Capability Based Clustering Mechanism in WiMAX

S.C. Wang, H.H. Liang and K.Q. Yan

***Abstract*—WiMAX is a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to wired broadband like cable and DSL. WiMAX can provide mobile wireless broadband connectivity without the requirement for direct line-of-sight with a base station. With the development of wireless network, WiMAX has long transmission distance, wide coverage, high speed, multiple bands, and support of multi-media. In a populated environment, the network becomes unstable and there are broadcast storms because of interferences by excessive communications when many users are using their mobile devices for communications, file or audio/video sharing. Therefore, the devices are clustered based on their properties and capabilities, in order to reduce packet collisions and rapid energy consumptions by excessive broadcast. In this way, the lifecycle of the device will be prolonged and the network can be made more stable.**

***Index Terms*—WiMAX, Broadcast Storm, Cluster, Network Performance, Life Time.**

I. Introduction

WiMAX is a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to wired broadband like cable and DSL. WiMAX provides fixed, nomadic, portable and mobile wireless broadband connectivity without the need for direct line-of-sight with a base station [3,9]. Together with today's multifarious habits and wide application of mobile devices, mobile audio and video, mobile medical service, mobile study and voice keep improving their service qualities. The era of next generation broadband wireless access is coming nearer. The original network structure cannot satisfy today's demands. Traditional Wi-Fi network does not support sufficient coverage and mobility. That is why the WiMAX (Worldwide Interoperability for Microwave Access) technology is developed. WiMAX has a long transmission distance, good mobility, and wide coverage. More important, WiMAX overcomes the limits of the last mile and is able to support the families, businesses, and general users in remote area.

In a WiMAX network, with the development of information technology, cell phones, PDAs, laptops, and all kinds of mobile devices will support WiMAX network. Supported by WiMAX, people will be able to communicate with the others, download files, share information, or enjoy a movie on their handheld mobile devices at anytime and anywhere using broadband service. However, in a downtown area with a dense population, if everybody tries to log into WiMAX network to communicate with the others or transfer files with a WiMAX enabled subscriber station (SS) from the street, a restaurant, a shop, or a park, WiMAX is more likely to generate radio interference, packet collision, unstable networking caused by broadcasting, and fast energy consumption of mobile device than a cable network [1,5,10]. To solve the above problems, a clustering system is proposed in this study. Mobile devices in a WiMAX network are clustered by their properties or applications, in order to reduce the chance of packet collision caused by massive transfer and improve network stability and expansibility. In other words, a clustered network topology based on the properties of mobile devices or the application in a WiMAX environment is constructed.

The remainder of this paper is organized as follows. Section 2 is a literature review. It explains the IEEE 802 family of wireless network, the characteristics of WiMAX, and today's WiMAX network topology. The Section 3 lists methods and architecture of the study. The clustering mechanism, including its initialization and adjustment is discussed in Section 4. A selection system for cluster manager (CM) is proposed in Section 5. The simulation results used to evaluate the performance of the proposed system are presented in Section 6. Finally, the conclusion is discussed in Section 7.

II. Related Work

In this section, the common WiMAX network topology is discussed. In a wireless network environment, nodes can be connected by radio waves to construct a network topology. Different environment and service demands may require different linkage. As a result, there will be different topologies. The topologies of WiMAX include PMP (Point to Multi-Point) and Mesh network [2,3,5].

PMP is one of the most common topologies available today. Data are transferred in a point to multi-point manner. The transferring way of PMP is Single Hop. Several Subscriber Stations (SSs) are connected to a Base Station (BS). There is no interconnection among the SS. The SS has to contact the BS if it needs to communicate with another SS or the other domain. Figure 1 demonstrates the PMP topology. PMP is good for its BS based data transfer. Packet loss and collision as a result of triangle routing problem are reduced and the chance of a broadcasting storm by excessive transfer is lowered [4,6-8]. On the other hand, BS is required for all data transfer based on this architecture. Therefore, BS may be

Manuscript received November 30, 2008.

