Efficient Routing For Intermittently Connected Mobile Ad hoc Network

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Summary

A Mobile Ad Hoc Network (MANET) is a collection of mobile nodes that can communicate with each other using Multihop wireless links without using any fixed infrastructure and centralized controller. Communication links are susceptible to frequent failures due to intervening objects, which can cause intermittent connectivity. Due to Intermittent connectivity, there is no end-to-end path exists between source and destination all the time. Existing ad hoc routing protocols unable to deliver packets in the presence of a network partition between source and destination since they are designed for network where end to end connectivity exists between nodes. To deal with such networks researchers have suggested to use flooding-based routing schemes and Message Ferrying Schemes. Flooding scheme is not suitable if partitions last for a long duration of time. Message Ferry distributes messages between nodes which are located in different partitions which may be disconnected. Ferry moves around a fixed path for providing regular connectivity in a disconnected network. But this scheme needs huge buffer space and also online collaboration between Ferry and other nodes in the network. With this in mind, a new routing scheme with two types of Ferries and Gateways has been proposed. This scheme improves delivery rate and delay and it does not need any online collaboration between ferry and mobile nodes.

Keywords:
Disconnected, Message Ferry, Epidemic routing, Delivery rate, Latency

1. Introduction

The sharing of the information is necessary for many tasks and the urgent information can be disseminated the sooner or better a task can be completed. With the development of cheap wireless technologies like GSM and Wi-Fi, information is often available anytime and anywhere. The limitation of these technologies is that they require an infrastructure ie., base stations for their functioning. In environments such as disaster areas or during wartime this type of infrastructure is generally not available, but information exchange is still desired. An option to communicate in these environments is to use long range radios that enable point-to-point communication. The problems with these are that they are often expensive, bulky and only provide low bandwidth communication. Hence multihop wireless ad hoc network is used. In a multihop wireless ad hoc network, mobile nodes cooperate to form a network without using any infrastructure such as access points or base stations. Instead, the mobile nodes forward packets for each other, allowing communication among nodes outside wireless transmission range.

Intermittently connected Mobile Ad hoc networks are mobile wireless networks where most of the time there does not exist a complete path from a source to a destination, or such a path is highly unstable and may change or break soon after it has been discovered. This is due to Node mobility, limited radio range, physical obstacles, severe weather, wide deployment area or other physical factors. Most ad hoc network routing algorithms are designed for networks that are always connected [1][2]. While it is certainly desirable to maintain a connected network, various conditions may cause a mobile ad hoc network to become partitioned, meaning that there is no single-hop or multiple-hop route between some (or all) source/destination node pairs., might prevent some nodes from communicating with others and result in a partitioned network. The existence of network partitioning requires a new routing approach other than the traditional “store-and-forward" routing paradigm used in most current ad hoc routing algorithms, in which messages are dropped if no route is found to reach a destination within a small amount of time[6].

1.1 Application scenarios of intermittently connected ad hoc network

- Ad hoc networks for low cost Internet provision to remote areas/communities
  - Africa, Saami, etc.
- Sensor networks for habitat monitoring and wildlife tracking
  - ZebraNet: sensor nodes attached on zebras, collecting information about movement patterns, speed, herd size, etc.
- Inter-planetary networks (extend the idea of Internet to space)
- Ad-hoc military networks
- Remote Village communication

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1.2 Background

The kind of communication networks addressed in this work are only viable for applications that can tolerate long delays and are able to deal with extended periods of being disconnected. In military war-time scenarios and disaster recovery situations, soldiers or rescue personnel often are in hostile environments where no infrastructure can be assumed to be present. Furthermore, the units may be sparsely distributed and mobile, so connectivity between them is intermittent and infrequent [4]. In any large scale ad hoc network, intermittent connectivity is likely to be the normal, and thus research in this area is likely to have payoff in practical systems.

