The University of Alabama

Delay Tolerant Network (DTN) Protocol Implementation

Fall 2011 CS613 Course Project

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1 – Introduction

In this project, we wanted to see some of the Delay Tolerant Network (DTN) routing protocols at work. DTN is different than traditional networks. Routing in a DTN is currently based on store and forward routing algorithms. Each node in the DTN is both responsible for forwarding the received packet to the next hop and if no other hops are active, it has to store that packet for future forwarding. For implementation purposes we have used a server oracle and implemented three different routing algorithms for DTN.

Server Oracle

We have used server oracle to simulate the mobility requirement of the DTN. DTN nodes are generally mobile nodes that is rarely connecting to the whole network structure. The bus example[1] is a perfect example with mobility pattern.

In our oracle, each node in DTN is designed as a client in a client-server architecture. Each node connects to the server at beginning and stay connected during the lifetime of the DTN. Server is responsible for managing link information, adding new links to DTN and removing links from it.

We also added some more functionalities to the server to track the DTN more effectively. Other functionalities are:

- Viewing the current link structure of the DTN visually.
- Activate/deactivate/delete link information.
- Logging messages sent and received by nodes
- Showing the statuses of each message and the history path visually.
- Modifying the configurations like TTL and the routing algorithm.
- Generating a random network by adding some links automatically.

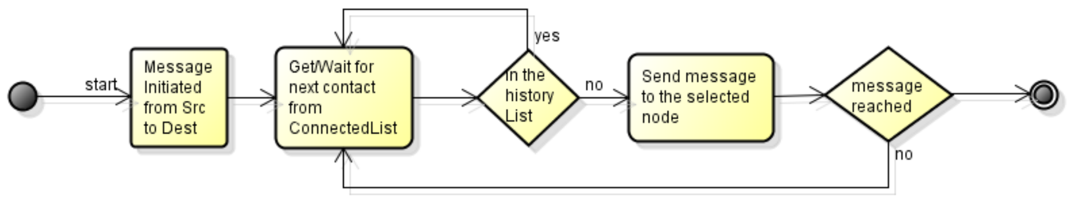
Routing Algorithms

We implemented two routing algorithms. One is First Contact[2] (FC). We designed two variations of FC. First one is with history and the other one is without history. The second algorithm we implemented is Epidemic[3].

First Contact

A contact is a chance to send data to another node along the time they are connected. First contact (FC) algorithm is based on sending the received/buffered message to the first node that is connected. For the implementation purposes, we have created two variants of FC.

1. First Contact with History: When a message is sent from source to destination, it will follow a path according to the first contact. Each message consists of a text and a history of the nodes it already passed. This algorithm routes the message to the next hop if the next hop is not already in the history list of the message. The flowchart of the algorithm is in Figure 1.



start
Message Initiated from Src to Dest
Get/Wait for next contact from ConnectedList
yes
In the history List
no
Send message to the selected node
message reached
no

Figure 1: Flowchart of First Contact with History

2. First Contact without History: The only difference of this algorithm with the first one is not taking the history of the message into account. It randomly chooses the next hop among the connected nodes and forwards the message to it. The flowchart is in Figure 2.

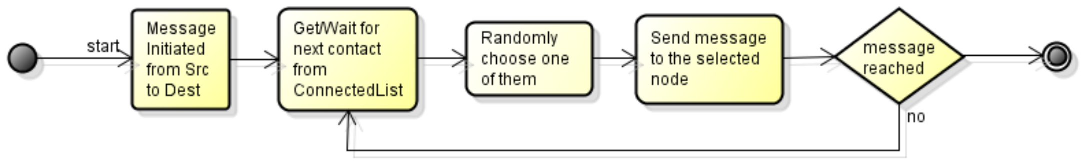

start
Message Initiated from Src to Dest
Get/Wait for next contact from ConnectedList
Randomly choose one of them
Send message to the selected node
message reached
no

Figure 2: Flowchart of First Contact without History

Epidemic

Epidemic algorithm is like a brute-force mechanism. It forwards the message to all of the nodes that it is connected. Since all nodes will have the copy of the message, the success of message delivery is guaranteed if there will eventually be a connection to the destination. The flowchart is in Figure 3.

