

# A Distributed Topology Adjustment Algorithm for Wireless Networks with Mobile Base Stations

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## ABSTRACT

Improper static network topology can reduce the capacity of wide area wireless access networks in which the distribution of subscribers' population often changes. This paper focuses on "fully wireless cellular networks" with mobile base stations, where the network topology can be dynamic due to the mobility of the base stations. In such environment, network topology can be properly controlled by the adjustment of mobile base stations' positions. A novel distributed topology adjustment algorithm is proposed in this paper. The proposed algorithm tracks subscriber's population by moving mobile base stations toward the center of their nearby groups of subscribers. At the same time, mobile base stations are also drawn outward their neighboring base stations in order to solve the "oversupply base station" problem. The balance between 2 movement forces determines the proper position of mobile base stations. The performance evaluation of the proposed algorithm shows that the proposed algorithm performs well, even in rapidly changes of subscribers' population or in the presence of failure of base stations.

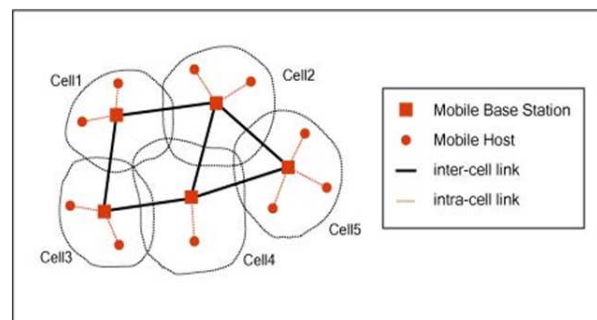
**Keywords:** Wireless cellular network, mobile base station, topology adjustment

## 1. INTRODUCTION

Recently, there has been much interests in dynamic wireless networks due to the availability of smaller, smarter and cheaper portable devices, in expensive wireless technology, and mobile user's demand for "anyone anywhere anytime" information access. Dynamic wireless networks reveal themselves into two forms, i.e. mobile ad hoc networks (MANETs) [1-3] and wireless cellular networks with mobile base station (MBS) [4-7]. Both are made up of heterogeneous nodes which can be classified as mobile host (MH) and cluster head (CH) in MANETs or base station (BS) in cellular networks. MHs access network resources through the CHs or BSs while the CHs

or BSs link together to form a network infrastructure. MANETs are initially designed for temporary and special use, such as on battle fields or in emergency rescue operation where there may not be any established infrastructure for networking. Nowadays, they are widely used for a number of applications, e.g. Intelligent Transportation System (ITS). Nodes in MANETs are assumed to be identical in resources such as energy, computation power, memory, etc. In each cluster, a node is selected to be the cluster head dynamically. The cluster head has the same resources as the other nodes in the cluster. On the other hand, cellular networks are designed as a wireless infrastructure for providing accesses to mobile users in a wide area environment. In cellular networks with MBSs, BSs are assumed to be rich in resources, i.e. having more energy, computational power, memory, etc, while MHs are assumed to be resource poor. Moreover, BSs are determined *a priori* rather than selected by MHs. Several implementations [8-10] for addition of the mobility to BSs by mounting on vehicles or even on unmanned aircrafts exist.

Figure 1 shows an example of cellular networks with MBSs. A geographical area is divided into smaller regions called "cells". Each cell contains a BS serving mobile hosts. The geographical area covered by the cell changed dynamically as the BS moves. The links between MBSs are wireless and referred to as inter cell links. MHs can communicate with the others in the system only through the BS of that cell. This communication between an MH and its BS is also through a wireless link and referred to as intra cell links.



**Fig.1:** A cellular network with mobile base stations.

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A cellular network with mobile BSs is very attractive. It is preferably deployed in situations where the traditional cellular networks with fixed BSs are not available, or the existing cellular network with fixed BSs is not suitable because of inconvenience, cost, etc. Such systems can be rapidly deployed to deal with emergency, to supply temporary needs, or to replace the traditional cellular networks in order to make cellular networks *more adaptive to changes* in the distribution of subscribers' population or traffic pattern, especially for Internet usage with which traffic is quite fluctuate.

Due to the mobility of BSs serving as access points to MHs, it is possible to adjust topology of BSs according to MHs' distribution by properly adjusting mobile BS's positions. Ref [7] initially presented such topology control algorithm. The algorithm tries to find a center of covered MHs that seems to be the suitable position for mobile BSs and then move each mobile BS towards that position independently to each others. Since mobile BS moves without considering the distance and cooperations with other mobile BSs, it leads to the "*over supply BS*" problems in which excessive numbers of mobile BSs exist in small area with high density of MHs. As a result, BSs' resources such as radio channel capacity are not best utilized. In this paper, a novel topology adjustment algorithm for wireless networks with mobile BSs is proposed. Our algorithm improves "centroid based algorithm" [7] by the addition of movement forces between BSs. BSs whose distances are too close/far will push/pull together. At the same time, each mobile BS will also be forced to move towards the center of their nearby groups of MHs. The balance between two movement forces determines the proper position of mobile BSs. The performance evaluation shows that the proposed algorithm outperforms the existing algorithms, even in rapidly changes of population or in the presence of failures of BSs.

