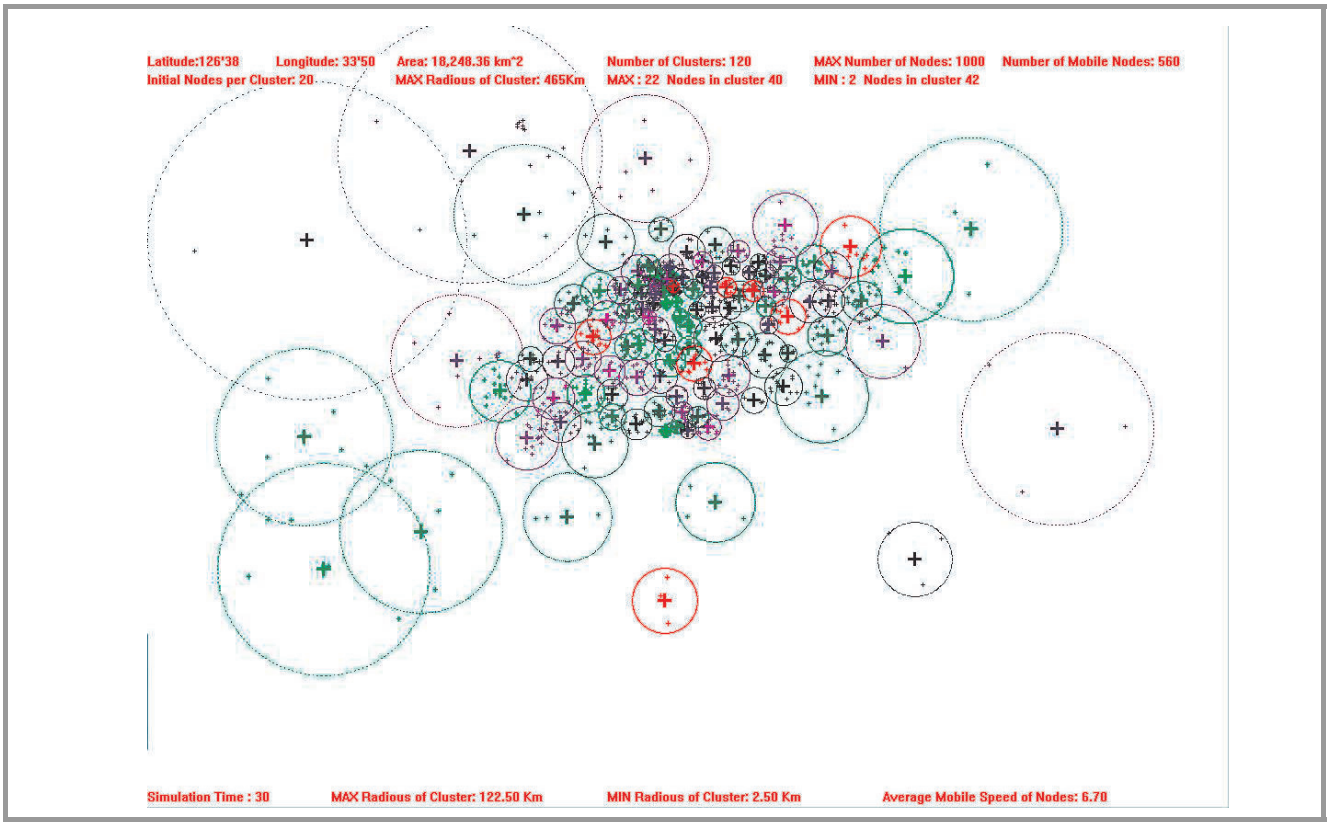

Fig. 8. Placement and coverage of MBSs after 30 min.