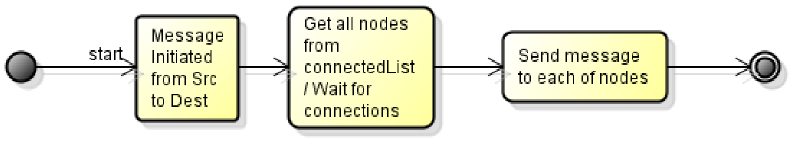
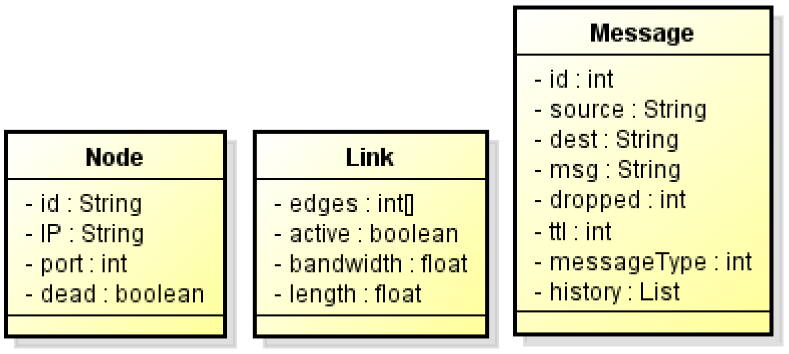

start
Message Initiated from Src to Dest
Get all nodes from connectedList / Wait for connections
Send message to each of nodes

Figure 3: Flowchart of Epidemic

2 – Implementation Details

Data Structures

The following data structures are used in our implementation.



Server

Server is a web server on Tomcat application[7] written in Java programming language. It has the capacity to store the list of all nodes, list of all links and list of all messages. Server also has the configurations of TTL and current algorithm type of the system.

API

The clients are communicating with the server via a servlet. The servlet has the following interfaces available to the clients.

ATTACH		
URL	<server IP>/dtn.serv	
Parameters	*type*	attach
	nodeId	
	IP	
	port	
Purpose	Introducing the node to the server	

When	Called when the client is connected to the server at the beginning of the client	
Execution	The node is added to the node list in the server.	
Output	None	
Consequences	All other connected nodes are notified about this new node.	

DETACH		
URL	<server IP>/dtn.serv	
Parameters	*type*	detach
	nodeId	
Purpose	Removing the node to the server	
When	Called when the client is closed	
Execution	The node is flagged as dead.	
Output	None	
Consequences	*All other connected nodes are notified about this new detaching. *The links of this node is set as inactive from that time (and can't be activated after that point). *Any messages in messageList that has that node as destination will be flagged as DEST_DETACHED.	

GETNODELIST		
URL	<server IP>/dtn.serv	
Parameters	*type*	getNodeList
Purpose	Getting the list of all nodes in DTN	
When	Called by each node when they started.	
Execution	All nodes in the nodeList is traversed and the id's are concantenated by a pipeline (|) sign if they aren't dead.	
Output	*id1|id2|id3|.....|idn*	
Consequences	None	

GETCONNECTEDNODELIST		
URL	<server IP>/dtn.serv	
Parameters	*type*	getConnectedNodeList
	nodeId	
Purpose	Getting the list of all nodes that is connected to the node in the parameter	
When	Called by each node while they are sending/forwarding a message	
Execution	All nodes in the nodeList is traversed and the id's that are connected to that node are concantenated by a pipeline (|) sign if they aren't dead.	
Output	*id1|id2|id3|.....|idx* *ERROR* if no connected node is found	
Consequences	None	

GETNODEINFO		
URL	<server IP>/dtn.serv	
Parameters	*type*	getNodeInfo
	nodeId	
Purpose	Get the IP and port information of a single node	
When	Called by each node to send a message to the node in the parameter	
Execution	The node is checked from nodeList and IP and port information is concantenated by a colon (:) sign.	
Output	*IPx:portx*	
Consequences	None	

LOG		
URL	<server IP>/dtn.serv	
Parameters	*type*	log

	msg	
Purpose	Send a message structure to server to log	
When	Called by each node while sending/forwarding a message or saving the message to the buffer	
Execution	The message is added to messageList if it doesn't already exist. If it exists, the historyList of the incoming message is appended to the existing one	
Output	None	
Consequences	None	

