Improving the Delivery Rate of Data with : DTN Routing Hierarchical Topology (DRHT)

El Arbi Abdellaoui Alaoui, Said Agoujil, Moha Hajar and Youssef Qaraai

***Abstract*—**This paper presents an approach to improve quality of service parameters over a delay tolerant network (DTN), which comprises of multiple message ferries, cluster heads of node clusters, and regular nodes. Intra-cluster routing is done via the mediation of cluster head; inter-cluster routing is done with the help of message ferries. This approach forms a structure capable to adapt dynamically to changes in the mobile environment. We provide also an asynchronous algorithm that will minimize the number of messages replicated and the network resources in general. Finally, we will present the simulation results demonstrating the effectiveness of the topology and routing protocol, particularly for high-density network nodes.

***Keywords*—** Delay Tolerant Networks DTN, Topology, Message Ferry, Hierarchy Routing, QoS.

I. Introduction

A delay tolerant networking (DTN), as described in [1] is a kind of MANET network Mobile Ad-hoc Networks. It consists of a set of self-organized stations fully decentralized, forming an autonomous network, dynamic and without pre-existing infrastructure. These stations communicate with each other through a radio interface. Only the elements that exist in the transmission range are able to communicate directly with each other. Otherwise, communication between the components takes place by connecting the close messages until the destination is reached. In this case, it is not easy to find an efficient routing between distant elements.

The mobility of stations and the lack of infrastructure have a significant impact on connectivity in such networks. Therefore, the topology of MANET network is rarely, if never, connected and the message delivery must be tolerant to delay [2, 3].

Intermittent connectivity, asymmetric flow, high error rate, long or variable delivery delay, extensive networks and high mobility of nodes characterize a DTN network. This latter creates new problems such as frequent disconnection, low communication rate, modest resources and limited energy source. These factors make the network spread on a large-scale, and therefore the delivery delay is very long and the delivery rate is potentially low. Thus, the choice of a technique for transmitting messages is then essential to ensure a great autonomy to these networks which are typically deployed in hostile or inaccessible areas.

The objective of this work is to solve effectively this problem of delivering information between different nodes of the network. Some parameters must be taken into account in order to save the bandwidth, the scarce radio resources, etc. The designed protocol must adapt to the increased number of participants and their mobility, so that they can function correctly.

Bearing in mind this problem, our approach to solve this problem is based on the idea of structuring and organizing the network before disseminating information by acting on the parameters to obtain proper network topology. The presence of such structure would reduce the impact of mobility, optimize both the delivery delay and delivery rate, particularly in the large-scale DTN networks and simplify routing.

Indeed, a DTN network can be used to ensure reliable transmission in hostile networks with a very long delivery delay and intermittent connectivity. To facilitate communication and optimize the tasks that involve multiple nodes at once, a network organization is required. This organization is guaranteed by the establishment of a logical topology in the network that allows imposing rules and constraints governing the operation of the network and the collaboration between the different nodes, especially when the destination is not in the same region of the source.

It is noteworthy to mention that the rest of this article is organized as the following: In Section II, we provide a background of the topology control in ad hoc networks and, in particular, the DTN networks. Then, in Section III, we provide a system model and problem statement. Then, we describe in section IV the model of the DTN routing hierarchical topology (DRHT). In Section V is devoted to the model of the success probability of delivery for a bundle with specific TTL and the average duration of inter-contact. In Section VI, we will describe the simulation environment and we will present the obtained results to assess the performance of the used topology control DRHT compared to Maxprop [4] protocols and Epidemic [5], Spray and Wait [6]. Finally, in Section VII, we present a conclusion.