1.3.Conventional MANET Routing Protocols

MANET routing protocols can be divided into two categories: Proactive (table-driven) and Reactive (on-demand) routing based on when and how the routes are discovered. Table-driven routing protocols attempt to maintain consistent, up-to-date routing information from each node to every other node in the network. Routing table is updated periodically. On demand routing protocol creates routes only when desired by the source node. If a node wants to send a packet to another node then this protocol searches for the route in an on-demand manner and establishes the connection in order to transmit and receive the packet. The route remains valid till the destination is reachable or until the route is no longer needed. Routing protocols for ad hoc networks must deal with limitations such as high power consumption, low bandwidth, high error rates and arbitrary movements of nodes.

1.4.Challenges in MANET

Two main challenges in MANETs (when tradional routing protocols fail) are Intermittent Connectivity and Network Partition.

Intermittent connectivity:

- When nodes are in motion, links can be obstructed by intervening objects
- When nodes conserve power, links are shutdown periodically

Network partition:

- When no path exists between source and destination, it is perfectly possible that two nodes may never be part of the same connected portion of the network.

1.5.Issues In Conventional MANET Routing Protocol

Intermittently Connected Mobile ad hoc network with long disconnection time creates network partition. In this context, conventional routing schemes fail, because they try to establish complete end-to-end path between source to destination before any data is sent. Existing Routing protocols [3] simply discard the packets if the packet is not delivered within a small amount of time. These routing protocols fail in Intermittently Connected Mobile Ad hoc networks because of the following characteristics of Network:

- Intermittent network contacts
- End-to-end path between the source and the destination may have never existed
- Disconnection and reconnection is common
- Highly variable link performance

2. Related Work

More number of works has been done on designing routing protocols in Mobile Ad hoc Networks. These routing protocols are all based on the assumption that the network is connected [7]. In reality, the network could be highly-partitioned due to the various reasons specified earlier. These networks are known as delay-tolerant networks (DTNs), and also disruption-tolerant networks[15]. Several models based on mobility assisted scheme have been proposed to deal routing in this type of network: The existing movement-assisted routing methods can be classified into two categories based on the mobility control. The first category uses the random mobility of nodes to transmit messages. The second category is controlled movement model, where nodes may change their original routes to collect and deliver messages.

One of the best existing random movement schemes is Epidemic routing [12]. Assumption for this algorithm is nodes are all mobile and have infinite buffers. It is a flooding-based algorithm it means whenever a node has a message to send; it propagates the message to all nodes it meets and the nodes which receive continue to propagate the message. Sooner or later the data is delivered to the destination with a high probability[10]. This approach can achieve high delivery ratios, and operates without knowledge of the network topology or communication pattern. This approach provides optimal delay only when the traffic is low. It is well-suited for networks where the contacts between nodes are unpredictable. Animal tracking networks such as SWIN and ZebraNet uses random node mobility and flooding-based relaying [5]. Due to the considerable number of transmissions involved, these techniques suffer from high contention and may potentially lead to network congestion. To increase the network capacity, the spreading radius of a message is typically limited by imposing a maximum number of relay hops to each message, or even by limiting the total number of message copies present in the network at the same time [9]. When no relaying is further allowed, a node can only send the message directly to destination when in case met. One example of such scheme is Spray and Wait. This scheme consists of two phases: in the first phase it distributes a fixed number of copies to the first few relays encountered, and in the second phase each of these relays waits until it encounters the destination itself. Spray and wait yields lower delay and reduces number of transmissions than epidemic routing. This protocol gets into trouble when the nodes' mobility is restricted inside a local area. In Spray-and-Wait[8], relay carries its copy until it encounters the destination or until the TTL (time-to-live) for the packet expires. Problem with this scheme is relay with a copy will simply wait until it moves within range of the destination itself. With this problem in mind, another method Spray and Focus is designed. In this method second phase is "focus" phase rather than (Wait phase) waiting for the destination to be encountered, each relay can forward its copy to a more appropriate relay.