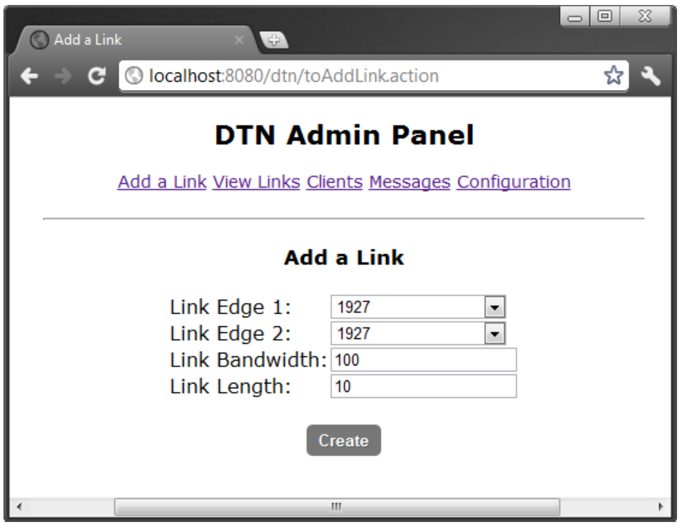
GETPROTOCOL		
URL	<server IP>/dtn.serv	
Parameters	*type*	getProtocol
Purpose	Get the protocol information from server	
When	Called by each node when they started	
Execution	Returns the existing algorithm information	
Output	*1* if algorithm is First Contact (with History) *2* if algorithm is First Contact (without History) *3* if algorithm is Epidemic	
Consequences	None	

GETTTL		
URL	<server IP>/dtn.serv	
Parameters	*type*	getTTL
Purpose	Get the TTL information from server	
When	Called by each node when they started	
Execution	Returns the existing TTL information	
Output	*ttl*	
Consequences	None	

Admin Interface of Server

Server has an admin panel which is accessible via web browser. Struts technology[6] is used in the admin panel. Struts lets developers easily maintain active web pages. Behind web pages, there is Java technology and in front Jsp is used to view web pages.

User can add/remove links from DTN. A screenshot of this page is in Figure 4. A self link can't be added.


Add a Link
localhost:8080/dtn/toAddLink.action
Add a Link View Links Clients Messages Configuration
Create

DTN Admin Panel

Add a Link

Link Edge 1:	1927
Link Edge 2:	1927
Link Bandwidth:	100
Link Length:	10

Figure 4: Admin Panel > Add Link Page

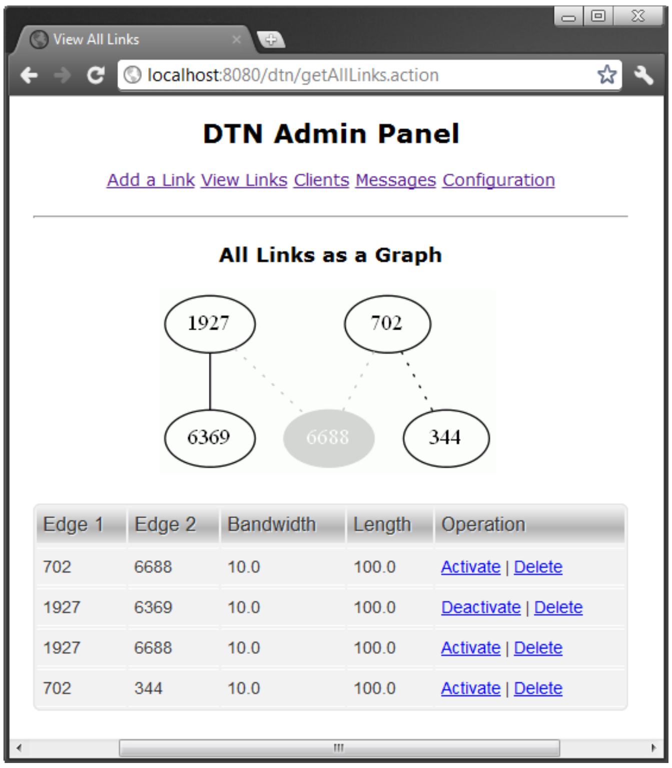
The current link information of DTN can be viewed from the panel. While drawing the current link structure of the network, we used DOT[4] graph language. DOT is a really simple graph language that is used to represent graphs as text. Figure 5 shows a simple graph written in DOT language with 4 nodes (A,B,C,D) and 5 links between these nodes (A-B, A-C, A-D, B-C, D-C).

```
graph G {
        A
        B
        C
        D
        A -- B
        A -- C
        A -- D
        B -- C
        D -- C
}
```

Figure 5: Sample DOT Graph

After the link structure is represented as DOT language, it is compiled by Graphviz[5] program and the picture is generated.