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II. RELATED WORK

The majority of the DTN protocols are based primarily on the Bundle Layer [7] to provide better interoperability between different networks and enable heterogeneous technologies in the lower layers. A variety of routing protocols has been developed especially for DTN networks in recent years. The lack of coordination between the nodes and the number of replication messages in these networks makes the task of routing more complex than in fixed networks. However, current solutions such as Data MULE [8] and Throwboxes [9] cannot be directly applied to DTN networks on a large-scale, because the generated control traffic is potentially as huge as the consumption of resources during the dissemination of messages in the network. In addition, the routing plan must adapt to the mobility of these networks while consuming the least number possible of resources because the devices' capabilities are, in general, highly stressed . These protocols can be classified depending upon the type of information collected by nodes and how the routing decision was taken. We can divide the proposed routing strategies for DTN into two main categories based upon the properties used to find the path of the data transmission. The first property, namely flooding strategy means that the strategy uses multiple copies of one message to deliver it to the destination. While the second property forwarding strategy uses different mechanisms to effectively select the relay nodes and to increase the probability distribution in case of limited resources [10][11][12]. Among the DTN protocols developed, we can find: Epidemic, Spray and Wait, Prophet and MaxProp

The topology determines the organization of nodes in the network. The topology control in the DTN network is a new research area [13][16]. It aims to maintain adequate topology controlling the links to be included in the network. Among the objectives, we mention optimizing the delivery rate, the delivery delay, reducing interferences and energy consumption and increasing the effective capacity of the network, etc. Some works are based upon these criteria to propose the construction of topologies adapted to their protocols. Due to limited capacities of mobile equipments in battery run, the first studies on topology control in DTN networks use energy consumption as an important metric.

In literature [14][15], the majority of routing protocols and transmission techniques designed for small or medium size DTN networks with a low density and mobility nodes provide good performance. However, when the movement of nodes is unpredictable and frequent disconnections divide the network into completely disjoint partitions without any communication link, traffic control predominates real-time communications. This leads to an increase in latency and a minimization of the number of messages delivered to the final destination.

To overcome these limitations, the hierarchical architecture of the DTN routing is considered one of the commonly effective solutions for data transmission and routing in DTN networks. It gathers nodes that are geographically close into groups also called "clusters" and sets different routing schemes inside the cluster (intra-cluster) and between clusters (inter-cluster). So it is essential to find an approach of coordination between different clusters particularly in large-scale networks.

Clustering techniques have some limitations and do not support mobility, especially in large-scale partitioned networks. Thus, clustering techniques designed, especially for ad hoc networks, cannot be applied directly to DTN networks as they do not take into account the specificities of these networks. For example, when a node moves out of the communication range of another, the link between nodes is cut and therefore the full path is destroyed. This link breaking divides nodes into parts between which there is no possible way. This prevents packets from reaching their destination in another part of the network. This phenomenon is the cause of network partitioning, which forms a critical hit on the DTN routing in terms of delivery delay and delivery rate. To improve reliability and energy conservation, large-scale partitioning should be avoided in DTN.

III. SYSTEM MODEL AND PROBLEM STATEMENT

In this section, we present the network model considered in this study. Table 1 summarizes the main notations and some assumptions used in this paper. Finally, we describe the problem statement and the function objective.

A. *Network model*

Let a DTN composed of $N+1$ nodes, i.e. mobile nodes. Two nodes can communicate only when they enter the reciprocal communication range and we consider this as a "contact" between them in the network DTN. Let the interval of pairwise inter-contact between n_i and n_j denotes the time duration from the instant when they leave communication range of each other to the next instant when they enter it. To improve the performance of DTN in the existing analytical results, we use the same mobility model, in which the interval of pairwise encounter fulfills the exponential distribution with the same rate λ . This model has been widely supported in the literature [17, 18] because it is considered as a good approximation for the interval of inter-contact in a significant number of realistic DTN networks [19].

B. *Notations*

For the rest of this work, we consider the following notations:

TABLE I. NOTATIONS USED FOR MODELING

Notations	Definition
N	Total number of nodes of the shared network
K	number of regions forming the network
C_k	Cluster of the network
N_k	Number of nodes in each area, with: $N = \sum_{k=1}^{K} N_k$
F	Message ferry
v	Speed of the ferry
P	Ferry route
$\|P\|$	Length of a ferry route
l_{ij}^{F}	Distance between the node n_i and n_j

$t_{w_{ij}}$	Time of wait to n_i before being transmitted to the ferry
$t_{c_{ij}}$	time of carrying to the ferry before delivered to n_j
d_{ij}^{P}	Average delay to transmit a message of n_i to n_j .
b_{ij}	Average traffic between node n_i and n_j .

