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EXAMPLE OF ROUTING PROTOCOLS IN DELAY TOLERANT NETWORKS

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Dedicated to the 75th birthday of Professor Eleonor Ciurea

Abstract

This paper is an extension of [7], which represents an overview of DTNs (Delay Tolerant Networks). The introduction of this article comes with a global view over this type of networks. The literature review section identifies some challenges that this type of network meets and one of the most important evaluation criteria for a DTN. This work comes with a new section which brings some examples of DTN routing algorithms that were introduced and presented in different papers. The personal remarks section contains some ideas about the routing algorithms and their performances in DTNs.

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1 Introduction

Nowadays we use networks in almost every domain. One of the most used networks is the Internet, which contains smaller networks with different communication protocols. The most used Internet protocol is TCP/IP. In addition to wired networks, there are also wireless networks. In the second category there are Mobile Ad Hoc Networks (MANETs) where two network devices connect if they are in the connection range of one another. Links between network connected devices may have periods when they are active and periods when they are inactive. The activity intervals are influenced by the limited energy resources of the devices or by their high mobility [1]. To deal with such challenges and limitations provided by network to communication protocols, another overlay network over MANETs has been developed. This type of network provides a powerful enough mechanism for storing data packets over a long period of time and redirecting

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them after re-establishing the connection [2, 3]. This overlapping network tolerates long links disconnections and very long data transmission delays. Networks of this type are called DTNs (Delay and Disruption Tolerant Networks), and their architecture is proposed by S. Burleigh & Co's articles in [2, 3].

Both wired and wireless networks are able to connect different devices on very large distances. Nowadays it can be possible to connect from a smart phone to many servers in all the world. Even if these type of networks are very powerful and successful, they can't reach every region on the earth and in some cases, the cost for developing them can be a high one. The limitation of traditional wired and wireless networks due to the fact that they are based on some technologies that work with a set of rules that cannot be applied in all environments. For that reason a network like DTN was created.

According to [4], a DTN is a network that can connect devices and area on the earth that cannot be served by a traditional network. This is due to the fact that there can be no continuous communication between the end points of communication (the source and the destination of the message). However, in order to make communication possible, the intermediate nodes must take over the custody of the transferred data and pass it on as soon as an opportunity arises. Both nodes and links between them are unsafe in a DTN, and disconnections can be long. A critical challenge for DTN networks is the determination of the transfer route of the message without ever having a previously established connection from the source node to the destination node.

According to its specifications, there are many applications for Delay Tolerant Network: wireless communication and monitoring, cargo tracking, agricultural crop monitoring, security and disaster communication, global airport traffic control, infrastructure integrity monitoring, animal migration, atmospheric and oceanographic conditions, unmanned undersea vehicles, oil and mining underground sensors, etc. DTN could also be used to receive data from everything ranging from sensors in oceans, to satellites in space.

2 Literature review

Delay Tolerant Networks are subject to challenges that are not present in traditional networks. These challenges come from the need to deal with the network interruptions that influence the routing and sending of the messages. Since this type of network connects various types of devices, there are many issues that the routing mechanism should know and manage.

In [4], Evan Jones identified the following challenges:

- Contact schedule - is one of the most important features of a DTN because one of the most significant factors is the waiting time of a node until it comes in contact with another node. This factor may vary from seconds to days and schedules can have variable precision.

- Links capacity - refers to the amount of data that can be exchanged between nodes. This depends both on the technology used for connection and on the duration of the connection. Even if the duration of the connection is known, it may not be possible to predict the amount of transferred data due to transmission fluctuations.

- Buffer size - is an important factor in DTN because, due to long network disconnections, the messages have to be stored in node buffers for a long time. This means that intermediate routers need to have buffers with enough space to store all the messages that are waiting for communication opportunities.

- Processing power - is another important factor in DTN because they connect various types of devices that cannot serve a traditional network. Such devices can have a very small dimension and, implicitly, a small processing capacity due to the processor and the memory. These nodes will not be able to run complex routing protocols.