Message Ferrying [13] is a mobility-assisted proactive routing algorithm that incorporates message ferries that allow communication among disconnected nodes. Ferries travel in a specified route, collecting data from sources and delivering data to the appropriate destinations. These message ferries allow nodes to communicate when the network is disconnected and when nodes do not have global knowledge of the network. It is a proactive routing algorithm created to address network partitions in intermittently connected ad hoc networks by establishing non-randomness in node movement. There are two types of nodes in MF scheme: Message Ferries and regular nodes. This classification is based on their roles in communication. Ferries are mobile devices which take responsibility of carrying messages among other nodes, while regular nodes are devices without such responsibility. Several MF extensions could be carried out by installing multiple ferries[14] in a set of subregions through partitioning. This idea can be used in remote village communications and remote area connectivity projects for providing Internet access. MF scheme provides regular connectivity in a disconnected network and also improves data delivery performance without global knowledge of each node's location. The main difficulty in designing ferry routes for arbitrarily moving nodes is that we cannot correctly predict the location of the nodes, and hence it may not be possible to correctly position the ferry to contact the nodes for huge deployed area. In our work, we address the above issue with certain system requirements like message delivery latency and buffer space.

3. Network Model

In this paper, we focus on the application of Message Ferrying system in disconnected Mobile Ad hoc networks. Regular nodes are assumed to move within the deployed area and perform the assigned tasks. It has limited in resources such as battery power, memory and computational power. Regular nodes are geographically distributed such that most of the time they cannot directly communicate with one another. Such a scenario is common in remote village communications. Remote village communication means communication between disconnected villages. Ferries are special mobile nodes which have more resources than regular nodes. For example, buses shuttle between remote villages which are equipped with memory (i.e. hard disks) and wireless interfaces can act as Ferries to collect and carry data among disconnected areas. One or more message ferry periodically visits each cluster/village to collect/deliver messages between disconnected nodes. In remote village communication, meeting point is an important place in the village where most of the people meets often regularly like bus stand, market places etc. In the meeting point, the ferry has the longest contact time with the visited nodes for exchanging message. In the regular/ Ferry nodes messages will be dropped when buffer overflows or timeout expires. Timeout value depends on the delay requirement of the applications. Message ferrying is suitable for the application which can tolerate long delay like file transfer, email and other non-real time applications.

In this proposed system, deployed area is divided into number of clusters. This system uses multiple message ferries to make connectivity between nodes. Here two types of ferries are used: Global Message Ferry(GMF) and Local Message Ferry(LMF). For each cluster there will be one LMF and one Stationary Gateway node. Stationary Gateway nodes are deployed at important meeting points. Regular nodes can move anywhere in the deployed area. In each cluster, there may be one or more network partitions due to mobility of the nodes or sparsely populated nodes. For each partition, location of one regular node which has more number of neighbors will be elected as Way Point for that partition. This is selected only for finding the route of the LMF. LMF's route is defined each time they starts it trip. Route is calculated using Shortest Path algorithm (TSP algorithm) which should cover all the Way Points in that cluster. For Way Point selection, location of nodes is required. Location of the nodes is found using Global Positioning System. There is no restriction on the path length of LMF. One assumption is regular nodes move occasionally then only LMF makes connectivity with more number of nodes.