C. Hypotheses

The study of the performances of the DTN network is constraining because of its various characteristics, in particular the mobility of nodes, the bandwidth and the resources of energy. This leads us to an approximation of calculations by the means of certain assumptions on the network considered. In fact, we focus on the connection between the nodes, the nature of circulation of flows on the routes ferry linking the various regions, the transmission range, and the law of behavior managing the contact between the areas. Thus, we summarize these assumptions by:

(H1): The nodes have the same range of transmission;
(H2): The regions of the network forming a cluster;
(H3): The movement of nodes is random between K regions;
(H4): The traffic in the network is unpredictable;
(H5): The range length of each cluster is strictly lower than the ferry route length;
(H6): The contact between the two regions C_k and C_k' follows an exponential distribution of the

$\lambda = \lambda_{k,k'}$

parameter .

D. Problem statement

A DTN network can be considered as a set of time-varying contacts (a contact is defined as an opportunity to send data). The maximum amount of data that can be transmitted on a contact is called the delivery rate, and is defined as the product of the contact duration and the number of messages received during this period. A path is defined as a sequence of contacts. The path volume is the minimum volume of contact of all contacts of the path. Messages are transferred along a path in storage and forwarding mode (store-and-forward). If the next contact is not available, messages are buffered until the contact becomes available or messages have expired.

In order to assure connectivity between clusters, we need to determine the positions where the multiple MF [20-22] must move in order to maximize the number of nodes covered. Movement of the multiple MF must also ensure a connected DTN network. In addition to the effective coordination with the optimal CH in each cluster.

E. Function objective

The objective function of the average delivery delay, for all the traffic in a given ferry route P , is defined as:

$$\Delta_d = \frac{\sum_{1\le i,j\le N} b_{ij} d_{ij}^{P}}{\sum_{1\le i,j\le N} b_{ij}} \quad (1)$$

The original problem of the ferry route is defined in [22] with two basic hypotheses, which are: firstly the nodes are fixed and their position is known, and secondly the average traffic b_{ij} between the node n_i and the node n_j can be estimated before calculating the route. However, as we have assumed according to the hypothesis (H4) b_{ij} cannot be determined in advance. Furthermore, when F (ferries) are dynamic, the delivery delay from one point to another is not fixed. Therefore, we need to change the objective-function of the average delivery delay for all the traffic, which is determined as follows:

Let's suppose that, in the time period $(0,t)$, there are M messages to be transmitted by ferries F . The message size $(1 \le i \le M)$, its source and its destination cluster are designated by μ_i , s_i and d_i respectively.
The objective-function of the average delivery delay in the DRHT, for all the traffic in a given ferry route, is defined as:

$$\Delta_{DRHT} = \frac{\sum_{i=1}^{M} \mu_i d_{ij}^{P}}{\sum_{i=1}^{M} \mu_i} \quad (2)$$

The main challenge in DTN networks is how to improve the performance of data delivery in large-scale networks. Our goal is to find an optimal route for the ferry in order to minimize the objective function.

The performance of the proposed topology is linked to parameters relating to the external environment such as: the mobility, the DTN protocols, the connectivity, the number of participating nodes, the generated traffic, the energy, the election of CH, etc. This will be the subject of the next section, in which we try to analyze the topology behavior particularly the methodology for electing a CH.

