An Efficient Mechanism for Network Management in Wireless Mesh Network

Muhammad Shoaib Siddiqui, Syed Obaid Amin, Choong Seon Hong
Networking Lab, Department of Computer Engineering,
Kyung Hee University,
Suwon, Korea.
{shoaib, obaid}@networking.khu.ac.kr, cshong@khu.ac.kr

***Abstract*—Wireless mesh networks are easy to deploy, self configuring networks which are rapidly becoming the network solution for various domains. Node mobility and power constraint make network management an important issue in wireless mesh networks. Security and network monitoring augment the concerns of efficient management within the network. In this paper, we discuss the issues of network management in wireless mesh network and propose an efficient mechanism of distributed network management. This mechanism also helps in making routing and security mechanism easy and efficient.**[1]

***Keywords*-Wireless mesh network, network management**

1. Introduction

Wireless Mesh Network (WMN) [1] is an emerging new technology which is being adopted as the wireless internetworking solution for the near future. Characteristics of WMN such as rapid deployment and self configuration [1] make WMN suitable for transient on-demand network deployment scenarios such as disaster recovery, hard-to-wire buildings, conventional networks and friendly terrains. WMNs are also an attractive technology for long-lived infrastructure network such as wireless municipal area network in dense metropolis, heterogeneous networks and for providing low-cost backhaul to cellular base station in remote rural areas and to sensor networks.

WMNs are extremely reliable [2], as each node is connected to several other nodes. If one node drops out of the network, due to hardware failure or any other reason, its neighbors simply find another route. Extra capacity can be installed by simply adding more nodes. Mesh networks may involve either fixed or mobile devices as shown in Fig. 1. The principle is simple: data will hop from one device to another until it reaches a given destination. One advantage is that, like a natural load balancing system, with the installation of more devices, more bandwidth becomes available. Since this wireless infrastructure has the potential to be much cheaper than the traditional networks, many wireless community network groups are already creating wireless mesh networks.

WMNs can be mainly categorized into three types according to their architecture: Infrastructure/Backbone WMNs, Client WMNs and Hybrid WMNs [2].

Infrastructure/Backbone WMNs consist of Mesh routers which are relatively static: make up a backbone and provide an infrastructure for the clients. These routers are usually gateways to wired networks or the Internet.

Client WMNs like conventional ad hoc networks consist of mobile wireless nodes. These are infrastructure-less networks with dynamically changing topology and mobility. In Client

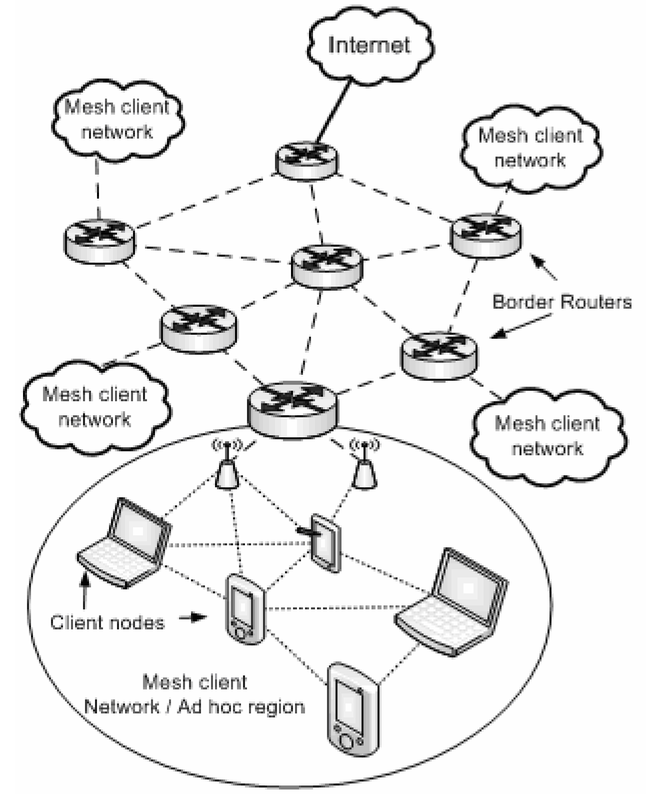


Figure 1. An example of a Hybrid Wireless Mesh Network.

