New DTN Routing Algorithm

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Abstract

Routing in Delay Tolerant Networks is currently considered as one of the most attracting research areas. While several efforts have led to the introduction of different routing protocols for Delay Tolerant Networks, there are few approaches, which aimed to improve existing protocols. In this paper, we present a new algorithm based on the predictability concept since it introduces better resources management in terms of bandwidth, messages delivery compared to other routing algorithms for DTN. We prove by large-scale simulations, the effectiveness of our algorithm in terms of eventually delivered messages, failed transmissions, dropped messages between nodes, buffer time and hop count enhancement.

Keywords: *Delay Tolerant Networks; routing; protocols; predictability; algorithms; ONE-Simulator.*

1. Introduction

Assuming that the path between source and destination, and large bandwidth are available, most classic wireless mobile networks based on the TCP principles have known a big success. Nevertheless, when a wireless mobile network suffers from the lack of path between source and destination, intermittent connectivity, as well as long latency and limited bandwidth, the TCP concept can, unfortunately, no longer be applied. In these particular circumstances, DTN networks were introduced. DTN networks are also infrastructureless wireless networks like Ad-hoc and mobile Ad-hoc networks (MANET) where the deployment does not rely on fixed infrastructure such as router and base station, instead the cooperation between nodes are required for successful data transmission [14]. These networks have a variety of applications in situations that include crisis environments like emergency response and military battlefields, deep-space communication, vehicular communication, and non-interactive Internet access in rural areas [12].

Through the implementation of a new layer (Bundle) over the transport layer and the deployment of the store and forward mechanism [10], DTN networks deal with the problems that are due to intermittent connectivity, long delay, asymmetric data rates and high error rate [1] .

A suitable routing protocol is considered as an important factor to ensure messages delivery between source and destination in DTNs. In this work, we propose an improvement of the predictability concept concerning Prophet routing protocol through a new algorithm and evaluate the efficiency of our proposed approach from different sides.

2. Routing in DTN

Routing in DTN is based on the choice of the optimized way connecting source to destination. The main goals of this choice are messages delivery rate, impact on network resources and latency optimization [13]. In this section, we will be presenting some of most famous DTN routing approaches and we will be discussing the store and forward concept.

2.1 Routing Concept

Messages delivery can be either randomly achieved or based on network topology information [5]. In fact several routing protocols have been proposed in the literature. Epidemic routing [6], Prophet [4], Spray and wait [8], MaxProp [11], Rapid [7] are only few among others.

The Epidemic approach is based on the replication process. This protocol ignores the fact that nodes have the appropriate information defining paths, leading to the destination. Instead, the source generates numerous copies of the same message to a group of nodes. Those nodes save the message in their buffers until the connection to destination is established. Once two nodes meet, they exchange the entire carried messages, so that finally both of them have the same list of messages. This approach leads to a fast distribution of messages. It can also be considered as an optimal approach when the nodes have enough buffers, infinite bandwidth and sufficient energy. Actually, it is not the real world [5].

Although the epidemic approach has many benefits such as high delivery rate and optimal latency, it presents a clear flaw described by a continuous spread of messages even if they are already delivered. This fact leads to a bandwidth overhead and high resources usage on the entire network.

To overcome some weaknesses caused by the epidemic approach, the continuous spread of messages for instance, Prophet Protocol (Probabilistic Routing Protocol using a History of Encounters and Transitivity) was introduced as an alternative to the previous one. Since nodes don't move in an entirely random way, we can consider that two nodes, which meet frequently each other, could have a high probability to get in touch again. We use this probability to estimate which nodes have the right predictability for next message hop.

The Prophet approach is based on the delivery predictability metric which is calculated at each node A for each known destination B [4] and which will be represented by P(A,B) $\in$ [0,1] in the rest of this paper.

This metric is calculated so that a node with a higher value for a certain destination is estimated to be a better candidate for delivering a bundle to that destination (if P(A,B) > P(C,B), bundles for destination B are preferable to forward to A rather than C) [4].

Unlike the epidemic approach, when two nodes using prophet approach meet each other, they exchange the values of the metrics P(A,B) for different known destinations. The calculation of the delivery predictabilities is built upon three parts.

When node A meets node B, A updates P(A,B) according to equation (1) [4].

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

This equation is used to associate the highest delivery predictability to nodes which meet each other more frequently. Once two nodes encounter each other, they exchange all probability held by each one of them, as well as the probability of delivery calculated for other nodes in the DTN network.

