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Hybrid Routing Protocol to Decrease Delay and to Extend Lifetime for Mesh Networks

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Abstract: Mesh networks consist of wireless nodes each of which can act as a router to relay packets for others without any preset infrastructure. These networks have a hierarchical topology. The upper layer is the backbone of the network formed by the mesh routers. Each mesh router acts as a local controller for some mesh clients, which form the lower layer of the mesh network. This study addresses the important challenges in mesh networks and proposes a hybrid routing protocol to reduce delay in routing discovery across the whole network and to improve energy efficiency of the mesh clients in the lower layer. This hybrid routing protocol applies a proactive protocol to the mesh router layer with the stationary mesh routers that have sufficient necessary resources such as energy and applies a reactive routing protocol to the mesh client layer to improve the energy efficiency by using the proposed average residual energy rule and the minimum residual energy rule. Simulation results show that this hybrid routing protocol reduces delay in routing discovery and improves energy efficiency of mesh clients.

Key words: Mesh networks, hybrid routing protocol, mesh router layer, delay, mesh client layer, energy efficiency

INTRODUCTION

In contrast to traditional wireless communication systems, which have wired or wireless infrastructures and access points, ad hoc networks (1) are multihop systems, (2) consist of wireless nodes, each of which can act as a router to relay packets for others and (3) do not need pre-existing infrastructure.

According to the different applications, ad hoc networks can be divided into the following four categories:

- Ad hoc sensor networks, the main purpose of which is to monitor the environment at fixed locations and to gather generated data;
- Mobile ad hoc networks (MANETs), the main purpose of which is to enable communication between nodes;
- Mobile ad hoc sensor networks, the main purpose of which is to track mobile targets and gather generated data;
- Mesh networks, the main purpose of which is to enable mobile terminals to access other networks such as the Internet, Wi-Fi and so on.

Compared to the other three types of ad hoc networks, mesh networks emerged more recently yet still play an important role because they enable mobile terminals to access many existing wireless networks such as wireless-fidelity (Wi-Fi), worldwide inter-operability for microwave access (WiMAX) and cellular networks with low costs, easy network maintenance and reliable network coverage (Akyildiz and Wang, 2005; Akyildiz *et al*., 2005; Bruno *et al*., 2005).

The two-tier network shown in Fig. 1 is a mesh network. The upper layer formed by the mesh routers is the backbone of the network. Each mesh router has some mesh clients that form the lower layer of the network. Although the absence of the pre-existing infrastructure presents more challenges to the topology and the routing protocol, this absence of an infrastructure requirement allows mesh networks to be easy to deploy and they have wide potential applications such as in:

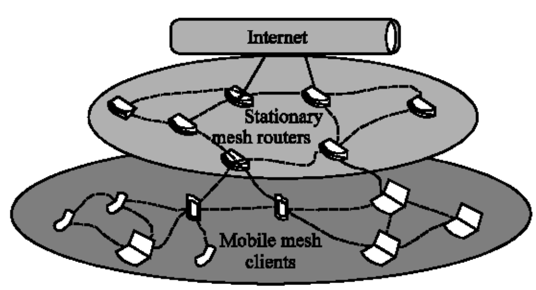

Fig. 1: Mesh network

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- Personal area networking;
- Emergency operations;
- Civilian, rural, or military environments;
- Tracking mobile targets or inspecting areas, etc.

These potential applications have attracted plenty of research and many routing protocols have been proposed, which are usually classified into three categories: proactive, reactive and hybrid routing protocols.

When a node is ready to send data using proactive protocol, it gets information about the route to the destination from its route table, which in turn increases the processing and memory overhead of the nodes.

In contrast, a node in a reactive protocol network does not read the route information from route tables to avoid the heavy overhead. When a node has a packet to send, it first consults its route cache to determine whether it already has an unexpired route to the destination. If it does not, it floods a route request to find available routes to the destination and selects one route to relay the data resulting in serious delay.