S.C. Wang is with the Chaoyang University of Technology, Taiwan, ROC (e-mail: scwang@cyut.edu.tw).

H.H. Liang is with the Chaoyang University of Technology, Taiwan, ROC (e-mail: s9630613@cyut.edu.tw).

K.Q. Yan is with the Chaoyang University of Technology, Taiwan, ROC (corresponding author to provide phone: 886-4-2332-3000; fax: 886-2374-2369; e-mail: kqyan@cyut.edu.tw).

overloaded and the network becomes unstable when the traffic is huge.

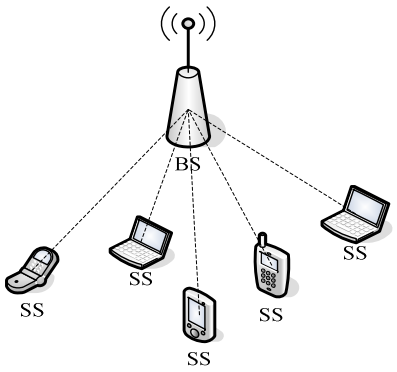

Figure1. The PMP network topology

Mesh is full-connected network architecture, as shown in Figure 2. Mesh network is different from the PMP topology by the fact that no BS is required for the communication between SS. In other words, multiple paths are adopted in the communication [1,2,9].

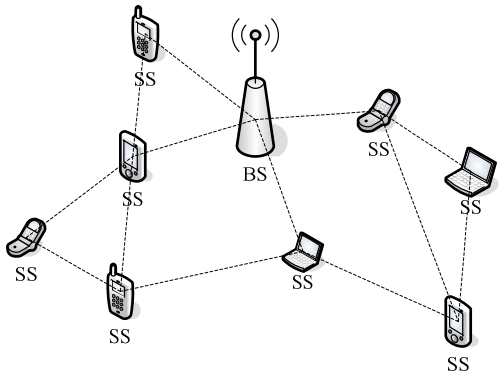

Figure 2. The Mesh network topology

Mesh network does not rely on a single path that connects to BS for data transfer. In PMP mode, a node becomes blind if the BS is down. Since the Mesh network utilizes multiple paths for data transfer, the link is optimized for validity, fault tolerance, and robustness. However, in a Mesh network, broadcast storm is common and the mobile devices consume more energy because of excessive network traffic, despite of the better transfer rate brought by multiple paths [9].

Both PMP and Mesh network have their advantages and disadvantages. It is a good idea to combine the two modes, keep their advantages, and overcome the disadvantages. In this study, a clustered WiMAX network topology is proposed. The advantages of PMP and Mesh are combined to optimize the performance and stability of the network.

III. Methods and Structures

WiMAX mobile network is adopted in this study. In this network, there are a lot of SSs with different CPU capacity, energy, application, and communication coverage besides base station. The SS can be classified into normal nodes (NN) and CM. In a WiMAX network, the mobile nodes are different from each other in CPU capacity, energy, and signal strength etc. because of the different device adopted in various application scenarios. To make our study practical, we assumed that BS and SS have their own properties, as defined in the followings:

Base station (BS):

1) BS is a fixed device.
2) Only one BS exists in this architecture
3) This BS covers all SSs in the topology.

Subscribe station (SS):

1) SS is a mobile device.
2) The SS is supplied with sufficient energy to transfer all required data.
3) CM is the most capacity SS selected from the cluster based on the factors like energy, CPU capacity, bandwidth, and distance from node to the center of cluster.
4) A CM can cover all of the members in the cluster.
5) In a cluster, a CM can communicate with a NN directly. Two NNs in the same cluster can also communicate with each other directly.
6) A CM of the source cluster and the BS, or a CM of the target cluster is required for a NN to communicate with another NN in a different cluster.