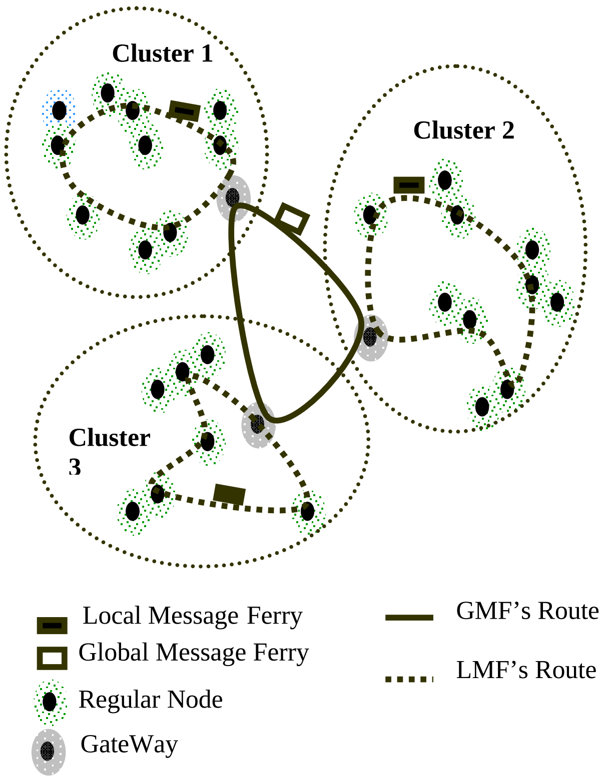

Figure.1 Routing in Clustered Ad hoc Network

GMF follows a fixed regular route and makes certain number of meeting points (where stationary Gateway nodes are present) in its route. LMF receives/deliver messages from/to Gateway/Regular nodes. There is no need for online collaboration between GMF, LMF and also with regular nodes.GMF carries messages between clusters. LMF carries messages between nodes within the cluster or exchange message with Gateway. Whenever source has a packet to send, it checks for a route to destination. If route found then deliver it, otherwise deliver the packet to LMF. LMF periodically checks any route to destination is found for the packet stored in its buffer. If LMF finds the route then it delivers the packet to destination otherwise exchanges message with the Gateway. Whenever connectivity occurs between GMF and Gateway then they exchanges the undelivered packets. Within each cluster, regular nodes use MANET protocol for traffic within the cluster (intra-cluster traffic). We choose AODV protocol because nodes are mobile and topology changes often. Minimal modification is required for MANET routing protocols used in clusters.

3.1 Pseudo code

3.1.1 Node operation

If node has a packet to send then perform the following:

1. If route to destination exists then deliver the packet to destination and remove this packet from its buffer
2. If route to LMF exists then Deliver the packet to LMF
   Else buffer the packet and wait for LMF's arrival

3.1.2 Local Message Ferry's Operation

1. LMF maintains list of nodes which are located in its cluster using GPS and update this information before calculating the route.
2. Before taking each trip, Way Points are selected for each partition in its cluster and route is calculated such that it covers all the Way Points.
3. If route exist for the buffered packet then deliver the packet and remove it from its buffer
   Else wait for connectivity with the Gateway
4. If LMF is within the range of Gateway then Exchange messages with the Gateway.

3.1.3 Global Message Ferry's Operation

1. If route exist for the buffered packet then
   i. Deliver the packet to destination
   ii. Remove the delivered packet from its buffer
2. Else if connectivity exists with the stationary Gateway and Destination node is present in the stationary Gateway's cluster then Deliver the packet to stationary Gateway.

3.1.4 Stationary Gateway's Operation

1. If route exists for the buffered packet then
   a. Deliver the packet to destination
   b. Remove the delivered packet from its buffer
2. Else if connectivity exists with the LMF and Destination node is present in its cluster then
   a. Deliver the packet to LMF
   b. Remove the packet from its buffer
3. else if connectivity exists with the GMF then exchange messages with the GMF.

3.1.5 Dynamic route calculation for LMF

1. **Find number of neighbor for each node in the cluster**

```
a. Let A be the set of nodes within the cluster
      A={ n1,n2,n3 ……nq}
b. For each node ni in A do
   Begin
      Initialize number of neighbor of ni to 0
            i.e.,  No-of-neighbor(ni)=0
      For each node nj ≠ni in A do
      Begin
         If nj is neighbor(ni) then
            no-of-neighbor(ni)=no-of-neighbor(ni)+1;
      End
   End
```