Hybrid protocols combine proactive and reactive protocols and are usually applied to hierarchical clustering ad hoc networks. In a hierarchical clustering ad hoc network, the nodes are grouped into clusters and in each cluster there is a cluster controller called a clusterhead (CH). The nodes which belong to more than one cluster are called gateway nodes. Others are member nodes of the cluster. Both CHs and gateway nodes form the backbone network. Typically, the intra-cluster communication uses the proactive protocol, whereas the inter-cluster communication uses the reactive protocol. The hybrid protocol in clustering ad hoc networks balances the overhead and delay in the network by combining the merits of proactive and reactive protocols.

The nodes in different layers in a mesh network are heterogeneous and have different characteristics. That is, the mesh routers in the upper layer are usually stationary whereas the mesh clients in the lower layer are usually moveable. This special topology structure of mesh networks formed by heterogeneous nodes makes the traditional proactive, reactive and hybrid routing protocols inefficient.

This study analyzes the characteristics both in the upper layer and in the lower layer. It also defines the issues that may be caused by using the traditional routing protocols. By addressing these issues, it then proposes a hybrid routing protocol to reduce the delay in routing discovery and to extend lifetime of the mesh clients.

EXISTING ROUTING PROTOCOLS FOR MESH NETWORKS

Due to the infrastructureless topology structure, a routing protocol becomes very important for mesh networks. Proactive, reactive and hybrid routing protocols are proposed.

Proactive routing protocols: In proactive routing protocols (Clausen *et al.*, 2006; Jacquet *et al.*, 2001; Perkins and Watson, 1994), the node can read the routing information directly from the route table thereby reducing the delay. The topology of the network may be changed because of the movement of the nodes or because of some nodes run out of energy, requiring the network to update the routing information in the route table. Proactive protocols update the route table by periodically broadcasting beacon messages.

The node in Optimized Link State Routing (OLSR) (Jacquet *et al.*, 2001) maintains topology information about the network by periodically exchanging link-state messages. OLSR reduces the size of each control message and the number of rebroadcasting nodes during each route update, by employing a multipoint replaying (MPR) strategy. During each topology update, each node in the network selects a set of neighboring nodes called MPR to retransmit its packets. Other nodes can read and process each packet but will not retransmit, so the cost of performing network-wide broadcasts of link-state information is reduced.

Reactive routing protocols: In reactive routing protocols (Gunes *et al.*, 2002; Perkin and Belling-Royer, 2003; Johnson *et al.*, 2004), if there is no route information in the route cache or the cached route is expired, the node that is ready to send the packet must find a route before it can forward the data to the destination.

When a source node in Dynamic Source Routing (DSR) (Johnson *et al.*, 2004) has a packet to send to some destination and it cannot find any route information in the route cache or the cached route is expired, it initiates routing discovery by broadcasting a route request. Each node that receives the packet checks whether it knows of a route to the destination. If it does not, it adds its own address to the route record of the packet and then forwards the packet along its outgoing links. This process continues until the destination information is reached and sent back to the source node. If there is more than one route available, the route with least number of hops will be selected to relay the data.

Hybrid routing protocols: Hybrid routing protocols (Woo and Singh, 2001; Radhakrishnan *et al.*, 1999; Nikaein *et al.*, 2000; Hass and Pearlman, 1999) are usually applied to hierarchical clustering networks.

From each node in Zone Routing Protocol (ZRP) (Hass and Pearlman, 1999), the set of nodes within pre-defined r hops is called a zone. Thus, the entire network is portioned into a number of zones. Routing inside a zone will follow the proactive protocol, whereas routing across zones will follow the reactive protocol.

PROPOSED HYBRID ROUTING PROTOCOL FOR MESH NETWORKS

The main purpose of this protocol is to reduce the delay in routing discovery and to improve energy efficiency of the mesh clients.