In a WiMAX network, the SSs can be distributed or gathered in different locations. Data transfers are required among them. How to implement an effective cluster and select the CM is a key to maintain network stability. The WiMAX network usually contains several small networks; there are many SSs in each of the small networks. The goal of this study is to find out how to set up clustering in a WiMAX network and establish a CM election mechanism. In the past, there have been a lot of discussions on CM election and clustering. Different methods demonstrate various impacts on the clustering results and the CM elected [4,5,10]. In a WiMAX network containing massive nodes, a good system and comprehensive consideration are important for CM election and clustering. In this study, we are trying to set up a proper system for them.

In this study, the moving speed of the SSs is not going to consider since there is no way for the mobile devices to know how fast they are in a practical environment. Although there were a few studies that have put the node speed into consideration, they were based on hypothetical data or the assumption that a GPS device was installed [5,8]. To be more practical, the mobility of device is put into consideration but ignore the impact of their speed.

Two mechanisms are proposed in this study: clustering mechanism and CM election mechanism. In the clustering mechanism, node capacity (P) is calculated based on energy, CPU capacity, bandwidth, and distance to the center for the cluster. The size of cluster is also adjusted by the mechanism to keep a balanced service quality. In the CM election mechanism, the center of each cluster is calculated firstly. Then, the closest node to the center is found. Together with the weight of node properties, the capacity value of the SS is calculated to find the best CM. A hierarchical structure of CM and SS are established. The hierarchical structure helps to improve the waste of bandwidth and the transmission efficiency. The clustering mechanism and CM election mechanism will be discussed in details in Section 4 and 5.

IV. CLUSTERING MECHANISM

In a WiMAX network, the devices are mobile. Simultaneous communications by the mobile devices may result in excessive network traffic, which consumes bandwidth and energy. In this study, all SSs are clustered in a WiMAX network by their capacity properties, in order to reduce the wireless traffic and maintain a stable data transfer. In this section, the initialization of cluster and the adjustment mechanism are introduced.

A. Cluster initialization

When initializing the cluster, each node will be given an initial counter value before being put into a cluster. The counter will be subtracted by one for every unit time until it is set to be zero [10]. At this time, this node will be named as Original Node. Then, the Original Node will broadcast clustering requests to the nearby nodes. In this study, to avoid failed clustering and unnecessary network traffic because of offline nodes due to insufficient energy before the clustering is completed, if some node is below the low energy threshold (e_low), it will be labeled and not be included in the cluster.

When clustering requests are broadcasted by the Original Node to the neighboring nodes, information like CPU capacity and bandwidth are included. A clustering response will be sent back to the Original Node if a clustering request is received. In the clustering response, there will be information like CPU capacity (c) and bandwidth (BW) of the responding node. After receiving these clustering responses, the Original Node will put all nodes that respond to the received clustering requests into a cluster. Then, the node with maximum node capacity value will be elected as the temporary CM. Node capacity value can be calculated using the formula (1).

$$P = w_1 * (c) + w_2 * BW; \sum_{i=1}^{2} w_i = 1 \quad \ldots(1)$$

In this study, the energy of node has been put into the consideration in the initialization stage. However, it has not included in the calculation of node capacity value. In a practical WiMAX environment, mobile devices can be recharged or its battery can be replaced at any time when necessary. Therefore, energy of node does not seem to be important.

The clustering mechanism proposed in this study utilizes a countdown system to trigger the cluster initialization. Although such mechanism shortens the CM election and accelerates the cluster initialization, it is common to see two nodes who have reached to zero in the countdown are close to each other. As a result, the numbers of nodes in two clusters are not balanced.

Excessive nodes in a cluster may result in overload of traffic and rapid consumption of energy. At the same time, the CM can also be overloaded and the communication performance and quality are worsened. Besides, the lifecycle of the CM will be shortened. To solve this problem, the total number of nodes in a cluster is set a limit. Suppose N is the node limit for the cluster. If total number of nodes in a cluster exceeds N, the CM will be overloaded easily. The N is decided by the actual situation of the WiMAX network. Figure 4 demonstrates the cluster initialization processes proposed in this study. After the cluster initialization, all of the nodes in the WiMAX network cluster will be put into some cluster. Meanwhile, total number of nodes in a cluster is limited. There will not be any CM overload.