Thereby, node A updates the delivery probability for each node C known by node B in accordance with equation (2) [4]. P_{init} is a constant which describes the initial predictability of all nodes they meet each other for the first time. β is a scaling constant that controls how large an impact the transitivity should have on the delivery predictability with $\beta \in [0,1]$ [4].

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

Finally, if two nodes do not encounter each other during an interval, they are less likely to be good forwarders of bundles to each other, thus the delivery predictability values must age and be reduced in the process. The aging equation is shown in equation (3), where $\gamma \in [0,1]$ is the aging constant and K is the number of time units that have elapsed since the last time the metric was aged. The time unit used can differ, and should be defined based on the application and the expected delays in the targeted network [4].

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

As mentioned above, there are other routing protocols which were presented such as Spray and Wait [8], MaxProp [11], Rapid [7] among other. In this paper, we focus only on the improvement of the prophet routing protocol compared to the classic prophet and to the epidemic approach.

2.2 Store and forward concept

During the movement between source and destination, which could be probably long, a node should have the opportunity to save messages until final delivery.

Through the store and forward mechanism, a node is equipped with a buffer in which messages are saved and carried along the movement process. Depending on the buffer size, each node has a limited capacity for saving messages. In case of buffer size exceeding, new messages will be automatically dropped due to congestion.

3. Proposed approach

Through this paper, we try to present our approach regarding the improvement of the prophet protocol with the proposal of new predictability equations. Our approach is based on the extension of the Prophet routing algorithm. This algorithm promotes the exchange between a node and another node that has a high probability to reach the destination compared to other mobile nodes.

But the raised problem is that:

- The number of messages reaching destination over the number of messages sent by the source is not always satisfactory.
- The number of hops between the source and the destination and the number of messages dropped during transmission between the source and the destination remains too large.
- The number of messages rejected because of congestion of the storage unit nodes is still substantial.

For these reasons, we introduce α as an improvement factor in equations 1, 2 and 3 with $0<\alpha<1$ in order to overcome the problems mentioned above as followed:

$$P_n(A,B) = P^{\alpha}(A,B)_{old} + (1 - P^{\alpha}(A,B)_{old}) * P_{init} \quad (4)$$

P_n denotes the new proposed probability. The purpose of this change is to increase the contact probability P (A, B) between the nodes A and B. If this probability increases, nodes A and B have a better opportunity to meet each other.

$$P_n(A,C) = P^{\alpha}(A,C)_{old} + (1 - P^{\alpha}(A,C)_{old}) * P(A,B) * P(B,C) * \beta \quad (5)$$

Mathematically, we can easily prove that: For $\forall\ \alpha \in [0,1]$ and $P \in [0,1]$ $P^{\alpha} \geq P$ (7)

Recalling the equation (1)

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

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

With P_c(A,B) the equation (1) of prophet and P_n (A,B) the new proposed predictability equation (our approach).

(7) ==> $P^{\alpha}(A,B)_{old} \geq P\ (A,B)_{old}$

==> $1 - P^{\alpha}(A,B)_{old} < 1 - P\ (A,B)_{old}$

==> $(1 - P^{\alpha}(A,B)_{old}) * P_{init} < (1 - P\ (A,B)_{old}) * P_{init}$

==> (b) – (a)

==>

$$P_n - P_c = P^{\alpha}(A,B)_{old} - P(A,B)_{old} + (P(A,B)_{old} - P^{\alpha}(A,B)) * P_{init}$$

==> $P_n - P_c = (P^{\alpha}(A,B)_{old} - P(A,B)_{old}) * (1 - P_{init})$

While $P^{\alpha}(A,B)_{old} - P(A,B)_{old}) \geq 0$ and

$1 - P_{init} \geq 0$

==> $P_n - P_c \geq 0$

==> $P_n \geq P_c$

This leads us to conclude that the contact between two nodes A and B is more favored in the case of P_n than the case of P_c.

Recalling equation (3):

==> $P\ (A,B) = P(A,B)_{old} * \gamma^{k}$

==> $\forall \alpha \in [0,1], \gamma^{k/\alpha} < \gamma^{k}$ with γ=0.98

==> $\forall \alpha \in [0,1], P(A,B)_{old} * \gamma^{k/\alpha} < P(A,B)_{old} * \gamma^{k}$

with $P_{naging}(A,B) = P(A,B)_{old} * \gamma^{k/\alpha}$ (6)

and $P_{caging} = P(A,B)_{old} * \gamma^{\alpha}$

P_{naging} presents the new aging equation of prophet with the implementation of the factor α. P_{caging} presents the classic aging equation of prophet. Since P_{naging} is lower than P_{caging}, P_{naging} will promote better results concerning the aging concept. In other words, P_{naging} will decrease the value of the predictability for the nodes which do not have enough opportunity to reach the destination. With the new equations (4, 5 and 6) mentioned above, we are interested in picking up the results concerning delivered, aborted transmissions and dropped messages among others and looking for, if they really present clear benefits regarding the classic prophet routing protocol.

