Maximizing the Delivery Rate for DTN Networks

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Abstract. In this article, we present the conception of a DTN routing topology. This topology improves the performance of a DTN network. The idea is to develop a topology based on the following notions : clustering, ferries messages and ferries routes. The simulation results are convincing and show the relevance of the idea which allows to improve the DTN performance compared to the already existing solutions.

Keywords: Ad hoc networks · Delay tolerant networks DTN · Bundles · Hierarchical cluster · TSP · Delivery success probability

1 Introduction

With the increasing use of mobile devices such as smart phones, tablets and laptop computers that are connected wirelessly to a network, these devices use potentially ad-hoc networks. Ad-hoc networks are the only option for some applications, to overcome some constraints such as intermittent connectivity. In most cases these networks do not contain an end-to-end path from source to destination. Delay Tolerant Network (DTN) is an emerging technology for communication without network infrastructure. This DTN network is able to interconnect devices in regions where an end-to-end connection may never be present [1,2].

The DTN communication suffers from certain constraints mainly the intermittent connectivity, the limited resources of the network, the bandwidth and the storage space, etc. These constraints create new problems such as frequent disconnection, low communication rate, modest resources and limited energy. 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.

In order to overcome these constraints of delivering information between different nodes of the network, we introduced our approach based on the idea of structuring and organizing the network before disseminating information by acting on some parameters in ordre to obtain our network topology. The presence

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of such structure would reduce the impact of mobility, optimize both the delivery delay and delivery rate, particularly in the large-scale DTN networks.

The rest of this paper is organized as follows. In Sect. 2, we present the system model, the notations and hypotheses employed in this paper as well as problem statement. Then, we define and study in Sect. 3 the DTN routing hierarchical topology (DRHT). In Sect. 4 is devoted to the model of the success probability of delivery for a bundle with specific TTL (Time To Live) and the average duration of inter-contact. In Sect. 5, we describe the environment and the simulation parameters. In Sect. 6, some numerical results are demonstrated to assess the performance of our approach the DRHT compared to TSP (Travelling Salesman Problem) [9,10]. Finally, in Sect. 7, we conclude our work.

2 System Model and Problem Statement

2.1 Network Model

We consider a DTN network composed of N mobile nodes. We assume that all the nodes of the network would like to transmit and receive data, when two nodes enter in the transmission range on the other it is called a contact. We assume that the interval of inter-contact between two nodes fills the exponential distribution with the same rate λ. This model has been widely supported in the literature because it is regarded as a good approximation of the interval of inter-contact in a significant number of networks DTN realistic [14].

2.2 Notations

For the rest of this work the following notation is used (Table 1):

2.3 Hypotheses

In [15] the notion of ferries routes is based on two fundamental hypotheses:

- The nodes are fixed and their positions are known for the ferry;
- The data traffic between two nodes can be estimated before the construction of the ferry route.

These hypotheses cannot be verified in a DTN network since the contact between the nodes is intermittent, the nodes are mobile and the data traffic cannot be appreciated in advance. Therefore, throughout this paper, we consider the following hypotheses:

- (H1): The nodes have the same range of transmission;
- (H3): The nodes movement is random between and into C_K clusters;
- (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 clusters C_k and $C_{k'}$ follows an exponential distribution of the parameter $\lambda = \lambda_{kk'} = \lambda_{k'k}$.

Table 1. Notations used for modeling

Notation	Definition
N	Total number of nodes of the shared 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
n_i	Node i in the network
v	Speed of the ferry
P	Ferry route
$\|P\|$	Length of a ferry route
l_{ij}^P	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 being delivered to n_j
d_{ij}^P	Average delay to transmit a message of n_i to n_j
μ_i	Message size $(1 \leqslant i \leqslant M)$

2.4 Problem Statement

The delivery rate and delivery delay of the bundles are among the major challenges of the DTN networks. Thus, the problem is how to make the whole network fairly connected in order to optimize the delivery rate and the delivery delay while taking into account the added delay before sending a message. A compromise must thus be found between the delivery rate of a bundle and the additional delay caused by its delay, so as not to overload the bundle layer with expired information.

