Wireless Ad-Hoc Networks with On-Demand Cache Routing

Dhanashri D. Dhobale and V. R. Ghorpade

Abstract—**This paper describes two novel routing algorithms that take into account the effect of distance between nodes and network congestion level on energy consumption. We formulate the routing problem as the minimization of energy Cost functions which reflect the key features of the problem under consideration. For route maintenance, we applied the least-recently used (LRU) replacement policy in caches to maintain route table and to remove the time-to-live parameter in some on-demand protocols such as Ad hoc on-demand distance vector (AODV). An on-demand routing protocol for mobile Ad hoc network (MANET) is one that searches for and tries to discover a route to some destination node only when a sending node generates a data packet addressed to that node. In order to avoid the need for such a route discovery to be performed before each data packet is sent, such routing protocols must cache previously discovered routes. But the cache itself may contain stale information due to nodes mobility. To solve the problem, we propose a new route cache scheme to improve the performance of route cache for finding more accurate and faster route to the destination. We developed an efficient algorithm for route discovery and management, and mobility handling for on demand cache routing on wireless mobile Ad hoc networks (MANET). We applied L-1 and L-2 route caches in each node to manage this algorithm efficiently. For mobility handling, we developed a sub-algorithm to handle node addition, deletion and movement in the network efficiently.**

Index Terms—**Wireless MANET, on-demand routing, route cache, route discovery, mobility management.**

I. Introduction

A wireless mobile Ad hoc network (MANET) is a collection of communication nodes that wish to communicate with each other, but has no fixed infrastructure and no predetermined topology of links. Individual nodes are responsible for dynamically discovering other nodes that they can directly communicate with. Due to the limitation of signal transmission range in each node, not all nodes can directly communicate with each other. Therefore, nodes are required to relay packets on behalf of other nodes in order to deliver data across the network.

A significant feature of Ad hoc networks is that changes in connectivity and link characteristics are introduced due to node mobility and power control practices. A MANET is a collection of communication nodes that wish to communicate with each other, but has no fixed infrastructure and no predetermined topology of links. Individual nodes are responsible for dynamically discovering other nodes that they can directly communicate with. Due to the limitation of signal transmission range in each node, not all nodes can directly communicate with each other. Therefore, nodes are required to relay packets on behalf of other nodes in order to deliver data across the network. A significant feature of Ad hoc networks is that changes in connectivity and link characteristics are introduced due to node mobility and power control practices. Ad hoc networks can be built around any wireless technology, including infrared and radio frequency (RF).

Usually, each node is equipped with a transmitter and a receiver to communicate with other nodes. Ad hoc networks are suited for use in situations where infrastructure is either not available or not trusted, such as a communication network for military soldiers in a field, a mobile network of laptop computers in a conference or campus setting, temporary offices in a campaign headquarters, wireless sensor networks for biological research, mobile social networks in MySpace and Face book, and mobile mesh networks for Wi-Fi devices [1]. The absence of fixed infrastructure in a MANET poses several types of challenges. The biggest challenge among them is routing. Many scientists have researched MANET routing protocols in the past decade. The proposed solutions could be grouped in three types: table-driven (or proactive), on-demand (or reactive), and hybrid protocols [2]. The reactive protocols have become the main stream for MANET routing. Energy consumption issue is an important research topic in wireless Ad hoc networks, because wireless nodes in such networks operate on limited battery power. Reference [3] describes two novel routing algorithms that take into account the effect of distance between nodes and network congestion level on energy consumption. Our algorithms adapt existing AODV routing protocol to improve performance in terms of energy conservation and other performance metrics. Reference [4] describes the mechanism that can balance forwarding states stored among routers and reduce the number of routers that store the forwarding states for a multicast tree.

II. On-Demand Protocols and Their Drawbacks

Some of the well-known on-demand protocols are hoc on-demand distance vector (AODV), dynamic source routing (DSR) and the temporary ordered routing algorithm (TORA). The major advantage of on-demand protocols is to establish a route only when it is required and hence the need to find routes to all other nodes in the network as required by the table-driven approach is eliminated. The major disadvantage

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is that the on-demand route discovery and connection setup delay for a long path is a considerable overhead [2], [5]-[7]. The event triggers required for AODV operation, the design possibilities and the decisions for AODV routing protocol implementation, AODV-UCSB is described in [8] is meant to aid researchers in developing their own on-demand Ad hoc routing protocols and assist users in determining the implementation design.