- Energy power - some nodes in DTN have limited power resources because they are mobile or because they are in a location without easy access to the power grid. The routing process consumes energy when sending, receiving or storing messages and that is why energy power is a crucial factor.

Routing protocols refers to the communication modality between routers for distributing messages through a network from the source node to the destination node. Routing algorithms determine a specific route between two nodes.

In [5] we can find DTN routing protocols divided into two major categories: forward based protocols and flooding based protocols.

Forward based protocols will keep a single copy of each message. This category is divided into three subcategories: infrastructure-based strategies, prediction-based strategies and social strategies.

The infrastructure-based approach is defined by:

- the existence of mobile agents, that will handle the transmission of messages where there are network disconnections

- the prediction-based approach, that uses historical knowledge to predict the motion of the nodes

- the social approach, that is based on knowing the social behavior of the network nodes and applying this knowledge to anticipate future changes.

Flooding based protocols have an opposite approach because they multiply the messages to spread them into the network. This category is divided into subcategories too: spray based, social based and coding based.

The spray-based approach applies a two-phase algorithm: a spraying phase that sends a number of copies of the message and a queuing phase where the nodes use the direct delivery. The social approach of the flood-based protocol is similar to the social approach of the previous protocol, but this time multiple copies of the message are created to increase the likelihood that messages will be delivered. The coding approach divides messages into smaller fragments, floods the network with them, and then nodes will be charged with the recombination and forwarding of these fragments. Once all the fragments have arrived at the destination, they are decoded and the original message is reassembled.

In order to compare routing strategies, certain performance criteria must be established. In [4] we find three such criteria: delivery rate, transmission and latency.

Delivery rate is an important evaluation criteria because a DTN cannot send a message for a long period of time because of the frequent network disconnections.

Some routing strategies send more messages than others, whether they use multiple copies of the same message or make different choices on setting up the next hop, or because they use more complex processing. The number of messages transmitted is an important evaluation criteria of a DTN since each message has certain processing needs, but also a measure of energy consumption because each message transmission consumes energy.

Latency is defined by the time period between the moment the message is generated and the moment it is received by the destination. This criterion is important because many applications can benefit from a short waiting time, even if they are able to tolerate long waiting times.

3 The Dynamic Nature of DTN

As mentioned above, by definition, the Delay Tolerant Networks have a dynamic character. This dynamism is imprinted to the network , first of all, by the nodes mobility. The mobility of wireless devices may be random or deterministic, determined in particular by a movement schedule or by the predictions that can be made based on the history of network nodes movement.

This mobility of network nodes can lead to different network topologies at different moments in time. Assuming that the network is modeled as a graph, at different times $t_i(i = 1, n)$, the graph may have a different configuration: new edges can occur, edges that have existed at one of the previous configurations can disappear, edges weight may change.

In order to make a good routing in a network with such behavior, it is advisable that the nodes know some network information (especially about their neighbor nodes) to make a more accurate prediction about the route they choose for the message they have in buffer and which they have to deliver to the destination.

The information that a node requires in order to be able to calculate the route of a message as efficiently as possible:

- the history of its encounters with other nodes, meaning the average of the waiting times up to the meetings with those nodes
- eventually the history of its neighbor's meetings with other nodes
- the connectivity duration with the nodes it came into contact with

- the space into its neighbor's buffers
- the bandwidth on network segments to its neighbors

The information that a node could use to better identify the next hop of a message it has in its buffer could continue this way. However, the more information it has, the more it needs a large processing capacity and also a large storage space.

Returning to modeling a network like a graph, some of the information we have discussed above can be encapsulated in the edge weight, to be considered when applying a shortest path algorithm that identifies the optimal route to be used for a message to follow from the source node to the destination node.