The link viewing page in admin panel consists of an image of links and also a list of all links and operation information. The current operations are activate/deactivate and deleting links. A screenshot of this page is in Figure 6.


View All Links
localhost:8080/dtn/getAllLinks.action
Add a Link View Links Clients Messages Configuration
1927
702
6369
6688
344

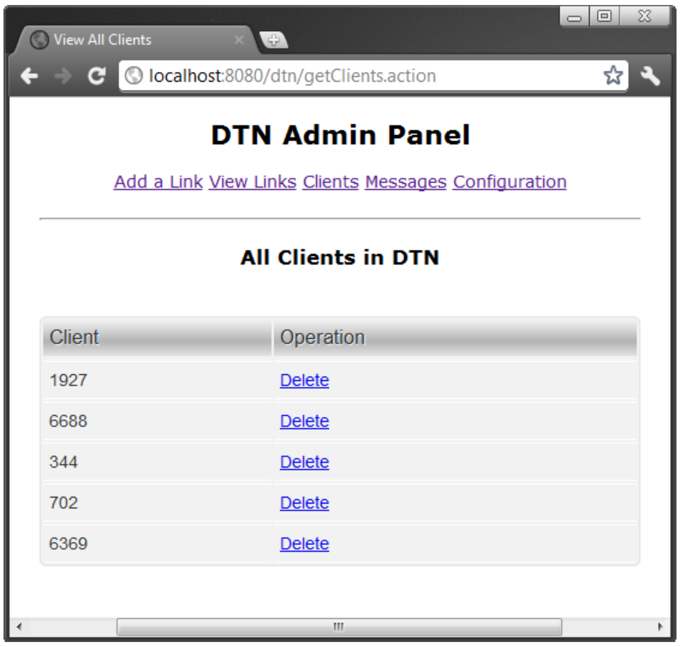
DTN Admin Panel

All Links as a Graph

Edge 1	Edge 2	Bandwidth	Length	Operation
702	6688	10.0	100.0	Activate | Delete
1927	6369	10.0	100.0	Deactivate | Delete
1927	6688	10.0	100.0	Activate | Delete
702	344	10.0	100.0	Activate | Delete

Figure 6: Admin Panel > View Links Page

User can also view the current links in the DTN. This page is shown in Figure 7 and has delete operation for the clients. When client is deleted from the system, it is not removed totally. It is lazy-deleted and flagged as deleted. We are using lazy-deletion method, because we use this feature while showing the message details (path history).


View All Clients
localhost:8080/dtn/getClients.action
DTN Admin Panel
Add a Link View Links Clients Messages Configuration