2.5 Function Objective

Our objective function of the delivery delay of our approach of routing the DRHT is written as follows:

$$\Delta_{DRHT} = \frac{\sum_{i=1}^{M} \mu_i d_{ij}^P}{\sum_{i=1}^{M} \mu_i} \tag{1}$$

3 DTN Routing Hierarchical Topology (DRHT)

3.1 Description of the construction of DRHT

The main objective of our approach is to improve the performance of DTN networks. Our approach of routing the DRHT is based on the principle of cooperation between ferries messages and clusters heads via ferries routes. Thus the construction of our approach is based on the following elements for each cluster [3–7]:

1. Cluster-head (CH);
2. Center of the cluster (CC);
3. Ordinary node (ON);

3.2 Analysis of Delivery Delay in the DRHT

We analyze the delivery delay in our approach the DRHT based on the works [15,16] and we distinguish two cases:

When nodes n_i and n_j are in the same cluster C_k. The delay of single ferry routing is:

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

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

$$d_{ij}^{P_k} = \frac{|P_k|}{2v} + \frac{l_{ij}^{P_k}}{v} \tag{3}$$

According to (2) and (3), we note that $d_{ij}^{P_k} < d_{ij_F}^{P}$ since $|P_k| < |P|$ and $l_{ij}^{P_k} < l_{ij_F}^{P}$. which 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.

When nodes n_i and n_j are situated in different clusters C_k and $C_{k'}$. From the Fig. 1, in the DRHT the delivery delay consists of three parts :

- Let $d_{ij}^{P_1}$ be the delivery delay in cluster C_1:

$$d_{ij}^{P_1} = \frac{|P_1|}{2v} + \frac{l_{ij}^{P_1}}{v} \tag{4}$$

- The delivery delay $d_{ij}^{P_{CC}}$ is the time of wait of the ferry and the time of carrying of the ferry in the point CC before delivering it to the cluster C_2:

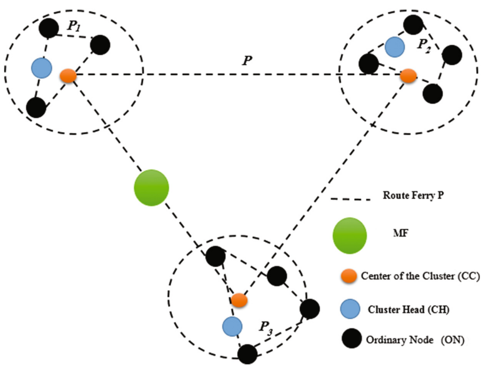

Fig. 1. Diagram of the DRHT.

$$d_{ij}^{P_{CC}} = \frac{|P_{CC}|}{2v} + \frac{l_{ij}^{P_{CC}}}{v} \quad (5)$$

– Let $d_{ij}^{P_2}$ be the delivery delay in cluster C_2:

$$d_{ij}^{P_2} = \frac{|P_2|}{2v} + \frac{l_{ij}^{P_2}}{v} \quad (6)$$

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:

$$\frac{|P_1|}{2v} + \frac{l_{ij}^{P_1}}{v} + \frac{|P_{CC}|}{2v} + \frac{l_{ij}^{P_{CC}}}{v} + \frac{|P_2|}{2v} + \frac{l_{ij}^{P_2}}{v} = \frac{(|P_1| + |P_{CC}| + |P_2|)}{2v} + \frac{l_{ij}^{P_1} + l_{ij}^{P_{CC}} + l_{ij}^{P_2}}{v} \quad (7)$$

From Fig. 1, we see that $|P_1| + |P_{CC}| + |P_2| < |P|$ and $l_{ij}^{P_1} + l_{ij}^{P_{CC}} + l_{ij}^{P_2} < l_{ij_F}^{P}$