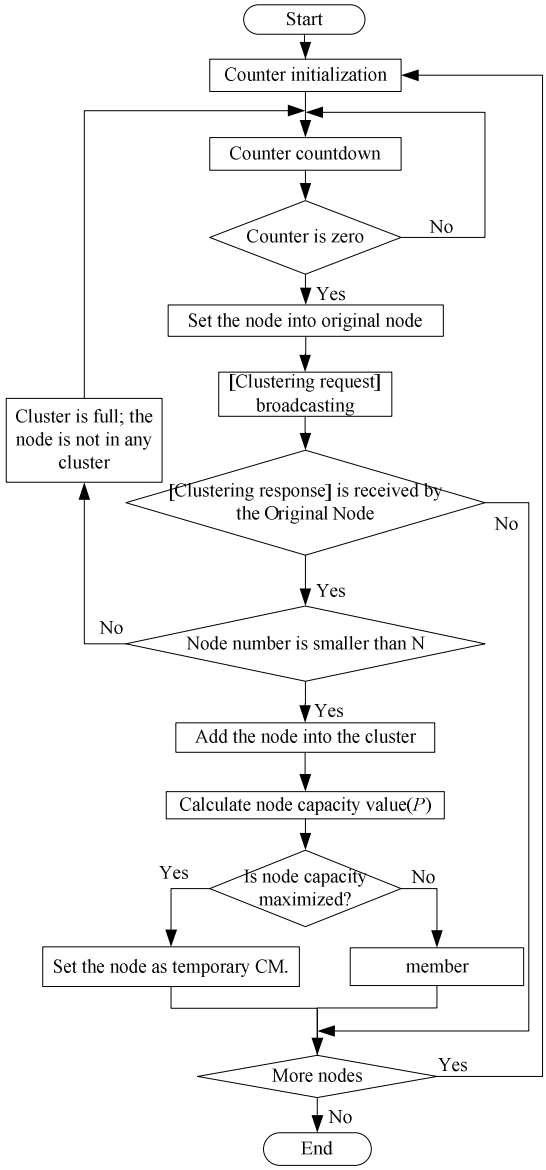

Figure 4. The flow chart of the initial cluster

B. Cluster adjustment

In a WiMAX network, the proposed clustering mechanism can be used to assign mobile nodes into clusters, in order to reduce the wireless communication traffic. However, if there are too many clusters, the number of nodes in a cluster will be excessive low. In such occasion, the information transfer will not be optimized. Therefore, to reduce the information transfer reasonably, the number of nodes in each cluster needs to keep above some certain standards, in order to reduce network traffic and optimize the networking capacity.

In this study, the minimum number of nodes in a cluster is defined as n and $N>2n$. If the total number of nodes in a cluster is smaller than n, the cluster will be classified into small clusters. The value of n should be decided by the actual application of the WiMAX network. If the total node number of the cluster is smaller than n, cluster adjustment will be required. Since $N>2n$, two nearby small clusters can be

merged. Result cluster will never exceed the capacity of the CM. There are two different situations in a cluster adjustment.

1) After all of the nodes in the network have been clustered, nearby small clusters will be merged. If there are two or more small clusters around, pick any of them. Keep merging small clusters until the node number in the cluster is greater than *n*.
2) After all of the nodes in the network have been clustered, there may be some cluster whose node number is smaller than *n* but all its nearby clusters are greater than *n* in node number. At this time, the small cluster should choose the closest cluster to its center for combination. If the total node number of the cluster after the combination is greater than *N*, the larger cluster will share several close nodes into the small cluster, until its node number is above *n*.

