Location Aware Routing in Intermittently Connected MANETs

Sadhana V, Ishthaq Ahamed K
G. Pulla Reddy Engineering College, Department of CSE
*Nandyal Road, Kurnool-518002,*Andhra Pradesh

Abstract
Existing mobile ad hoc routing protocols like AODV, DSR and GPSR allow nodes to communicate with one another with an assumption that there exists a connected path from source to destination. Due to limited transmission range, power limitations, mobility of nodes, and the wide physical conditions over which ad hoc networks must be deployed; in some scenarios it is likely that this assumption is invalid leading to intermittent connectivity and absence of end-to-end connections. In this work, we propose a geographical routing algorithm called location-aware routing for delay-tolerant networks (LAROD), enhanced with a location service, location dissemination service (LoDiS), which together are shown to suit an intermittently connected MANET (IC-MANET). LAROD uses a beaconless strategy combined with a position-based routing for forwarding the packets resulting in less overhead. LoDiS maintains a local database of node locations, which is updated using broadcast gossip combined with routing overhearing.

Keywords— Delay-tolerant networks, location service, mobile ad hoc networks (MANETs), routing protocols, intermittent connectivity.

I. Introduction

Intermittently connected mobile ad hoc networks (IC-MANET) are wireless networks where the nodes do not form a completely connected network. Instead, they will form connected partitions that changes their topology often. This kind of intermittent connectivity may happen when the network is quite sparse, in which case it can be viewed as a set of disconnected, time-varying clusters of nodes. Intermittently connected mobile ad hoc networks is a type of Delay Tolerant Networks (DTN) [1], that is, networks were incurred delays can be very large and unpredictable. There are many real networks that fall into this category. Examples include disaster scenarios and military operations, wildlife tracking and habitat monitoring sensor networks (IPN) etc.

Since in the IC-MANET model there may not exist an end-to-end path between a source and a destination, existing ad-hoc network routing protocols, such as GPSR, DSR, AODV etc., would fail. To overcome the disconnected nature of IC-MANETs and to successfully route the packets under such conditions, a store-carry forward technique is used. Mobility can be exploited when wireless nodes cannot forward the packet.

In this paper we present a geographical routing protocol called Location Aware Routing for Opportunistic Delay-Tolerant networks (LAROD) which relies on position information of the nodes. LAROD is a beaconless protocol that greedily forwards packets towards the destination. When greedy forwarding is not possible a packet is temporarily stored by the current custodian until a suitable forwarding node comes up. Routing of packets toward the geographical location has shown to work well in IC-MANETs.

Clearly, a geographical routing protocol needs to be supplemented by a location service [2] that can provide the current physical location of the destination node for a packet. A location service can range from simple flooding-based services to hierarchical services. There have been many suggestions on how a location service can be provided in MANETs, but there have been no suggestions on how this service can be provided in an IC-MANET or DTN setting. The location dissemination service (LoDiS) is the first location service for IC-MANETs which disseminates node locations in the network using a Brownian gossip technique.

In the next section we go over some existing routing algorithms for IC-MANETs and location services. Section III presents LAROD and LoDiS protocol. Section IV, presents our evaluation of LAROD with LoDiS and compare the results with spray and wait. Finally in section V we end the paper with some conclusions and ideas on future work.

II. Background And Related Work

Proposals on how we can route packets in fully connected MANETs have been studied to a great extent. In the last decade, this interest has broadened into networks with intermittent connectivity. In this section, we give an overview of IC-MANET routing and location services.

A. Routing in IC-MANET

In a wireless mobile ad hoc network where an end-to-end path can never be assumed to exist between any two nodes, mobility can be used to bridge the partitions. When there is no suitable forwarding node, a routing node can choose to temporarily store a packet until node mobility presents a suitable forwarding node. This routing principle is called store–carry–forward.

The design of an IC-MANET routing protocol depends on the amount of contact information available with the node. The mobility of the nodes will constantly change the network topology and that nodes constantly come in contact with new nodes and leave the communication range of others. Node contacts can be classified based on their predictability into scheduled, predicted and opportunistic contacts. In scheduled contacts, the nodes know when they will be able to communicate with a specific node. In predicted contacts, nodes can estimate likely meeting times or meeting frequencies with specific nodes. If no such contact information is available with node then the contacts are opportunistic. LAROD neither requires scheduled contacts nor predicted contacts and is thus well suited for networks with opportunistic contacts.