[1]"This research was supported by the MIC under the ITRC support program supervised by the IITA" (IITA-2006-(C1090-0602-0002). Dr. Hong is corresponding author.

WMNs every node needs to perform the task of self configuration and routing as there is no router available.

A Hybrid WMN consists of many ad hoc components (mobile clients WMNs) and an infrastructure WMN, as shown in Fig. 1. The ad hoc components are composed of many mobile wireless clients such as PDAs, cell-phones, laptops etc. In Fig. 1, the dotted lines show the limited transmission range of the client nodes. On the other hand, the backbone routers are relatively static in nature or have very limited mobility. Mesh routers have wider transmission ranges; shown in the Fig. 1 as dashed lines. Each ad hoc component is connected to one of the routers present in the router backbone. Each Router manages its own ad hoc component, providing addresses, routes to destination, authentication and secure communication to nodes present in its ad hoc region. Mesh routers are also gateways to wired networks or WANs represented by the solid line in Fig 1.

Since the nodes in ad hoc components can be highly mobile, the topology changes frequently within the ad hoc region and the nodes are dynamically connected in an arbitrary manner. Moreover, these wireless clients have low transmission power, limited computation power and limited radio ranges. The small transmission range limits the number of neighboring nodes, which in turn increases the frequency of topology change, owning to node mobility. Bu adding up all these factors we can conclude that network management is not a trivial task in WMN.

WMN has been a field of active research in recent years. However, most of the research has been focused around various protocols for multi hop routing leaving the area of network management mostly unexplored. In this paper, we provide a management mechanism for hybrid wireless mesh network. In section 2, we discuss the different aspects of network management. In section 3, we pin-point the management issues on wireless mesh networks and propose an efficient mechanism for network management in wireless mesh network. In section 4, we provide the simulation results and analysis. In section 5, we conclude our proposal.

2. Network Management

Network management refers to the maintenance and administration of large-scale computer networks and telecommunications networks at the top level. In some cases, it involves a solitary network consultant monitoring network activity with an outdated protocol analyzer. In other cases, network management involves a distributed database, auto-polling of network devices, and high-end workstations generating real-time graphical views of network topology changes and traffic. In general, network management is a service that employs a variety of tools, applications, and devices to assist human network managers in monitoring and maintaining networks.

The fundamental network management concepts in wireless mobile network are mobility management, power management and network monitoring, which are discussed as follows:

A. Mobility Management

Mobility management consists of two important tasks: location and handoff management [3]. Location management handles location registration and call delivery, while handoff management is responsible for handoff initiation, new connection generation, and data flow control for call handoff [2].

Location service is a desired feature in ad hoc networks as it is responsible for providing location information of the nodes in the network. Location information can enhance the performance of MAC and routing protocols. It can help to develop promising location-related applications as it helps in deciding which neighbor to forward a message in the neighborhood.

B. Power Management

The goal of power management varies with the node types in the network. Power management aims to control connectivity, interference, spectrum spatial-reuse, and topology. If a single channel is used in each network node, the interference among the nodes directly impacts the spectrum spatial-reuse factor. Reducing transmission power level decreases the interference and increases the spectrum spatial-reuse efficiency. However, more hidden nodes may cause performance degradation in MAC protocols. Thus, power management schemes are closely coupled with MAC protocols [4]. Moreover, since connectivity affects performance of a routing protocol, power management is also crucial for the network layer.

