A HIERARCHICAL ROUTING TREE TOPOLOGY BASED ON PROBABILISTIC SELECTION OF CLUSTER HEAD AND SUPER CLUSTER HEAD TO OVERCOME INTER-CLUSTER AND INTRA-CLUSTER ROUTING PROBLEMS IN DTN NETWORKS

EL MASTAPHA SAMMOU
Cadi Ayyad University, Faculty of Science and Technology, Department of Computer Science, Marrakesh, Morocco
Email: sammou.elmastapha@yahoo.fr

ABSTRACT

DTN networks are environments that are characterized by a dynamic topology and which can change randomly and unpredictably due to high node mobility, frequent node disconnections, low node density and energy failures. All these factors create a set of routing problems namely: a very long delivery delay, a very low delivery rate and a significant increase in the resources consumed in the network. With all these problems, the hierarchical topologies proposed by the researchers are ineffective in terms of coordinating communications and data exchanges between the nodes of the different network clusters and are characterized by the absence of any kind of forecast against the premature death of cluster-Heads (CHs) and message ferries (MF). Therefore, it is necessary to develop hierarchical routing topologies adapted to routing problems in DTN networks to encourage the cooperation of nodes in the same cluster and also to coordinate communications between different clusters in the network. In this article, we will discuss routing improvement in DTNs by exploiting three factors: (a) hierarchical routing topology, (b) the probabilistic election of Cluster Head (CH) and the optimal election of Super Cluster Head (SCH), (c) inter-cluster and intra-cluster routing. We propose a hierarchical routing tree topology (HRTT) based on a probabilistic approach for the election of Cluster Head (CH) and Super Cluster Head (SCH) on the basis of three criteria: The probability of contact of the Message Ferry (MF), the residual energy and the node mobility model. The results of the simulations carried out show the efficiency of the topology (HRTT) with a considerable increase in the delivery rate and a minimization of the average latency in the DTN networks.

Keywords: *Delay Tolerant Networks (DTN), Tree Topology, HRTT, Super Cluster-Head, Cluster Head Election, Hierarchical Routing, ONE Simulator.*

1. INTRODUCTION

The field of Delay Tolerant Networks (DTN) has really emerged in recent years to provide routing protocols and topology control mechanisms [2] to solve communication problems and routing-related problems in networks. DTN and which are essential in environments where it is impossible to find an end-to-end connection such as isolated villages or which are essential in environments where the establishment of communication is not sufficient such as the Internet objects (IoT), drones etc.

To solve these problems, researchers have proposed the use of routing protocols adapted to heterogeneous equipment of new technologies [1,5,6] and hierarchical topologies [1,3,4] feasible and robust for new technological applications such as, the Internet of Things, drones, IoT smart cities, etc. The hierarchical routing topologies proposed by the researchers is characterized by the absence of the prediction against the premature death of the cluster-Heads (CHs) and message ferries (MF) and also is characterized by the absence of the coordination of the communications and data exchanges between the nodes of the different network clusters. Therefore, it is necessary to develop hierarchical routing topologies adapted to the different problems of DTN networks to encourage the cooperation of nodes and the coordination of communications between the different clusters of the network. We propose in this work a hierarchical tree topology suitable for routing in delay tolerant networks (DTN) for the new range of applications. This topology plays a very important role in the design and implementation of routing protocols adapted to heterogeneous equipment of new technologies in the DTN network which is characterized by the absence of any infrastructure and any centralized administration with intermittent connectivity. Indeed, we develop a hierarchical routing tree topology (HRTT). This topology integrates several notions, namely: cluster-members (CM), clusters, cluster-heads (CH), super-clusters, super-cluster-heads (SCH), messages and ferry routes as well as the intra-cluster and inter-cluster routing. Intra-cluster routing is managed by the cluster head (CH), inter-cluster routing is managed by ferry messages while super-cluster routing management is carried out by the super-cluster head (SCH) in order to form a hierarchical routing tree structure (Figure 3). The root of this tree is the super-cluster head (SCH), the nodes of this tree are the cluster-head (CH) and the leaves of this tree are the cluster members (CM). This routing tree structure allows us to improve the performance of DTN networks.

2. ROUTING PROTOCOLS FOR DTN NETWORKS

Routing protocols in the DTN network are classified according to several properties namely: the replication and the degree of knowledge that a node has concerning its future contacts with other nodes and how a node can make a routing decision. The main objective of routing protocols is to maximize the message delivery rate and to minimize the average latency and delivery delays. Several routing protocols have been proposed for DTNs, namely:

2.1 Epidemic routing protocol

Epidemic protocol [7] is essentially based on the duplication of a fairly sufficient number of copies of the same message to the nodes (relay nodes) of the network. The copy of the message is stored until it is delivered to the destination regardless of latency and regardless of storage space. By analogy epidemic routing is seen as the spread of a disease, each node of the DTN network infects other nodes by transmitting a copy of its messages. Figure 1 below shows an example of epidemic routing. With this routing technique, the destination will receive the message in a shorter time and with a high probability of delivery. However, the epidemic protocol has the disadvantage of consuming a lot of network resources (bandwidth, capacity of storage units and the energy of different nodes). Thus, the message continues to propagate through the network by unnecessary message transfers even after the message is delivered.