To reduce small clusters, the cluster adjustment mechanism proposed in this study will merge the small cluster with the nearby clusters. After the combination, the new cluster requires one temporary CM in cluster administration. Therefore, the CM of two small clusters should be compared in their capacity values and the better one should be elected as the new temporary CM. The detailed cluster adjustment mechanism proposed in this study is listed in Figure 5. Via cluster adjustment, information transfer will be optimized.

V. The Cluster Manager Election Mechanism

After the cluster initialization and adjustment, all of the nodes in the network have been put into clusters and each cluster has its size settled. Now, it is time to elect a real CM for the cluster. During the clustering, only CPU capacity and bandwidth are considered in order to finish the job as soon as possible. As a result, the location of CM can be far away from the cluster center. In such occasion, there will be relatively more energy and cost in the data transfer. In this study, a CM is found with better location. In other words, new CM should be the best in both capacity value and location [10], in order to achieve lowest cost and best communication.

First of all, the cluster center of each cluster is discovered. Then, the capacity values for all of the nodes are calculated. The most powerful node is elected as the CM. While looking for the cluster centers, we assume that the cluster *j* has *i* nodes. Q_j is the total node number of the cluster *j*. The position of node Q_{ji} is (X_{ji}, Y_{ji}). The center position (CX_j, CY_j) of cluster *j* can be calculated by the formula (2).

$$CX_j = \frac{\sum X_{ji}}{Q_j} \quad CY_j = \frac{\sum Y_{ji}}{Q_j} \quad \ldots(2)$$

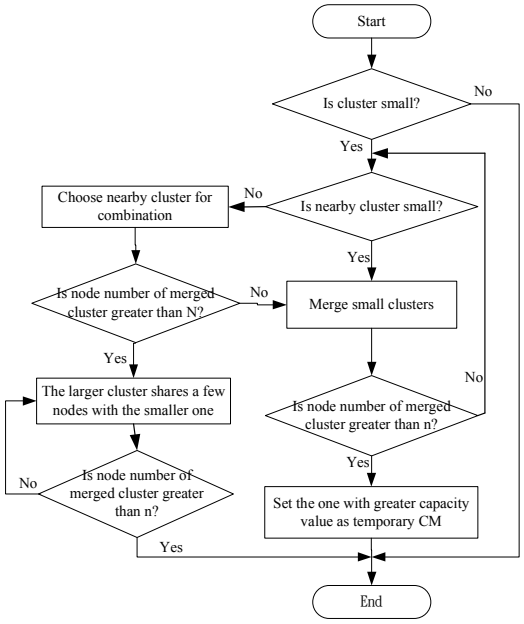

Figure 5. The flow chart of the adjusting mechanism

The cluster center is the point that has the shortest distance to each node in the cluster. Therefore, the node at the center will be best for coverage. In this study, distance of node to the cluster center will be put into consideration of CM election. If the distance between the node and the center is d_{ji}, the formula (3) is shown in the following.

$$d_{ji} = \sqrt{(X_{ji} - CX_{ji})^2 + (Y_{ji} - CY_{ji})^2} \quad \ldots(3)$$

If CM is elected only based on the distance to the center, it is possible that the node is not good in energy, CPU capacity, or bandwidth. To avoid such situation, factors like energy (e), CPU capacity (c), and bandwidth (BW) will also be considered besides distance from the node to the cluster center in CM election. Among them, the low energy threshold (e_low) is considered but not included in the calculation of capacity value for the node, since it is possible to recharge the mobile devices or replace their batteries whenever necessary. Based on the calculation of formula (4), the capacities of nodes can be turned into capacity values.

$$P = w_1 * (c) + w_2 * (BW) + w_3 * (1/d_{ji}); \ \sum_{i=1}^{3} w_i = 1 \quad \ldots(4)$$

Then, the one with greatest capacity value is elected as the CM. Three weight factors ($w_1 \sim w_3$) can be set according to the practical environment. The process of electing CM is shown in Figure 6.