The rest of this paper is organized as follows. Section II presents related works with section II emphasizing the system model. In section IV, the proposed algorithm is presented in details. Simulation results and discussions are given in section V Section VI concludes the paper.

## 2. RELATED WORKS

Topology adjustment is a function of the topology control which is a technique used to change topology of BSs serving as access points for MHs according to the distribution of MHs' population. Effective algorithm should locate the distribution of BSs most suitably to the distribution of MHs so that network resources can be best utilized by MHs and at least one BS should be reached by any MHs.

In [11] and [12], the distribution of fixed BSs for traditional cellular network with fixed BSs can be designed according to the expected distribution of MHs by formulating as the optimization problems.

In [13], Ram et al. proposed topology control algorithm by using a power-controllable radio technology. The topology control is formulated as a constrained optimization problem minimizing transmission power subject to the network being connected or bi-connected. Two distributed heuristic algorithms for mobile networks, that adaptively adjust node transmit powers in response to topological changes and attempt to maintain a connected topology using minimum power, are presented. However the approach using power adjustment may be suitable to networks whose MHs move within small area because of distance limitation of radio power adjustment and the complexity in avoiding improper cell overlaps within a wide area network.

In [14] and [15], ad hoc networks are used within the cell of a cellular network to dynamically expand the last mile of network coverage. The architecture consists of a cellular network, supported by a number of local ad hoc networks that are established on demand. Local ad hoc networks are used to forward the data onto users located outside the radio channel range of the cell coverage. Even through this multi-hop cellular architecture is quite effective, additional complexity relevant to ad hoc functions needs to be deployed on every MH. Such design is quite difficult since MHs' feature should be kept as simple as possible in order to save energy consumption. In addition, the reliability issue in ad hoc network in a wide area environment is still questionable.

This paper emphasizes on the approach that allows BSs to change their positions according to changes of MHs' distribution since additional complexity will be implemented only in BSs which are normally considered to be rich in resources, compared to MHs. One major problem in realization of such mobile BSs is how to solve the channel allocation problem among BSs if BSs change their positions. Several papers [4,6] address this problem. Most of the papers define protocol and algorithm to reallocate channel dynamically when BSs move. In [6], the fault-tolerance issue is also considered. A cell (i.e., mobile BS) can borrow a channel as long as it can form a subset of cells from which a reply message has been received and there is at least one common available channel in the subset. The proposed algorithm in [6] can guarantee that the time to respond to an MH's request for supporting a call is upper-bounded.

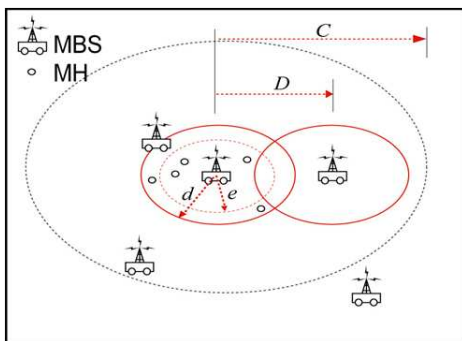
Ref [7] initially proposed an algorithm which controls movement of mobile BSs in cellular networks. The

mobile BS in Ref [7] follows MHs by estimating the center of MHs in its current cell for the next movement period, then moves to that point. Since each mobile BS decides to move independently with each other, the “*over/under supply mobile BS*” problem happens especially when large groups of MHs often move. This problem leads to the reduced coverage area of networks and under utilization of network resources. The “*over/under supply mobile BSs*” problem is solved in this paper by the repulsive and attractive forces between mobile BSs to avoid this situation.

In this paper we also assume that the location estimation and trajectory prediction algorithm proposed in [5] is employed in BSs. This algorithm can be used to accurately predict the next movement of MHs with less system complexity. A robust extended kalman filter is used to derive MH’s movement from MH’s location and heading direction, etc. As a result, mobile BS can follow groups of MHs more accurately.

### 3. SYSTEM MODEL

A system consists of a set of mobile base stations (MBSs) and mobile hosts (MHs) connected by the completely wireless links as shown in Figure 2. MBSs serve as access points to networks for a group of MHs in their radio range, i.e. cell area with radius  $d$ . The cell size,  $d$ , of each MBS may be adjusted by increasing/decreasing intra-cell radio power. An MH will be served by only one MBS at a time even though it is in radio range of several BSs. An MH which moves out of cell area of its currently serving BS needs to be handed over to another BS which it can reach. Any of the MHs at the edge of a BS’s cell area is considered having high possibility to perform handover procedure in the proposed algorithm. The edge area of a cell is defined as the area in between the edge distance,  $e$ , and the cell’s radius,  $d$ . In the model, the fixed BS of traditional cellular network may be thought of as an MBS with zero movement.