C. Network Monitoring

Network management is a very vast field. A lot of functionalities are performed by a network management protocol. A continuous monitoring of all the nodes is required in order to maintain the performance of the network. The statistics in the MIB (management information base) of nodes are reported to one or several servers. This information is rendered and analyzed by a central server or in distributed environment to find the anomalies in the network. In case any abnormal symptom is detected, the server reacts to take responses, for example, triggering an alarm. Based on the statistical information collected from MIB, data processing algorithms can also accomplish many other functions such as network topology monitoring.

3. Network Management Mechanism

Although wireless mesh networks are self organizing but they are also scalable and as the number of nodes increase in the network the size of the network makes network management essential. Network management helps in detecting abnormalities in the network and may help in other issues such as routing and guaranteeing QoS. Currently, no research has been done on the network management issues in wireless mesh networks. We provide a mechanism which makes network management simple and efficient.

A. Assumptions

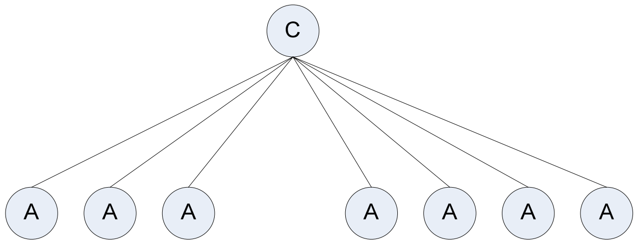
Wireless mesh network has a hierarchical structure with mesh router making a routing infrastructure and mobile wireless clients making up ad hoc networks at the second level of the network. Each ad hoc network of wireless mesh clients has one or more routers from the router infrastructure in the ad hoc region. Our mechanism assumes that these router nodes are powerful enough to provide management functionality to the wireless mesh network. The routers which are connected to the mesh client nodes are named as boundary routers or manager routers. The mesh client networks are also termed as ad hoc regions/components. Nodes in the client mesh are also termed as client nodes (as shown in Fig. 1).

B. Mechanism

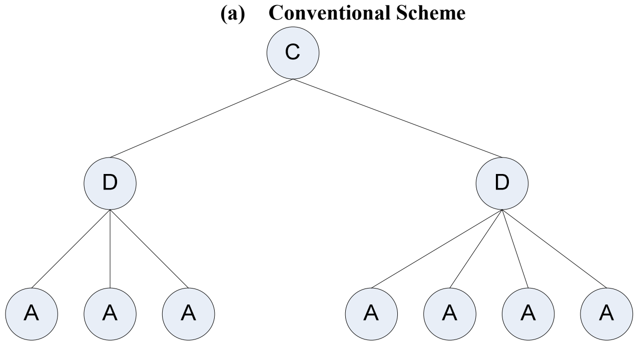
The routers in the infrastructure backbone are static and have better power, computation and storage resources. In a hybrid mesh, there are several client mesh network. By associating each mesh client network with one router of infrastructure mesh, the management of the whole wireless mesh network would become simple. Each mesh client network can be managed by a boundary router. This router is responsible of provide addresses, routing assistance, mobility management, power management and network monitoring to the mesh client networks. Security mechanism can also be enhanced by centralizing the mesh client network.

With the implementation of this scheme, each mesh client network is now centrally managed by the manager router of that region. But the over all mesh network is still distributed. Each manager router communicates with other routers, collaborates and manages the whole wireless mesh network.

As shown in Fig. 2, in the conventional management scheme, each node (shown as node 'A') is managed by the centralized server (shown as node 'C'). While in our proposed scheme, router nodes (shown as node 'D') manage client mesh networks in a distributed way and then these routers are managed by a centralized manager.



(a) Conventional Scheme



(b) Centrally-controlled Distributed Scheme

Figure 2. Network Management schemes for managing Wireless Mesh Network

We discuss the addressing, routing assistance, mobility management, power management, network monitoring and security assistance by this mechanism.

C. Addressing

Addresses for mobile clients are allocated dynamically by the router of that region. This address defines the location of the mobile client i.e. in which ad hoc region the mobile node is present. Similar to IP networks in which we can identify the network by the IP address of a node [5].