2. Find way points for route calculation

```
a. Mark all the nodes in A as unvisited node
b. Find highest neighbor node for each partition in the
   cluster
   Let B={ ϕ } be the set of highest neighbor nodes
   While( any unvisited node exists in A) do
    begin
      height-neighbor=0
      for each unvisited node ni in A do
      begin
        if no-of-neighbor(ni) >= highest-neighbor then
           highest-neighbor=no-of-neighbor(ni)
           Highest-neighbor-node=ni
      end
      B=B ∪ highest-neighbor-node
      Mark highest-neighbor-node and all its neighbor
      nodes as visited nodes
  end
```

3. Design a route which covers the location of all the nodes in the set B using Shortest Path algorithm(TSP algorithm)

4. Discussion

4.1 Performance Metrics

Data delivery rate, buffer space, node density and message delay metrics are considered for evaluating the performance. Data delivery rate is defined as the ratio of number of successfully delivered messages to the total number messages generated. The Average end-to-end delay is defined as the average delay time between the time a message is generated at the source and the time the message is received at the destination. These metrics reflect how efficiently the data is delivered. In epidemic routing, multiple copies may be delivered to the destination. Hence delay is computed based on the time the first copy is delivered.

4.2 Analysis of Performance

In this section, we analyse the performance of our protocol with epidemic routing protocol. We will discuss the performance metrics- delivery ratio and delay with number of hosts and buffer space for both the protocols.

Delivery Rate Vs Number of nodes: Assume buffer size is unconstrained. Message Ferry achieves an improvement in performance than that of epidemic routing protocol. Epidemic suffers from the inability to deliver messages to recipients that are in other disconnected cluster. In this protocol, message is propagated only to the accessible hosts until the TTL of the message expires. When TTL of the message expires message will be dropped. One reason for message dropping is that the recipient remains in the same disconnected cluster for long duration of time which is longer than TTL of the message. In our new scheme, message is carried by GMF and creates regular connectivity between clusters. Message delivery within each cluster is performed by LMF and Gateway. LMF creates connectivity between almost all the nodes in the cluster. This scheme does not require any online collaboration between regular nodes, GMF and LMF. This will increase the probability of delivering the packet.

Buffer size Vs Delivery Rate: When the buffer size is small, probability of message dropping will be high and number of messages exchanged also will be low. At the other end, as buffer size increases, number of message drop will be reduced due to overflow. This will improve delivery ratio. In general, as the buffer space increases, the data delivery ratio increases. On the other hand, with limited buffer space, new packets may replace the old undelivered one. This results in packet drops and low delivery ratio. Epidemic routing protocol propagates the packet to all the accessible hosts. All the hosts in the network required to exchange message for all the remaining nodes in the network. Hence all the nodes need more buffer space. If number of nodes is increased then nodes need to have more buffer space. In the new protocol, regular nodes deliver messages to destination/LMF and also receive messages, which are intended for it. Hence regular nodes do not require more buffer space and buffer space of regular nodes does not affect delivery rate. Gateway and LMF also does not require huge buffer space because it carries messages for the nodes which are located in its cluster. GMF carries messages between cluster hence it needs more buffer space than LMF. Hence nodes in the new scheme may require very small amount of buffer space than epidemic routing protocol.

No.of Nodes Vs Delivery delay: In epidemic routing protocol, number of nodes increases the connectivity between nodes and thus reduces the delay; this improvement is only up to certain limit because more number of nodes increases the congestion. If the destination is in the same cluster as the source or route exists between source and destination then the message is delivered more or less immediately in both the protocols. Consider the situation that the destination is in other cluster which is disconnected from the source cluster. In this situation whenever connectivity occurs due to mobility of the node before the lifetime of the packet expires is only delivered in epidemic routing protocol. If delivery is important than any other metric, node has to wait for connectivity. This increases delay time. But in the new scheme, Global Ferry makes connectivity between clusters periodically and also Local Ferry makes connectivity among disconnected nodes within the cluster. This will reduce delivery delay. If node has connectivity with the Gateway then the message is delivered quickly. If message is far away from the Gateway then the message is delivered to LMF and LMF deliver it to the destination whenever route to destination occurs.

