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Application of Graph Theory in DTN Routing

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Abstract: ***Delay tolerant network is proposed as a solution for Interplanetary Networks to provide communication between base stations and the satellites. DTNs allow for information to be shared between nodes even in the presence of high delays, which are typical in spatial communications. Routing in delay tolerant networks is a challenging problem in networking research. The common issue of these environments consists in the absence of guarantees about the existence of continuous end-to-end paths between source and destination nodes. Several protocols have been developed to increase the success rate of message delivery, such as probability of meeting between nodes, packet replication and flooding. Important feature of these protocols is using local connection information to find the "best" path with high likelihood to deliver a message. From a global view, a general disconnected network can have many small clustered mobile nodes. Identifying relevant nodes to carry and deliver messages becomes important in order to reduce message delay and overhead ratio. The proposed method tackles this issue by utilizing articulation nodes among a local sub-graph formed by including all directly connected neighbors of two meeting nodes. Articulation nodes are the cut vertices of this local sub-graph, and their elimination will disconnect the connected subgraph. Packets will be stored in these nodes and forwarded when the connection is established. This process is repeated until messages reach their destinations. The experimental results show that the proposed algorithm performs better than related protocols in terms of delivery rate, overhead ratio and efficiency.***

Keywords: DTN, MANET, Routing Protocol, Connectivity

1. Introduction

Mobile network techniques allow users to communicate in situations that were not present in traditional wired Internet. Networking opportunities extend to scenarios where connections to other nodes are intermittent. In addition, a mobile ad hoc network can turn to bearing such links when the number of nodes in the network becomes sparse. These connection disruptions create several disconnected partitions in the connected network, to other nodes or Internet are intermittent. Delay tolerant networking architecture has been analyzed connection disruptions create several disconnected partitions in the connected network. Thus, a hybrid network with DTN and MANET is required to assist message delivery. Many applications are developed on this hybrid network approach such as ocean sensor networks [1], and vehicular networks [2]. Conventional MANET routing protocols do not apply when the entire network is not fully connected. The main challenge of routing in the hybrid delay tolerant MANET is the uncertainty in the network conditions.

Researchers have proposed several approaches to find a best path to deliver the message with limited local information. Those approaches include estimating the probability of nodes meeting by using different mechanisms and packet replication. The probabilistic approach suffers from high failure rate of delivering messages since it only keeps one copy of a message along the network, while packet replication suffers from high overhead of storing and forwarding multiple copies of messages. In this paper, we proposed a hybrid model of routing for delay tolerant networks.

Articulation nodes are the cut vertices of this local sub-graph, and by definition are the nodes, whose elimination will disconnect the graph. The cut nodes have higher probability to deliver the message outside the local sub-graph. Unlike the computation of cut vertices in graph theory, the articulation nodes are locally computed without the knowledge of the entire graph. When two nodes meet each other, sub graph is formed for their directly connected neighbors. They may not be actual cut vertices because their removal does not necessarily disconnect the whole graph, but instead their removal disconnects the local sub graph.

The major highlights of this paper are: (1) We proposed a new routing protocol combining the concept of store-carry-forward and articulation points of the local graph. (2) The proposed protocol requires relatively little overhead for computing and storing information: since each node only computes the connectivity of a local sub-graph and forwards packets to the nodes which are identified as “articulation nodes”. (3) Our protocol provides high message delivery ratio and less overhead.

2. Related Work

A. Routing Protocols: Routing in DTN has drawn a lot of interest because traditional routing protocols of MANETs cannot apply directly. It is observed that though a path from a source to a destination does not exist at the instantaneous moment, such a path may occur after some time. In DTNs, when a packet cannot be routed to its destination, it is not immediately dropped but is instead, stored and carried until a new route becomes available. Packets are removed from the buffer when their lifetime expires or for buffer management reasons.DTN routing protocols have targeted at many application scenarios. Among them, a few have utilized real world contact patterns. Here we briefly discuss routing protocols that are close to our approach.

The simplest DTN routing protocol is epidemic flooding [4]. The basic idea of this protocol consists in the continuous relying of the message to each node that has still not got a copy of message, with the aim that the message is surely delivered. The advantage of this protocol consists in its simple structure, which requires a simple network configuration. When a link between source and destination node is established, all messages are correctly delivered, without any configuration. The only disadvantage in real cases is that the protocol is not effective from the energy point of view. Several researchers tried to reduce the replicated packets along the network by using historic node meeting information [2, 5-7].