As the WMN clients are mobile, they may change position from one ad hoc region to the other as shown in Fig. 3. To facilitate this mobility, the routing protocol should provide proper addressing to these nodes so that they can be identified in their region and within the network. We use the techniques of Mobile IP [5] to provide addresses to client nodes. Similar to mobile IP, a client node has two addresses [6]; one to identify it in its home ad hoc region and the other one is for the other ad hoc regions.

Whenever a node enters the network for the first time, an address is assigned to it by that region's router. This router in the home (ad hoc) region of the client node serves the purpose of 'Home Agent'. When a client node changes it location and goes into another region, it is provided a second address from the router of that region (foreign agent, as shown in Fig. 3). The client node informs its 'home agent' and its 'foreign agent' about this new address and location [6], so that a packet directed to the client node is redirected to its new address.

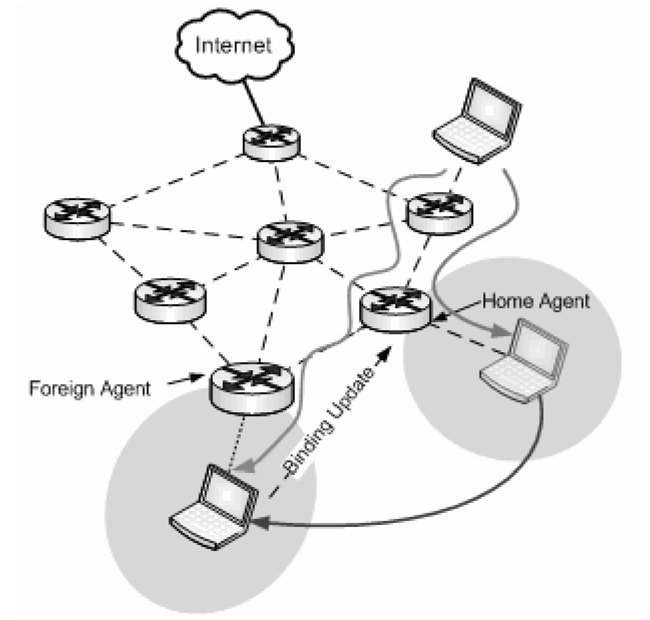


Figure 3. Addressing in Hybrid WMN. Mobile node chaging a client mesh network is provided with a care-of-address by foreign agent. Messages to the node are diverted by home agent to the new location.

D. Routing Assistance

Our mechanism also helps the routing mechanism. As the border router manages the addresses and monitors the network, it can help in routing decisions. The manager router can find optimal paths between two nodes, detect link losses and find alternate paths when a link is lost, within the client mesh network. Network monitoring may keep a topological view which can also help in routing. Localization can help in geographic routing protocols by helping in decisions such as which neighbor node to forward the data to reach the destination node.

The manager router can also work as a gateway between the static router infrastructure and the mobile client mesh network. Different routing protocols can be used in different regions with the router node working as the routing gateway.

E. Mobility Management

The mobility management schemes developed for cellular [2] or mobile IP networks [7] could be useful for WMNs. However, the centralized scheme is generally not applicable on WMNs which are based on distributed and ad hoc architecture. Thus, distributed mobility management is a preferred solution for WMNs. Mobility management schemes of ad hoc networks are mainly comprised of two types: distributed and hierarchical mobility management [8] and group mobility management [9]. These schemes may not perform well for WMNs due to the specific features of WMNs. More specifically, the backbone of WMNs does not have high mobility as mobile nodes in ad hoc networks, but connections between all mesh routers are wireless. Mesh clients may constantly roam across different mesh routers. These features also render the mobility management schemes for cellular networks ineffective for WMNs. As a result, new mobility management schemes need to be developed for WMNs.

In our mechanism, mobility of each client node can be easily managed. As a node moves from one client network to another its home agent or manager router is informed about its movement and this router knows the new location of the node. In this way locality information of each node is maintained by the manager routers.