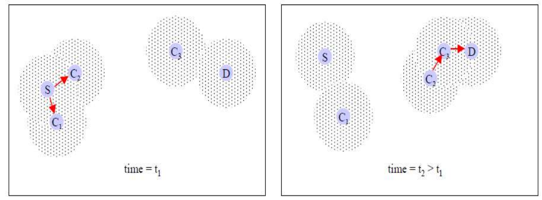

Figure 1 : Epidemic Routing [7]

2.2 Spray and wait routing protocol

The Spray and wait protocol [8] is a variant of the epidemic protocol with a pre-limitation of the number of copies of the messages to be broadcast. It limits the number of copies of messages circulating in the network. When a node sends a message, two phases occur (Figure 2):

A. The Spray phase

For each new message that has just been generated by the source, L copies of the same message will be broadcast to the first L distinct nodes (distinct relays) encountered by the source. (i.e., the number of copies equals the number of relay nodes).

B. The Wait phase

If a message could not reach its destination during the first Spray phase, each of the L relays waits to be in contact with the recipient to send the message. The parameter L is a debatable parameter by the researchers in order to be able to optimize the resources of the nodes. Generally, the parameter L is chosen according to the network density and the transmission delay.

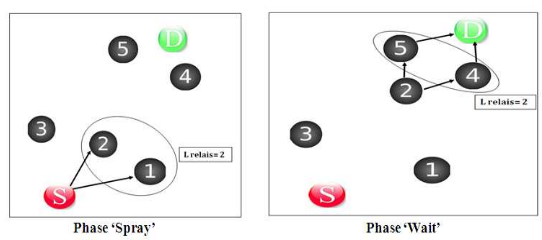

Figure 2 : Spray and Wait Routing

2.3 Prophet Routing Protocol

Prophet [9] (Probabilistic Routing Protocol using History of Encounters and Transitivity) is a probabilistic routing protocol that uses the encounter history of mobile nodes to calculate the probability of delivery (Delivery Predictability). Message delivery probabilities are calculated based on encounter frequency. Delivery probability is the probability that a message will arrive at the

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

destination via a given intermediate node. Each node maintains a list of all known destinations (possibly all nodes) with the associated delivery probabilities. PROPHET exchanges summary vectors containing these probabilities to allow nodes to update their delivery estimates. Prophet introduces the probability of delivery, P $(A, B) \in [0,1]$. This metric is calculated by each node A of the DTN network and this for each known destination B and it will be used to decide which messages to exchange each time two nodes meet.

PROPHET uses a very simple strategy. When a node encounters another node that has a higher delivery probability for the message, it forwards that message to that node, and still stores that message to forward to other nodes in the future.

The calculation of the probabilities of delivery is done in three steps:

- When an A node encounters a B node, they exchange their summary vectors. A updates P (A, B) in accordance with the following equation:

$$P(A, B) = P(A, B)_{old} + (1 - P(A, B)_{old}) * P_{init} \quad (1)$$

- A node A updates the delivery probability for each node C known to B according to the following equation:

$$P(A, C) = P(A, C)_{old} + (1 - P(A, C)_{old}) * P(A, B) * P(B, C) * \quad (2)$$

- When the two nodes A and B are absent for some time, their probability of delivery weakens periodically according to the following equation:

$$P(A, B) = P(A, B) * \Upsilon^{k} \quad (3)$$

2.4 MaxProp Routing Protocol

MaxProP[10] is a routing protocol designed to optimize the two routing metrics, delivery rate and message delivery time in the presence of bandwidth and storage constraints. MaxProp uses knowledge of previously encountered nodes to decide which messages should be forwarded or discarded by maintaining an ordered queue based on each message's destination. To do this, the messages are ranked according to the Delivery Likelihood metric. This metric represents the probability of delivery of each message to its destination.

MaxProp uses very simple mechanisms to define the order in which messages are transmitted and deleted. Higher priority messages are delivered first, and low priority messages are first removed from the buffer when the buffer is full.

When two nodes meet, they exchange their delivery vectors, which are estimates of a cost assigned to each destination. The delivery vector allows them to calculate the shortest distance to reach the destination.

The delivery vector allows them to calculate the shortest distance to reach the destination according to the following formulas:

MaxProp considers the probability, f(i,j) to be the probability that j will be the next node to make contact with node i.

$$1/(\mathrm{Card}(s) - 1) \quad (4)$$

The cost of a path comprising nodes (i, i + 1, ..., d), will be the sum of the probabilities that each connection along the path is not established. Each node transmits the messages by the least expensive path. The cost of a journey is calculated using the following formula:

$$C(i, i+1, \dots d) = \sum_{x=1}^{d-1}[1 - (f(x, x+1))] \quad (5)$$

2.5 Message Ferry (MF)

Message ferrying is used to improve connectivity and to establish connectivity in a network partitioned into several clusters. The authors in [11,12] use mobile nodes called message ferries adopting a more or less planned displacement model often deduced from human activity. The role of ferry nodes is to collect and transport messages between nodes in the network called regular nodes. Information is collected using two possible approaches:

- The approach initiated by regular nodes (Node-initiated message ferrying): To transmit data, ferry nodes follow a random movement pattern on known trajectories of regular nodes. When the regular nodes wish to send information towards a destination, they approach the trajectory of a ferry
- The approach initiated by the ferry nodes (Ferry-initiated message ferrying): The ferry nodes adapt their movements according to the CHs that wish to send data to a destination. A ferry node begins by broadcasting its position periodically to the CHs. Then, the regular nodes interested in sending messages respond with a request. Once the request has been received by a ferry, it adapts its trajectory according to the requests.