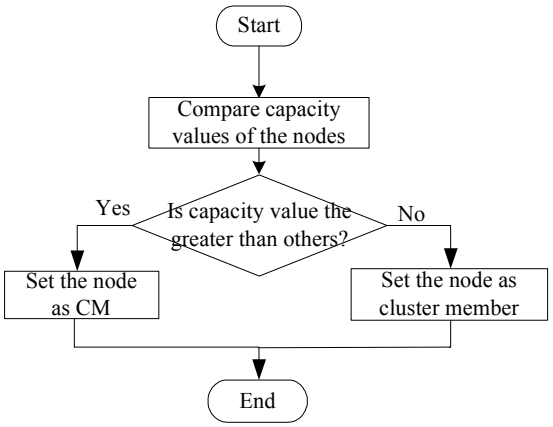

Figure 6. The flow chart of CM election

In a WiMAX cluster network, if transmitting and receiving nodes are in the same cluster, they can communicate with each other directly to reduce the burden of CM. If they are not in the same cluster, the source node sends the message to the CM of target cluster by the CM of source cluster. The target CM then forwards the message to the destination node.

VI. Experiment

In this section, we are going to test the method proposed in this study and validate its clustering capability based on transmission properties and capacities of the mobile nodes that is supposed to reduce the excessive traffic, packet collision, and energy consumption, and prolong the lifecycle of mobile devices and make the network more stable. The simulation is conducted in a populated environment to reflect the reality: a shopping mall or a department store. Broadcast communication of Mesh and cluster topologies are adopted in the simulation. NS2 is adopted in the simulation to generate 50 and 100 mobile nodes respectively. The simulated environment covers 100m * 100 m. Borland C++ is adopted to realize the cluster adjustment system proposed in this study. Relevant parameters are listed in Table 1.

Table 1. The parameters of simulation environment

Area	100*100 m^2		
Nodes	50 nodes and 100 nodes		
Factor weight	CPU	Bandwidth	CoreDistance
	0.5	0.2	0.3
Countdown value	0~20seconds		
Cluster diameter	30m		
Simulation duration	30s, 60s		
Total simulations	30		

Since the most important factor as a CM is its message forwarding capability, mobile device's CPU capacity turns out to be very important. Therefore, the weight of CPU related factor is set to 0.5. Secondly, the distance between the CM and all cluster members should be considered. Closer the CM to cluster center, better it will be. As a result, the weight of distance between the nodes and the cluster center is set to 0.3. Since all of the nodes utilize WiMAX in communication, they have similar bandwidths. It is not so important to consider the bandwidth factor. In our simulation, the weight of bandwidth factor is set to 0.2. The sum of CPU capacity, bandwidth, and distance to cluster center is always one. The countdown before clustering takes 0 ~ 20 seconds. This is to avoid too many small clusters generated in the initialization and unnecessary costs. In this simulation, the initializing cluster is set to be 30m in diameter while 3 times of 30m is near to 100m. That is good for a 100*100m space to make the clusters well proportioned in size. In the simulation, the comparison of the situations under 50 and 100 nodes are given separately. The simulation durations are 30 and 60 seconds respectively. The number of effective communications of the proposed cluster and Mesh WiMAX topologies is adopted to evaluate. In short, the experiments in this research are divided two parts as follows, with 30 times of repeated experiments for getting result that is more practical.

Figures 7 and 8 demonstrate the number of effective communications of the proposed cluster and Mesh WiMAX topologies under 50 nodes and 30s/60s. We find that the number of effective communications of cluster topology is lower than Mesh for about 1000 times. It indicates that cluster topology can reduce the effective network traffic significantly and improve the network performance.

