A Novel Cross-Layer Management Mechanism for Ad hoc Network

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Abstract

In this paper, we present a novel Ad hoc network management mechanism UANM to provide unified management functionalities for nodes in an Ad hoc network. UANM adopts a cross layer cooperating management scheme to coordinate the pertinent behaviors of routing and application layer modules. It employs manager and agent model as SNMP. Nevertheless, when manager node needs to send management data packets to agent nodes and there is no available communication route, it will send out the management data packets in the process of route discovery. Thus manager node can finish part of the management work with much less delay and there will be significant energy consumption reduction for the nodes that are involved in the related communications. The simulation results verified the efficiency of UANM.

Keywords: *Ad hoc Network, Network Management, Cross Layer*

1. Introduction

Ad hoc network is composed of a group of mobile nodes with wireless communication transceiver device without network infrastructure [1]. These nodes are usually powered by batteries and have relatively limited energy. Behaviors of each node must be carefully designed to reduce their energy consumption, and then make the network survive longer. As ad hoc networks are becoming increasingly important in a wide range of applications, mechanisms of network maintenance, reconfiguration, and recovery mechanisms should be deployed to enable effective network management. However, the design of network management system for ad hoc network is much more difficult than for traditional wired networks [11]. Besides the aforementioned functionalities, ad hoc network management mechanism should also be able to autonomously control network topology, monitor nodes' failure and other events, and operate with limited computing resource, memory and bandwidth. Given that the whole network is composed of nodes with limited energy, in order to provide these capacities it is important to have management mechanism optimized for power saving. In addition, the key mission for a network management in the manager and agent model is to have manager node get all kinds of data from agent nodes regularly and in time. Therefore, in the mobile and unstable environment of ad hoc networks, when agent nodes need to answer the information query from the manager, it is vital to reduce the packet round-trip delay to ensure the validity of the management information.

Motivated by these needs, we propose a novel cross-layer ad hoc network management mechanism UANM (United Ad hoc Network Management). UANM coordinates the behaviors of the functionality modules at application, transport and network layers when conducting network management work. As a result, it will save nodes' energy, the cumulated energy consumption in the whole network, reduce the network traffic load and reduce the management packet round-trip delay.

The rest of this paper is organized as follows. In Section 2, we give a review of the related works of current ad hoc network management systems. In Section 3, the proposed mechanism is described in detail. Performance evaluation results are reported in Section 4. Some concluding remarks are included in Section 5.

2. Related Work

There have been some related researches regarding ad hoc network management reported in the literature. Daniel et.al proposed a way to realize the bandwidth management protocol for mobile ad hoc networks, which employs a backpressure restoration technique based on swarm intelligence. It uses two agents; one is acting as load agent and another as strategy agent to ensure better performance. The strategy agent controls and guides the load agents forward or backward. Network activities such as link failure and restoration of link information will be directly reported to reduce congestion in network and improving network bandwidth utilization [2].

Moursy, et al., designed an autonomous network performance management (ANPM) framework to assist the autonomous network performance management decision-making process. Their method monitors, simulates, optimizes and configures the manageable nodes and parameters of the whole network system to satisfy the overall performance objective [3].

There are also some cross layer management schemes reported in the literature. Nieminen et.al proposed an adaptive cross-layer energy scheduling and queue management framework EAED (Energy Awareness Early Detection) to reduce energy consumption by constraining the target delay and packet loss. EAED aims to save energy by extending latency and dropping packet in early phase when facing the constraints on transmission delay and packet loss. However, this scheme can only be applied to the scenarios which have low network load and short distance among the nodes [4].

Tang, et al., proposed a multi-layer energy efficiency design which integrates factors on physical, link, routing layer and media access control layer to achieve overall energy saving. These factors include battery discharge nonlinearity, node circuit multi-mode operation, signal low-power transmit, a variable-length TDMA scheme and multi/single-hop routing etc. Based on these factors, the minimization problem of total energy consumption across different network layers will be formulated, and then it can be numerically analyzed and optimized [5].