**Fig.2:** The system model.

We assume that channel allocation algorithm in Ref [6] is used to solve a problem of inter-cell radio frequency conflict when MBS moves. Equilibrium

distance,  $D$ , is defined as the appropriate distance between BSs in the cellular networks which arrange their cells to be hexagon [11,12]. The  $D$  value can be determined by equation (1) for a cellular network with uniform distribution of MHs.

$$D = \sqrt{3}d \quad (1)$$

If the distance between MBSs is less/more than  $D$ , they tend to be pushed/drawn together in order to maintain such hexagon shape of topology as possible. In the proposed distributed algorithm, MBS will collect information such as its neighboring MBSs and MHs’ position from those MBSs. The distance  $C$  is defined as the cutoff distance within which an MBS will contact other MBSs for the information. The  $C$  value can be adjusted by increasing/decreasing the inter-cell radio power of a BS. We assume that the  $C$  value is more than  $2D$  in the proposed algorithm. Increasing cutoff distance will increase the algorithm accuracy but have to trade with more complexity.

### 4. THE PROPOSED TOPOLOGY ADJUSTMENT METHOD.

The proposed algorithm uses the approach which changes positions of MBSs in following groups of MHs and, at the same time, controls groups of MBSs so that they will not be too scattered or too condensed. Generally, each MBS will find necessary information either by calculating by itself or by collecting from its neighboring MBSs as described in section 4.1. Then location adjustment forces, influenced by both group of MHs and neighboring MBSs will be calculated according to procedure in section 4.2. Finally the movement decision algorithm explained in section 4.3 will be executed. Note that each MBS will execute the algorithm periodically and independently with each other. Even though MBSs run algorithm independently, the corporations among MBSs occur from the movement forces proposed in the algorithm.

#### 4.1 Position Information Exchange

The position of an MH,  $h_{x,y}$ , and the position of a neighboring MBS,  $O_{x,y}$ , can be tracked by the MBS whose cell area covers the MH and the neighboring MBS is in the range of the cutoff distance  $C$ . The tracking algorithm is based on adaptive smart antenna [16,17] and prediction method as in Ref [5]. Each MBS will exchange the position information of MHs in its own service area with the neighboring MBSs. Thus each MBS at the position  $b$ ,  $B_{x,y}$ , have enough information to calculate the following parameters used in the proposed algorithm.

- $N_b$ : The number of MHs within its service area when the MBS is at the position  $b$ .
- $E_b$ : The number of MHs within the edge of its service area when the MBS is at the position  $b$ .

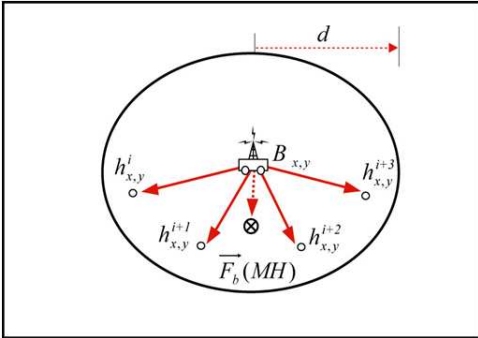
- $\vec{F}_b(MH)$ : The force influenced by MHs within its service area when the MBS is at the position  $b$ .
- $\vec{F}_b(BS)$ : The force influenced by neighboring MBSs within its cutoff distance  $C$  when the MBS is at the position  $b$ .

## 4.2 Location Adjustment Forces

There are two type of forces influenced by group of MHs (within service area with radius  $d$ ) and group of neighboring MBSs (within cutoff distance  $C$ ).

### 4.2.1 Forces between an MBS and its covered MHs

MBSs try to follow groups of MHs within its radio range by calculating the centroid of MHs as in equation (2). The centroid is the point where sum of weighted distances (reversely proportional to radio signal strength) from MHs is minimized. Then, the force which attracts the MBS to the group of MHs can be found as in equation (3). Figure 3 shows its conceptual diagram. The direction of the force is from the current position of the MBS to the centroid position and the size of the force will be proportional to the distance between the current position of the MBS and the centroid position.



**Fig.3:** Force between an MBS and its covered MHs

$$C_b = (c_x^b, c_y^b) = \left( \frac{\sum_{i \in S^b} w_i h_x^i}{\sum_{i \in S^b} w_i}, \frac{\sum_{i \in S^b} w_i h_y^i}{\sum_{i \in S^b} w_i} \right) \quad (2)$$

$$\vec{F}_b(MH) = [(C_x^b - B_x)\hat{x} + (C_y^b - B_y)\hat{y}] k_c \quad (3)$$

Where,

$k_c$  is the proportional constant.

$(C_x^b, C_y^b)$  is the  $(x, y)$  position of the centroid for the set of covered MHs,  $S^b$ , when the MBS is at the position  $b$ ,  $(B_x, B_y)$ .

$h_x^i, h_y^i$  is the  $(x, y)$  position of the  $i^{th}$  MH.

$w_i$  is the weight of the  $i^{th}$  MH.

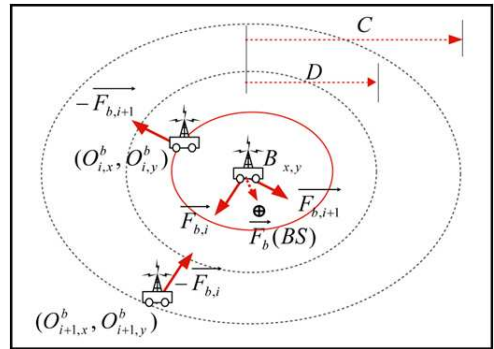
$\hat{x}$  is the unit vector in the x-axis direction.