Criteria that can influence the weight of an edge:

- average waiting times between two consecutive meetings of a pair of nodes
- the space in the neighbor node buffer

The longer the waiting time for connecting the two nodes is, the higher the weight on edge between them will be. As the volume of messages in the neighbor node buffer is closer to the maximum limit, the greater the weight of the arc between the two nodes will be. In this way, a classical shortest path algorithm, such as Dijkstra algorithm, will be able to determine an optimal route for delivering messages to the destination.

4 Routing protocol examples

There are areas where there is no Internet connection, but there are computers connected to each other through a network. This network can communicate with the Internet using one or more mobile devices which are able to receive, store and send data. When one of these mobile devices are in the coverage range with the local network, it can receive information from it. The device will store the information until it is in the coverage area of the closest city with an Internet connection and there it will send the data received from the local network. Of course, the communication is possible in the opposite direction, too. The figure below illustrates this situation.

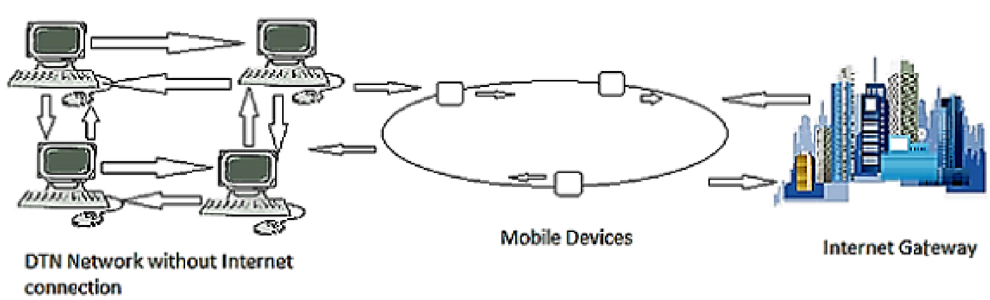

Figure 1: An ad-hoc network communication with Internet via DTN

In situations like that, the DTN network must make the best decisions for sending the messages to optimize the network evaluation criteria. The messages delivery can be done either randomly or based on network topology information. Some of the main routing protocols proposed by the specialty literature are: Direct Contact or Direct Delivery, Epidemic [8], PRoPHET [9], MaxProp [10], Spray and Wait [11], RAPID [12], SimBet [13].

Direct Delivery - is the simplest approach of a forward-based routing protocol. The node will deliver the message only to the destination, when they meet. This is a method completely based on chance and it proves to be quite useful if the movement of the nodes is random and the nodes have a high probability to meet each other. If the nodes don't meet frequently, this approach will not work properly.

Epidemic Routing [8] - is the basic form of the flood-based routing. This algorithm involves the creation of multiple copies of the message. According to [8], when two nodes meet, they send information about their buffers and identify the packages the other node has and it doesn't. They exchange the missing packages such that, at the end of the process, the two nodes have the same content in their buffers. This process repeats every time two nodes have contact. The Epidemic approach seems to be efficient for the networks that are not very loaded. For busy networks, this algorithm will became completely inefficient.

PRoPHET [9] - is a flood-based routing protocol, similar to Epidemic, but when two nodes meet, they use the information from the other node's buffer to update its predictability array. Each node computes the predictability of its messages delivery. After that, the node will forward messages only to the nodes that have a bigger delivery predictability than himself.

MaxProp Routing [10] - is a routing protocol based on prioritization of sending and dropping messages. It is based on a buffer with sorted messages. Using this buffer, the algorithm will decide which messages will be sent first and which will be dropped first. The specificity of the algorithm is to obtain the probability of encountering the nodes. In this way, every node will keep an array with n-1 elements, where n represents the number of all nodes in the network. Those arrays store the probabilities of meeting the other nodes. First, all nodes are initialized with probabilities equals to $\frac{1}{n-1}$. In this way, in the very beginning, all nodes have equal probabilities to meet. When two nodes meet, they increase by 1 their former probability of meeting and after that they compute again all the probabilities.