Ad hoc networks are characterized by multichip wireless connectivity, frequently changing network topology and the need for efficient dynamic routing protocols. Recent comparative studies between Ad hoc on demand routing protocols like AODV routing and DSR (the two on demand routing protocols for Ad hoc networks) have shown that AODV performs better than DSR for high mobility cases but faces the problem of high routing and MAC load as compared to DSR. This is because DSR resort to aggressive use of caching of routes while AODV does not [9]. Caching of routes in AODV can lead to significant reduction in routing and MAC load as well as in delay in delivering the packet as compared to AODV without much compromise in terms of packet delivery fraction.

III. Caching Strategy Design Choice

These design choices generally fall into three areas: cache structure, cache capacity, and cache timeout. First, in developing a caching strategy for an on-demand routing protocol for wireless Ad hoc networks, one of the most fundamental design choices that must be made is the type of data structure used to represent the cache. In DSR, the route returned in each Route Reply that is received by the initiator of a Route Discovery represents a complete path (a sequence of links) leading from that node to the destination node. By caching each of these paths separately, a path cache can be formed. Alternatively, a link cache could be created, in which each individual link in the routes returned in Route Reply packet is added to a unified graph data structure of this node's current view of the network topology. Fig 1 (a) and (b) illustrate an examples of path cache and link cache for some node S in the Ad hoc network.

A path cache is very simple to implement and easily guarantees that all routes are loop-free, since each individual route from a Route Reply is loop-free, but its data structure cannot effectively utilize all of the potential information that a node might learn about the state of the network. On the other hand, link cache can effectively utilize all of the potential information, but to find a route, a node must use a much more complex graph search algorithm.

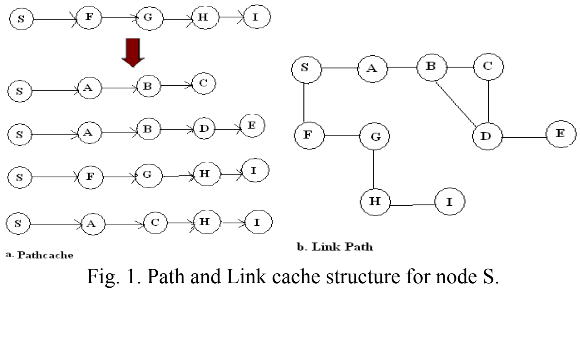

Fig. 1. Path and Link cache structure for node S.

Second, the capacity of a route cache is another important area of choice in designing a caching strategy for on-demand routing protocols. For a link cache, the logical choices is to allow the cache to store any links that are discovered, since there is a fixed maximum of N links that may exist in an Ad hoc network of N nodes. However, for a path cache, the maximum storage space that could be required is much larger, since each path is stored separately and there is no sharing in the data structure even when two paths share a number of common links.

Finally, cache timeout policy also introduces a number of design choices to consider in a caching strategy. While a path cache generally has a mechanism for removing entries through a capacity limit, the timeout on each link in the link cache may be either static or adaptive. For a static timeout, each link is removed from the cache after a specified amount of time has elapsed since the link was added to the cache. For an adaptive timeout, a node adding a link to its cache attempts to determine a suitable timeout after which the link will be deleted from the cache and this timeout value should be based on properties of the link or the nodes that are the endpoints of the link.

IV. The on-Demand Cache Routing Algorithm

In this section, we present an efficient algorithm for Route Discovery, route management and mobility handling for on-demand routing. We call it as "on-demand cache routing" (OCR) algorithm since we applied caches in each node to improve the routing performance. In our network, each node equips L-1 (level 1 or primary) and L-2 (level 2 or secondary) caches. Usually, the size of L-1 cache is about 64 to 256 KB and L-2 cache is about 256 KB to 2MB). For memory address mapping, they use 2-, 4- or 8-way set associative scheme. Each data entry in a cache is called a "cache line". Most caches use the least-recently used (LRU) policy for cache line replacement. All cache lines can be searched in parallel in a few processor cycles. This is an important reason why many routing protocols adopted cache for route management. We call this cache as "route cache" because it stores the routing information in the network [10].