IV. DTN Routing Hierarchical Topology (DRHT)

A. Description of the construction DRHT

The main idea is to build a topology of routing in a large-scale DTN network. The dominant character in the DRHT is the number of nodes (MF) that cross the diffusion paths to ensure connectivity between clusters. The choice of data carrying nodes (MF) is an important step in the construction of the set of clusters. In addition, each cluster is identified by three categories of nodes:

1. The cluster head (CH) is a dominant node, it is the head of the cluster;
2. The center of the cluster (CC) is a point of exchange at which messages can exchange data between different CHs via MF within each cluster;
3. The ordinary node (ON) are not dominating nodes.

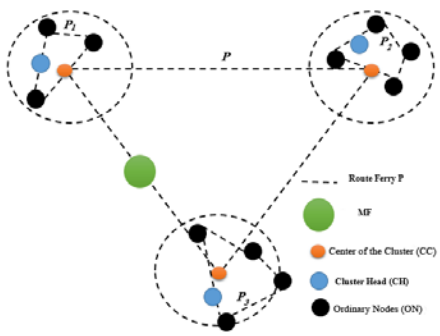

Fig 1. Diagram of the DRHT.

Consider a DTN network of N mobile nodes and F ferries, each one with a value of communication range equals to r . Supposing that the network is partitioned into K components, each one forms a cluster the chief of which is the cluster head CH. To simplify the problem, we limit the movement of a CH in a circular area. The center of the cluster C_k is noted as a point of CC.

Here is a description of the different stages of the DRHT algorithm that is divided into five phases:

1. The network partitioning;
2. The choice of the broadcaster node;
3. The scope and density of clusters;
4. The calculation of the ferry cluster route. For each cluster, ferry route can be calculated by the algorithm proposed in[21];
5. The calculation of the global ferry route. Along the direction of the route P, the global ferry route can be obtained by connecting the CH position of each cluster.

B. *Routing phases in the DRHT*

The DRHT divides the routing of data into two parts: intra-cluster and inter-cluster. Each cluster-head is responsible for communication within its cluster and maintains the information of routing that allows joining the other ordinary nodes. Moreover, since the other cluster-heads are not directly connected, multiple MF are also used to ensure communication between cluster-heads located in two different clusters.

1) Intra-cluster routing phase

This phase allows to a source node to reach a node recipient inside the cluster. It is the CH that has a total knowledge of the cluster, it checks the presence of the node recipient there. Thus, any message must obligatorily pass by it.

2) Inter-cluster routing phase

This phase allows a source node (or intermediate) to reach a destination node located in a different cluster via MF, if a ferry stops at CC, it would be able to communicate with the CH cluster C_k. A simple contact between the ferry and CH is enough to deliver messages to other members.

These multiple MF allow reducing the number of duplicated messages by lessening the traffic flowing through the network, and furthermore reducing the energy of consumption. Moreover, the transmission of data to other clusters through a single MF becomes almost impossible when the extent of the network increases. To solve this problem, routing of multiple MF is the communication mode adopted to transmit data between the different clusters.

Furthermore, once the nodes of different clusters are connected, we can use conventional protocols such as Epidemic, Prophet, Spray and wait and Maxprop for communication between the CH and the other members.

It is noteworthy to mention that the delivery delay required for transmission of messages within a cluster C_k (intra-cluster communication) is much shorter than between different C_K clusters (inter-cluster communication), and it is less relevant for the ferry route. However, the two have a high importance in the communication process especially in the DRHT.

C. *Analysis of delivery delay in the DRHT*

Depending upon many works in this field [20, 21], this section we will present basic concepts to model and analyze the delivery delay introduced by the DRHT, following certain scenarios in which nodes n_i and n_j are located in different position. When F crosses node n_i, a message destined to the node n_j is produced. The delivery delay of this message is analyzed as follows:

- The time of wait in n_i before being transmitted toward F is:

$$t_{w_{ij}} = \frac{|P|}{2v} \tag{3}$$

- The time of carrying of the ferry of n_i to n_j is:

$$t_{c_{ij}} = \frac{l_{ij}^{P}}{v} \tag{4}$$

- The delay between the instants to generate the message in the node n_i and to deliver the message in the node n_j is:

$$d_{ij}^{P} = t_{w_{ij}} + t_{c_{ij}}$$
$$\rightarrow \ d_{ij}^{P} = \frac{|P|}{2v} + \frac{l_{ij}^{P}}{v} \tag{5}$$