PROPHET, which was the first contact history based protocol, relies on self-defined delivery predictability metric. PROPHET [7] uses past node meeting information to compute the suitable relay nodes. Nodes that are encountered frequently have higher probability to meet again and older contacts degrade over time. Messages are only replicated when the probability exceeds certain threshold.

SimBet [8] is similar to our approach, it also uses neighbor information to construct local graph to calculate graph properties of the encounter events. SimBet uses social metrics, such as the node's number of links in the social graph or their centrality, to choose the next forwarding node. When two nodes meet, they compute the SimBetUtil scores, and the packet is forwarded to the node with higher score. Here, the social networking feature helps to identify nodes that are more capable in meeting other nodes for message delivery. A potential drawback could occur when stable social relationships (so stable encounter patterns) do not occur in a particular DTN application.

Spray and Wait [5] is a simple but effective protocol which decouples the number of generated copies of the message, so the number of transmissions to be performed. There are two phases: the spray phase (for each message generated from source node, L copies are forwarded to L distinct nodes) and wait phase (if destination node has not been identified in the spray phase, each of the L nodes perform. a direct transmission, i.e. forward message to its destination).

B. Related Graph Theory: DTN can be represented as an undirected graph in which nodes represent the mobile stations and edges represent the communication links between mobile stations. In this paper, we make use of the cut vertex concept from graph theory in order to find the appropriate nodes required to carry and deliver the messages. Articulation point or cut vertex is defined as: a vertex in the graph such that removal of that vertex disconnects a connected graph. The concept of cut vertex can be applied to both directed and undirected graphs.

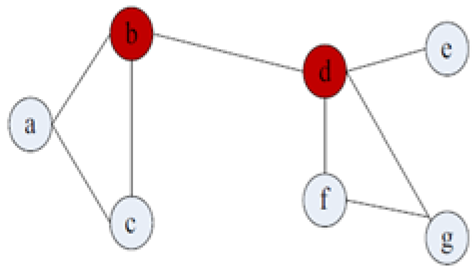

Figure 1: An undirected graph with two cut vertices b and d

The nodes b and d in Fig. 1 are the cut vertices of an undirected graph. The removal of either node b or d will disconnect the graph. However, knowledge of the whole graph is required to compute cut vertices. In DTN, we cannot depend on the knowledge of the global network. We modify this concept and propose cut nodes which are cut vertices of a local sub-graph.

C. Depth First Search: A depth-first search is an algorithm for traversing a finite graph. Depth-first search algorithm visits the child nodes before visiting the sibling nodes; that is, it traverses the depth of any particular path before exploring its breadth. The algorithm begins with a chosen "root" node; it then iteratively transitions from the current node to an adjacent, unvisited node, until it can no longer find an unexplored node to transition to from its current location. The algorithm then retracts along previously visited nodes, until it finds a node connected to yet more unexplored section. It will then proceed down the new path as it had before, backtracking as it encounters dead-ends, and ending only when the algorithm has backtracked past the original "root" node from the very first step. DFS is the basis for many graph-related algorithms, including topological sorts and planarity testing.

3. The Proposed Method

A. Articulation Node Computation: In many applications involving communication or transportation networks, it is necessary to identify points through which all network traffic must flow. A vertex in an undirected graph is an articulation point if removing it disconnects the graph. Articulation points represent susceptibility in a connected network – single points whose failure would split the network into 2 or more disconnected components. Cut vertices are useful for designing reliable networks. For an undirected graph, an articulation point is a vertex removing which increases number of connected components.

When two nodes meet each other, they will exchange a list of their directly connected neighbors along with any known connections among those neighbors. Thus, they can construct a connected sub-graph G' (V', E') where V' is the vertex set which includes the two nodes and all nodes with direct connection to them and E' is an undirected edge set which represents the known connections among those nodes. We then compute the cut vertices of G' by using depth first search algorithm.

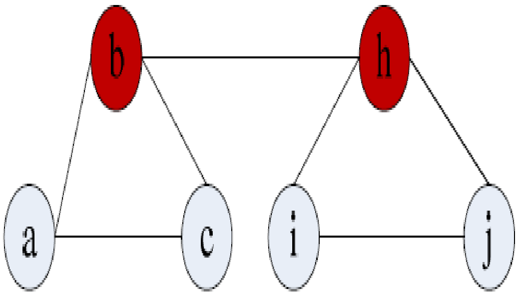

Figure 2: A local graph G' is constructed when node band h meet

Testing for articulation points by brute force is easy. Temporarily delete each vertex u, and then do a DFS traversal of the remaining graph to verify whether it is still connected. The time complexity of this method is O [V (E + V)]. There is a clever linear-time algorithm, however, that tests all the vertices of a connected graph using a single depth-first search. The algorithm utilizes the properties of the DFS tree. In a DFS tree, a vertex x is parent of another vertex y if y is discovered by x. A vertex x is articulation point if one of the following two conditions is true:

- x is the root of the DFS tree and has at least two children.
- x is not the root and no vertex in the sub tree rooted at one of the children of x has a back edge to an ancestor of x.