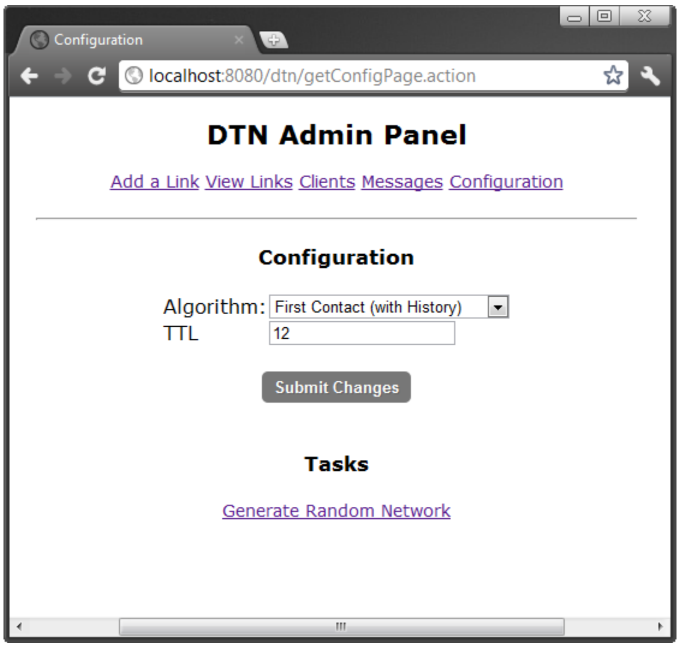
All Clients in DTN

Client	Operation
1927	Delete
6688	Delete
344	Delete
702	Delete
6369	Delete

Figure 7: Admin Panel > View Clients Page

The configuration page is used for modifying the current variables in DTN. We have two variables for now. First one is the algorithm type which is mentioned earlier. Second one is TimeToLive (TTL) value for messages in DTN. TTL is used for preventing the messages to be forwarded forever in the network. After TTL amount of forwarding, the message will not be forwarded any more.

Configuration page has also a link for random generation of networks. When this link is clicked, the server randomly adds a specific number of links to the system. A screnshot of the configuration page is in Figure 8.


Configuration
localhost:8080/dtn/getConfigPage.action
DTN Admin Panel
Add a Link View Links Clients Messages Configuration

Configuration

Algorithm: First Contact (with History)
TTL 12

Submit Changes
Tasks
Generate Random Network

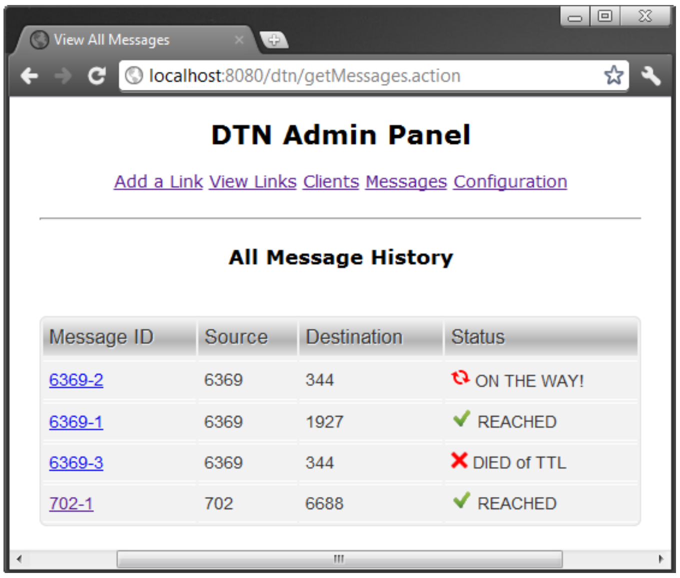
Figure 8: Admin Panel > Configuration Page

When a variable is modified in the configuration page, this change will automatically be broadcasted to all connected nodes in DTN.

Server has also a messages page, where we can see all the messages and their statuses in the network. A message may be in one of the following status:

- Died of TTL: The message is died because TTL is not enough for the message to reach to destination.
- On the way: The message is buffered in one (or more) of the nodes and will be forwarded again if any other links is available.
- Reached: The message succesfully reached to destination.

A screenshot from the message history page is in Figure 9.



DTN Admin Panel

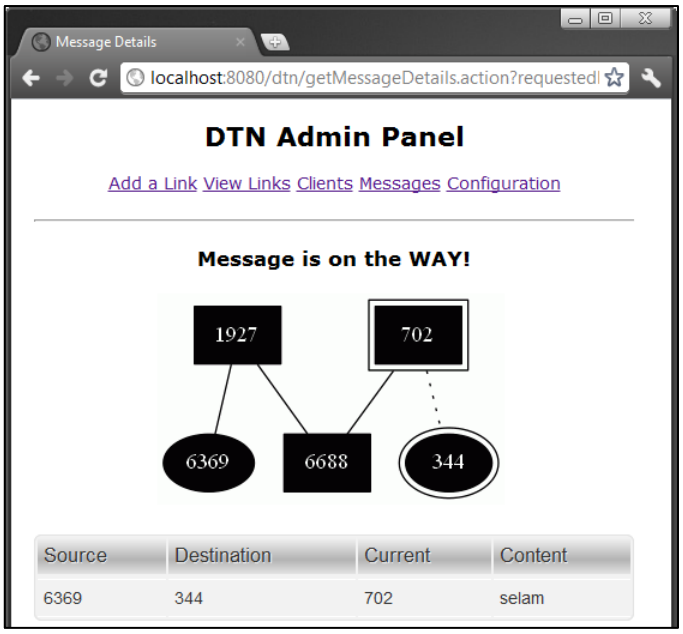
Add a Link View Links Clients Messages Configuration