First, the existing routing protocols are analyzed and then the proposed protocol is presented in detail.

Analysis of existing schemes: This sub-section analyzes the existing proactive, reactive and hybrid routing protocols for mesh networks.

The proactive routing protocol should update the route table information by flooding beacon messages, however this process is unnecessary if the topology of the network is stable. Therefore, a proactive routing protocol is efficient for ad hoc networks with stable topology, for example, sensor networks, the nodes of which are usually stationary after they are set. However, the mesh clients that form the lower layer of the mesh network can usually move freely. The movement of the clients may change the topology of the network, thus requiring the proactive routing protocol to update the route information frequently. Therefore, the flooding occurred in updating the routing information is significant and will consume much resources of the network, such as energy, bandwidth and so on. It may also increase congestion in the network. Therefore, a purely proactive routing protocol is inefficient for mesh networks.

Because a reactive routing protocol only maintains the route information of the nodes that participate in relaying the data, it is therefore efficient for mobile ad hoc networks where the topology is changed frequently due to the movement of the nodes. However the mesh routers that form the upper layer of the mesh network are usually stationary. The application of a reactive routing protocol to this layer increases the delay in routing discovery. Therefore, a purely reactive routing protocol is also inefficient for mesh networks.

The hierarchical topology structure of a mesh network does not necessarily mean that the traditional hybrid routing protocol is efficient. Typically, in traditional clustering networks, intra-clustering (lower layer) communication uses a proactive routing protocol whereas inter-cluster (upper layer) communication uses a reactive routing protocol. When the traditional hybrid protocol is used in mesh networks by the same method that it is applied in clustering ad hoc networks, the proactive routing protocol is used in the mesh client layer and the reactive routing protocol is used in the mesh router layer. Unfortunately, both the application of the proactive protocol to the mobile client layer and the application of the reactive protocol to the stationary router layer are inefficient as analyzed above.

Upper mesh router layer: The special topology structure of the mesh network requires a new routing protocol. The mesh routers that form the upper mesh router layer usually exhibit the following characteristics: (1) they are stationary after being set, making the topology more stable; (2) they have sufficient necessary resource such as memory and energy. These characteristics determine a proactive routing protocol is more efficient for this layer compared to other routing protocols which furthermore reduces the delay in routing discovery so that improves the Quality of Service (QoS) of the entire network.

Lower mesh client layer: The movement of the mesh clients may change the topology in the lower layer frequently, thereby requiring that the routing protocol for this layer to maintain the topology efficiently. As analyzed, a reactive protocol is more efficient compared to a proactive protocol in topology maintenance, therefore a reactive routing protocol should be applied to this layer. Figure 2 shows the reactive routing protocol. When the source node is ready to send the data, if the cached route is expired, it will flood a route request to find available routes. Once the source node gets the response from the mesh router, if more then one route is available, it will pick up the route with the least number of hops to relay the data.

Most mesh clients in this layer, however, are battery driven so that their energy is constrained, thereby necessitating improvements in energy efficiency during the routing protocol design. Although the selected route with the least number of hops is the most energy efficient one when the mesh clients have fixed transmission power, some specific routes may be selected to relay the data more frequently making the nodes in these routes run out of energy more rapidly. The running out of energy in some nodes may disconnect the network and thereafter affect the lifetime of the entire network. Therefore two energy efficient rules called (1) the average residual

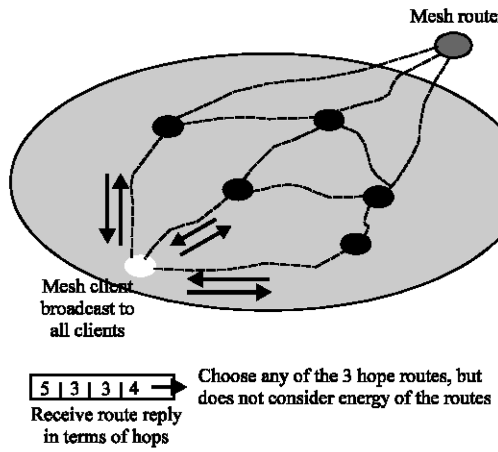

Fig. 2: Reactive routing protocol

energy rule and (2) the minimum residual energy rule are proposed to balance the power consumption among the nodes, so that the energy efficiency of the mesh clients can be improved.