4. ONE: Simulation Environment

The simulator we use in our work is ONE: Opportunistic Network Environment (ONE). Unlike other DTN simulators, which usually focus only on simulating routing protocols, the ONE combines mobility modeling, DTN routing and visualization in one package that is easily extensible and provides a rich set of reporting and analyzing modules [2].

A detailed description of the simulator, the ONE simulator project and the source code are available in [2] and [3].

Node movement is implemented using movement models. These are either synthetic models or existing movement traces. Connectivity between the nodes is based on their location, communication range and the bit-rate. The routing function is implemented using routing modules that decide which messages to forward over existing contacts. Finally, the messages themselves are generated through event generators. The messages are always unicast, having a single source and destination host inside the simulation world. The simulations can contain any number of different types of agents, i.e., wireless nodes. The nodes are presented in groups and each group shares a set of common parameters such as message buffer size, radio range and mobility model. Because different groups can have different configurations, creating a simulation with pedestrians, cars and public transportation for example is made possible [2].

4.1 Mobility Modeling

Mobility models dictate how the nodes move during the simulation. Three different types of mobility models were initially implemented for ONE. For reference purposes, ONE includes the basic Random Waypoint movement model. For more realistic mobility scenarios, ONE provides variety of map-based movement models which constrain the node movement to predetermined paths. Finally, ONE also supports importing mobility data from external sources [2].

Map-based movement models accept map data that is described using a subset of the Well Known Text (WKT) format. WKT is an ASCII based format that is commonly used in Geographic Information System (GIS) programs. Since basically all the digital map data is available in some format that GIS programs understand, they are usually easily convertible to the form supported by the ONE. Also, GIS programs can be used as powerful map editors for the ONE [2]. The free, Java-based, open source GIS program Open JUMP [10] was used for editing and converting the maps in our experiments. Different node groups can be configured to use only certain parts of the maps which can prevent cars, for example, from driving on pedestrian paths or inside buildings (if paths in buildings are also defined) [2]. The Map-based movement model is the one which we used in our simulation. There are of course other mobility models which are supported by ONE such Shortest Path Map-Based movement Model (SPMBM) and external mobility model.

4.2 Routing Simulation

While the mobility models decide where the nodes should move next, the routing modules get to decide where the messages, or bundles, end up. The ONE has six implementations of different well known routing algorithms and also a passive routing module that can be used for interaction with external DTN routing simulators [2]. The active routing modules included in the ONE are: epidemic routing [6], Prophet [4], Spray and wait [8], MaxProp [11], Rapid [7].

When two (or more) nodes meet and there is a chance to exchange messages, all of the routing modules first check if they have any messages that are destined for the other node and try to send them. If the message was already received by the node, it declines receiving it and other messages can be tried.

Generally, if any messages are exchanged, the behavior with the rest of messages depends on the routing algorithm.

4.3 Graphical User Interface mode

In the GUI mode the simulation is visualized in real time as shown in Figure1. The largest part of the GUI is taken by the play field view which contains a bird's-eye view of the geographical simulation area. Node locations, their radio range, current paths, amount of messages etc. are visualized on the play field view. If the current movement model is mapbased, also the map path segments are drawn in the view. Additionally, a background image, such as an aerial photograph or a raster map, can be displayed under the other graphics [2].