This method improves the packet routing performance compared to other models. Indeed, by knowing the different positions and by adapting the movements to these positions, the latency to transport a packet from end to end can be reduced considerably, which can be advantageous when the nodes are constrained in energy and memory capacity.

3. ROUTING PROBLEMS IN HIERARCHICAL TOPOLOGIES

The topology of DTN networks changes in an unpredictable way due to the high mobility of the nodes, it is very difficult to obtain information about the dynamics of the network and the routing becomes a major problem. To solve these problems researchers [1,2] have proposed an optimal routing of data within the framework of a hierarchy process based on three factors: a hierarchical routing topology, Message ferry (MF) and the optimal election of the cluter-head. In hierarchical topology, nodes are grouped into clusters. A cluster is made up of a cluster-head (CH) and member clusters (CMs). Routing In hierarchical topology is divided into two types of routing: intra-cluster routing and inter-cluster routing. Each cluster head (CH) is responsible for communication within its cluster and maintains cluster data and routing information that allows it to reach other cluster members (CMs). In addition, the CH is also responsible for communicating with the other cluster heads (CHs) via ferry messages (MF). This type of routing is faced with several constraints such as:

3.1 The cluster head (CH) death or destruction problem

In the intra cluster routing proposed by [1,2], entrusting the responsibility of managing a cluster and communicating with other clusters to a single node at all times. This type of routing has the advantage of being optimal in terms of resources, delivery rate and delivery delay. However, it presents the risk of losing routing information and cluster data if its cluster head (CH) is destroyed or fails. This Problem of death or destruction of the Head cluster influences both intra-cluster routing and inter-cluster routing.

3.2 The cluster head selection problem

Electing a specific node as cluster leader is not an easy task. The researchers in [1,2] propose different factors, such as geographical location of the node, mobility, energy, etc. This type of selection faces several constraints such as:

- The absence of prevention against the premature death of cluster-Heads (CHs) and message ferries (MF) in order to extend the lifetime of the network.
- The absence of any technique for periodic re-election of cluster-heads by clus-ter-members to react effectively to changes in topology.
- The absence of a temporary support of routing information and data of clusters and cluster heads for the prevention of any kind of problem in the Network.

With all these problems, the hierarchical topologies proposed by the researchers [1,2] is characterized by the absence of any kind of prediction against the premature death of cluster-Heads (CHs) and message ferries (MF) and also show inefficient in terms of coordinating communications and data exchanges between nodes of different network clusters. Therefore, it is necessary to develop hierarchical routing topologies adapted to the different problems of DTN networks to encourage the cooperation of nodes in the same cluster and also to coordinate communications between the different clusters of the network.

4. OUR APPROACH FOR DTN NETWORKS

4.1 Overview of our approach

Hierarchical Routing Tree Topology (HRTT) is constructed by grouping nodes that are geographically close to each other into clusters. The members of a cluster (CM) elect the cluster head (CH), which coordinates all information exchanges and communications within the same cluster. The member nodes of all the clusters constitute the first level of the tree topology and the cluster-Heads form a higher level. The -Head clusters can group together in turn to form a super-cluster. Cluster-Heads elect the super-cluster head (Super Cluster Head: SCH) to form a connection control tree (CCT) (Figure 3):

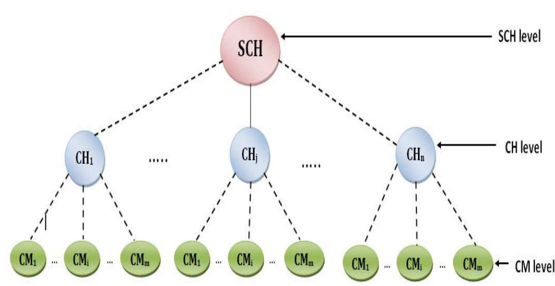

Figure 3 : Diagram of the CCT tree

4.2 Probabilistic election of a cluster Head (CH)

The election of the cluster-heads (CHs) is defined as the essential part of the control of the hierarchical routing tree topology (HRTT). The cluster head selection problem is also defined as an NP-complete problem [13].

Journal of Theoretical and Applied Information Technology
15th February 2023. Vol.101. No 3

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

In our approach, the probabilistic election of a cluster Head (CH) and the election of a super cluster-head is done according to the following three criteria:

(1). Message Ferry contact probability [15]: Message Ferry contact probabilities are computed locally in each cluster

(2). Battery life and residual energy [16].