However, there's no work which were reported to realize the efficient ad hoc network management by making application, transport and network layer cooperate effectively. Our UANM mechanism will coordinate behaviors of these layers when a node is involved in network management work. By dividing the management related information into public and private categories and handling them differently to save unnecessary overhead, and unifying the route discovering process with management information propagating process, UANM can significantly reduce nodes' energy consumption, traffic load and communication delay which are incurred by network management work.

3. The Management Mechanism

There are a number of routing methods for ad hoc networks, among which the reactive routing protocols are widely used in energy saving oriented scenarios. Thus the description in this section and the simulation experiments reported in next section assume that on demand routing is used at network layer. Nevertheless, with minor modifications, UANM can also work with other types of routing methods.

3.1 The Overall Design

For a manager node which employs traditional reactive routing method, say AODV, when it needs to send a management packet to an agent and there is no available communication route, the manager will first launch the route discovery process. That is to say, it will first broadcast RREQ packet in the whole network; then establish a reversed route between manager and the targeted agent; then the targeted node or an intermediate node which knows the route to reach the targeted node replies a RREP packet along the reversed route which was just found; then the forward route is established [6]. Once the forward route is ready, the manager can send management packet to the agent.

To let the manager node manage the network more efficiently, UANM alters the behaviors of the network layer module. When the management packet arrives at routing layer, if there is no available route, UANM module at the routing layer will combine RREQ with the management message to produce URREQ message, and then broadcast it. Correspondingly, when the broadcasting packet gets to the targeted agent, it will be divided into RREQ message and management message at the network layer, and then the management message is handed to the upper layer and the RREP message is put into cache. When the reply message is transferred from application layer, the UANM module recombines the RREP message with reply message to get URREP message, and sends it to the application layer of the manager node. Figure 1 shows the format of URREQ and URREP packet. The message exchanging sequence diagram for UANM and traditional SNMP is presented in Figure 2 and Figure 3 respectively. The length of management and reply message relies on the length of messages that manager sends to manage the network and the length of the reply message that destination node sends back. Similar to SNMP, the management packet of UANM is transferred in UDP, and the packet format of on-demand route protocols is known, e.g. RREQ and RREP packet of AODV. Thus we only need to append management message or reply message to the appropriate packet directly, and make the corresponding modifications on the length of new message.

Byte 0	Byte 1	Byte 2	Byte 3
Type		Reserved	Hop Count
RREQ ID			
Destination node IP address			
Destination node sequence number			
RREQ source node IP address			
RREQ source node sequence number			
UANM management message ……			

A). Format of URREQ msg

Byte 0	Byte 1	Byte 2	Byte 3
Type	Reserved	Length	Hop Count
Destination node IP address			
Destination node sequence number			
RREQ source node IP address			
Lifetime Span			
UANM reply message ……			

B). Format of URREP msg

Figure 1. Definitions of URREQ and URREP Messages

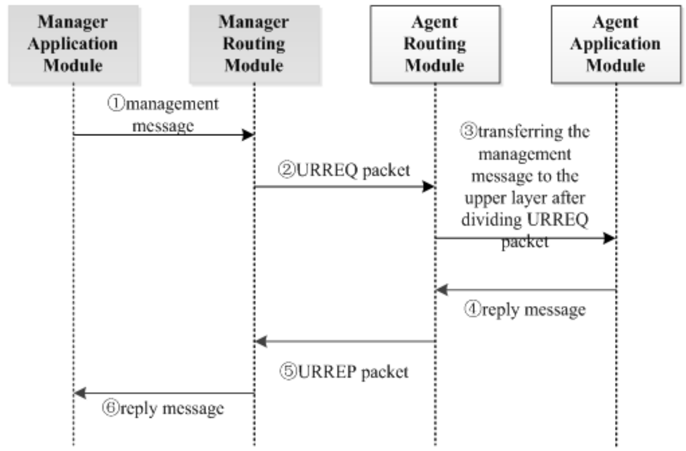

Figure 2. Sequence Diagram of Message Exchanging between Manager and Agent with no Available Communication Route when UANM is Used