5. Simulations Results

For our simulation, we are interested in communications between pedestrians in a part of Cadi Ayyad University campus in Marrakech/Morocco. We also suggest one

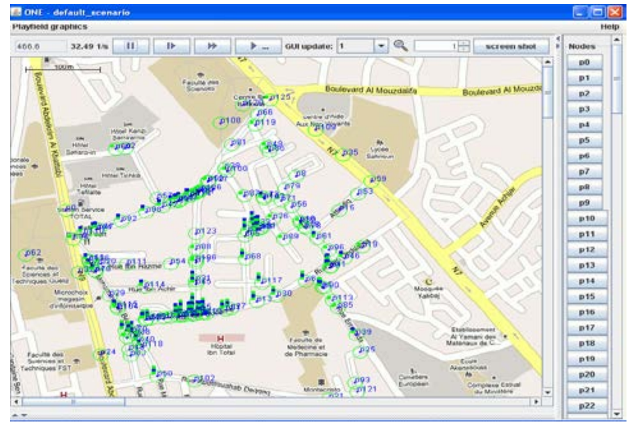

Fig. 1 ONE GUI mode of the ONE Simulator area: Cadi Ayyad Campus.

group of nodes is distributed between two faculties as depicted in Figure1

Moreover, we suggest a multi way path between the two parts of the campus. We have chosen this path model in order to monitor messages delivery-rate, aborted transmissions, dropped messages, buffer time average and the hop count state when the number of hosts increased. The chosen simulation area is a part of Cadi Ayyad University campus in Marrakech / Morocco. It is about (3500x3500m) and is connecting two faculties: Faculty of Sciences and Techniques (FST) and the Faculty of Sciences Semlalia (FSSM).

We run simulations with a various number of nodes: 4, 8,16,32,64 and 128 expanded across the above area during 5 hours (around 18000 seconds). For the group of nodes, we run numerous simulations with different values of the predictability improved factor (α). We used: $2*10^{-3}$, $2*10^{-4}$, $2*10^{-5}$, $2*10^{-6}$ and $2*10^{-7}$ as discrete values for (α). We, then, compare the results obtained to the classic prophet protocol where α=1, and to epidemic routing, through the MessagesStatsReport mentioned in the report subdirectory of the ONE simulator. Regarding Movement model, we choose the MapBasedMovement since nodes should follow the drawn map joining the two parts of the campus. The movement path in accordance with the campus map was drawn with help of OpenJUMP [9]. The characteristics of nodes used during the simulations are described as follows: - Transmit Range (set to10m): Range (meters) of the hosts' radio devices. - Transmit Speed (set to 250k): Transmit speed of the hosts' radio devices (bytes per second). - Wait Time (set to 0,120s): Minimum and maximum of the wait time interval (seconds). Defines how long nodes should stay in the same place after reaching the destination of the current path. - Walking Speed (set to 0.5, 1.5): Minimum and maximum of the speed interval (m/s). Defines how fast nodes move. - Buffer Size (set to 5Mbytes): Size of the nodes' message buffer (bytes). When the buffer is full, node cannot accept any more messages unless it drops some old messages from the buffer. We notice, first of all, that the amount of delivered messages increases when α takes the value $2*10^{-5}$, $2*10^{-6}$ and $2*10^{-7}$. These values can be considered as better delivery improved factors compared to the classic prophet where α=1 and also to epidemic routing protocol. Figure2 illustrates this improvement in messages delivery.

Concerning the aborted transmissions due to the intermittent connectivity, we notice as shown in Figure3. , that the amount of aborted transmissions with our approach is reduced compared to the classic prophet where α=1 also to epidemic routing protocol. Again we prove that $α=2*10^{-7}$, $2*10^{-6}$, $2*10^{-5}$ presents a good improvement for reducing the amount of aborted transmissions. The dropped messages issue is related to the buffer size overload, as shown in Figure4, the amount of dropped messages with our approach is reduced compared to the classic one.

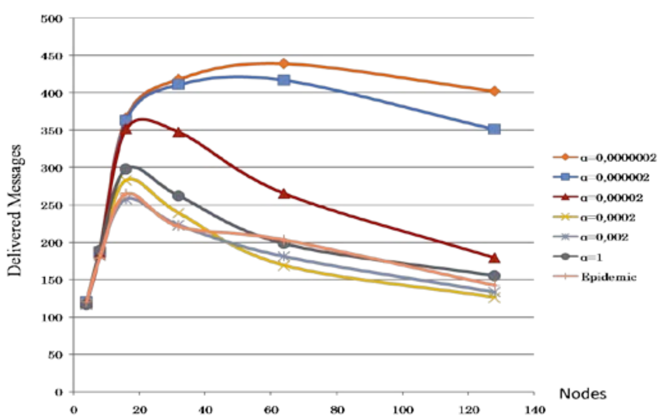

Fig. 2 Comparison of delivered messages between our approach and others routing algorithm.