(3).The degree of knowledge that a node has regarding its future contacts [14] with other nodes in the same cluster. In particular, future contacts can be planned, controlled, predicted, and probabilistic.

• For the election of the Cluster Head(CH): Our approach proposes a metric called Ferry message contact probability, $P_C(N_i, MF_j) \in [0,1]$. This metric is calculated by each node Ni of the cluster and this for each Message Ferry MFj visiting the cluster. This metric will be used to decide which node will act as the cluster head each time two nodes meet. The message ferry (MF) is considered as the first destination of the message and the destination node is considered as the second destination of the message. Each node in the cluster maintains a list of all nodes in the cluster with associated contact probabilities. When a node Ni encounters a node Nj, they exchange their Contact Probabilities of MF. The node having the highest contact probability is considered as the cluster-Head (CH)

• For Super Cluster Head (SCH) election: Our approach proposes battery lifetime and residual energy [16] as criteria for the election of the super cluster head. The cluster head that has the longest battery life and has the largest memory capacity is considered the Super Cluster-Head (SCH).

5. HIERARCHICAL ROUTING TREE TOPOLOGY (HRTT)

5.1 Description of HRTT topology

A DTN network is a medium characterized by frequent disconnections that often occur due to low node density, node mobility and energy blackouts. All these factors create a set of problems such as: a very long delivery delay, a very low delivery rate and an increase in the resources consumed such as: bandwidth, capacity of storage units and the energy of the various nodes, etc. So, it is necessary to develop hierarchical routing topologies to maximize the performance of the DTN network and to encourage cooperation between cluster nodes (Inter-cluster) and also to coordinate communication with nodes of the same cluster (intra-cluster). The researchers proposed the use of hierarchical topologies that adapt to new communication technologies such as the DRHT topology proposed by [1, 2] based on the optimal selection of the cluster leader, (figure 4).

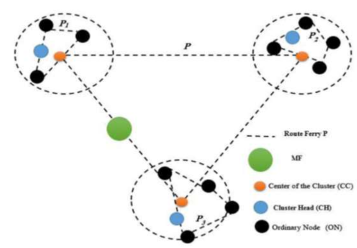

Figure 4 : Diagram of the DRHT [1, 2]

In this work, we propose a hierarchical routing tree topology (HRTT) adapted to DTN networks. This topology allows the design and implementation of routing protocols used in new communication technologies such as: the Internet of Things (IoT), drones, smart cities IoT, etc. The main elements of the hierarchical routing tree topology (HRTT) are: (Figure 5)

The cluster head (CH): A node that is responsible for managing the nodes of its own cluster and communicating with other clusters, generally a CH plays the role of a mobile access point to the cluster.

The super cluster head (SCH): A node responsible for coordinating the communication between the CHs to encourage cooperation between the nodes of the clusters

The cluster member (CM): Are nodes that are just cluster members, calculate the shortest paths to reach their cluster-head

The Message Ferry (MF): A special node that traverses a route to provide connectivity between Clusters Heads (CHs)

The cluster center (CC): is the center of data exchange between the CHs via an MF

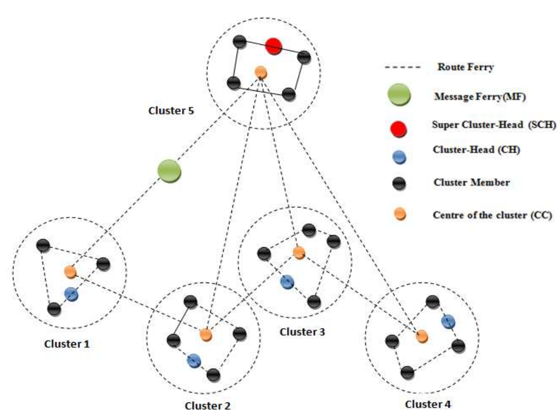

Figure 5 : Diagram of the HRTT

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

5.2 Routing in the HRTT

With the HRTT Topology, we can distinguish two types of routing: intra-cluster routing and inter-cluster routing. Each cluster head (CH) is responsible for the communication within its cluster and maintains the routing information which makes it possible to reach the other members of the cluster (CMs).
In addition, several messages ferry (MF) are also used to ensure communication between the cluster-heads (CHs) located in the different clusters (Figure 6).

5.2.1 Intra-cluster routing

Intra-cluster routing occurs when the source node and the destination node are in the same cluster. In intra-cluster routing, communication between a source node and a destination node does not go directly but through intermediate nodes (relay nodes). All communications between a source node and a destination node must pass through a cluter-head (CH) which has full knowledge of the dynamics of the cluster. Any message as well as any routing information must necessarily pass through the cluster-head (CH). The CH also verifies the presence or absence of the destination node in the cluster.