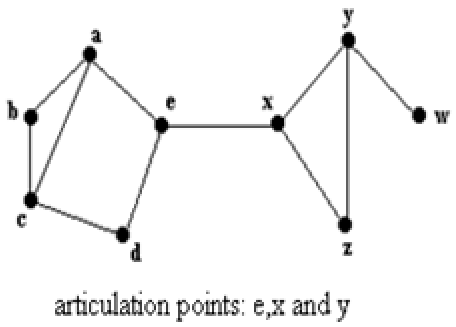

Figure 3: Articulation points

B. The Protocol: Every node in the network has a message vector, neighbor vector and cut vector. The definitions of these vectors are described as follow:

Message Vector: This vector stores messages which need to be forwarded. When the vector overflows, the oldest message will be replaced by newest message.

Neighbor Vector: This vector stores directly connected neighbors along with their neighbors.

Cut Vector: This vector stores all the cut nodes the node has met.

In the proposed method, when a node wants to send a message to a destination node, it will check if the destination node is in its neighbor vector, if so it will deliver the message to the destination node directly. Otherwise, it will store a copy of the message in its message vector and forward the message to all of its directly connected cut points. These cut nodes will then attempt to deliver the message in the same manner as the source node.

Algorithm describes the communication between nodes p and q when they met each other. When node q receives a hello message from node p, it will look in its neighbor vector to determine if p is a new neighbor. If it is the case, it will also search the destinations of the messages in its message vector, and any message with destination p is delivered. At this point, node q also asks node p for its neighbor vector. Node p will send the neighbor vector back to node q.

Algorithm. Pseudo-code of node q
upon receive Hello message from node p do if newNeighbor(p) == true if messageVector.containDestinationOf (p) == true deliverMessages(p) requestNeighbor (p)
upon receive neighbor vector qv from node p do updateNeighbor() calculateCutVertex(bv) propogateCutNodes() if isCutNode(q) == true || isCutNodeNeighbor (q) ==true requestMessage (p)
upon receive message vector pv from node p do updateMessageVector (pv) confirmReceiving()

Node q will construct a local sub-graph after receiving the neighbor vector. Then it will compute the cut vertices of this local graph. If node q is a cut node, node p will forward all current messages it carries to node q. Node q then becomes a carrier of those messages and vice versa. If neither node is a cut node, then messages will be forwarded from q to any neighbor of p that is not a neighbor of p and is a cut node. If none of the cases exists, then both nodes will keep the message.

4. Experimental Results

We have implemented ANBR Protocol and also the Epidemic flooding protocol using ONE (Opportunistic Network Emulator) simulator. ONE simulator allows users to create scenarios based on different movement models and real-world traces and offers a framework for implementing routing and application protocols. The GUI of ONE simulator is good for getting an intuitive overall picture of what is happening during the simulation, more rigorous ways to visualize node relations, message paths and performance summaries are provided by post processed report files.

ANBR Protocol & Epidemic flooding protocol are simulated and reports are generated which are shown in Fig.4 and Fig.5.simulation has been repeated for various buffer sizes. The focus of the simulator is on modeling the behavior of store-carry-forward networking, and hence we deliberately refrain from detailed modeling of the lower layer mechanisms such as signal attenuation and congestion of the physical medium. Instead, the radio link is abstracted to a communication range and bit-rate. These are statically configured and typically assumed to remain constant over the simulation. However, the context awareness and dynamic link configuration mechanisms can be used to adjust both range and bit rate depending on the surroundings and the distance between peers.

```
Message stats for scenario ANBR NewReport
sim_time: 31000
created: 1025
started: 8123
relayed: 7763
aborted: 122
dropped: 6994
removed: 0
delivered:300
delivery_prob: 0.2929
response_prob: 0.0000
overhead_ratio: 24.96
latency_avg: 3454.5342
latency_med: 2815.2018
hopcount_avg: 1.8987
hopcount_med: 1
buffertime_avg: 2101.6215
buffertime_med: 2100
```