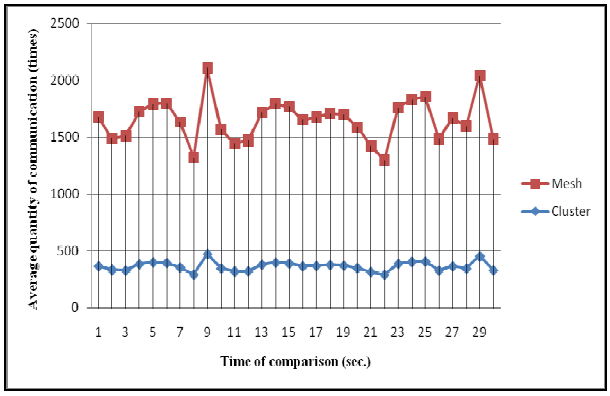

Figure 7. Compare the number of effective communications under 50 nodes and 30s

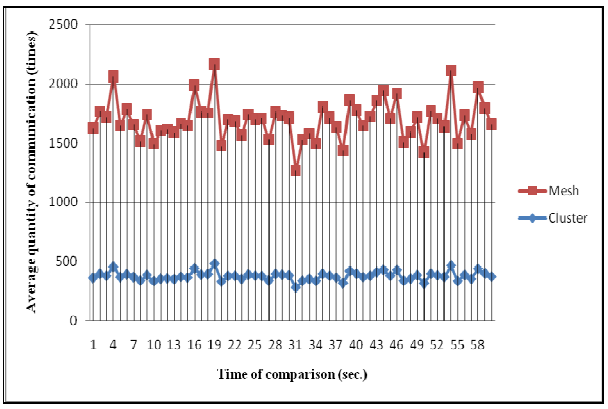

Figure 8. Compare the number of effective communications under 50 nodes and 60s

Figures 9 and 10 demonstrate the number of effective communications of the proposed cluster and Mesh WiMAX topologies under 100 nodes and 30s/60s. We find that the number of effective communications of cluster topology is lower than Mesh for about 4000 times. It indicates that cluster topology can reduce the effective network traffic significantly and improve the network performance.

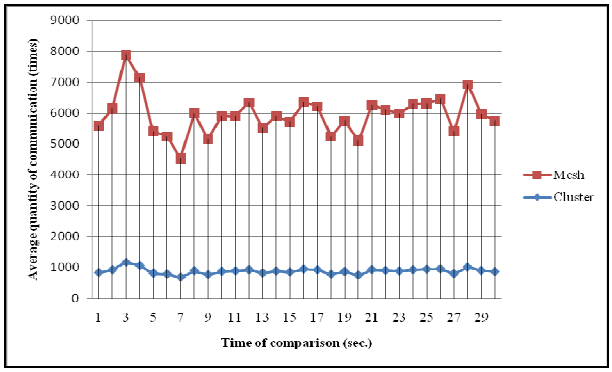

Figure 9. Compare the number of effective communications under 100 nodes and 30s

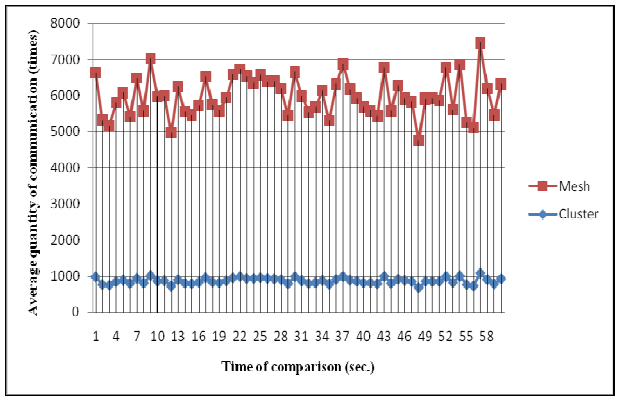

Figure 10. Compare the number of effective communications under 100 nodes and 60s

From Figures 7 to 10, we find that the number differences of effective communications of the proposed cluster and Mesh WiMAX topologies under 50 and 100 nodes are around 1000 and 4000 respectively. It indicates that the number of nodes may affect the effective communication numbers in a network.

VII. Conclusions

WiMAX technology is based upon the IEEE 802.16 standard, enabling the delivery of wireless broadband services anytime, anywhere. WiMAX products can accommodate fixed, portable and mobile usage models. The IEEE 802.16 standard was developed to deliver non-line-of-sight (NLoS) connectivity between a SS and BS with typical cell radius of three to ten kilometers [11]. However, WiMAX has enough bandwidth to simultaneously support hundreds of businesses, thousands of residences, and thousands of mobile Internet users.