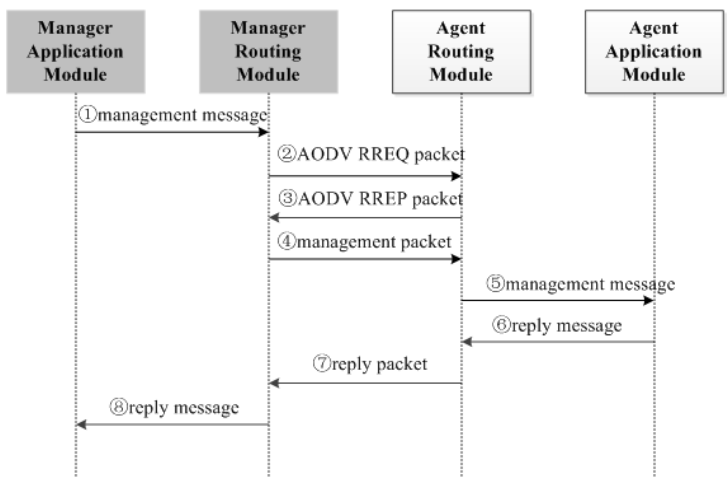

Figure 3. Sequence Diagram of Message Exchanging between Manager and Agent with no Available Communication Route when SNMP is Used

Therefore, by using this cross-layer cooperating scheme, while manager has no communication route to an agent, it will combine management message and RREQ packet together into one URREQ packet. When the destination agent node receives the URREQ packet, it also receives management message at the same time. Hence, the manager saves the whole process of separately communicating management messages with the agent. Consequently, UANM decreases not only manager's energy consumption but also the energy consumption of all the intermediate nodes along the communication path, the traffic load of whole network, and the RTT of management packets.

Table 1. Sample Information Classification

Public Info.	System configuring info	**Private Info.**	Temperature sensors data
	Energy managing info		Humidity sensors data
	Topology configuring info		Brightness sensors data
	Security management info		Pressure sensors data
	Cluster configuring info		Work mode configuration
	……		……

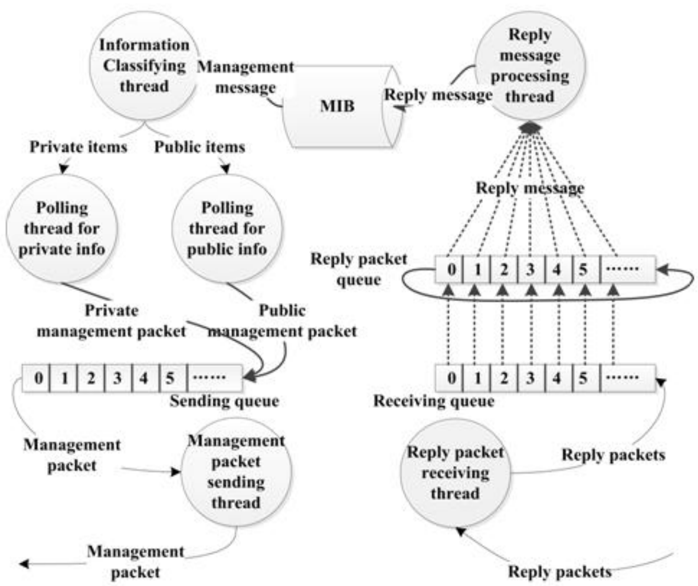

Figure 4. The Classified Information Based Management in UANM

3.2. Information Classification Based Management

3.2.1. The Classification of Information: In UANM, management information is divided into public and private type to reflect properties of different types of management information. The public information is defined as the information that all agent nodes require. When obtaining or configuring the information, manager may broadcast management packet in the whole network. The private information is defined as particular information that only some particular nodes owns, or determined by the function of the nodes themselves. For the former, manager can make broadcasts to perform the management work; for the latter, manager has to talk to agent nodes individually. Table 1 briefly lists a sample classification of the information that needs to be managed in the network.