1) When nodes n_i and n_j are in the same cluster:

The delay of single ferry routing is:

$$d_{ij_F}^{P} = \frac{|P|}{2v} + \frac{l_{ij_F}^{P}}{v} \tag{6}$$

In the DRHT, let P_k be the ferry route for cluster C_k and let $l_{ij}^{P_k}$ be the distance between node n_i and node n_j in route P_k. The delay introduced by DRHT is $d_{ij}^{P_k}$: (7)

$$d_{ij}^{P_k} = \frac{|P_k|}{2v} + \frac{l_{ij}^{P_k}}{v}$$

According (6) and (7), we note that $d_{ij}^{P_k} < d_{ij_F}^{P}$ since $|P_k| < |P|$ and $l_{ij}^{P_k} < l_{ij_F}^{P}$. That means that when the node

n_i and the node n_j belong to the same cluster, the delay of routing of DRHT is lower to the single message ferry.

2) When nodes n_i and n_j are situated in different clusters k and k'

The delay of routing of the single message ferry when the nodes n_i and n_j are located in different clusters is the same that when the node n_i and the node n_j are in the same cluster.

Based on the figure 4, the delivery delay consists of three parts in the DRHT.

- Let $d_{ij}^{P_1}$ be the delivery delay in cluster 1.

$$d_{ij}^{P_1} = \frac{|P_1|}{2v} + \frac{l_{ij}^{P_1}}{v} \quad (8)$$

- The delivery delay is the time of waiting of the ferry and the time of carrier of the ferry in the point CC before delivering it to the cluster 2:

$$d_{ij}^{P_{CC}} = \frac{|P_{CC}|}{2v} + \frac{l_{ij}^{P_{CC}}}{v} \quad (9)$$

- Let $d_{ij}^{P_2}$ be the delivery delay in cluster 2 :

$$d_{ij}^{P_2} = \frac{|P_2|}{2v} + \frac{l_{ij}^{P_2}}{v} \quad (10)$$

Therefore, the total delivery delay of the message is $d_{ij}^{P_{all}} = d_{ij}^{P_1} + d_{ij}^{P_{CC}} + d_{ij}^{P_2}$ and one writes:

$$\frac{|P_1|}{2v} + \frac{l_{ij}^{P_1}}{v} + \frac{|P_2|}{2v} + \frac{l_{ij}^{P_2}}{v} + \frac{|P_{CC}|}{2v} + \frac{l_{ij}^{P_{CC}}}{v} = \frac{(|P_1| + |P_{CC}| + |P_2|)}{2v} + \frac{l_{ij}^{P_1} + l_{ij}^{P_{CC}} + l_{ij}^{P_2}}{v} \quad (11)$$

From figure 4, we see that $|P_1| + |P_{CC}| + |P_2| < |P|$ and $l_{ij}^{P_1} + l_{ij}^{P_{CC}} + l_{ij}^{P_2} < l_{ij_F}^{P}$

V. The Probability of Success to Deliver a Bundle with Specific TTL

The probability of success to deliver a bundle is an important metric for the evaluation of data delivery quality in the DRHT under our approach of the election of the CH.

In this section, we try to determine the relations between the probability of delivery success and the TTL of bundles, which can help us to configure a reasonable TTL in order to improve the probability of delivery success of bundles. To do this, we will initially model the time of inter-contact between the reception of the n^{th} and the $(n+1)^{th}$ bundle then we will model the probability of success under the constraint of TTL [23].

A. Modeling of the inter-contact time

The inter-contact time is a property of the mobility, defined as the time passed between two successive contact windows for a given pair of nodes. This latter can exert a considerable influence on the latency in partially connected networks.