5.2.2 Inter-cluster routing

Inter-cluster routing occurs when source node and destination node are not in the same cluster. In the inter-cluster routing the communication between a source node and a destination node is done through three main elements: the cluster heads (CHs), the Message Ferry (MF) as well as the super cluster-head (SCH). (Figure 6). A source node of a cluster can communicate with a destination node of another cluster through multiple (MFs) and the super cluster head (SCH). When the MFs arrive at the centers of the clusters, each CH transmits its information from its cluster to the SCH through the intermediary of the MFs. The SCH uses this information to construct the connection control tree (CCT) and also to organize the transmission of data. The SCH broadcasts the CCT tree to all the CHs and the CHs in turn broadcast the CCT tree to all the CMs. Once the nodes of the different clusters are connected, the SCH and the other CHs then use this CCT to organize the transmission of data according to the routing protocols designed for DTN networks such as Epidemic, Prophet, Spray and wait and Maxprop. The contacts between the MFs, the CHs and the SCH effectively reduce the number of message copies and network traffic as well as energy consumption.

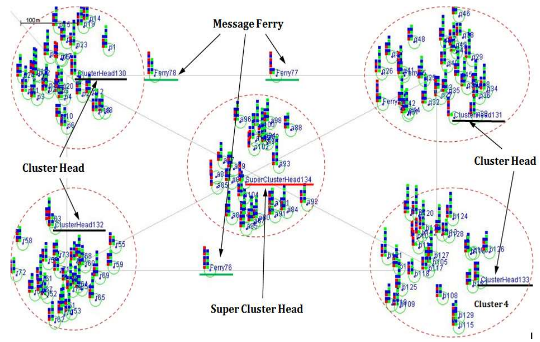

Figure 6 : Routing scheme in the HRTT

5.3 HRTT Connection Control System

5.3.1 Construction of the connection control tree (CCT)

The clusters are initially generated and the CHs and SCHs are chosen. Each cluster comprises M cluster members (CM) and the super cluster comprises N cluster head members (CH). The cluster head collects all of the control information received from its own cluster members. Each CH forwards its connection control information to the super cluster head (SCH). The SCH creates the connection control tree (CCT). The SCH then uses this CCT to organize the transmission of data for each cluster according to the routing protocols designed for DTN networks. The algorithm below describes this technique.

5.3.2 Connection control algorithm in HRTT

Table 1: Notation of abbreviations

Notation	Explanation
CM_{id}	Identity of the cluster member
CH_{id}	Identity of the cluster head
SCH	Super Cluster Head
RE	Residual Energy
CCT	Connection Control Tree
CH_j	cluster head of j^{th} cluster
CM_i	cluster member of i^{th} cluster

including $\{CH_{id}, CM_{id}, RE\}$ to its CM_i as well as to their neighbor CH_{jk}. The CM_i sends its information to its CH_j . CHj collects the information that is received. Each CHj transmits its information to the super cluster head (SCH). The SCH records the information that is received. The SCH then constructs a CCT from among the set of CHj and CMi. The SCH uses this information to organize the transmission of the data. The SCH broadcasts the CCT tree to all the CHj and the CHj broadcasts the CCT tree to all the CMi. As a result, the receiver uses the CCT tree to connect all the clusters in the network, which allows reliable data transmission for each cluster according to the routing protocols designed for DTN networks (Prophet, Maxprop, spray and wait, Epedimic). The connection control algorithm of the HRTT is presented in figure 7:

1.For each CH_j,j=1, 2,…n

$\{CH_{id}, CM_{id}, RE\}$

2.$CH_j \rightarrow CM_i, CH_{jk}$

3.$CM_i \rightarrow CH_j$

4.CH_j transmits the information $\{CH_{id}, CM_{id}, RE\}$ to SCH

$CH_j \rightarrow SCH$

5. If (CH_{id}, CM_{id} and RE is received by SCH from CH_j) then

6. SCH saves the CH_{id}, CM_{id} *and RE*

7. SCH constructs CCT between all CHj and CMi

8. SCH **broad**cast CCT tree to all CH_j

9. CH broadcast CCT tree to all CM_i

10.End if

11. SCH and CHj organize the transmission of data for each Cluster according to routing protocols designed for DTN networks (Prophet, Maxprop, Spray and wait and Epidemic)

12.Periodic re-election of CHj by CMi

13. Re-election of SCH by CHj

14.End For

Figure 7. Connection control algorithm in HRTT

5.4 Routing Architecture in HRTT

In hierarchical routing, nodes are grouped into clusters in which cluster heads (CHs) act as a temporary sub-sink of connection control information. The other nodes that are just cluster members (CMs) calculate the cluster-head's contact probability (in terms of battery life, message ferry contact probability, node mobility and the degree of knowledge that 'a node has regarding its future contacts with other nodes in the same cluster). As well as the cluster-heads are grouped into super clusters within which the super cluster-head (SCH) acts as a temporary sink of connection control information and communicates with the CHs through Ferry messages. The SCH is in charge of creating the connection control tree (CCT) and distributing it to all the CHs and CMs of the DTN network. The SCH then uses this CCT to organize the transmission of data for each cluster according to the routing protocols designed for DTN networks. The routing architecture proposed in the HRTT is shown in Figure 8:

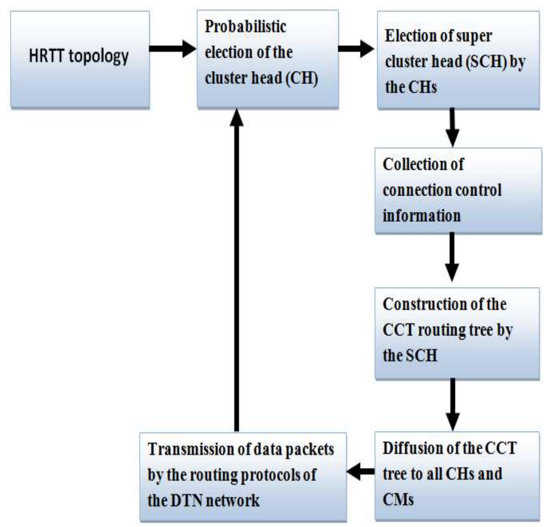

Figure 8: Routing Architecture in HRTT

5.5 Advantages and main problems solved by the HRTT topology

- ✓ The HRTT topology can effectively reduce the number of message copies and network traffic as well as resources consumed in the network (such as power consumption, memory, etc.)
- ✓ The HRTT topology has a significant impact on increasing delivery rate and minimizing average latency
- ✓ The use of a super cluster Head in the HRTT topology has several advantages, namely:
- The prevention against the premature death of cluster-Heads in order to extend the life of the network.
- Periodic re-election of cluster-heads by cluster-members to react effectively to changes in topology.
- Periodic re-election of super cluster-head by cluster-heads to react efficiently to changes in topology

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

- Enables rotation of the cluster-head role between the nodes to improve the delivery rate and energy efficiency.
- Reconstruction of the connection control tree (CCT) in the case of destruction of a cluster-head (CH) or a super-cluster head (SCH).

6. SIMULATION

5.1 Stimulation tool used

In this work, we used the ONE simulator [17] (Opportunistic Network Environment) in which we implemented our topology (HRTT) and DTN routing protocols. The choice of the ONE simulator is justified by several reasons, namely:

- The ONE has been used by many researchers in the context of their work.
- The simulator is an ideal tool to evaluate the routing and the routing protocols dedicated to the DTN networks.
- The simulator allows users to quickly and flexibly create scenarios based on various analytical or real models.
- ONE's design allows for the implementation of new routing approaches.
- Simulation results are primarily gathered and collected through reports generated during simulation execution.
- The ONE simulator also has a graphical user interface (GUI) to follow the progress of the simulation. As shown in Figure 9 below.

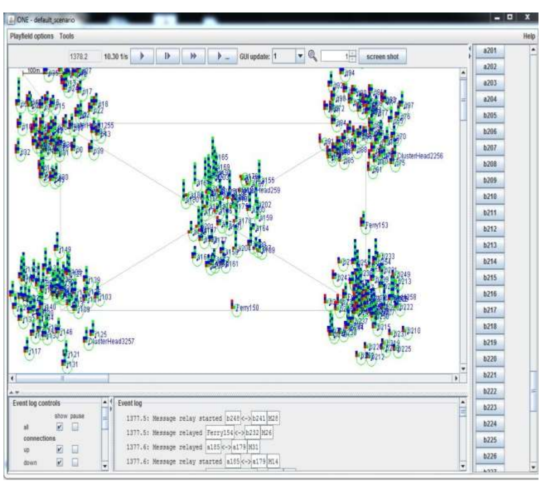

Figure 9: Screenshot of our simulator

5.2 HRTT approach performance metrics

In this section we evaluate the performance of existing DTN routing protocols namely: Epidemic, Spray and Wait, Prophet, and Maxprop on our HRTT routing topology. To do this evaluation, we define the following routing metrics: Delivery delay and Average latency.

5.3 Simulation parameters

Table 2 summarizes the parameters of the simulation used to evaluate the performance of the DTN routing protocols on our HRTT routing topology.

Table : Basic simulation parameters

Parameter	Value
Total Simulation Time	5h
World Size	4500 X 3400 *m2*
DTN Routing Protocol	Epidemic, Spray and Wait, Prophet, MaxProp
Buffer Size	5M
Total No. of nodes	25, 50, 75, 100, 125.
Number of ferries	5
Number of clusters	5
Transmit Speed	2 Mbps
Message TTL	300 minutes
Interface Transmit Range	10 metres
Node Movement Speed	Min=0.5 m/s Max=1.5 m/s
Message Creation Rate	A message by 25-35 sec
Message Size	50 KB to 150 KB

7. ANALYSIS OF SIMULATION RESULTS AND DISCUSSION

In the simulation environment, we compare the performance of the different DTN routing protocols on our HRTT topology and we define the following routing metrics: Delivery delay and Average latency.

6.1 Delivery rate

The delivery rate is the ratio of messages successfully received in the destination to the number of messages sent from the source node. The delivery rate is the most important metric when comparing the performance of different DTN routing protocols on our HRTT topology. This metric characterizes how complete and efficient routing is on the HRTT topology. This setting should be as high as possible for best network performance.