All Message History

Message ID	Source	Destination	Status
6369-2	6369	344	ON THE WAY!
6369-1	6369	1927	✓ REACHED
6369-3	6369	344	✗ DIED of TTL
702-1	702	6688	✓ REACHED

Figure 9: Admin Panel > View Messages Page

Each message can be tracked from this page. We can also show the details of the message like which nodes it passed while going to destination, what is the source and destination and the current node. In epidemic algorithm, the message is buffered in more than one nodes but DTN will again show one node has it as current. The message details page is in Figure 10.



DTN Admin Panel

Add a Link View Links Clients Messages Configuration

Message is on the WAY!

Source	Destination	Current	Content
6369	344	702	selam

Figure 10: Admin Panel > Message Details Page

Shape Legend in Views

In both link viewing and message detail viewing, the following legend is used.

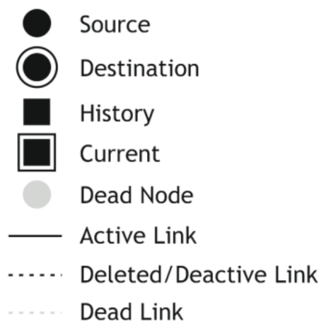
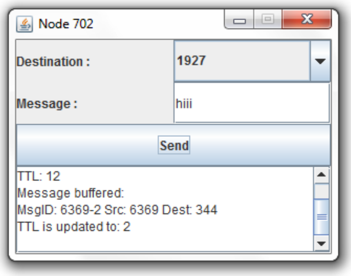


Figure 11: Legend

Client (Nodes)

The nodes are simple Java programs with a graphical user interface (GUI). At the beginning of the nodes, the node is asking for the server connection information. The node will try to connect and attach itself to the network. Then, it will receive all node list from the server. After that, a GUI like in Figure 12 will be shown to the user.



```
TTL: 12
Message buffered:
MsgID: 6369-2 Src: 6369 Dest: 344
TTL is updated to: 2
```

Figure 12: The GUI for Client

GUI has a destination field, which is updated automatically by the server when a new node is connected to the network, a message field and a log area. Log area is used for logging all events that happened in the node. The events are:

- Node attach.
- TTL and algorithms updates.
- Message send and buffer.
- Received message.

Each client has a message buffer. This buffer is used for storing purposes. If no links are available to forward the message, the message is stored here. Each client is also storing a variable for current algorithm and current TTL. At start, client makes api calls and get these variables from server.

Node Communication

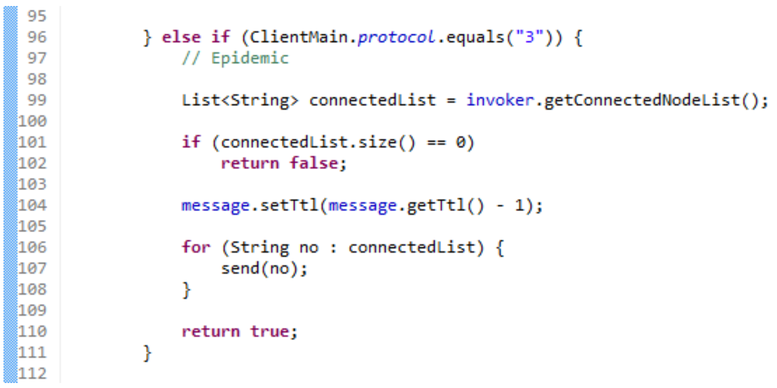
The nodes are communicating with eachother via UDP connection. Each node is opening a UDP socket and listening that socket for incoming messages as a seperate thread. This thread accepts messages from other nodes and also from server. The accepted message types are:

- Normal Message: A message from another node.
- Notify About New Link: A message received from server that a new link is created. After this message is received, message buffer is checked if any of the messages can be forwarded through that link.