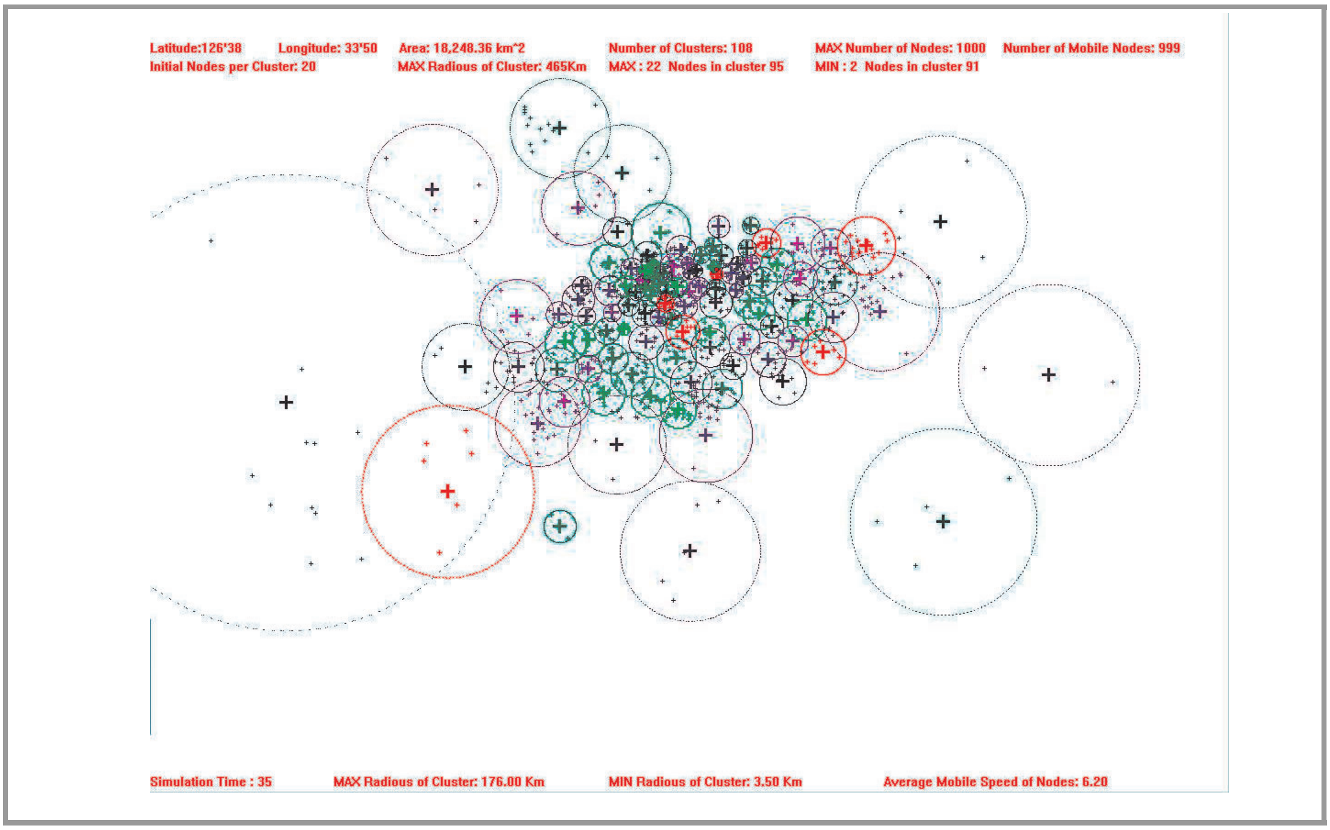

Fig. 9. Placement and coverage of MBSs after 35 min.