Routing in IC-MANETs with opportunistic contacts is challenging since contact information is not known in advance. Three simple location unaware routing protocols for this environment are Randomized Routing, Epidemic Routing and Spray and Wait. Randomized Routing [3] is a single copy routing scheme in which a packet randomly moves around the network until it reaches the destination. Epidemic routing [6] extends the concept of flooding in IC-MANETs where every node in the network receives a copy of the packet. Spray and Wait [5] routing protocol "sprays" a limited number of copies into the network, and then "waits" until one of these nodes meets the destination.

If nodes are location-aware, then the relative position of the nodes can be used to make the forwarding decision. This is a property used by LAROD. In addition to LAROD there are two other delay-tolerant geographical routing protocols published. These protocols are motion vector (MoVe) and GeoDTN+Nav. Both these protocols are used in vehicular ad hoc networks (VANETs) and assume the destination to be static.

Most of the proposed MANET routing protocols transfer packets between nodes in a unicast transfer mode and thus does not exploit the broadcast nature of wireless transmissions. Opportunistic routing (OR) [8] fully embraces the broadcast nature of wireless medium and thus an optimal route is constructed between the source and the destination by selecting the "best" next forwarder. One way of selecting the best forwarder is by geographical selection that is the selection depends on closeness to the destination. This approach is used in contention-based forwarding (CBF) [11] and beaconless routing (BLR) [10]. LAROD is built on these principles and extends them to meet the requirements of an IC-MANET.

B. Location Services

A geographical routing protocol must be complemented by a location service that can provide position information for all potential destinations. In this section, we will give an overview of the location services [2] used in MANETs and discuss why most of them are not directly applicable to an IC-MANET.

Fig 1 shows taxonomy of the location services. At the top level, location services can be divided into flooding-based and rendezvous-based or mapping-based approaches. A major difference between the flooding-based location services and the mapping-based services lies with the number of nodes that act as location servers.

In the flooding-based services, all nodes in the network act

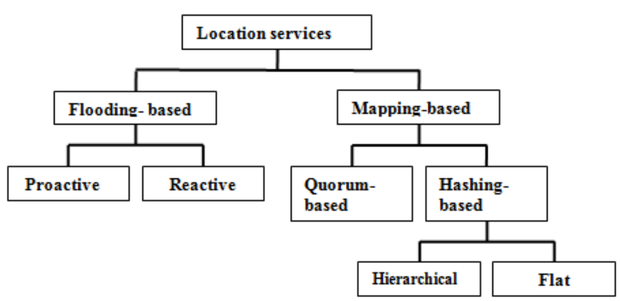

Fig. 1 Taxonomy of location services

as location servers. In the mapping-based services, only a subset of the nodes in the network act as location servers and the location queries must be routed to one of these location servers.

In a mapping-based location service, the node that needs the location information of the destination node sends the request to one of the node that act as location servers. In a delay-tolerant perspective, this case will significantly delay the time until a message can be sent toward its destination due to the transport time for a location request and its response.

In the flooding-based services, the location information is located in the source node itself so there is no delay for reaching the location service, but the time to acquire the location information differs between proactive and reactive location services. A reactive location service tries to obtain the destination position information only when needed. If the required information is not available in the local cache, then the location server broadcasts a location query over the

network. Due to the disconnected nature of the network, the reactive location services will result in delays as for the mapping-based location services. To limit the cost of a location request the location service uses a Brownian gossip [13] technique. In Brownian gossiping, nodes exchange information on previous encounters when two nodes meet. This information can be used to guide a location request toward the destination node's position.