$\hat{y}$  is the unit vector in the y-axis direction

This force between MBS and MHs will be used in the movement decision algorithm. The weight  $w_i$  gives a difference preference to an MH to which the MBS will move closer. The closer distance between an MBS and an MH is, the higher quality of service the MH will get. This is due to stronger radio signal and lower possibility to be handed over to other MBSs. Therefore, the  $w_i$  of MHs which have similar characteristics, e.g. average holding time, type of service or antenna power gain, and require the same quality of service should be set to the same value in the real operating environment.

### 4.2.2 Forces between an MBS and its neighboring MBSs

In order to prevent the "over/under supply MBS" problem, movement force among MBSs is defined so that MBSs will be arranged themselves to the equilibrium hexagon shape [11,12]. Figure 4 shows the resultant force influenced by 2 neighboring MBSs at the considered MBS. A pair of an MBS and the  $i^{th}$  neighboring MBS, whose distance is *less/greater* than equilibrium distance,  $D$ , will have *repulsive/attractive* force,  $\vec{F}_{b,i}$ , as in equation (4). The force's size,  $|L_i^b|$ , is half of the difference of those distances. The half is derived from the concept that the force should be split to equally influence each of the considered MBS-pair. (Note that, if there is only the considered MBS-pair in the system and each MBS is influenced to move by the half value, the desired  $D$  distance should be achieved.) For an MBS at the position  $b$ ,  $B_{x,y}$ , the resultant force will be the weighted sum of all forces from its neighboring MBSs within the cutoff distance,  $C$ , as defined in equation (7).



**Fig.4:** Force between an MBS and its neighboring MBSs

$$\vec{F}_{b,i} = [L_i^b \cos(\theta_i^b)\hat{x} + L_i^b \sin(\theta_i^b)\hat{y}] k_{MBS} \quad (4)$$

$$L_i^b = \frac{\sqrt{(O_{i,x}^b - B_x)^2 + (O_{i,y}^b - B_y)^2} - D}{2} \quad (5)$$

$$\theta_i^b = \arctan \left( \frac{O_{i,y}^b - B_y}{O_{i,x}^b - B_x} \right) \quad (6)$$

$$\vec{F}_b(BS) = \frac{\sum_{i \in M^b} v_i \vec{F}_{b,i}}{\sum_{i \in M^b} v_i} \quad (7)$$

Where,

$k_{MBS}$  is the proportional constant.

$(O_{i,x}^b, O_{i,y}^b)$  is the  $(x, y)$  position of the  $i^{th}$  MBS in the set of neighboring MBSs,  $M^b$ , when the considered MBS is at the position  $b$ ,  $(B_x, B_y)$ .

$v_i$  is the weight of the  $i^{th}$  MBS.

By setting different value of the weight  $v_i$  to each MBS, it is possible to make the force,  $\vec{F}_{b,i}$ , influence each of the MBS-pair at different level. Higher  $v_i$  will drive the movement of the other MBSs more than the lower value. In the real environment, the MBS with less mobility (less preference to move) will be assigned higher value of  $v_i$ .

### 4.3 Movement Decision Algorithm

The movement decision algorithm is designed with the following objectives.

- Maximize the number of serviced MHs.
- Minimize the possibility of call (connection) blocking or discontinuation as possible.
- Maximize coverage area as possible.

Figure 5 shows the movement decision algorithm for an MBS. The algorithm has two phases: move decision phase and next position determination phase. Periodically, each MBS will start the algorithm by deciding whether it should change its position or not. The number of serviced MHs,  $N_{cur}$ , the number of edge MHs,  $E_{cur}$ , the MHs' force,  $\vec{F}_{cur}(MH)$ , and the MBSs' force,  $\vec{F}_{cur}(BS)$ , are calculated. The  $N_{cur}$  is firstly considered whether it is more than zero or zero. In the first case ( $N_{cur} > 0$ ), it will check further on the additional two parameters. If the MHs' force is greater than zero and the  $E_{cur}$  is more than the threshold edge MHs,  $E_{max}$ , then it will consider changing its location to the next better location. The direction of the movement will be the direction of the MHs' force and the tentative next position will be far apart from the current position with the distance equal to the size of MHs's force. Note that the MHs' force is primarily considered in order to realize the objective (A), by making an MBS follow groups of MHs as much as possible. The objective (B) is realized by considering the edge MHs. The movement of MBS should be kept as few as possible since it may generate the calls' discontinuation causing from MHs' handover procedure. In case of high value of the current edge MHs, it is worth changing the position since the possibility of MHs' handover is quite high. In the

second case ( $N_{cur} = 0$ ) or the isolated MBS, it will consider changing its location to the next better location by taking into account the influences from its neighboring MBSs,  $\vec{F}_{cur}(BS)$ . The direction of the movement in this case will be the direction of the MBSs' force and the tentative next position will be far apart from the current position with the distance equal to the size of the MBSs' force.