For the initial settings of our MANET, we assume 1) the communication media among nodes (e.g., laptop computers) is RF; 2) each node has an identification (ID) number; 3) each node keeps an ID list in its own cache (see Fig. 2); 4) the wireless links in the network are symmetric (i.e. bi-directional transmission); and 5) the network is scalable and heterogeneous. This means the number of nodes in the network is changeable anytime, and the processor architecture, transmission radius and battery life of each node can be different.

Algorithm: On-Demand Cache Routing (OCR)

Inputs: Node identifications (IDs) in the MANET.

Outputs: Transmitted data packets on the network.

Begin

1) If any node in the network wants to send a data packet, at first it has to search the best route (usually the least hop-count route) from its cache. If the route does not exist, go to Step 2. Otherwise (i.e. the route exists) go to Step 3.

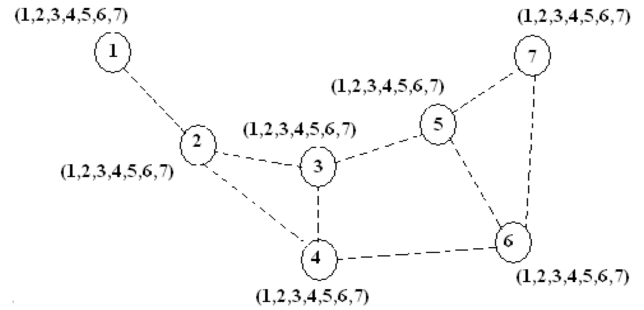

Fig. 2. A simple MANET with an ID list in each node, where 1, 2, 3, …are nodes, and dotted lines are wireless links in the RF transmission radius.

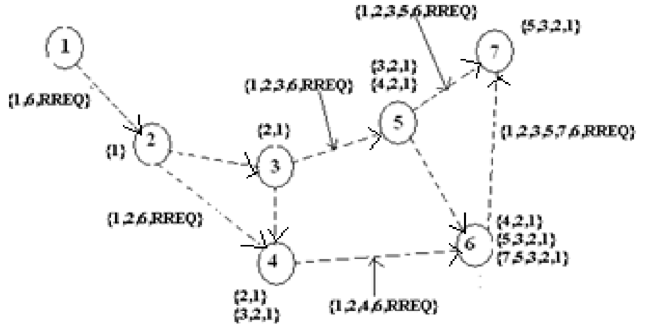

Fig. 3. The routes stored in each node after broadcasted the RREQ packet from node 1 to node 6. Node 6 did not forward the packet to other nodes because it is the destination node.

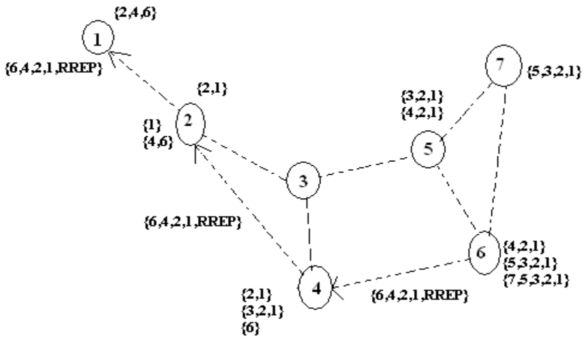

Fig. 4. The routes stored in each node after sent the RREP packet from node 6 back to node 1. Note, nodes 1, 2, and 4 created one more route {2, 4, 6}, {4, 6} and {6} in their caches.

2) The source node looks up the destination node in its ID list (as in Fig. 2). Then it executes the Route Discovery Algorithm (RDA) to create the best route to its destination node in the network. For instance, in Fig. 3, best route from node 1 to node 6 is {1, 2, 4, and 6}.
3) The source node attaches its ID, destination node ID and the packet number to each data packet, and sends the packet to the destination node along the best route.
4) Each intermediate node uses the best route to the destination node in its cache to forward the data packet to the next or destination node.
5) If any node leaves from, joins to, or moves around the network, it has to execute the Mobility Handling Algorithm (MHA) to notify other nodes about this change and to update their own route information in their caches.
6) Repeat Steps 1 to 5 until the whole network is terminated. End of On-Demand Cache Routing.