In the proactive location service, each node periodically distributes its location information to other nodes in the network, which means that location information is immediately available when needed in the source node. Examples of proactive location services are: 1) the DREAM location service (DLS) [9] and 2) the simple location service (SLS) [9]. In DLS, a node broadcasts its location to nearby nodes at a given rate and to nodes far away at a lower rate. The rates depend on a node's speed. In SLS, location data are only exchanged between neighbors. This exchanging of location tables between neighbors keeps the communication local while permitting the location data to be distributed globally in the system. In both DLS and SLS, if the required location data are not available in the source node, they inquire a node location by broadcasting a request. As previously discussed, these systemwide broadcasts are problematic in an IC-MANET.

In order to minimize routing delays in an IC-MANET, all nodes must have a location service that has location data for all other nodes in the network. Due to the disconnected nature of IC-MANETs, this information provided by the location service might be old for some nodes. Even such inaccurate data can be used to route the packets successfully with a proper design of the routing protocol. LoDiS is based on SLS and modify the concept as required to meet the demands of an IC-MANET environment.

III. Location Aware Routing

This section describes the IC-MANET geographical routing protocol LAROD [4], followed by a description of the IC-MANET location service LoDiS.

A. LAROD

LAROD is a geographical routing protocol for IC-MANETs that use greedy packet forwarding when possible. When greedy forwarding is not possible, the node that currently holds the packet (the custodian) waits until node mobility makes it possible to resume greedy forwarding. It is a beaconless protocol that combines geographical routing with the store–carry–forward principle.

A custodian forwards a message toward the destination by simply broadcasting it. All nodes within a predefined forwarding area are called tentative custodians and are eligible to forward the packet. All tentative custodians set a delay timer *td* specific for each node, and the node whose delay timer expires first is selected as the new custodian. The new custodian forwards the message in the same manner as the previous custodian. The old custodian that forwarded the message and other tentative custodians will overhear this broadcast and conclude that a new node has taken over custody of the packet. If the current custodian does not overhear any such broadcast within an interval of *tr* (rebroadcast time), it repeats the broadcast of the message until a new custodian becomes available due to node mobility.
It is also possible that all nodes in the forwarding area may not overhear the transmission made by the new custodian, thereby producing packet duplicates. This case will not only increase the load in the system but results in exploration of multiple paths toward the destination. When the paths of two copies cross, only one copy will continue to be forwarded. When the time to live *tTTL* for a packet, which is expressed as duration, expires, a packet is deleted by its custodian. This is done to prevent a packet from indefinitely trying to find a path to its destination.

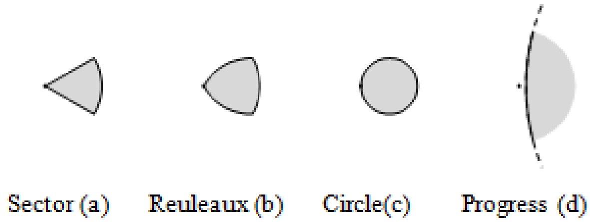

Fig 2 LAROD forwarding areas

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Source node at data packet generation
    Get location data for destination from location service
    Broadcast data packet
    Set up the timer for rebroadcast to tr

Destination node at data packet reception
    If the packet is received for the first time
        Deliver data packet to application
        Broadcast ack packet
    Else
        Broadcast ack packet

All intermediate (non-destination)  nodes at data packet
reception
    Update location service with location information of the
    data packet
    //Packet has been received by the destination
    If an ack has been received for the packet
        Broadcast ack packet
    //The node is a tentative custodian
    If the node is the forwarding area
        If the node has an active copy of the packet
            Set up timer for rebroadcast to td
        Else
            Do nothing
    Else
        Remove active copy of the packet if it has one

At ack packet reception
    Update location service with location information of the
    ack packet
    If the node has an active copy of the packet
        Broadcast ack packet
        Remove data packet
    Else
        Do nothing

When a data packet rebroadcasting timer expires
    If the packet's TTL has expired
        Remove packet
    Else
        Update data packet's location information with
         location server data
         Broadcast data packet
         Set up the timer for rebroadcast to tr
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Fig 3 LAROD pseudo code

The forwarding area can have many shapes as shown in fig 2. Examples of shapes include a 60◦ circle sector, a Reuleaux, triangle, or a circle [Fig. 2(a)–(c)]. The longest distance between two points within these shapes must be the assumed radio range. If we want to maximize the probability of determining a new custodian, then the forwarding area should include all nodes that guarantee progress toward the destination [Fig. 2(d)]. In this paper, we have chosen progress forwarding area.