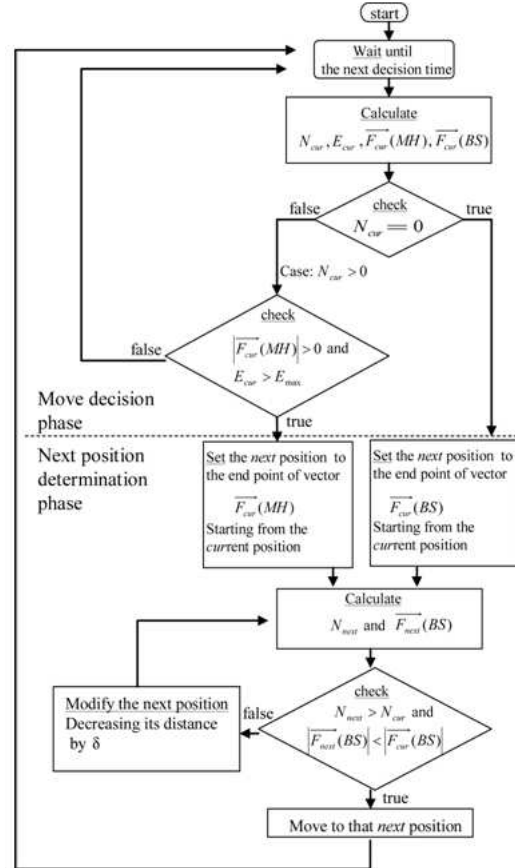


Fig. 5: The movement decision algorithm.

The next phase determines where should be the next best position. It starts by setting the tentative next position as mentioned above. Then the following two conditions are tested for that next position.

- The number of covered MHs at the tentative next position is greater than the serviced MHs at the current position, and
- The size of neighboring MBSs' force,  $\vec{F}_{next}(BS)$ , at the tentative next position is less than that of at the current position,  $\vec{F}_{cur}(BS)$ .

The first condition guarantees that the next position should cover more MHs than the current position. At the same time, the second condition considers the objective (C) so that the next position should be in balance with other MBSs better than the current one. Too scattered or condensed MBSs will generally give larger size of the parameter. If those conditions are satisfied, the MBS will use that next position

for the movement in this period. Otherwise it will modify the tentative next position by decrementing the distance from current position to that tentative next position by the delta parameter,  $\vec{F}_b(BS)$ , then begins testing the conditions again. Those steps are repeated until those two conditions are satisfied or the tentative next position becomes the current one. In the last case, no movement happens in this period.

## 5. PERFORMANCE EVALUATION

Event-driven simulations are conducted to evaluate the performance of the *proposed* algorithm, comparing to the traditional cellular network with pre-designed *fixed* BSs [12] and the cellular network with mobile BS movement using the *centroid* based algorithm [7].

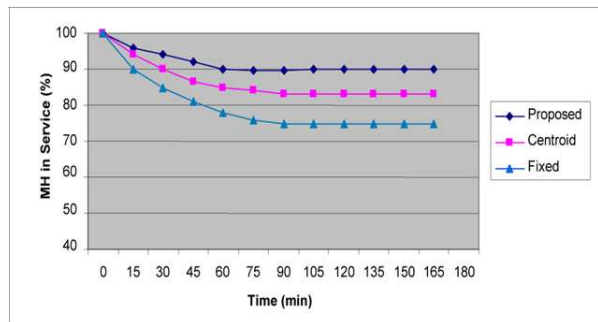
Three performance metrics, which are the coverage area, the call (connection) failure and the MH in service, are defined. The coverage area is the geographical area in the simulation which can be reached by the radio signal of at least one base station. The MH in service is the number of mobile hosts which can contact to a base station and can make the call or connection. The call failure is the number of events including the following three cases.

- Call drop: An MH cannot acquire a communication channel from a new base station, when it moves to the new cell area, since all available channels are occupied by other MHs. Then the current connection is terminated.
- Call blocking: An MH can contact to a base station but all available channels of the base station are occupied by other MHs when it is going to make a connection.
- Out-of-service call: An MH cannot reach a base station when it is going to make a connection.

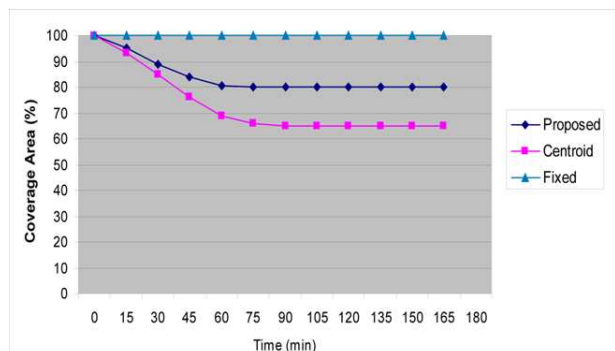
In the simulation, MBSs will be initially simulated as the hexagon shape of the cell layout with equal amount of MHs generated with normal distribution (See appendix A) in each cell. The base station uses intra-cell radio power which can cover geographical area with the radius,  $d$ , of 5 km. The edge distance,  $e$ , is set to 85% of  $d$ , or 4.25 km. The inter-cell radio power is set so that the cut-off distance,  $C$ , is  $2D$  or 17.32 km. After the initial state, MHs are simulated to move randomly. Each MH's motion is randomly generated from the speed within the range of 11 m/s (40 km/hr) up to 20 m/s (72 km/hr) [7], independently with each other. The MBS will move according to the topology adjustment algorithm with the speed 40 km/hr. The threshold edge-MH,  $E_{max}$ , of the proposed algorithm is set to 15% of the capacity of each MBS. The max concurrent call for each base station is set to one-tenth of the capacity of each base station. The average time for the randomly generated call is

set to 1.5 minutes [18,19]. For the simulation in each scenario, fifty thousand simulations have been run, the average values of considering metrics are plotted in the graphs. Note that the fixed base station of the traditional cellular network is modeled as the MBS without any movement.