Resource Utilisation: In Epidemic routing protocol, all the nodes in the network store and carry the message. Hence all the nodes need more resources. In our new scheme regular nodes does not carry the messages and thus needs less resources but GMF, LMF and Gateway nodes need to buffer the messages and thus needs more resources.

Computational Overhead: Epidemic routing protocol needs less computational power hence there is no special nodes in the network and also nodes just store-carry-and-forward the message. For providing better performance all the nodes in the network should implement a buffer allocation policy. Our new scheme uses number of special nodes called GMF, LMF and Gateway. Regular nodes do not provide any special function other than forwarding the message if route exists to destination. Hence regular nodes do not require any additional computation. GMF follows a fixed regular route and carry the message between disconnected partitions; hence it just implement a buffer allocation policy for better performance and does not require additional computational power for calculating the route. LMF dynamically calculates the route based on the current location of the nodes before starting each trip and also it carries the message to regular nodes; thus it needs more computational power than GMF. Gateway nodes just buffer and deliver the message; it does not require additional computational power.

4.3 Route Length and Contact Opportunities

Let G={ $G_1, G_2, \ldots G_k$} be the set of Gateways.

Let d_{ij} be the distance between Gateway G_i and G_j in meters.

Global Ferry visits all the Gateways in the network. Hence route length of the Global Ferry is sum of the distance between all the Gateways in its route.

i.e., Route Length of the Global Ferry =

$$\sum d_{ij} = d_{12} + d_{23} + d_{34} \ldots\ldots d_{k1}$$

Assume Speed of the Global Ferry is X meters/seconds and waiting time of Global Ferry at each gateway is Y seconds.

Time taken to complete each round of GMF =

$$t = \frac{\sum d_{ij}}{X} + (k * Y)$$

Once in the duration of t, the Global Ferry creates regular connectivity between partitioned clusters. Route length of Local Ferry varies depending on the location of nodes. Connectivity time between LMF and Gateway is not same always.

5. Conclusion

In this paper, we develop a technique which allows a message delivery in the situation where a connected path from source to destination never exists in mobile ad hoc networks. There are number of applications like disaster recovery scenarios, remote village communications where nodes are disconnected. Existing ad hoc routing protocols unable to deliver packets in the presence of a network partition between source and destination since they are robust to rapidly changing network topology. For delivering packets in such scenarios, numbers of protocols were developed such as Epidemic routing protocol, Message ferrying protocol etc. Epidemic routing protocol delivers a packet only when connectivity occurs between destination node and any one of the node which carries the source packet. Message Ferry needs more buffer space to carry the messages between nodes. If Message Ferry needs to cover huge area and nodes are mobile then probability of delivering the packet is less and also takes more time to deliver the packets. To increase the above metrics more number of ferries can be used.

The goal of the new scheme is to maximize message delivery rate and to minimize message latency while also minimizing the total resources (e.g., memory and network bandwidth) consumed and also remove online collaboration between communication entities in the network. In this scheme, nodes are grouped into clusters to reduce communication overhead. To reduce the communication delay, Local ferries are employed in each cluster to deliver messages within the cluster. Using GPS, node locations are identified and the location information is used for selecting WayPoints and LMF's route is calculated to connect all the Way Points to improve the delivery rate. In this work, we take packet delivery ratio, end-to-end delay and computational overhead to analyze the performance of a routing protocol. The discussion shows that the performance of a routing protocol varies depending on node density and buffer space used. We observe that this new scheme produces highest throughput than Epidemic Routing protocol and also with single Ferry in long lived disconnected partitioned networks. Both schemes produce the same result when the network is connected or disconnected partitions with very less disconnection time. Future enhancement is to employ efficient buffer allocation scheme for Ferries and also to investigate the impact of having different classes of traffic.

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