Average residual energy rule: The following presents how to improve energy efficiency by using the information of average residual energy of the nodes along the route. Figure 3 helps to explain the rule.

Unlike traditional reactive routing protocols, this reactive protocol requires the node that is ready to send the data to update the routing information regardless whether the cached route has expired or not. When a mobile client is ready to send data, it will find the route with the least number of hops called the new route and check whether it is the cached one. If there is no cached route or the cached route is expired, the node will then use this new route to relay the data. Alternatively, the protocol will process an energy optimization procedure to update the route information. To do this, it adds the residual energy of each node along the new route, so that the average residual energy information of the nodes along the new route is achieved. It will also acquire the average residual energy information of the cached route. It then sets this value as a rule to select the route, that is, the route with a higher average residual energy will be selected to relay the data.

An example of this rule is provided in Fig. 4. In this scenario, two routes have the same least number of hops from A to the mesh router. If it is supposed that the cached unexpired route is A-2-5-8-mesh router which has 58.3% average residual energy, then A-1-4-7-mesh router which has 65% average residual energy is a new route that A finds. Under this rule, the new route will be selected to relay the data. As the energy will be consumed by transmitting or receiving the data, this route may have

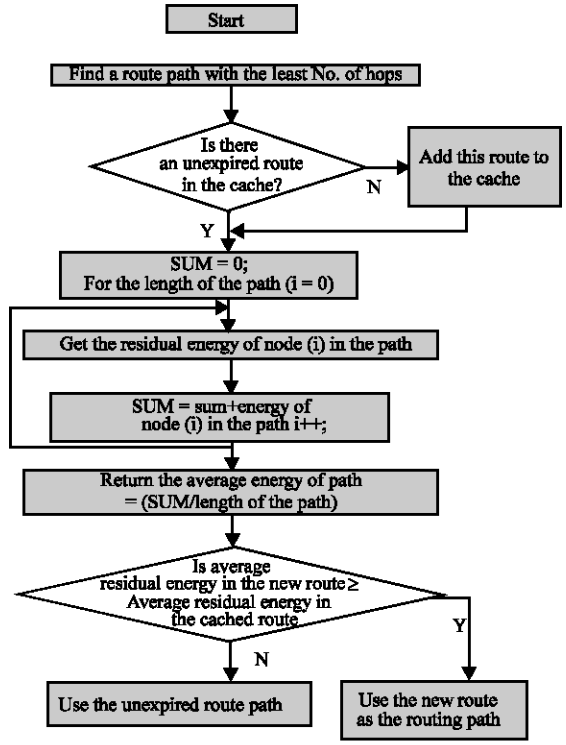

Fig. 3: Average residual energy rule

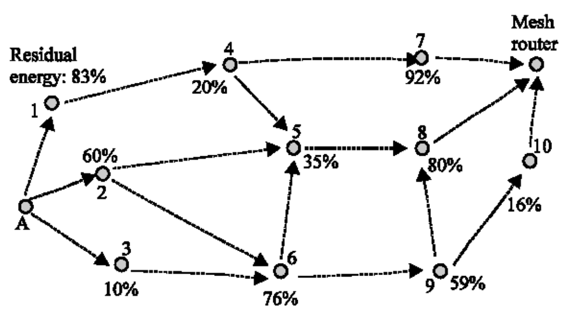

Fig. 4: Example of energy efficient rule

lower average residual energy. The source node A will then select another new route with a higher average residual energy to forward the packet, avoiding the frequent usage of one specific route so that the power consumption is balanced among the routes.