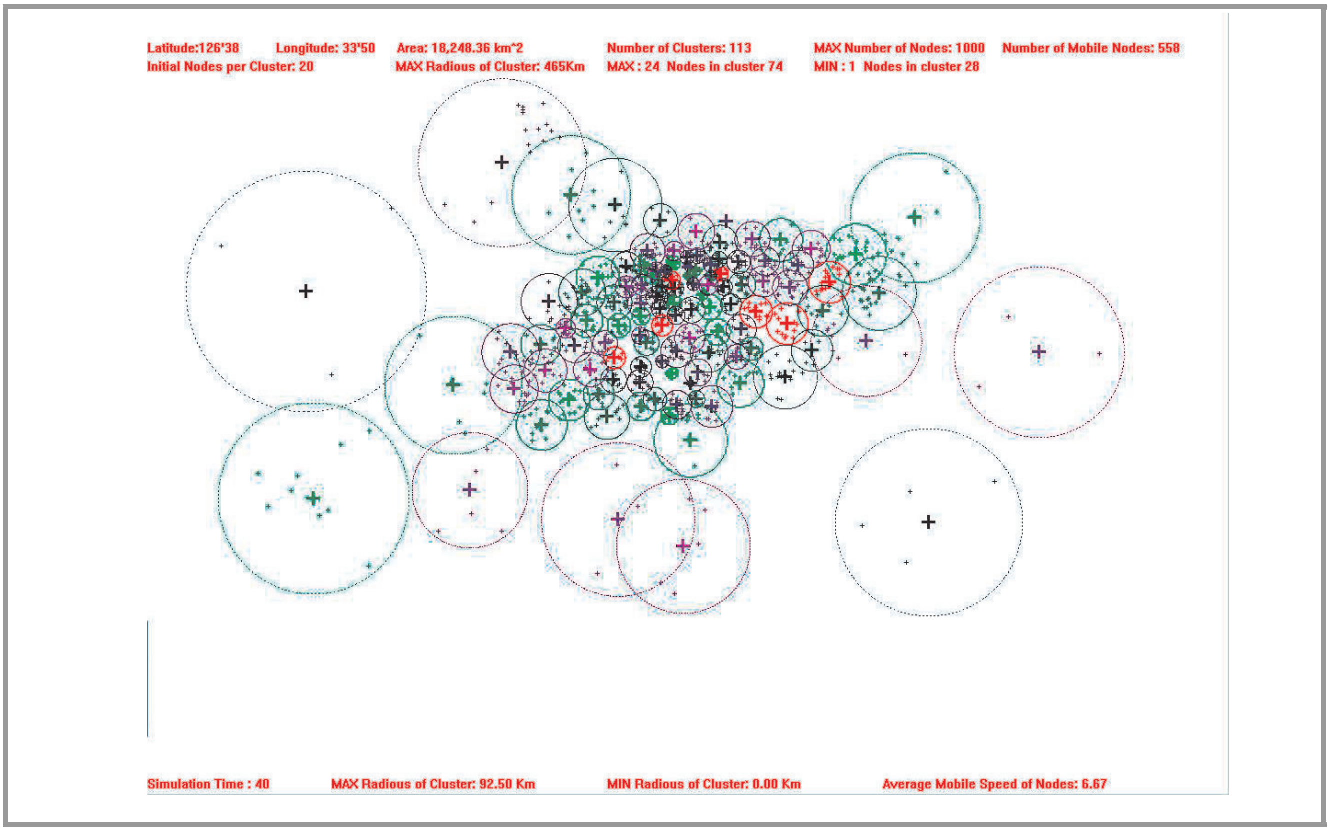

Fig. 10. Placement and coverage of MBSs after 40 min.