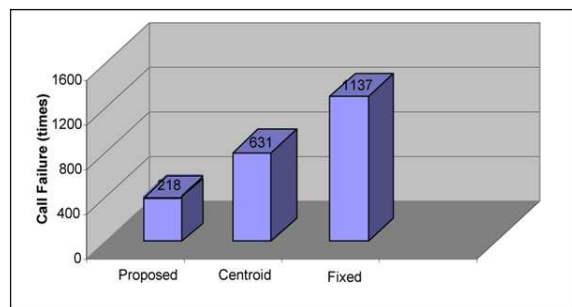
Figures 6, 7 and 8 show the results of the first scenario in which 20 BSs are generated in the system and 280 MHs are randomly generated in each BS. Therefore, there are 5,600 MHs in each network and each BS can support a maximum concurrent call of 28 calls.



**Fig. 6:** MHs in Service in case of normal distribution of MHs.



**Fig. 7:** Coverage Area in case of normal distribution of MHs.



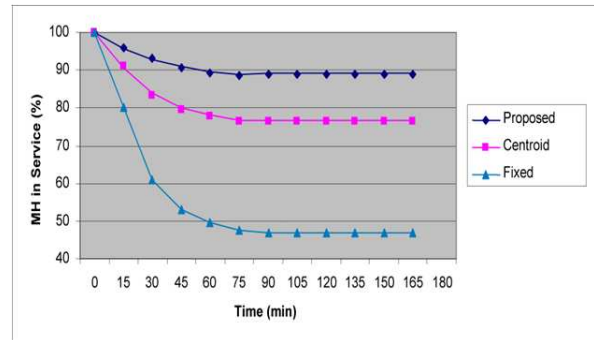
**Fig. 8:** Call Failures in case of normal distribution of MHs

Figure 6 shows the results of MH in service of the

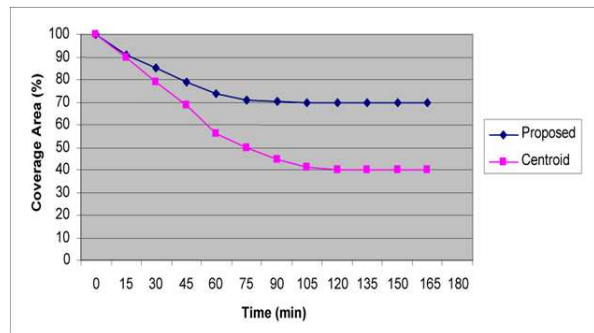
proposed algorithm, centroid-based and the fixed network. When the simulation starts (time=0), each MBS is equally filled by MHs at its max capacity (280). Since the number of MHs within each MBS does not exceed the MBS's capacity, the MH-in-Service of all algorithms starts at 100%. Later on, each MH moves randomly. The number of MHs in MBSs becomes unbalanced. Some MBSs have to service MHs more than its own capacity while some need to service only few MHs. As a result, the average MH-in-Service of all algorithms begins decreasing. The rate at which the MH-in-Service decreases depends on how properly the algorithm can move according to the MHs' movement. Finally, it reaches to the steady state where there is a balance between MHs moving in and out MBSs. As a result, the MH-in-Service becomes unchanged. Based on the results in Figure 6, the proposed algorithm can adjust MBSs' topology according to the MHs' movement better than the others since it can reach the steady state *faster* than the others and its final MH-in-Service is also *higher* than the others. The proposed algorithm outperforms approximately 7% and 17% over centroid-based algorithm and the fixed base station network respectively. Figure 7 shows the coverage area of three algorithms starting from the beginning to the steady state. As expected, the proposed algorithm can cover more area compared to the "Centroid". Note that 100% of coverage area can be achieved by the "Fixed" along the simulation time since the MBSs in the "Fixed" do not move at all. Even the MH-in-Service and the Coverage-Area improvement of the proposed algorithm over the "Centroid" may not be large in this simulation scenario, its improvement in the number of call failures is significant, which is illustrated in Figure 8. The number of call failures in MBS network with the proposed algorithm is at only *one-third* of that in centroid-based approach, and at *one-sixth* of that in fixed network. The reasons of performance boost up of our proposed algorithm are that the proposed algorithm considers the corporation between MBSs, so there is less overlapped cell area in this network. As a result, the number of MHs in service becomes increased. Moreover, the distance (between MBSs) consideration will guarantee the smooth hand-off of MHs. This leads to a low possibility of occurring call drops, and out of services MHs.

In the second scenario, we simulate the high density of MHs in some cells to which large population of MHs will move. There are 20 BSs in each network and 280 MHs are randomly generated in each BS at the initial state. Then some area in the network (approximately 25% of total areas in the system) becomes popular later on. For the simulation, 75-80% of MHs belonging to each cell move towards the target popular areas, and the minority of MHs are still in their own cell. Each BS can support maximum concurrent

calls of 28 calls. Figure 9 depicts the MH-in-Service of the three networks.