Minimum residual energy rule: The following sub-section presents how to improve energy efficiency by using the information of minimum residual energy of the nodes along the route. Figure 5 is used to explain this rule.

From Fig. 5, it can be seen that the minimum residual energy rule differs from the average residual energy rule in that it compares the residual energy of the nodes in the new route to get the minimum residual energy information

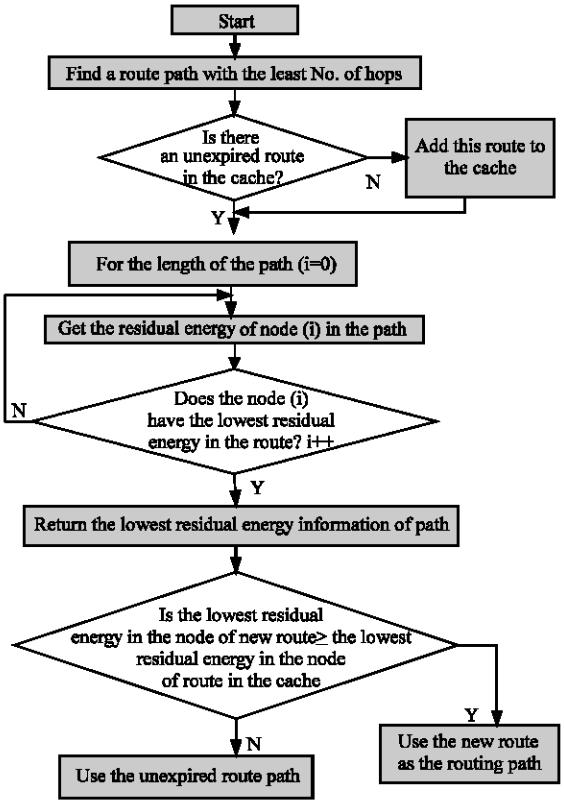

Fig. 5: Minimum residual energy rule

of the node in the route. It will also get the minimum residual energy information in the cached unexpired route. It then sets this value as a rule to select the route, that is, the route with a higher minimum residual energy will be selected to forward the data.

We also use Fig. 4 as an example to explain this rule. If it is supposed that the cached unexpired route is A-2-5-8-mesh router which has 35% minimum residual energy in node 5, A-1-4-7-mesh router which has 20% minimum residual energy in node 4 is a new route that A finds. With this rule, the cached unexpired route will be selected to relay the data to prevent the energy deficient nodes in the new route from relaying the data. As the energy will be consumed by transmitting or receiving the data, another new route with a higher minimum residual energy will be selected to forward the packets.

The structure of the proposed hybrid routing protocol: The whole structure of the proposed protocol, based on the above analysis, is shown in Fig. 6.

The reactive routing protocol is applied to the mesh client layer to efficiently maintain the topology and to improve the energy efficiency under the proposed energy efficient rules. The proactive routing protocol is applied to the mesh router layer to reduce the delay.

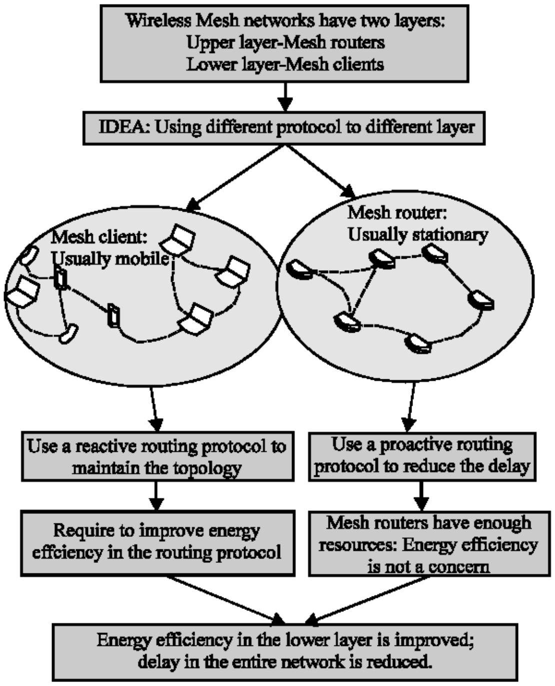

Fig. 6: Proposed hybrid routing protocol

PERFORMANCE EVALUATION

This section evaluates the performances of the proposed hybrid routing protocol.