3.2.2. Management on Classified Information: Traditional SNMP which works in a synchronous polling manner [12], which is not efficient in terms of performing management work to all the network nodes. Unlike SNMP, UANM manages the classified information by using two concurrent threads, one is responsible for polling the public information, and the other is in charge of the polling of private information. Together with other threads which are performing communicating work, the whole UANM system is working in an asynchronous manner as shown in Figure 4. According to the simulation result in [9], broadcast is not always better than unicast polling. Sometimes the large number of data packet may lead to the aggravating overhead for the network. Thus, for public information, if manager has available route to get to all agent nodes, UANM will do unicast polling. If the manager only has available route to some agents or no available route to any agent completely, UANM adopts the cross-layer scheme to complete management packet transmission. Thus, for the public information, UANM combines cross-layer scheme with the information classification, and does the polling work as shown in Figure 5. And Figure 6 shows the polling process performed by SNMP. By comparing these two flows we can find that, as to the polling of public information, when manager has available route to all the agent nodes, both UANM and SNMP adopt the unicast polling. When there is no available route, SNMP won't care whether the information is public or not, manager will always launch routing discovery process before sending management packet. If the number of agent nodes is *n*, the whole network would see the broadcasts *n* times in the worst condition, which would lead to severe overhead and energy consumption in the network. On the contrary, UANM have much better performance than SNMP. That is because SNMP not only needs to launch route discovery process *n* times, but sends management packet to each agent node separately later, while UANM can send management massage to all agent nodes with broadcast in one time.

As to the management of private information, manager generates management packets for private information by using the private information polling thread and adds them to the transmit queue. Since manager knows the routes to all the agents after performing one round of public management, the manager will always knows the route to send private packets to the agents if the private management is performed after public management. Correspondingly, the route discovery process can be avoided when manager sends private information management packet. Nevertheless, this doesn't exclude the situation that UANM allows the private management packet be sent to an agent node *k* before the manager successfully performs public management to *k*. If the manager conducts private management before performing a public management, the management information would also be sent to the agent in the process of route discovery, thus the overhead of a separate management communication process is saved.