4 The Probability of Success to Deliver a Bunble with Specific TTL

4.1 Modeling of the Inter-contact Time

Proposition 1. *Let the punctual process defined by* $\{T_n, n = 1, 2, ...\}$*. This process is a Poisson process of lambda if the variables are random* $\pi_n = T_n - T_{n-1}, n = 1, 2, ...$ *and also are identically distributed according to exponential law with parameter* λ*. We can calculate the average duration of inter-contact using the following formula [8]:*

$$E(\tau_n) = \frac{1}{\lambda} \quad (8)$$

4.2 Probability of Successful Delivery

From the Proposition 1, we obtain an exponential distribution of the contact between two nodes. We exploit this proposition in order to model a main performance metric in the context of DTN routing. This metric is represented by the delivery rate of the bundles. Therefore, suppose that a message arrives in the bundle layer at time T_n, let π_n be the inter-contact time of n^{i} and $(n+1)^{\mathrm{i}}$ bundle. The delivery probability of the bundle before the expiration of TTL (Time To Live) is calculated according to the following formula [8]:

$$P_r(T_n \leq t_{TTL}) = 1 - e^{(-\lambda t_{TTL})} \quad (9)$$

5 Simulation

We have implemented our approach the DRHT as well as the approach TSP under the ONE (Opportunistic Network Environment) simulator [20] for the purpose of conducting an evaluation of our approach of routing the DRHT with that of TSP. The Table 2 shows the configuration of our simulation.

Table 2. Parameters of simulation

Parametre	Value
Total simulation time	12 h
World size	$4500 \times 3400\ m^2$
Routing protocol	Spray and Wait and Maxprop
Node buffer size	5 M
No of nodes	10, 20, 30, ..., 100
Interface transmit speed	2 Mbps
Interface Transmit range	10 m
Message TTL	60 min
Node movement speed	Min = 0.5 m/s Max = 1.5 m/s
Message creation rate	One message per 25–35 s
Message size	50 KB to 150 KB

6 Results and Discussion

In this part, we focused on evaluating the performance of our approach the DRHT in comparison to the TSP approach in terms of delivery rate.

6.1 Delivery Rate

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. We compared the perfomance of delivery rate between DRHT and TSP, the results are shown in Fig. 2.

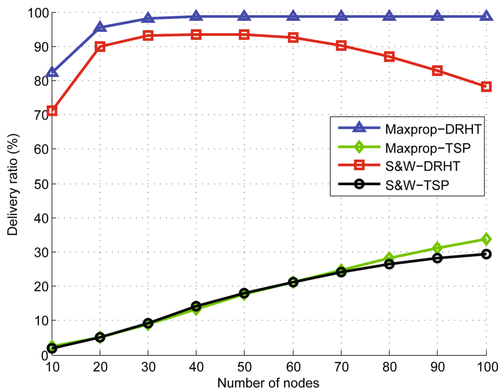

Fig. 2. Variation of the delivery rate depending upon the number of nodes.

In Fig. 2, we represent the delivery rate of bundles for both approaches: DRHT and TSP in combination with DTN routing protocols, according to the network density. We note that for a weak density (equal to 10 nodes), both approaches give a low rate of delivered bundles. 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 expiry. For a medium density (between 20 and 25 nodes), both approaches have a high rate of delivered bundles. For DRHT, this rate is very interesting and far exceeds 90% of sent bundles contrary to TSP that doesn't exceed 35%. However, an observed drop with increasing density follows this rate's increase in the DRHT. This drop is noticed for Spray and Wait protocol while Maxprop keeps a constant rate for all values of density considered by the scenario (until 100 nodes). In fact, for Spray and Wait protocol, at high density, each node must be able to forward more traffic of control. 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 protocol is able to keep a constant rate of delivered bundles. In sum, the DRHT, compared to the TSP, gives a very important delivery rate close to 90% or even more, and this in combination with any routing protocol.

7 Conclusion

This article deals with the implementation of a routing topology named after the DRHT. Thanks to the superposition of three notions : ferries message, ferries routes and clustering, we are able to improve the performance of DTN networks. The results of the simulations show that the proposed approach the DRHT improves the performance of delivery rate compared to existing approaches such as TSP.

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