- Node Joined: A message received from server that a new node is joined to the network. After this message, node makes an api call to `getNodeList` and updates the destination field.
- Algorithm Change: A message received from server that the algorithm is changed from configuration page of admin panel. The node makes an api call to `getProtocol` and updates the current algorithm.
- TTL Change: A message received from server that the TTL variable is changed from configuration page of admin panel. The node makes an api call to `getTTL` and updates the current TTL.

Routing

The routing is done in the `route` function of `MessageSender` class of Client codes. The epidemic algorithm routing code is shown below in Figure 13.



```
 95
 96         } else if (ClientMain.protocol.equals("3")) {
 97             // Epidemic
 98
 99             List<String> connectedList = invoker.getConnectedNodeList();
100
101             if (connectedList.size() == 0)
102                 return false;
103
104             message.setTtl(message.getTtl() - 1);
105
106             for (String no : connectedList) {
107                 send(no);
108             }
109
110             return true;
111         }
112
```

Figure 13: Code Fragment for Epidemic

In the 99th line, we are receiving the list of nodes that is connected to current node. If there are no connected nodes, we are returning false. That will put the current message to the buffer. If there are connected nodes, then we will decrease TTL of the message by one and we are sending the message to each of the connected nodes.

Unique Message IDs

Each message has a unique ID. An internal counter is maintained by the nodes and this counter is incremented by one at each message sending. Unique ID is generated by appending the node ID and the value of the internal counter together.

3 – Conclusion

DTN routing is always a challenging issue since the partial connected structure of the network. In this project, we have implemented and run some scenarios on the DTN. The content of these scenarios and consequences are added in Appendix A. Only some edge scenarios are selected.

One can implement more routing algorithms by adding the implementation to the `route` function described in Figure 13. Also some more additions must be done in the admin panel configuration page (Figure 8).

Also the operation manual is added in Appendix B for future usage purposes of the project.

4 – References

[1]: Utku G Acer; Paolo Giaccone ; David Hay; Giovanni Neglia; Timely Data Delivery in a Realistic Bus Network, Saed Tarapiah

[2]: S. Jain, K. Fall, R. Patra, Routing in a Delay Tolerant Network, SIGCOMM, Aug/Sep 2004

[3]: Amin Vahdat and David Becker. Epidemic routing for partially connected ad hoc networks. Technical Report CS-2000-06, Department of Computer Science, Duke University, April 2000

[4]: http://www.graphviz.org/doc/info/lang.html

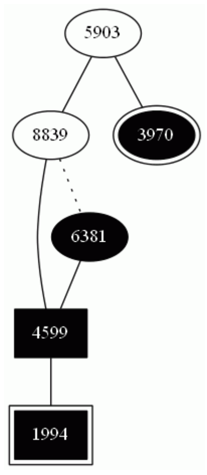
[5]: http://www.graphviz.org

[6]: http://struts.apache.org/2.x/

[7]: http://tomcat.apache.org

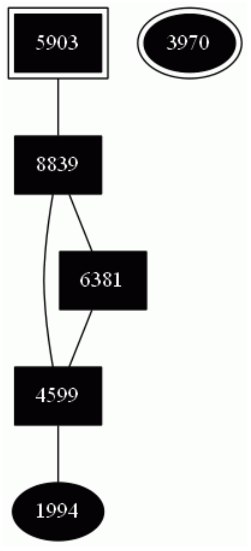
Appendix A – Scenarios

Scenario 1



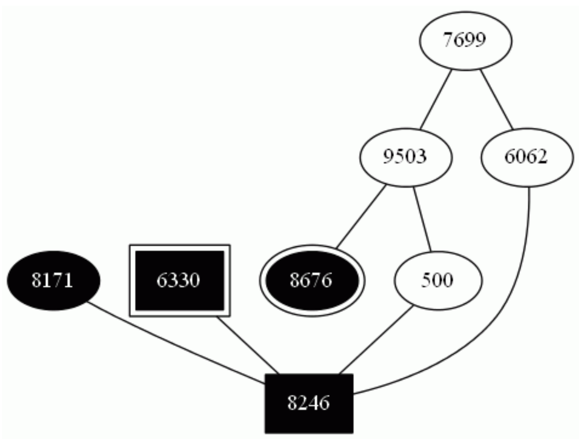
Algorithm: First Contact with History
TTL: 12
Source: 6381
Destination: 3970
Consequences: The message started its journey from source node which is 6381. It chose the only available node (4599). After that, 4599 forwarded the message to 1994. Now the message stuck in 1994 until another new link will be available. It can't go back, because 4599 is already in the history list.