In our mechanism, the handoff management is similar to the scheme used in mobile IP [6]. Whenever a node moves from one region to another region, the manager router of the new region provides new address to the node and the node remains connected to the network. The home agent directs the communicating node to the mobile nodes' new location.

F. Power Management

The goal of power management for WMNs varies. Usually, mesh routers do not have a constraint on power consumption; but the client nodes have limited power. In contrast to mesh routers, mesh clients may expect protocols to be power efficient. For example, some mesh clients are IP phones or even sensors; power efficiency is the major concern for them. Thus, it is quite possible that some applications of WMNs require power management to optimize both power efficiency and connectivity, which results in a complicated problem.

For power concerns, our mechanism can help in making routing and other protocols energy efficient. As the manager router has more power, it can help mesh clients such as in routing and security issues. For example, in security the client nodes can have total trust on the manager router and then all the cryptographic computation and transmission can be done by router node on behalf of the client nodes. This saves client nodes' power and increase lifetime of the network.

G. Network Monitoring

The network topology of WMNs is not always fixed due to mobility in mesh clients or possible failures in some mesh routers. Thus, monitoring the network topology is a desired feature for WMNs.

A few network management protocols [10] have been proposed for ad hoc networks. However, the efficiency of these schemes needs to be improved for a large scale mesh network. In addition, in order to accurately detect abnormal operation of WMNs, effective data processing algorithms are needed.

We can designate the responsibility of network monitoring of a single ad hoc region to a single manager router. Then all the client mesh networks can be monitored in a centralized way. These routers collaborate to perform the task of monitoring for the whole WMN in a distributed environment.

H. Security

Security is the most critical concern of every network. These days resource consuming public key cryptography is used to provide security which is not feasible for the client nodes. Our architecture presents an efficient way of reducing the security overhead.

Whenever a new node comes into an ad hoc region, the manager router provides an address to this client node along with its public key and starts the process of mutual authentication with the node. The public key of the router node assures the authenticity and integrity of the following messages as all those messages are encrypted by the private key of the router node.

The client node encrypts the messages by its private key and sends the messages to the router node. This process authenticates the node and ensures the message is not altered. For the authenticity of each other, the router node or the client node can contact the CA to verify the digital signature of each other. During this time of mutual authentication both node share a secret key using authenticated Diffie-Hellman [11] algorithm so that in the future they are not required to use public key cryptography. In the same way all the nodes within an ad hoc region has a secret key shared by the manger router of that region. Now the communication of each node with the router node is secure and high resource consuming public key cryptography is not required at the client nodes.

In this way, we can reduce a lot of security overhead from the network.

4. Simulation & Analysis

We compared our proposed management mechanism with the conventional centralized mechanism. We have compared the amount of energy consumed by these schemes at each node.

A. *Network & Communication Model*

We performed the simulation in NS-2 [12]. The network model was consisted of 49 client nodes placed randomly within an area of 1000 x 1000 m2. There are 16 mobile router nodes deployed in a grid environment to make up the mesh infrastructure. This scenario constructed 10 different mobile client networks. Each node has a propagation range of 150 meters with channel capacity 2 Mbps. The speed of mobile nodes is set to be 0 or 20 m/s. The size of the data payload is 512. Each run of simulation is executed of 1000 seconds of simulation time. The medium access control protocol used is IEEE 802.11 DCF.

B. *Results*

Fig. 4 shows the energy consumption by the nodes running with different with different management schemes. Each node is provided with 10 joules of initial energy. As the nodes perform transmission and receive messages their energy level is decreased. The graph in Fig. 4 shows that conventional centralized management scheme uses high amount of energy which means it has much higher amount of transmissions than our proposed scheme.

C. *Simulation Analysis*

From the results, we observe that our proposed distributed management scheme consumes very little amount of energy, hence it has low overhead. In conventional management scheme each client node sends information to the centralized management server. This requires more messages and thus produces huge overhead in the network.