Figure 7 shows the simulation scenario. Twenty six mesh routers (nodes numbered from 25-50) were placed in the upper mesh router layer with only node 50 accessing the Internet directly. That is, any mesh router or client that wants to access the Internet should access wireless router 50 first, thereby making node 50 become the final sink of all nodes in the network. Each mesh router has 25 mobile clients. For simplicity purpose, 25 mesh clients (nodes numbed from 0-24) locally controlled by mesh route 25 as shown in Fig. 7 are used to complete this simulation.

As explained, the protocol focuses on reducing the delay in routing discovery and on improving energy efficiency for the mesh clients. This simulation therefore expects to output these two parameters. Because the research (Samba *et al.*, 2004) has been proved that a reactive routing protocol is more energy efficient than a proactive routing protocol for mobile ad hoc networks, as in the lower layer of the mesh network, this simulation only compares the energy efficiency among the proposed protocols with the energy efficient rules and the purely reactive routing protocol, which uses the reactive routing protocol both in the lower layer and in the upper layer. It also compares the delay in routing discovery between the purely reactive routing protocol and the proposed hybrid

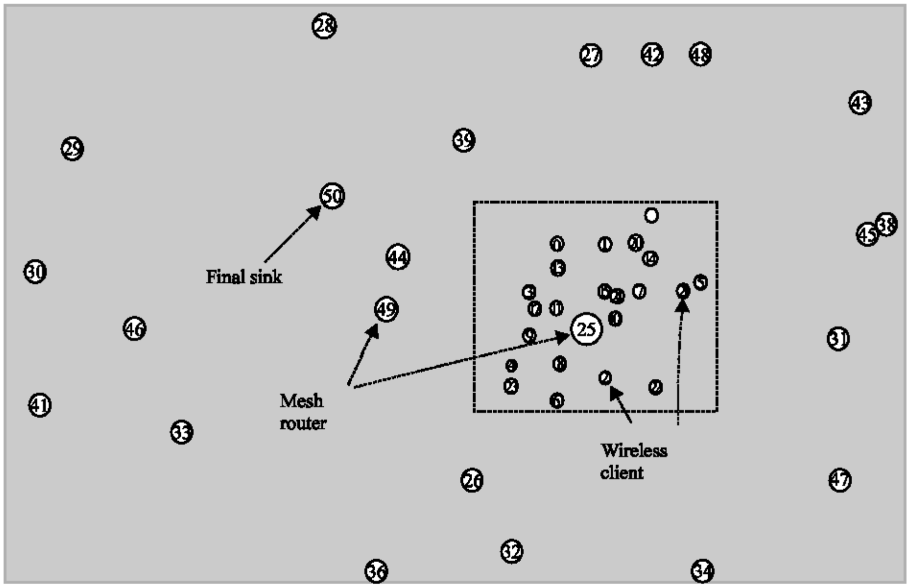

Fig. 7: Simulation setup

Table 1: Parameters and their meanings

Simulation time (sec)	20
Packet size	512 Kb
Packet interval	1s
Data rate	1Mbps

Table 2: Parameters and their meanings

Parameters	Upper layer (Mesh routers)	Lower layer (Mesh clients)
Mobility rate of nodes	Stationary	Varies from 2-10 m sec^{-1}
Initial energy	Energy is not a concern	1 Joule
Transmission range of the nodes	1000 m	250 m
Simulation area	4000 m*4000 m	1000 m*1000 m
No. of nodes	26	25