Scenario 2



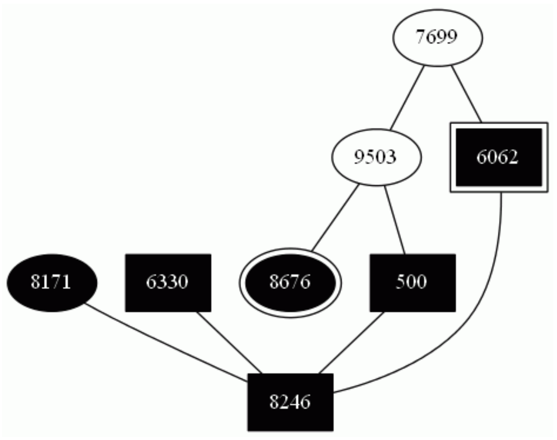
Algorithm: Epidemic
TTL: 12
Source: 1994
Destination: 3970
Consequences: The message started its journey from source node which is 1994. Since the algorithm is epidemic, now the message is broadcasted to all connected nodes in all stations. But it is still stuck in 5903. Because there is no connection to the destination. In this case, the message is buffered in all of the nodes, until a link is created between one of them and the destination (3970).

Scenario 3



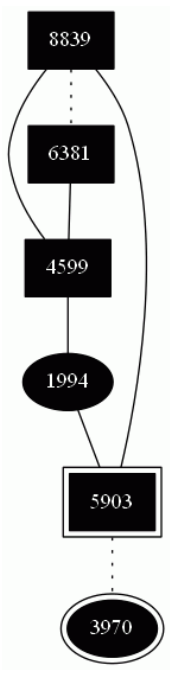
Algorithm: First Contact without History
TTL: 3
Source: 8171
Destination: 8676
Consequences: The message started its journey from source node which is 8171. It is forwarded and not it is on 6330. But 6330 will not forward the message once again, since TTL of the message is reached to 0 and the message died in the network. The message traversed 3 nodes (including source)

Scenario 4



Algorithm: First Contact without History
TTL: 7
Source: 8171
Destination: 8676
Consequences: The message started its journey from source node which is 8171. This case is the same as scenario 3 but this time TTL is 7. But the message tracked a path that it used all TTL until reached to destination and died. The path of the message is 8171→8246→6330→8246→500→8246→6062.

Scenario 5



Algorithm: First Contact without History
TTL: 20
Source: 1994
Destination: 3970
Consequences: The message started its journey from source node which is 1994. First Contact without History algorithm has a flaw. Since it will not keep the history of the previous path, if there is no connection to the destination, the message will bounce between the connected nodes until TTL is finished. That will cause the message die unnecessarily. In the figure above, the message is died even though TTL is very big, but the connection to destination is deactive.

Appendix B – Operation Manual

In order to run the DTN, we need the following programs installed with correct versions and correct places.

- Apache Tomcat 5.5.34 (core)
    - http://tomcat.apache.org/download-55.cgi
- Graphviz 2.28.0
    - http://www.graphviz.org/pub/graphviz/stable/windows/graphviz-2.28.0.msi
- Java Runtime Environment (Version > 1.5)
- WAR file of DTN Project
    - dtn.war (which is sent with this report)
- Node GUI Application
    - client.jar (which is sent with this report)

The folder structure must be in this order:

```
+ apache-tomcat-5.5.34
        +bin
                + Graphviz2.28
                …
        …
        +webapps
                +dtn
                …
```

We can install Graphviz to the folder under `apache-tomcat-5.5.34/bin`. For satisfying dtn folder, we will use the admin panel of Tomcat. After extracting Tomcat to disk, we can change port of Tomcat if we want (Google will help). Then we have to execute `bin/startup.bat` to start Tomcat.

The startup must be quick. After that, we can go to a browser and open `http://localhost:8080` for the admin panel of Tomcat. From the admin panel, we can deploy our dtn application (Google will help while deploying).

After deploy, now our program is ready to run. Just point `http://localhost:8080/dtn` from a web browser and we can see the admin panel.

The server is up and running now. We can run some clients, point the server's IP and port information and if they are correct, client will join to the DTN.