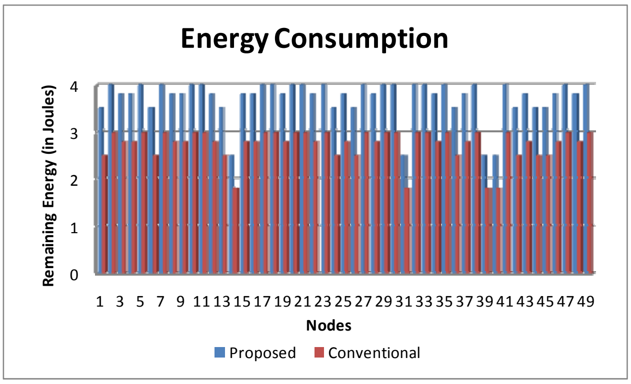


Figure 4. Shows the amount of energy remain at each client node in the WMN after 1000 seconds simulation.

In our distributed scheme, client nodes communicate with only the manager router of their mesh network. The rest of the communication is the responsibility of the router nodes. This reduces the overhead from the client nodes and consumes less energy.

5. Conclusion

In this paper, we have discussed the characteristics of wireless mesh networks and point out that the network management is an essential issue in wireless mesh networks. We discussed the different aspects of network management in WMNs. We also proposed a mechanism which makes network management in WMNs very simple and efficient. This mechanism also helps in routing and security issues. This mechanism reduces the amount of energy consume by the client nodes and thus increase the life of the network.

References

[1] Bruno, R. Conti, M. Gregori, E. "Mesh networks: commodity multihop ad hoc networks", IEEE Communications Magazine, March 2005, Volume: 43, Issue: 3, pp: 123- 131

[2] Ian F. Akyildiz, Xudong Wang and Weilin Wang, "Wireless Mesh Network: A Survey" in Computer Networks and ISDN Systems, Vol. 47, Issue 4, March 2005.

[3] I.F. Akyildiz, J. McNair, J.S.M. Ho, H. Uzunalioglu and W. Wang, Mobility management in next generation wireless systems, IEEE Proceedings 87 (1999) (8), pp. 1347–1385.

[4] L. Krishnamurthy, Making radios more like human ears: alternative MAC techniques and innovative platforms to enable large-scale meshes, Microsoft Mesh Networking Summit, June 2004.

[5] C.E. Perkins, "Mobile networking through Mobile IP" in IEEE Internet Computing, Volume 2, Issue 1, Jan.-Feb. 1998 Page(s):58 - 69

[6] C.E. Perkins, "Mobile-IP, ad-hoc networking, and nomadicity" in Proceedings of 20th International Computer Software and Applications Conference, COMPSAC '96, 21-23 Aug. 1996 Page(s):472 – 476

[7] I.F. Akyildiz, J. Xie and S. Mohanty, A survey of mobility management in next-generation all-IP-based wireless systems, IEEE Wireless Communications 11 (2004) (4), pp. 16–28

[8] J. Sucec, I. Marsic, Location management for hierarchically organized mobile ad hoc networks, in: IEEE Wireless Communications and Networking Conference (WCNC), 2002, pp. 603–607.

[9] W.-T. Chen, P.-Y. Chen, Group mobility management in wireless ad hoc networks, in: IEEE Vehicular Technology Conference, Fall 2003, pp. 2202–2206.

[10] C.-C. Shen, C. Srisathapornphat and C. Jaikaeo, An adaptive management architecture for ad hoc networks, IEEE Communications Magazine 41 (2003) (2), pp. 108–115.

[11] W. Diffie, P. van Oorschot, and M. Wiener. "Authentication and authenticated key exchange. Designs, Codes and Cryptography, 2(2)", 1992, pages 107–125.

[12] "UCB/LBNL/VINT Network Simulator - ns 2" URL: http://www.isi.edu/nsnamjns.