When a packet has been received by the destination, it sends an acknowledgement packet (ack) to stop further transmission of a packet by custodians and tentative custodians. All nodes that hear an acknowledgement will store the acknowledgement information until the packet times out. If a node receives a packet for which it previously has received an acknowledgement, then it broadcasts an acknowledgement packet to stop further transmission of the packet.

LAROD inquires the location service at each packet hop to overcome the inaccuracies of an IC-MANET location service, and if more recent position data are available, then the routed packet is updated. In this way, the location data is incrementally updated with accurate data as the packet approaches the destination. To still improve the quality of the location data in the location service, LAROD routing protocol provides it with the location data available in received packets. Fig. 3 shows the pseudocode for LAROD routing protocol.

B. LoDiS

Due to the network partitioning of an IC-MANET environment, the information exchanged between the nodes can be delayed, which means that any time-dependent information that is received is more or less inaccurate. This indicates that any location service in an IC-MANET will generally provide inaccurate location data. This may be due to the time taken for a location update to reach the location server and/or the time taken for a location request to be answered by a location service. To avoid such delays, in LoDiS, every node acts as a location server, and location updates are made by data exchanges as nodes encounter each other. The reason for treating all nodes as location servers is to avoid delaying the packet at the source node.

When the routing protocol requests a location from the location service, LoDiS, the location data provided by LoDiS will be wrong due to the mobility of the nodes, but if the provided location points the data packet in the approximate right direction, it should be possible to use it as an initial estimate. To limit the location error, the geographical routing protocol should update the packet's location information for each node that the packet traverses. This is carried out by inquiring the node's local location server whether it has more accurate location information for the destination. This is based on the fact that nodes closer to the destination should have correct information on the destination's location. Thus the accuracy of the destination location is incrementally increased.