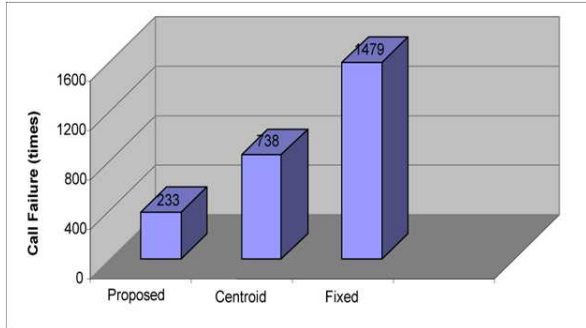
**Fig.9:** MHs in Service in case of congestion of MHs in popular area.



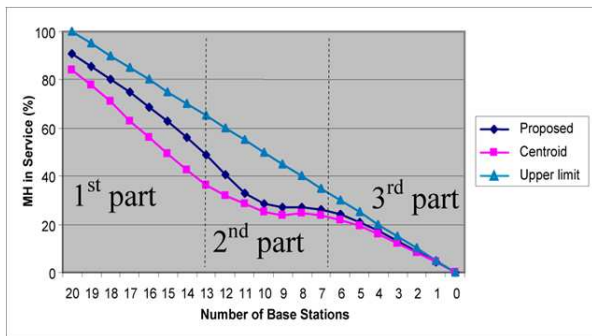
**Fig.10:** Coverage Area in case of congestion of MHs in popular area.

The performance improvement of the proposed algorithm over the centroid-based and the fixed network are now 12.5% and 43% respectively, better than in the normal distribution of MHs scenario. The reason is that the proposed topology adjustment algorithm is designed with respect to arranging their cells to be hexagon in order to fulfill the high coverage area and the minimum overlap area at best, contrasting to the centroid-based algorithm which will only move toward the group of MHs and will not consider the distance between MBSs. Therefore, the proposed algorithm will not abandon the area with few MHs in order to only cover the majorities of MHs like in centroid-based algorithm. This can be seen in Figure 10 where up-to 30% of coverage area in the network can be improved and the "over-supply MBS" phenomenon which happens in the centroid-based algorithm has been solved by the proposed algorithm. Moreover, the proposed algorithm still considers the center of covered MHs to be a factor of making decision so MBSs can fulfill both MHs in service and coverage area at the same time. Consequently, MBS can be used more effectively and the call failure including call drop, call blocking and out of service MH become quite low even in the event of congestion of

MHs. This is shown in Figure 11 in which the proposed algorithm can maintain the increase in the call failure at only 8% while the increases are at 17% and 30%, compared to the case of the centroid and the fixed base station.



**Fig.11:** Call Failure in case of congestion of MHs in popular area.

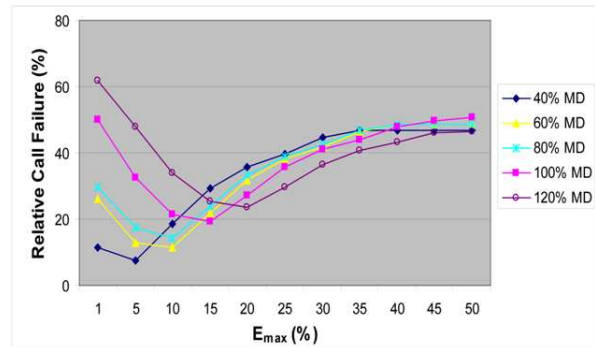


**Fig.12:** MHs in Service in case of base stations' failures.

In the third scenario, BSs' failures are simulated with other parameter settings the same as in the first scenario. The MH in Service of the 150<sup>th</sup> minute is plotted corresponding to the number of base stations remaining in the system. As shown in Figure 12, the proposed algorithm still works well and can track the upper limit line in the 1<sup>st</sup> part (less than 30% of base stations' failures). The performance of the proposed algorithm drops quickly and converges to the result line of the centroid algorithm on the 2<sup>nd</sup> part (failures between 30% and 75%). In this part, only few cooperation between MBSs happens since the number of base stations is low. Therefore the behavior of our algorithm becomes quite similar to the centroid algorithm. In the 3<sup>rd</sup> part where number of base stations is very low, there will be MHs in any place to which base stations reach. Thus the results of both algorithms converge to the upper limit line.

In our next analysis, the performance of the proposed algorithm is studied according to the adjustable parameter, i.e. the  $E_{max}$ , of the proposed algorithm. Figure 13 shows the Relative Call Failure (%), which

is defined as the number of call failures of the *MBS network* with the proposed algorithm *divided* by that of the *fixed network*, when the  $E_{max}$  is varied from 1% to 50% of the maximum capacity of an MBS in the network and the other simulation settings are set as in the 1<sup>st</sup> simulation scenario. Each line ( $x\%$  MD) illustrates simulation results of the networks with different MH density (MD), which is defined as the number of MHs generated in the system compared to the maximum number of MHs supported by all MBSs at their maximum capacity.