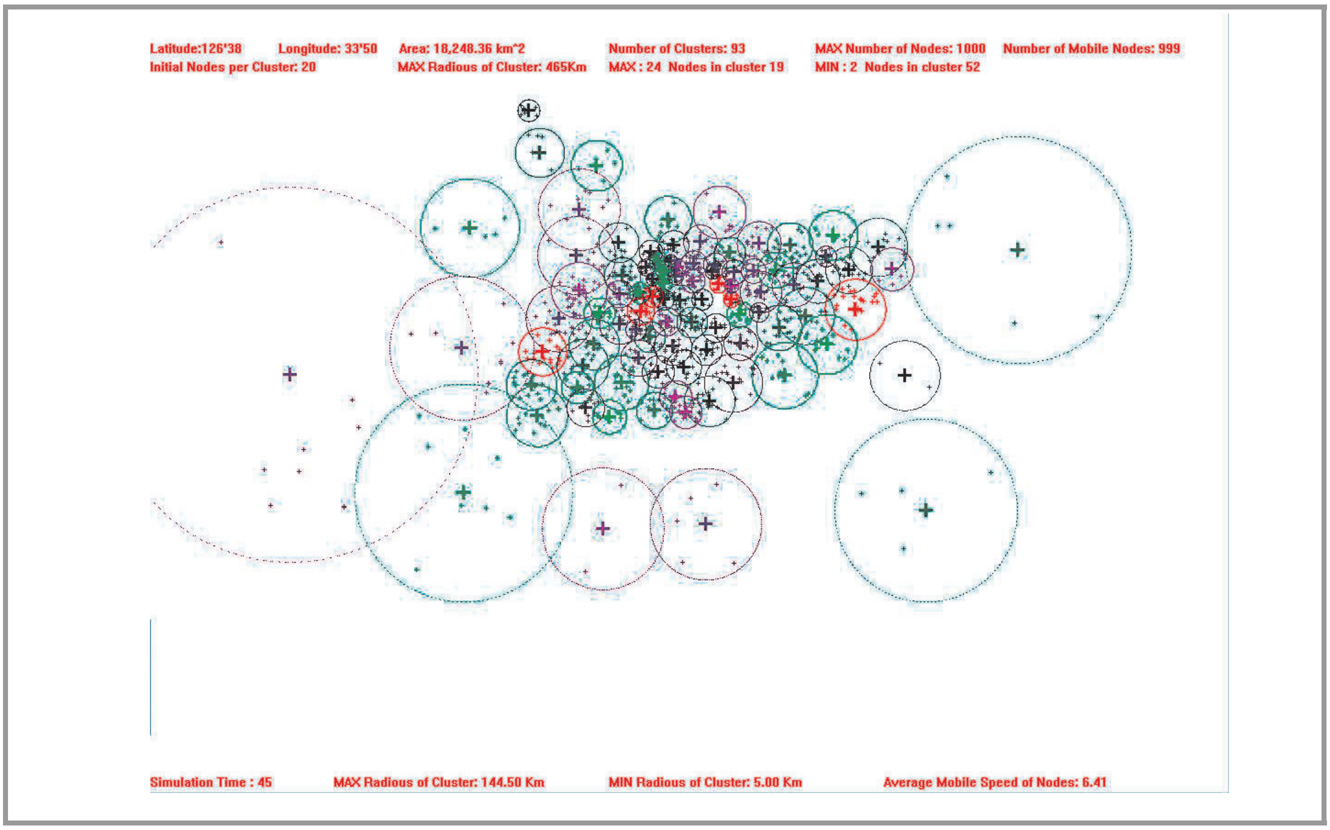

Fig. 11. Placement and coverage of MBSs after 45 min.

Fig. 12. Placement and coverage of MBSs after 50 min.