LoDiS is built on the conceptual solution used by SLS. A LoDiS location server periodically broadcasts the information it has in its location table. Any node receiving this broadcast compares the information with the one it has, and the most recent information will be propagated when that node makes its LoDiS broadcast. In this way, the location information is distributed throughout the network. In addition to this

```
Broadcast location data at a set interval
   Select location data vector with elements(node, location,
   timestamp)
   Broadcast location data

When a LoDiS broadcast is received
   If the received location data is more recent
     Update the entry in the LoDiS server

When the location data is received from the routing protocol
   If the data received is more recent
     Update the entry in the LoDiS server
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Fig 4 LoDiS pseudocode

routing protocol. The geographical routing protocol provides the location service with location information present in the packet that it routes, which helps to improve the data in the location service. The pseudocode for LoDiS is shown in Fig.4.

IV. EVALUATION

In this section, the results from the evaluations of LAROD–LoDiS are shown. The routing protocols have been evaluated in the network simulator ns-2. The LAROD–LoDiS scheme is compared with an efficient delay-tolerant routing algorithm called spray and wait and is shown to have a competitive edge, both in terms of delivery ratio and overhead.

Delivery ratio and effort required for each generated data packet (overhead) are the two main evaluation metrics used. The delivery ratio determines the quality of service as perceived by the user or application and it is the most important evaluation criterion. The effort will be measured as the number of transmissions performed per generated data packet.

Comparing the delivery ratio and overhead of LAROD–LoDiS with spray and wait, a leading nongeographic delay tolerant routing scheme, we see that the benefit of using geographical information and active forwarding is very high (see Figs. 5–8). Fig. 5 shows the impact of the packet lifetime on the delivery ratio. As shown, both routing protocols benefit from having more time to find a path from the source to the destination. The performance of LAROD is high compared to spray and wait because spray and wait mainly uses node mobility to forward packets, whereas LAROD actively forwards the packet through peers toward the destination. Due to frequent node encounters, the protocols that actively forward the packets outperform protocols that rely on node mobility. As shown in fig. 6, the overhead for spray and wait is about double that of LAROD–LoDiS. Overhead in spray and wait are due to the beacons and the query and response packets, i.e., packets not present in LAROD–LoDiS.

Comparing the two routing protocols with respect to varying node densities, we can make some interesting observations. For both routing protocols, the delivery ratio improves with increased node density (see Fig. 7). Looking at

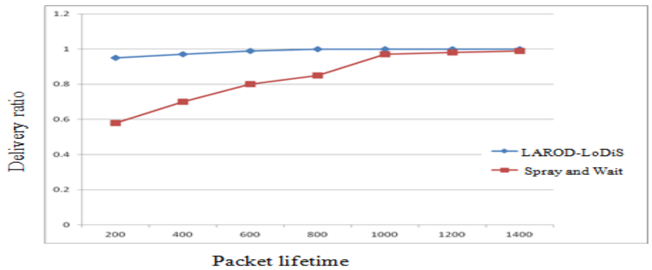

Fig 5 Delivery Ratio for different packet life times

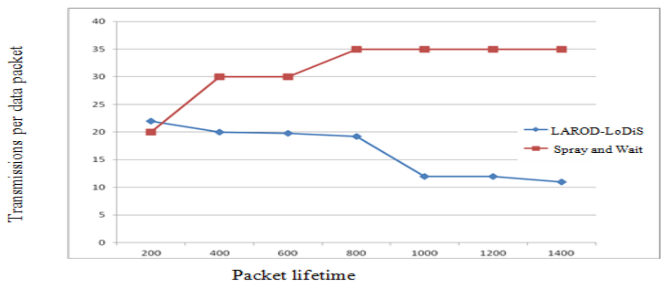

Fig 6 Overhead for different packet lifetimes

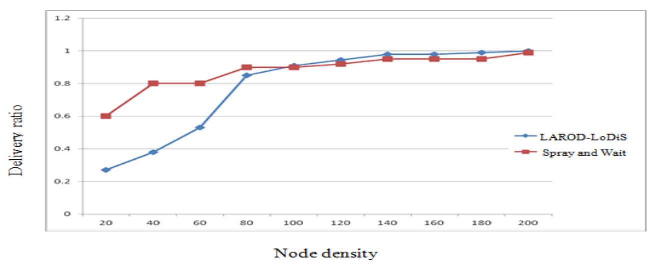

Fig 7 Delivery ratio for different node densities

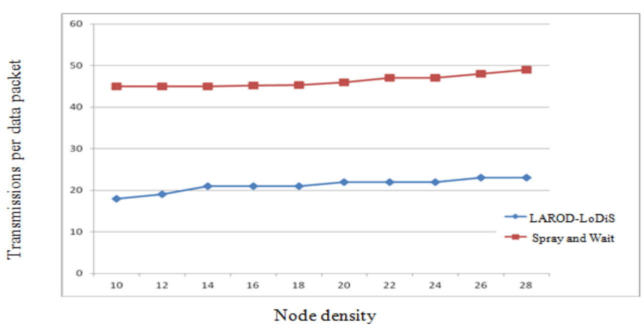

Fig 8 Overhead for different node densities

the overhead in Fig. 8, we observe that the overhead for LAROD-LoDiS is less compared to spray and wait.

V. CONCLUSION

Geographical routing protocols works efficiently in MANETs and IC-MANETs due to the availability of node location information. One major criterion for a geographical routing protocol is a well-performing location service. The location service provides the location information of the destination to route a packet toward.

This paper has shown that, by continuous updation of packet‘s location information, geographical routing in IC-MANETs is possible. The location service (LoDiS) has then been integrated with a routing protocol (LAROD) and thoroughly studied in comparison with a high-performance baseline.

Further studies can be done on different location services for MANETs and IC-MANETs. Performance metrics can be evaluated for LAROD-LoDiS based on the location service chosen.

LAROD-LoDiS routing algorithm handles intermittent connectivity but it is not suitable for systems with varying density (sparse and dense areas). For sparse systems, distribution of location information takes much time. For very large systems with thousands of nodes, the difficulty will be to distribute the location information to all the nodes in the system. The transfer of location information in such dense systems consumes much bandwidth of the network. In such scenarios, one can probably employ the density based techniques to overcome the density variation problem. The basic idea behind this technique is to detect the density of the network and defining the broadcast rate based on density.

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