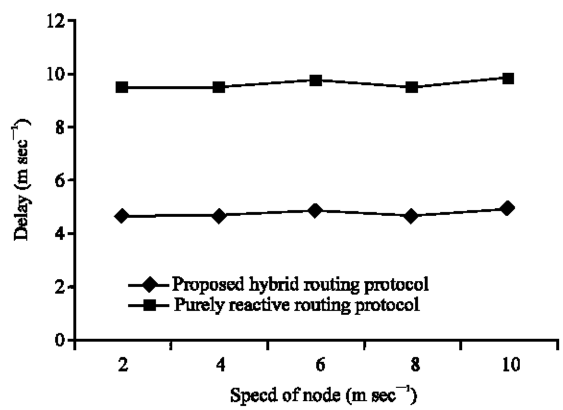

Fig. 8: Delay in routing discovery

protocol that uses the proactive protocol in the upper layer and the reactive protocol in the lower layer without considering the energy efficiency.

The mesh routers have enough energy. Therefore the energy efficiency of the mesh routers in this simulation is not a concern.

Table 1 provides the parameters and their values for this simulation for both the upper layer and the lower layer. Table 2 provides the different simulation parameters and their values for the mesh router layer and the mesh client layer, respectively.

From Fig. 8, the purely reactive protocol has a greater time delay than the proposed hybrid protocol. This is because the proactive routing protocol is used in the mesh layer causing almost no delay in this layer. In this simulation scenario, the hybrid protocol has almost half the time delay of the purely reactive routing protocol. This is because almost the same number of nodes was put in both layers.

From Fig. 9, it can be seen that the first node both under the reactive protocol and under the average residual energy rule reactive protocol runs out of energy at 10 sec whereas at 11.5 sec under minimum residual energy rule reactive protocol. This is because the minimum residual energy rule prevents the energy deficient nodes from relaying the data. If the lifetime of the network is defined as the first node running out of energy, the proposed minimum residual energy rule can extend the lifetime by 15%.

The first node running out of energy, however, does not mean the clients cannot send the data to the mesh router. The connectivity between the mesh clients and the mesh routers is usually still retained. The simulation then defines the lifetime of the network as the connectivity of the network being lost. From Fig. 9, when 15 nodes run

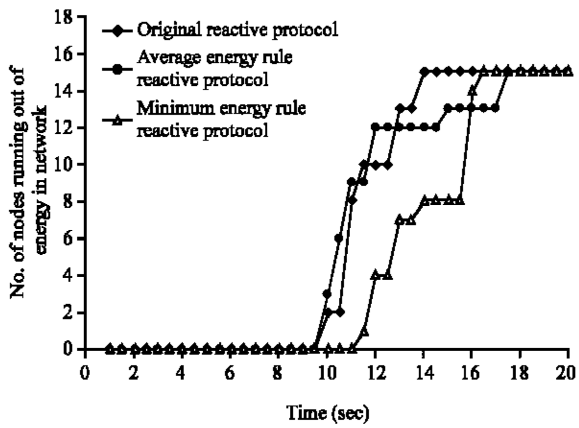

Fig. 9: Lifetime of the lower layer with different protocols

out of energy in all three routing protocols, no node will die as a result. This is because the connectivity between the mesh clients and their mesh router is lost when so many nodes run out of energy so that no mesh client can find any available route to the mesh router. Therefore no node will send data resulting in almost zero power consumption so that will not die. From the definition of the lifetime based on the connectivity of the network, the proposed average residual energy rule and the minimum residual energy rule reactive protocols extend the lifetime by 25 and 18% compared to the original reactive routing protocol.