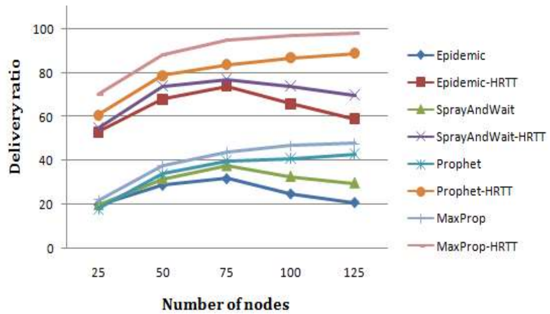

Figure 10: Delivery Rate According To The Number Of Nodes.

In Figure (10), we present the delivery rate as a function of the network density, by varying the number of nodes. In this curve, the delivery rate increases with the increase in the number of nodes. In Figure (10), we noticed that for low node density all four routing protocols (Epidemic, Spray and Wait, Prophet, and Maxprop) gave a generally low delivery rate.

This decrease is mainly due to the low connectivity of the network and the absence of any cooperation between the nodes and consequently, the protocols do not find paths to reach certain destinations, and especially when the destination is not in the same cluster of the source. Indeed, the Maxprop-HRTT routing protocol has the highest delivery rate which exceeds 98% unlike the same protocol in the case of absence of the HRTT topology which does not exceed 48%. The Prophet_HRTT Protocol presents a delivery rate of 89% while the same protocol presents a delivery rate of 43% in the absence of the HRTT topology. The Spray and Wait-HRTT Protocol presents a delivery rate of 70% while the same protocol presents a delivery rate of 30% in the absence of the HRTT topology. The Epidemic-HRTT protocol presents a delivery rate of 59% while the same protocol presents a delivery rate of 21% in the absence of the HRTT topology. In particular for HRTT topology. We find that the HRTT topology has a significant impact on the delivery rate for the four DTN routing protocols (Epidemic-HRTT, Spray and Wait-HRTT, Prophet-HRTT, and Maxprop-HRTT) and this because of the cooperation between nodes. In addition, ferry messages (MF) are also used to ensure communication between cluster-heads (CHs) located in the different clusters.

6.2 Average latency

Latency is the time that elapses between the creation of a message by the source and its successful delivery to the destination. It is also known as the "average delay". This parameter should be lower for better network performance.

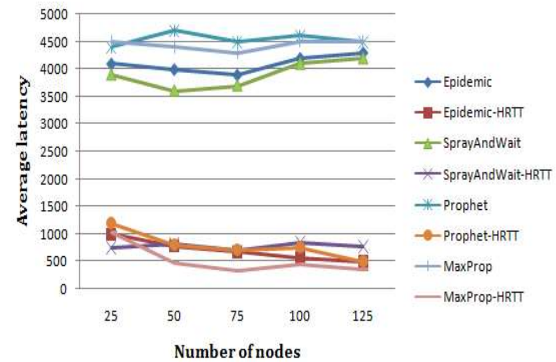

Figure 11: Average Latency Depending On The Density Of Nodes

In Figure 11, we present the average latency as a function of node density. Figure 11 shows that, for a low density of nodes, the average latency of the four routing protocols (Epidemic, Spray And Wait, Prophet, and Maxprop) is quite large due to the absence of any cooperation between the nodes and especially when the source nodes and the destination nodes are not in the same cluster, which increases the distances separating the nodes.

In particular, for the HRTT topology, the average latency decreases with the increase in the density of the nodes and this because of the cooperation between the nodes provided by the clusters Head (CH) and the messages ferries (MF) which increase the contact opportunities and minimize end-to-end time. Indeed, the Maxprop-HRTT routing protocol is the most efficient among the four routing protocols (Epidemic-HRTT, Spray and Wait-HRTT, Prophet-HRTT, and Maxprop-HRTT) in terms of average latency.

We find that the HRTT topology has a significant impact on the average latency for the four DTN routing protocols (Epidemic-HRTT, Spray and Wait-HRTT, Prophet-HRTT, and Maxprop-HRTT).

According to the simulations performed, we find that the HRTT topology has a significant impact on the delivery rate and the average latency for the already existing DTN routing protocols, however its efficiency can still be improved.

8. CONCLUSION

In this article, we have discussed improving routing in DTNs by exploiting three factors: (a) hierarchical DTN routing topology, (b) probabilistic election of Cluster Head (CH) and Super Cluster Head (SCH), (c) inter-cluster and intra-cluster routing. Indeed, we have proposed a hierarchical routing tree topology (HRTT) based on a probabilistic approach for the election of Cluster Head (CH) and Super Cluster Head (SCH) on the basis of three criteria: The contact probability of ferry message, residual energy and node mobility model. In addition, the HRTT topology uses the super cluster head (SCH) which plays the role of a temporary storage medium for data and routing information of clusters and cluster heads for predicting the premature death of cluster-Heads (CHs) and message ferries (MF), thus the HRTT topology uses cluster heads (CHs) and message ferries (MFs) to induce the cooperation of nodes in the same cluster and also to coordinate communications between the different clusters of the network. Finally, the contacts between the MFs, the CHs and the SCH allow to increase the cooperation between the nodes of the network in order to effectively reduce the number of copies of messages and the network traffic as well as the energy consumption. From the simulations performed by the ONE simulator, we found that the HRTT topology has a significant impact on the delivery rate and average latency for the four DTN routing protocols (Epidemic-HRTT, Spray And Wait-HRTT, Prophet -HRTT, and Maxprop-HRTT) and this because of the cooperation between the nodes.