In a WiMAX network, traditional topologies are PMP and Mesh. In the PMP mode, BS is overloaded, resulting in an unstable or stopped network. In the Mesh mode, multiple paths are adopted. That also brings broadcast storms easily [2,3,9].

Therefore, in this study, the PMP and Mesh modes are combined and a clustered topology with a proposed mechanism is established. The method proposed in this study not only reduces effective communications but also reduces packet collisions and broadcast storms. The clustering and CM election mechanisms in this study include many research achievements and overcome many possible problems [2,3,9]. In addition, a comprehensive method with ease and efficiency is proposed.

Besides, an effective cluster adjustment mechanism is also proposed to avoid excessive nodes and huge traffic, which may result in rapid energy consumption, traffic overload, delays, or network failure. The cluster adjustment mechanism can avoid extreme small cluster, which is not good for traffic reduction. The simulation is conducted in a populated environment. In an area of same size, more nodes lead to better effective communication reduction. On the contrary, fewer nodes cannot reduce effective communication effectively.

Acknowledgment

This work was supported in part by the Taiwan National Science Council under Grants NSC NSC93-2213-E-324-007, NSC94-2213-E-324-001 and NSC96-2221-E-324-021.

References

[1] J.H. Chang and L. Tassiulas, “Routing for maximum system lifetime in wireless ad hoc networks,” *37th Annual Allenton Conference on Communication Control and Computing*, 1999, pp. 413-419.

[2] D.S.J.D. Couto, D. Aguayo, B.A. Chambers and R. Morris, “Performance of multi-hop wireless networks: shortest path is not enough,” *First Workshop on Hot Topics in Networks*, 2002.

[3] L. Fu, Z. Cao and P. Fan, “Spatial reuse in IEEE 802.16 based wireless mesh networks,” *IEEE International Symposium on Communications and Information Technology* , Vol. 2, 2005, pp. 1358-1361.

[4] I. Gerasimov and R. Simon, “Performance analysis for ad hoc QoS routing protocols,” *International Mobility and Wireless Access Workshop*, 2002, pp. 212-219.

[5] G.Y. Lazarou, J. Li and J. Picone, “A cluster-based power-efficient mac scheme for event-driven sensing applications,” *Ad Hoc Networks* , Vol. 5, No. 7, 2007, pp. 1017-1030.

[6] K. Paul, S. Bandyopadhyay, A. Mukherjee and D. Saha, “A stability-based distributed routing mechanism to support unicast and multicast routing in ad hoc wireless network,” *Mobile Networks and Applications Computer Communications*, Vol. 8, No. 9, 2001, pp. 128-135.

[7] C.E. Perkins and E.M. Royer, “Ad-hoc on-demand distance vector routing,” *Second IEEE Workshop on Mobile Computing Systems and Applications* ,Vol. 3, No. 2, 1999, pp. 90-100.

[8] B. Shen, S.Y. Zhang and Y.P. Zhong, “Cluster-based routing protocols for wireless sensor networks,” *Journal of Software* ,Vol. 17, No. 7, 2006, pp. 1588-1600.

[9] H.Y. Wei, S. Ganguly, R. Izmailov and Z.J. Haas, “Interference-aware IEEE 802.16 WiMAX mesh networks,” *Vehicular Technology Conference* , Vol. 5, 2006, pp. 3102-3106.

[10] K.Q. Yan, S.C. Wang and Y.P. Tung, “Efficient load-balance clustering mechanism for wireless sensor network,” *International Journal of Advanced Information Technologies* , Vol. 1, 2007, pp. 2-20.

[11] WiMAX Forum, (2008, 8, 30). *Frequently Asked Questions*. Available: http://www.wimaxforum.org/documents/faq/)