CONCLUSIONS

Mesh networks have a hierarchical topology. The upper layer is the backbone of the networks formed by the mesh routers, which usually have sufficient necessary resources and are stationary after being set. Each mesh router is a local controller for mesh clients that (1) form the lower layer of the network, (2) can move freely and (3) have a limited energy supply.

The traditional routing protocols have some limitations if they are applied to these networks. The proactive routing protocol is inefficient in maintaining the topology of the mesh client layer. The reactive routing protocol increases the delay in routing discovery in the mesh router layer. The traditional hybrid routing protocol, that is usually applied to hierarchical clustering networks, requires intra-cluster (lower layer) communication with the proactive protocol and inter-cluster (upper layer) communication with the reactive protocol, reducing the efficiency in maintaining the topology of the lower layer and increasing the delay in routing discovery of the upper layer, respectively.

A hybrid routing protocol is therefore proposed based on the consideration of the delay in routing discovery and the energy efficiency of the mesh clients. The reactive routing protocol is used to efficiently maintain the topology in the client layer whilst the energy efficiency for this layer is improved by using the proposed average residual energy rule and minimum residual energy rule. The proactive routing protocol is used in the mesh router layer to reduce the delay in routing discovery.

Simulation results support the protocol. The performances of the networks are improved by employing this proposed hybrid routing protocol.

REFERENCES

Akyildiz, I.F. and X. Wang, 2005. A survey on wireless mesh networks. IEEE Radio Communications, 9: S23 - S30.

Akyildiz, I.F., X. Wang and W. Wang, 2005. Wireless mesh networks: A survey. Computer Networks, Elsevier, 47: 445-487.

Bruno, R., M. Conti and E. Gregori, 2005. Mesh networks: Commodity multihop ad hoc networks. IEEE Communications Magazine, 3: 123-131.

Clausen, T., C. Dearlove and P. Jacquet, 2006. OLSRv2 IETF Internet-Draft. http://www.ietf.org/internet-drafts/draft-ietf-manet-olsrv2-02.txt.

Gunes, M., U. Sorges and I. Bouazizi, 2002. ARA-The ant-colony based routing algorithm for MANETs. Proc. of ICPP Workshop on Ad Hoc Networks (IWAHN), pp: 79-85.

Hass, Z.J. and R. Pearlman, 1999. Zone routing protocol for ad-hoc networks. IETF Internet Draft, draft-ietf-manet-zrp-02.txt.

Jacquet, P., P. Muhlethaler, T. Clausen, A. Laouiti, A. Qayyum and L. Viennot, 2001. Optimized link state routing protocol for ad hoc networks. Proc. IEEE INMIC.

Johnson, D., D.A. Maltz and Y. Hu, 2004. The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks (DSR). IETF Internet-Draft. http://www.ietf.org/internet-drafts/draft-ietf-manet-dsr-10.txt.

Nikaein, N., H. Laboid and C. Bonnet, 2000. Distributed dynamic routing algorithm (DDR) for mobile ad hoc networks. Proc. of the MobiHOC.

Perkins, C.E. and T.J. Watson, 1994. Highly dynamic destination sequenced distance vector routing (DSDV) for mobile computers. Proc. of ACM SIGCOMM'94 Conference on Communications Architectures.

Perkins, C. and E. Belding-Royer, 2003. Ad hoc On-Demand Distance Vector (AODV) Routing-Request for Comments-RFC3561. http://www.ietf.org/rfc/rfc3561.txt.

Radhakrishnan, S., N.S.V. Rao, G. Racherla, C.N. Sekharan and S.G. Batsell, 1999. DST-A Routing Protocol for Ad Hoc Networks using Distributed Spanning Trees. Proc. IEEE WCNC.

Samba, S., Z. Yang, B. Qi and J. He, 2004. Simulation comparison of four wireless ad hoc routing protocols. Information Technol. J., 3: 219-226.

Woo, S.-C. and S. Singh, 2001. Scalable routing protocol for ad hoc networks. Wireless Networks, 7: 513-529.