**Fig.13:** Relative Call Failure vs.  $E_{max}$  in case of 40%, 60%, 80%, 100% and 120% of MH Density (MD).

Based on the results, there is the same trend of the changes in the proposed algorithm's performance among different MH densities according to the  $E_{max}$  setting. When the  $E_{max}$  is set too low ( $E_{max} = 1\%$ ), there is high possibility that MBSs move too often, i.e. every times of the movement decision schedule. As a result, the handover possibility in the system is very high, thus the consequent call failures become quite high. When we increase the  $E_{max}$ , the call failure line declines until it reaches to the point of the optimal  $E_{max}$  value where the call failure is at the lowest value (the best performance) since there is a balance between the possibility of the MBSs' movements and the MH density. After that the call failure becomes increasing until it reaches to the steady state where the increase of the  $E_{max}$  value rarely affects to the number of call failures. When the exceeds the optimal point, the frequency of MBSs' movements turn to be lower than necessary. However, if the reaches to the point which is large enough to make the number of MHs within the edge area become rarely possible, then the possibility of MBS's movements become unchanged. This is the range of the steady state in the relative call failure line. The  $E_{max}$  should be set to the optimal value in order to make the proposed algorithm perform at it best. In addition, we found that networks with higher MH density require lower value of the optimal  $E_{max}$ . This is because the proposed algorithm should allow MBSs to move more often (lower  $E_{max}$ ) when MHs density is quite low and to move less often (higher  $E_{max}$ ) when MHs in



the network become quite condensed in order to let MBSs follow groups of MHs more properly. The relationship between the optimal  $E_{max}$  against the MH density of the networks is illustrated in Figure 14. As shown in the figure, the relationship between the  $E_{max}$  and the MH density seems to be a linear function with positive slope, especially in the real network operating range, i.e. MH-density between 40-100%. Note that each plotted optimal  $E_{max}$  is the estimated (extrapolation) lowest point from the RelativeCall-Failure& $E_{max}$  curve of each case of the MH density.

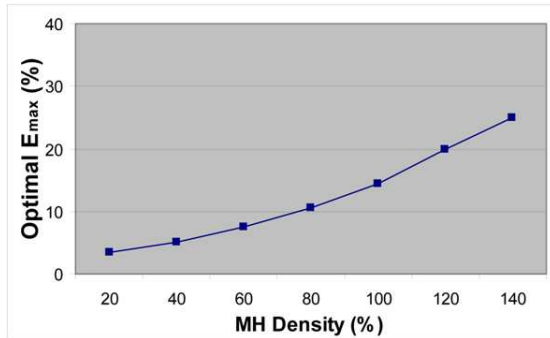


Fig.14: Optimal  $E_{max}$  vs. MH Density.

## 6. CONCLUSION

We have provided a distributed algorithm for topology adjustment for wireless networks with mobile base stations. We employed the approach in which base stations appropriately moves according to changes in subscribers' population. In the proposed algorithm, we extend the existing centroid based algorithm by adding the concept of forces between base stations, instead of only the forces from mobile hosts. Both forces are properly used in our proposed algorithm to solve the problem of "over/under supply base stations" happening in the existing algorithm. The simulation results proved that the proposed algorithm outperforms the existing one, especially in the cases of overload capacity and the base station failure. In addition, the proposed algorithm can be used in the migration period from the fixed base stations to the full mobile base stations since it is designed as the distributed algorithm in which each mobile base station uses only information acquired by itself. Even though the proposed algorithm can achieve better performance than the existing algorithm, it should be noted that the performance gain is traded with higher computational requirement. Compared to the centroid algorithm, the proposed algorithm requires more computation in calculating the  $F(\text{BS})$ . However, the additional computation can be limited by setting appropriate cut-off distance,  $C$ , of the algorithm. For example, the additional computation of the proposed algorithm is only about 1.4 time of that of the centroid in the simulations with  $C = 2D$  setting. In

the future, further investigation will be done on applying this algorithm to multi-hop cellular network with mobile base station in which the last mile of base stations can be extended by the localized ad hoc networks dynamically.

## 7. APPENDIX A

MHs are generated within a coverage (cell) area of an MBS according to the normal distribution whose probability density function is defined as in Equation (A.1). Note that the x-y coordinate (0,0) is set as the location of the MBS. When the variance,  $\sigma^2$ , is set to 1, the probability density function can be shown as the Figure 15.

$$f(x, y) = \frac{1}{2\pi\sigma} e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (\text{A.1})$$

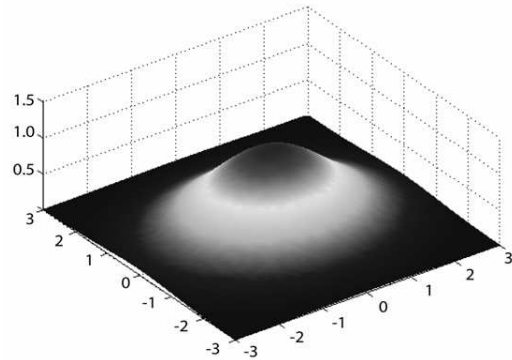


Fig.15: The probability density function of the normal distribution used to generate MHs within the cell area of an MBS.

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