REFERENCES:

[1] El Arbi Abdellaoui Alaoui, Stéphane Cédric KoumétioT ékouabou, Antoine Gallais, Said Agoujil, DTN Routing Hierarchical Topology for the Internet of Things, *Procedia Computer Science*, Volume 170, 2020, Pages 490-497 https://doi.org/10.1016/j.procs.2020.03.107

[2] E. A. Abdellaoui, Agoujil, S., Hajar, M., and Qaraai, Y. (2016). Optimal cluster head in DTN routing hierarchical topology (DRHT). *International Journal of Communication Networks and Information Security*, 8(2), 101.

[3] M. Saadeh, A. Sleit, K. E. Sabri, W. Almobaideen, Hierarchical architecture and protocol for mobile object authentication in the context of iot smart cities, *Journal of Network and Computer Applications* 121 (2018) 1-19.

[4] E. A. Abdellaoui and Khalid Nassiri." Stochastic analysis of dtn routing protocols in delay tolerant network routing hierarchical topology." *International Journal of Wireless and Mobile Computing* 15.1 (2018): 28-46.

[5] E. A. Abdellaoui Alaoui, Hanane Zekkori and Said Agoujil," Hybrid delay tolerant network routing protocol for heterogeneous networks", *Journal of Network and Computer Applications-Elsevier*, Vol. 148, 2019; DOI:10.1016/j.jnca.2019.102456

[6] E. A. Abdellaoui Alaoui, S. Koumetio Tekouabou and A. Gallais, Efficient Forwarding Strategy in HDRP Protocol based Internet of Things, in *Elsevier Computer Communications*, Volume 170, 15 March 2021, Pages 164-176

[7] A. Vahdat and D. Becker. "Epidemic Routing for Partially Connected Ad Hoc Networks." *Technical Report CS-200006*, Duke University, Durham, April 2000.

[8] T. Spyropoulos, K. Psounis, C. S. Raghavendra, Spray and wait: an efficient routing scheme for intermittently connected mobile networks, in: 870 *Proceedings of the 2005 ACM SIGCOMM workshop on Delay-tolerant networking*, ACM, 2005, pp. 252-259.

[9] A. Lindgren, A. Doria, O. Schelen, Probabilistic routing in intermittently connected networks, in: Service assurance with partial and intermittent resources, *Springer*, 2004, pp. 239-254.

[10] J. Burgess, B. Gallagher, D. Jensen, B. N. Levine, Maxprop: Routing for vehicle-based disruption-tolerant networks, in: INFOCOM 2006. *25th IEEE International Conference on Computer Communications. Proceedings, IEEE*, 2006, pp. 1-11.

[11] K.Harras and K.Almeroth. Transport layer issues in delay tolerant mobile networks. in International Conference on Research in Networking, pp 463–475. 2006. *Springer.*

[12] Wenrui Zhao, Mostafa Ammar, and Ellen Zegura. Controlling the mobility of multiple data transport ferries in a delay-tolerant network. In *Proceedings of the 24th Annual Joint Conference of the IEEE Computer and Communications Societies*, INFOCOM '05, pages 1407–1418. IEEE, 2005.

[13] M.V. Bharathy, K.K.C. Rao "One-leap fuzzy enabled clustering technique for under water wireless sensor networks to improve the stability and energy exhaustion rate of the nodes" *J. Phys. Conf. Ser.*, 1172 (2019), Article 012080; *DOI:10.1088/1742-6596/1172/1/012080*

[14] EL MASTAPHA SAMMOU, "Efficient Probabilistic Routing in Delay Tolerant Networks", *International Conference on Multimedia Computing and Systems*,10-12 May 2012, Movenpick - Tangier, Maroc

[15] Mao, Y.; Zhou, C.; Ling, Y; Lloret, J. An Optimized Probabilistic Delay Tolerant Network (DTN) Routing Protocol Based on Scheduling Mechanism for Internet of Things (IoT). *Sensors* **2019**, *19*, 243.

[16] M Kaviani, B Kusy, R Jurdak, N Bergmann. Energy-Aware Forwarding Strategies for Delay Tolerant Network Routing Protocols. *Journal of Sensor and Actuator Netwotks* . 2016, 5(4),18; *https://doi.org/10.3390/jsan5040018*

[17] A. Keränen, J. Ott, T. Kärkkäinen. "The ONE simulator for DTN protocol evaluation". In SIMUTools '09, *Proceedings of the 2nd International Conference on Simulation Tools and Techniques*, ICST: New York, NY, USA, 2009; Article No.55.