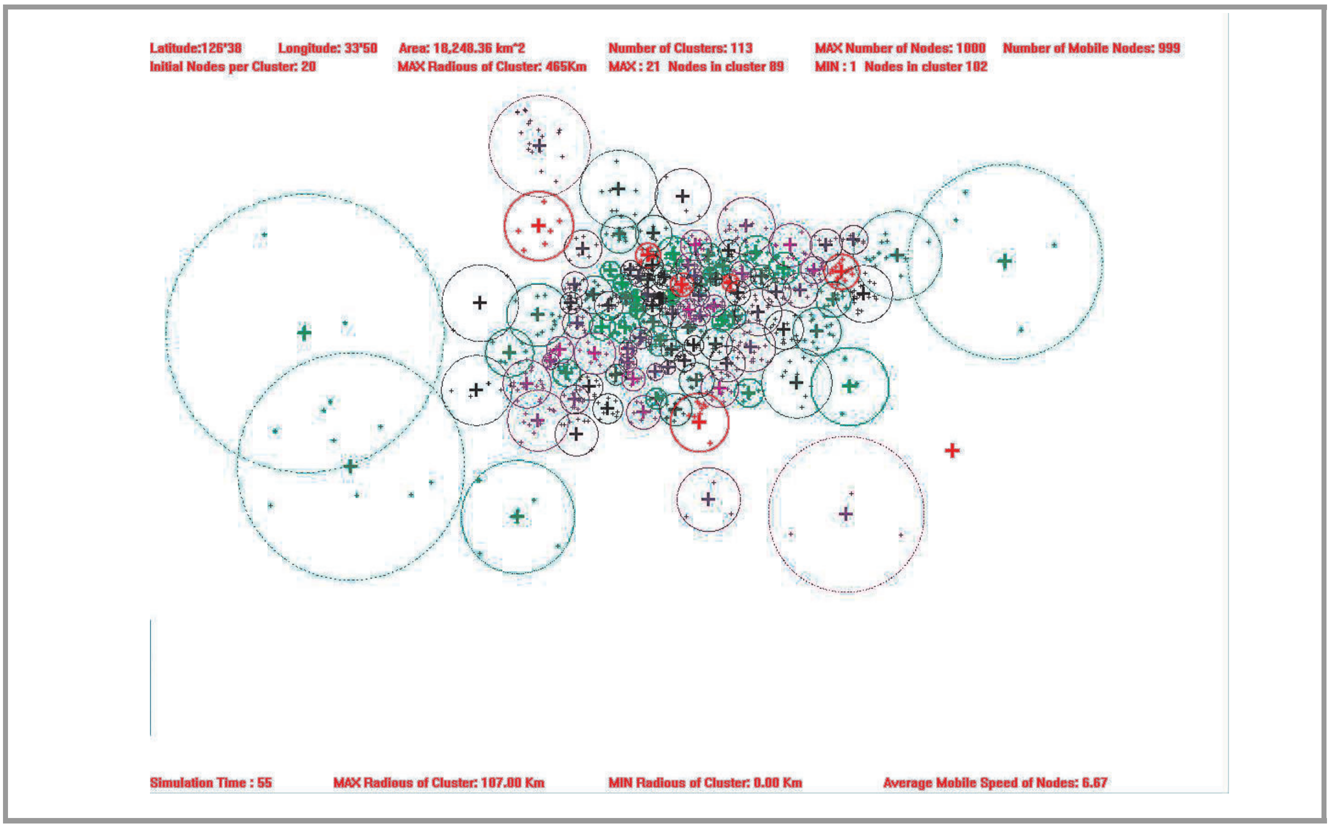

Fig. 13. Placement and coverage of MBSs after 55 min.

with smaller number of nodes must be merged. The ultimate goal of postprocessing is to assign adequate number of nodes equally likely to clusters. We experienced the overloaded clusterhead (MBS) is usually a problem for network configuration. We will provide a simple postprocessing algorithm in Section 6.

We experienced less than 1 s for each clustering with usual Pentium based personal computers. We believe this guarantees realtimeness of our clustering algorithm.

6. Conclusion and Future Research

In this paper, we present a HAP MBS placement solution over multiple HAP based wireless network. Considering the number of ground nodes and area coverage, mobile ground nodes are clustered in order to prepare placement location. As a result, each HAP based MBS can be placed at geographically suitable location in order to serve as a BS of a cluster. We experiment these scenarios by simulation and the results are visualized in a specific area of Cheju Island.

However, we can find several problems regarding the clustering results.

First, we must suppress of mobility of MBSs for stable network service. Even if we assumed mobility of HAP MBSs, high mobility of existing MBSs would cause instable network service.

Second, other than K-mean algorithm, more sophisticated algorithm must be introduced. We are now focusing on EM and BIRCH [12], [13] as a core algorithm for HAP MBS placement. For uncertain coordinates of highly mobile nodes we can adjust probabilities for such nodes to be members of a specific cluster with the speed of mobile node or so. Then this probability set will be directly applied to EM based clustering.

Third, the number of nodes per cluster must be distributed evenly for stable network bandwidth allocation. Since there are no clustering algorithms that calibrate the number of elements per cluster, a new clustering algorithm must be introduced. And we sometimes observe inclusive clusters and semi-inclusive (highly overlapped) clusters in simulation results. BIRCH has the abilities of splitting or merging clusters by use of CF tree. These capabilities can be a useful method to assign evenly distributed number of nodes to clusters.

These combination of clustering algorithms ultimately leads to a multiphase clustering algorithm. We are now considering the following process.

1. Preprocessing with static clustering algorithms such as K-mean.
2. Main clustering with dynamic clustering algorithms such as EM.
3. Postprocessing for split and merge of clusters with algorithms such as BIRCH.

We believe the outmost clustering algorithm would be BIRCH since it requires another clustering algorithm for core clustering features.

For postprocessing as mentioned in Section 4, we have the following idea. We can merge a cluster into outer cluster when the cluster is inclusive under the condition:

$$|C_1 - C_3| + R_3 < R_1 \quad \text{and} \quad N_1 + N_3 < N$$

where C_i is a coordinate for cluster i, R_i is a radius for cluster i, and N_i is number of nodes in a cluster i.

The first term stands for cluster C_3 is totally inclusive in cluster C_1 and the second term restricts merge if the total number of nodes in two clusters exceeds a desired number of nodes N in a cluster.

Similarly we can merge semi-inclusive clusters where most part of a cluster, e.g., 75%, is covered by another cluster.

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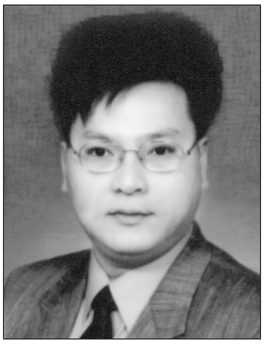

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