V. Caching in AODV

We saw that AODV finds new routes by making a route request broadcast which travels through various intermediate nodes before reaching the destination node. These requests carry a lot of information about the network topology as they pass through different nodes but due to lack of caches at intermediate nodes, this information cannot be tapped by the nodes to be used later. So by providing all the nodes with an extra cache and by making changes in the RREQ packet such as to enable them to carry the information about the nodes through which they pass, intermediate nodes can save the information about the network topology contained in the RREQ packets. This reduces the time and overhead to find new routes in cases of route failure. From now on, we will call the AODV with cache enabled as AODV-WC and AODV without caching as AODV-WOC.

VI. Implementation Details for Caching of Routes in AODV

To implement caching in AODV, we made the following modifications to the present AODV:

1) Each node now has a separate queue (apart from the queue which AODV has for maintaining routing Information) which acts as a cache for the routes. For this purpose, we have used the same queue structure which AODV uses for maintaining its routes.
2) To reduce the problem of stale caching, a cache timer is introduced in the caches and an appropriate cache timeout value is found to get the maximum efficiency from the cache even in the case of high mobility (low pause time). So any route that does not get updated within the cache timeout period from the time of its addition to the cache is discarded as stale.
3) Route request packets (RREQ) should be able to carry the node addresses and latest sequence numbers (It is the same sequence number as used by AODV to check the freshness of a route) of the Intermediate nodes they have passed before reaching the destination node. For this purpose, we have implemented a special data structure in the AODV RREQ packet header which forms a link list of node addresses and sequence numbers of the nodes through which the packet has crossed.
4) All the nodes on receiving a route request packet should, apart from doing their already specified tasks, read the node addresses and sequence numbers in the packet and add them to their caches as the nodes reachable from the last node through which the packet is coming. Then before broadcasting the packet to the neighboring nodes, the nodes should append their own address and a latest unused sequence number into the packet.
5) As AODV is not a source routing protocol like DSR, so caching of routes can cause the problem of looping of data packets because of deletion of routes due to cache timeout. In order to avoid the looping of packets, a packet sequence number is generated by the source node before sending the packet by incrementing by one the last sequence number used by that node. This sequence number is attached with each packet so that the packet

sequence number along with the source id uniquely determines a packet and so nodes can detect the packets forwarded by them self. On encountering a packet which has looped, the node drops the packet and deletes the path on which it was last forwarded which resulted in the loop and informs the source of the packet that the path to the destination does not exist anymore.

6) Caching of routes enables intermediate nodes to salvage data packets as alternate routes may be available with every node. So if the older route breaks the intermediate node which detects the route. Failure first looks for an alternate route in its cache and if it finds any route, it sends the packet on that route. But it informs the source that the old route has expired so that the source can initiate Route Discovery to find a new route. This prevents over lengthening of routes after many routes have expired.

VII. Performance Metrics

Four important performance metrics are evaluated:

1) **Packet delivery fraction**: The ratio of the data packets delivered to the destinations to those generated by the CBR sources. Also a related metric, received throughput (in Kilobits per second) at the Destination has been evaluated in the case of analysis of TCP traffic.
2) **Average end-to-end delay of data packets**: This includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at the MAC, and propagation and transfer times.
3) **Normalized routing load:** The number of routing packets transmitted per data packet delivered at the destination. Each hop wise transmission of a routing packet is counted as one transmission.
4) **Normalized MAC load:** The number of routing, address resolution protocol (ARP), and control (e.g., RTS, CTS, ACK) packets transmitted by the MAC layer for each delivered data packet. Essentially, it considers both routing overhead and the MAC control overhead. Like normalized routing load, this metric also accounts for transmissions at every hop.

VIII. Conclusion

We have discussed techniques for providing hard latency limits on transmissions in an Ad hoc network. Such techniques can also be applied to other protocols that require such hard limits. This approach can also easily be generalized to support nodes having more than one network interface.

AODV cannot compete with DSR in terms of Routing and MAC load mainly because it does no caching of routes, but it perform better than DSR in terms of Packet delivery fraction for high mobility scenario. So we have implemented caching of routes in AODV with the aim to overcome this drawback of AODV but still maintaining the distinguishing characteristics of AODV like it is not being a source routing protocol.

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