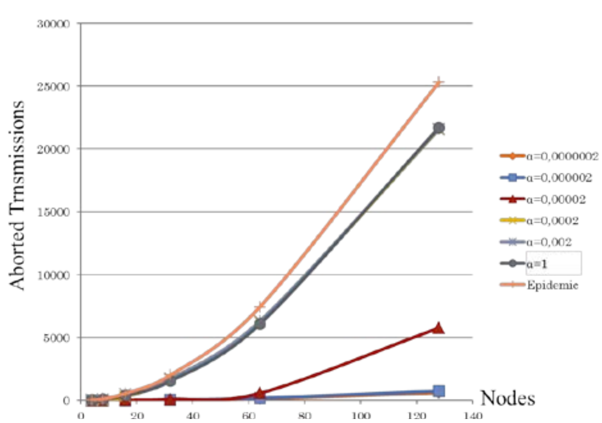

Fig. 3 Comparison *of aborted transmissions between our approach and others routing algorithm.*

Since the amount of dropped messages is reduced, these messages have the opportunity to stay longer at the buffer. Finally, Figure 6 shows the state of the hop count average. In our approach, the hop count is decreased in comparison to the classic prophet where α=1 also to epidemic routing protocol. Thereby a message sent from a source needs fewer hop count than before to arrive to the destination.

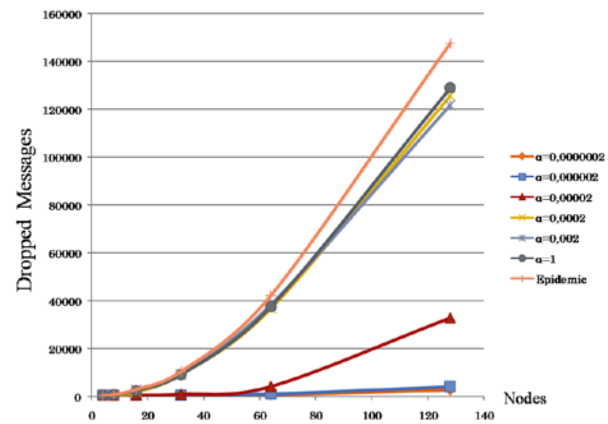

Fig. 4 Comparison *of dropped messages between our approach and others routing algorithm.*

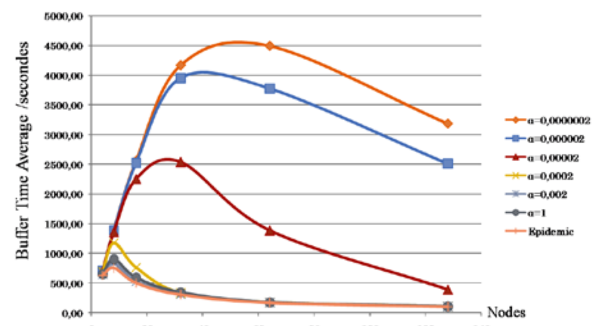

Fig. 5 Comparison *of Buffer Time Average between our approach and others routing algorithm.*

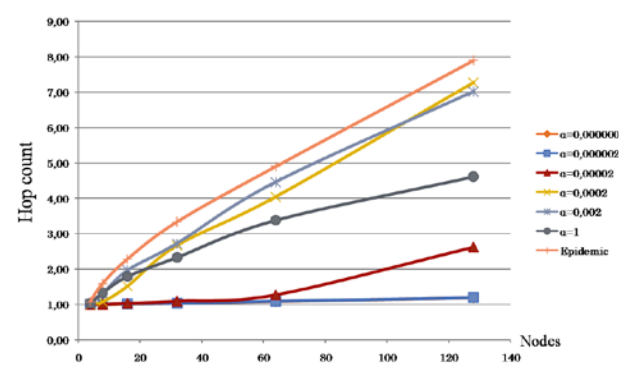

Fig. 6 Comparison *of Hopcount Average between our approach and others routing algorithm.*

6. Conclusions and future work

In this paper, we focused on the improvement of the prophet routing protocol through a new approach by implementing the predictability improved factor. We were interested in the amount of finally delivered messages to the destination, the amount of aborted transmissions, dropped messages, the buffer time and the hop count state.

Compared to the classic prophet algorithm and to the epidemic routing protocol, our approach has proved a clear improvement of the predictability concept. Through the new approach, more messages can arrive to the destination with less aborted transmissions. Moreover, messages have an opportunity to stay for a longer time in the buffer and are proved to require fewer hops between source and destination leading to more energy efficiency.

Future work will focus on assessing the impact of having different nodes' energy levels while searching for forwarding nodes. It will also focus on introducing the priority concept in message delivery between the nodes.

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