In this paragraph we study the transfer time of a bundle in a DTN network and the distribution of the necessary time before that two nodes may (again) communicate. In other words, it is the time during which two nodes are in mutual vicinity. The duration of contact is the duration from which a contact finishes and the next one starts. Thus, it determines how many times a communication is possible. We use stochastic formulas to calculate the intensity of inter-contact λ and to analyze the duration of inter-contact between two nodes n_i and n_j. Consequently, we define the following proposal:

1) Proposition 1

Let $\{T_n, n = 1, 2, \dots\}$ *be a punctual process with a counting function*. Then the process $\{T_n, n = 1, 2, \dots\}$ is a Poisson process with rate λ if and only if:

(i). $X(0) = 0$

(ii). The process $\{X(t), t > 0\}$ is with independent increments;

(iii). For any $0 \le s < t$, the random variable $X(t) - X(s)$ follows a Poisson distribution with parameter $\lambda(t - s)$.

Let $\{T_n, n = 1, 2, \dots\}$ be a Poisson process. By convention we put $T_0 = 0$ and we assume that the first arrival occurs at T_1. We define the n^{th} inter-contact τ_n as the duration passed between the n^{th} and the $(n+1)^{th}$ contact, let:

$\tau_n = T_n - T_{n-1}, n = 1, 2, \dots$

with $T_0 = 0$

The sequence $\{T_n, n = 1, 2, \dots\}$ is called the sequence of inter-contact times. Inter-contact time is a very important property that characterizes the Poisson process; we define the following proposal:

2) Proposition 2

The punctual process $\{T_n, n = 1, 2, \dots\}$ is a Poisson process with rate λ if and only if random variables $\tau_n = T_n - T_{n-1}, n = 1, 2, \dots$ are independent and identically distributed according to an exponential law with parameter λ ; λ is the intensity of inter-contact.

We conclude this paragraph by calculating the average duration of inter-contact, which can be given using the following formula:

$$E(\tau_n) = \frac{1}{\lambda} \quad (12)$$

A shorter inter-contact time means that two nodes n_i and n_j meet themselves quite often. In other words, if two nodes

n_i and n_j have a short inter-contact time, this means that we can wait the next contact to send data directly. Thus, the more enormous λ is, the more reduced the average duration of inter-contact per unit time is. The number of these contacts and the distribution of average durations of inter-contact are two main factors in determining the capacity of opportunist networks. They give an overview of data quantity that can be transferred in each contact opportunity.

B. Probability of successful delivery

We take again the proposals (1) and (2), it is observed that the contact between nodes is distributed exponentially. We use these proposals to model the metrics of performance in the context of the DTN routing system. We use the delivery rate of bundles, the delivery delay and the buffer memory occupation, which are among the principal metrics of performance. Thereby, for a message entering the bundle layer at T_n time, let τ_n be the time of inter-contact between the n^{th} and the $(n+1)^{th}$ bundle. The probability that the bundle is delivered before the TTL expires is calculated using the following formula:

$$P_r(T_n \leq t_{TTL}) = 1 - e^{-\lambda t_{TTL}} \quad (13)$$

VI. Simulation & Results

A. Simulation

Observing that they do not rely on analytical models, the exact evaluation of certain aspects of these protocols is very difficult. This is the reason that leads us to make simulations to study its performance. Our simulation is performed thanks to the ONE (Opportunistic Network Environment) simulator [24], which allows generating a classification of the different routing protocols studied using performance metrics.

B. Results

1) The delivery probability

The successful delivery of bundles is the main task of a DTN routing protocol. Therefore, the probability of successful bundles delivery is the most important parameter when comparing the different DTN routing protocols. This metric characterizes how complete, correct and efficient a routing protocol is. It describes how many bundles were lost, as well as the maximum number of bundles that the network can support.

In figure 2 we show the ratio of delivery of bundles for each protocol by the number of nodes in the network. We noted that for a weak density (equal to 10 nodes) the three DTN protocols gave a low rate of bundles delivered. In fact, since the network's connectivity is weak because the density is weak, protocols do not find any path to reach some destinations, particularly after bundles' TTL expires.