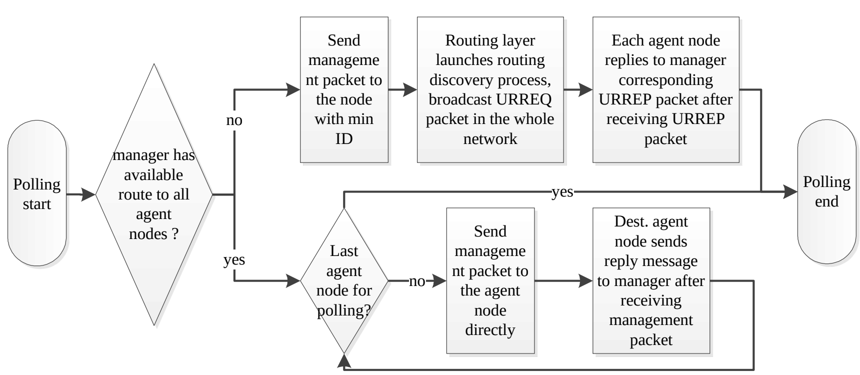

Figure 5. The Flow Chart for the Polling of Public Information in UANM

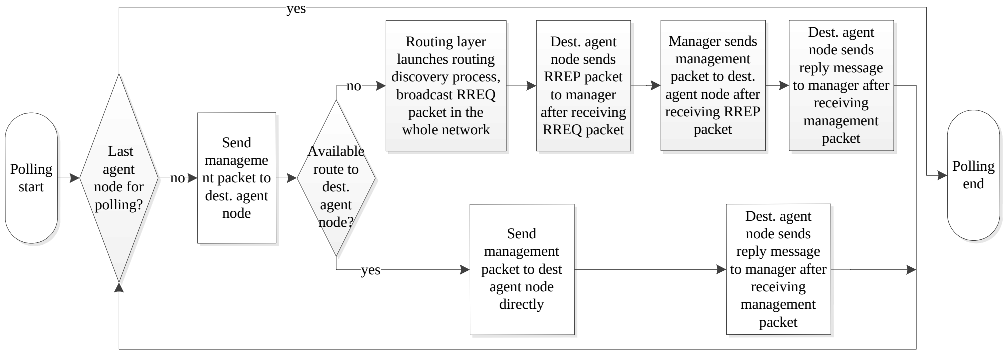

Figure 6. The Flow Chart of Polling in SNMP

4. Performance Evaluation

In this section, we describe the results obtained from simulation experiments that were conducted to evaluate the performance of the proposed cross-layer management mechanism. Firstly, we describe our methodology, configuration of simulation environment and the performance metrics we used. Then we examine the performance of UANM in greater detail.

4.1 Simulation Configurations

Simulations are carried out on NS-2 [13]. Two most important performance metrics, cumulated network energy consumption and management delay of the procedures of UANM polling and SNMP polling are compared. An 800*600m matrix area is set up as the simulating area. Node 0 which is located in the center of the area is assigned to be the manager node. To observe the performance of UANM, we create different number of nodes as agent nodes in the different experiments. The transmission range of wireless nodes is set to 250 meters to try to assure most nodes can be reached with the wireless ad hoc communicating manner. However, since the node generation is random, so there still might be some nodes that cannot be reached because its location is at edges of the simulated area. 802.11 protocols are used as MAC layer protocol, AODV is used as the routing method, and the interface queue is IFQ. Other pertinent settings are as follows:

a) The interval between polling of two nodes is 1.0 second so that the manager can send managing packets to two adjacent agent nodes without crossing.

b) According to a), we know that the polling cycle is in proportion to the network scale. For instance, polling cycle of 20, 40, 60 agents are 20 seconds, 40 seconds and 60 seconds.

c) The default active time of each routing term for AODV nodes is 10 seconds, so after polling, all the routing information of each node will be invalid.

d) The locations of nodes are decided by random numbers. We use the same seed to generate random numbers so that we can make sure that we have the same topology when simulating different protocols.

e) Locations of nodes are fixed. According to c), although the locations of the nodes are fixed, the manager will still launch a query to get routing information when it sends managing packet to each agent, so whether the nodes move does not affect the simulation results.

f) Simulation time is for one polling cycle. As long as there is no node consume all its energy. No matter how many cycles of polling there are in the simulation, in each single cycle, the total energy consumption of all the nodes should be the same.

g) Assume there is no special circumstance such as node failure, etc.

4.2 Simulation Results

According to the above configuration settings, by analyzing the trace files created by simulations on UANM and SNMP, we can get the cumulated energy consumption of all the nodes of the network, E_c, and the total delay of the manager's polling when sending packets to all agent nodes for one polling cycle, D_{total}. Assuming the number of nodes in the simulated network is n, the initial energy for each node is E, remaining energy of each node is E_i after the polling cycle, then E_c can be obtained by the following equation:

$$E_c = n \cdot E - \sum_{i=0}^{n-1} E_i \quad (1)$$

As we separate the management messages into private and public categories, let the probability of seeing private packet for each agent be ρ_i, energy spent for sending private messages be E_{iPri}, and energy spent for public ones be E_{iPub}, then E_c can also be obtained by:

$$E_c = \sum_{i=0}^{n-1} \left(\rho_i \cdot E_{iPri} + (1-\rho_i) \cdot E_{iPub} \right) \quad (2)$$