Figure 4: Snapshot of ANBR Report

The performance metrics chosen for comparison are delivery probability, overhead ratio and hop count average etc. Delivery probability is defined as the ratio between the number of messages delivered to the destination and the total number of messages generated at the source. Its value ranges between 0 and 1. If all the messages are successfully delivered to their corresponding destinations, then the delivery probability is 1. So, delivery probability is an important metric to compare the routing protocols for Delay Tolerant Networks. Overhead ratio is required for proper buffer management.

```
Message stats for scenario EpidemicReport
sim_time: 30000
created: 1015
started: 310862
relayed: 306380
aborted: 4450
dropped: 296550
removed: 0
delivered: 280
delivery_prob: 0.2758
response_prob: 0.0000
overhead_ratio: 637.2917
latency_avg: 4643.8248
latency_med: 4127.2000
hopcount_avg: 9.5146
hopcount_med: 8
buffertime_avg: 907.5372
buffertime_med: 659.2000
```

Figure 5: Snapshot for Epidemic Router Report

A. Message delivery statistics: Fig.6 shows the comparison between Epidemic routing and ANBR protocols in terms of message delivery probability. The Epidemic Routing Protocol suffers from buffer overflow problem when the buffer size is less. But, our proposed routing algorithm delivers more number of messages than Epidemic Flooding, when the buffer size is less. .The message delivery probability increases with increase in buffer size. Epidemic Router forwards messages to all the nodes which are connected to it, the message buffers in receiving nodes may run out of their capacity and hence leads to the message dropping and finally it affects the delivery probability of the Epidemic Router.

B. Message Overhead Ratio: This metric is used to estimate the extra number of packets needed by the routing protocol to deliver the data packets. Overhead ratio is the perfect parameter for buffer management. It is defined as (Number of Packets Relayed - Number of Packets Delivered) / (Number of Packets Delivered). Epidemic routing creates replicas of messages for each time it forwards to the connected neighbors. So, Epidemic routing puts lot of overhead on the network by the creation of large number of duplicate copies. But, our proposed algorithm forwards messages only to the articulation nodes. So, the overhead ratio is very less compared to Epidemic algorithm. The statistics are shown in the Fig. 7. It is observed that the overhead ratio increases with the increase in buffer size as it prevents some of the messages to be dropped due to insufficient buffer space and hence increases the overhead ratio of the traffic.

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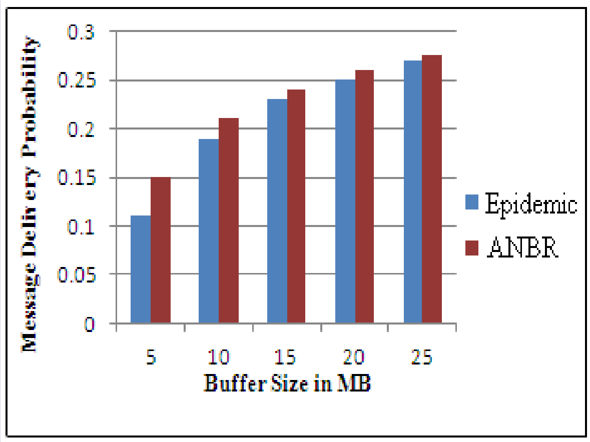

Figure 6: Message delivery statistics

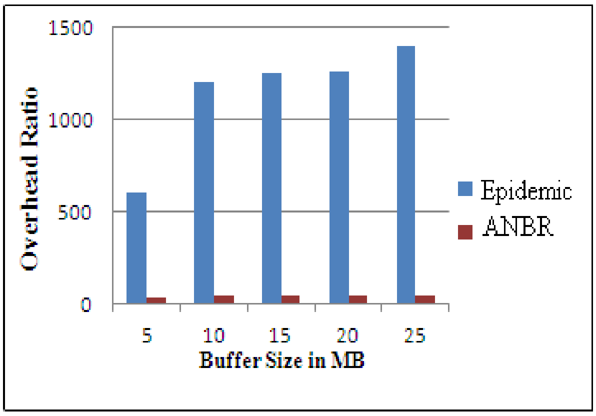

Figure 7: Statistics for Message Overhead Ratio

5. Conclusion

In this paper, we proposed an algorithm which utilizes graph theory to solve the routing problem in DTNs. In our algorithm, when two nodes meet each other, they will exchange their neighbor information and construct a local sub-graph to identify articulation points. We named these points as articulation or Cut Nodes. These nodes have high probability to deliver messages outside the local cluster and have high probability to forward messages to their destination. We simulated our algorithm using ONE simulator for various buffer limits and compared with Epidemic flooding algorithm. Simulation results show that ANBR protocol gives better performance over epidemic flooding in several aspects.

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