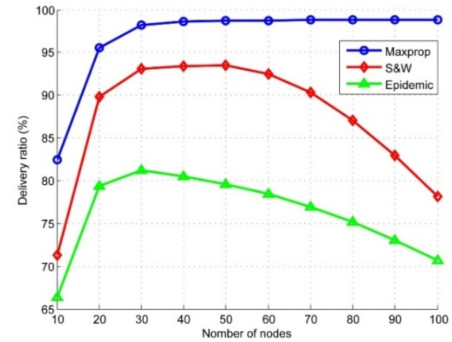

Fig 2. Variation of the delivery probability depending upon the number of nodes.

For medium density (between 20 and 25 nodes), the three protocols had a high ratio of bundles delivered. This is quite an interesting ratio and is much higher than 90% of sent bundles. However, an observed drop with increasing density follows this ratio's increase. This drop is noticed for every protocol except Maxprop, which keeps a constant ratio for all values of density considered by all scenarios (until 100 nodes). In addition, for Epidemic and Spray and wait protocols, at high density, each node must be able to forward more traffic. This traffic increases the rate of collision, interferes with the data's traffic and therefore increases the loss of bundles. Because of its low traffic of control at high density, Maxprop keeps a constant ratio of delivered bundles. These results, which offer a fairly high dilevery rate in the DRHT, can be explained by the use of multiple MF and an optimal CH in each cluster.

2) Average duration of inter-contact

A shorter average life of contacts corresponds to a more dynamic topology of the network. In fact, great values of λ are reflected in shorter contact and inter-contact times and then an increase in contact opportunities. The bundles can benefit from it and their delivery probability increases when λ grows. Conversely, a very great instability of contacts and a lack of connection between nodes tend the delivery probability of bundles towards 0 because there are less contacts lasting in time.

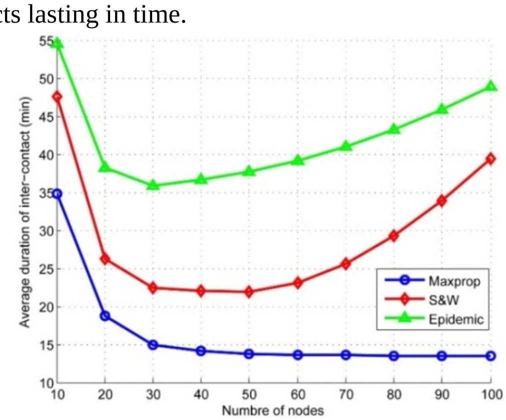

Fig3. Average duration of inter-contact of different protocols evaluated depending upon the number of nodes.

The figure 3 shows clearly that, for a low density, the average duration of inter-contact of the three protocols is quite large because the distances separating nodes increase. We can also note that the average duration of inter-contact of the protocols decreases when nodes density increases. These results are explained by the increment of nodes average degree. Consequently, the end-to-end time becomes minimal. However, for Epidemic and Spray and Wait protocols with high density, each node is held to generate more traffic of control (overhead). This traffic of control increases the rate of collision and disturbs data traffic, and consequently the average duration of inter-contact increases. Thus, we note that Maxprop protocol remains the most efficient among the three routing protocols studied in terms of average duration of inter-contact, which will allow it to minimize the delay of delivery between the source and the destination.

VII. Conclusion

In this research paper, we presented a proposition of a DTN hierarchical topology routing based on three fundamental notions: multiple MF, ferry routes and clusters. Thanks to the superposition of these three notions, we are able to improve the performance of DTN routing in the case of large-scale networks. In fact, DRHT uses multiple ferry messages to make the whole network related. In addition, we showed that the DRHT has a significant impact on the rate and on the delivery delay. In order to evaluate the performance of our proposition, we implemented it in the case of the simulator; ONE and we compared its performance with the performance of Maxprop, Spray and Wait and Epidemic protocols. The results show that Maxprop offers excellent performance in terms of the delivery rate and the delivery delay of bundles.

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