Supposing that in one cycle, the time that manager sending packets to node i is T_{si}, and the time that node i sends message back to manager is T_{ai}, so the cumulated delay that the manager performs one management work on all the agent nodes can be obtained by:

$$D_{totol} = \sum_{i=0}^{n-1} \left(T_{ai} - T_{si} \right) \quad (3)$$

Similar to eq. (2), when observing the polling delay for private and public messages of each agent separately, given the probabilities, D_{total} can also be obtained by:

$$D_{totol} = \sum_{i=0}^{n-1} \left(\rho_i \cdot D_{iPri} \right) + \sum_{i=0}^{n-1} \left((1-\rho_i) \cdot D_{iPub} \right) \quad (4)$$

In order to get a thorough understanding on the performance of UANM and SNMP and eliminate the impact from exceptional cases, such as the case that there is node that are out of reach, we conducted a number of simulations for these two management mechanism in at least 10 different random topologies respectively, and then get the average of the simulation results. As UANM treats public and private messages differently as described in section 3, we also simulate the public and private management separately. This way we can better understand performance of UANM. The performance comparison in terms of cumulated energy consumption and average packets delay between UANM and SNMP are shown in Figure 7 and Figure 8 respectively. Since the public management and private management can be performed independently in UANM, we collected the simulation results for both of them and plot the curves for public, private and mixed management. The data for the mixed management is presented as the curve for UANM. It was obtained by assuming that 50 percent of the management messages are private. As shown in these figures, by incorporating management messages into the route discovery broadcasting, UANM is much more effective than traditional SNMP in terms of management delay and network energy consumption, especially when the management messages are public for all the agents. Moreover, comparing to SNMP, UANM can save one unicast polling process when performing the private management work, thus even the private management for individual agent is also more efficient than SNMP.

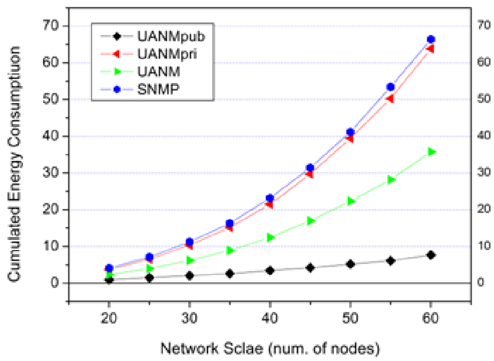

Figure 7. UANM v.s SNMP on Energy Consumption

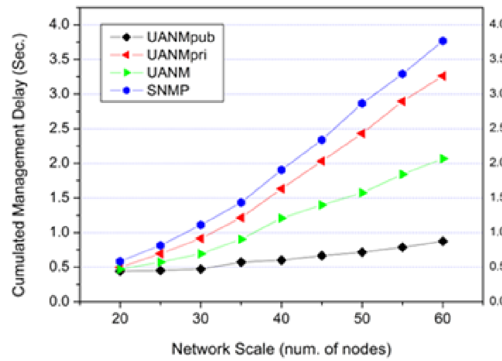

Figure 8. UANM v.s SNMP on Management Delay

5. Conclusions and Future Work

This paper presents a novel cross-layer collaborating management scheme UANM for ad hoc networks. When the manager sends managing packets to agent nodes and there's no available route, UANM combines management packets, reply packets with REEQ, and RREP packets respectively in the on-demand routing path discovery process. This significantly reduces energy consumption of all the nodes in the network for network management. Meanwhile, by categorizing management information, the efficiency is further increased when the manager performs public management work. Based the simulation results, it can be concluded that UANM is an efficient mechanism for ad hoc network management. In the future, we will research what the ratio is for public and private management in real applications. We will also keep working on the detailed design and implementation of various network management functions to apply UANM in real ad hoc network environment.

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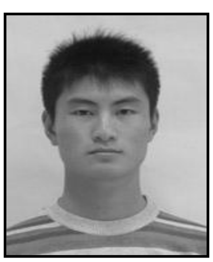

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