Suppose that we have the network in the following image, where we consider that node 1 is the current node. This node will have an array with meeting probabilities of node 1 with nodes 2, 3, 4 and 5. Those probabilities will be initialized with $\frac{1}{5-1} = 0.25$. The array of node 1 will be [0.25, 0.25, 0.25, 0.25].

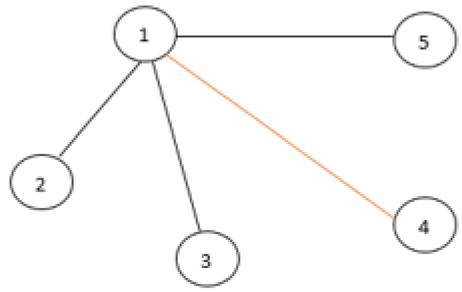

Figure 2: Graph with 5 nodes

When node 1 meets node 4, their meeting probability will increase by 1 and the array will became [0.25, 0.25, 1.25, 0.25]. The values in the array will be calculated again so we get their sum equals 1. The array will became [0.125, 0.125, 0.625, 0.125]. After the probability recalculation, the nodes exchange their probability arrays. Ideally, all nodes have the array of each other node. In this way, the algorithm can calculate the shortest path of the messages through the destination.

The functionality presented above represents the core of MaxProp algorithm, but there is some completion for that core. A complementary mechanism will give higher priority to the nodes with fewer hops up to moment. The packets in the buffer (queue) are classified in two categories: those that are below n-hop threshold up to the moment and those that are above the threshold. The newest packages, that didn't travel too much, are considered with a higher guarantee of reaching the destination. This algorithm needs a buffer with a high capacity and a high power consumption. The approach is a disputed one because of the delivery problems that could appear due to the preferential treatment the newest packages have.

Spray and Wait [11] - is a flood-based routing protocol that requires the presence of some large buffers attached to nodes. This algorithm has two phases: one for flooding messages into the network and one for waiting to meet the destination. The algorithm appeared in [11] and it has two variants. These variants are based on the number of message replicas.

The basic variant is the one in which the source node has to send "L" copies of the message. When it meets a node that does not have a copy of the message, it will send one of the copies. At the end of the "spray phase", the source node and another "L-1" nodes will have only one copy of the message. When a node receives a copy of a message, it reaches the "wait phase" and it waits to meet the destination node.

Another variant of the Spray and Wait algorithm is the binary one. The source node creates "L" copies of the message and when it meets a node which doesn't have a copy, it sends it half of its copies, and so on until it remains with only one copy of the message in the buffer. After that, the source enters the "wait phase" and acts like in Direct Delivery routing protocol. Not only the source node acts like this, but every node that has a number of message replicas.

This algorithm can be applied successfully in small networks, whose nodes have a random movement. If the nodes movement has a uniform distribution, then it is better to use the binary version than the classic one, because it will flood faster the message into the network.

RAPID Protocol [12] - is the abbreviation of Resource Allocation Protocol for International DTN Routing. This is an algorithm developed in Massachusetts Amherst University. The authors want to increase the following performances: average delivery delay, maximum delivery delay and missed deadlines. These three performance are transformed into only one called *utility function*. That function has a *utility value* associated, denoted by $\mathrm{U_i}$ for every i package sent in the network. In this way, $\mathrm{U_i}$ represents the contribution of package i to the algorithm improving performances. The RAPID protocol will replicate the packages in decreasing order of utility function improving.

Let S be the set of packages in a node buffer and D(i) the estimated delay of the i package. In the following table the routing metrics for RAPID protocol and the *utility functions* associated will be presented.

The RAPID algorithm is defined by three major parts:

1. **A selection algorithm** that identifies the required packets to be replicated between two nodes, based on utility value per packet.

2. **An inference algorithm** used to estimate the packet utility, using the following routing metrics: average delivery delay minimization, maximum delivery delay minimization and missed deadlines minimization.

3. **A control channel** which sends the metadata required by the algorithm from 2. In this way, the information about network packages is exchanged between the nodes.

SimBet Protocol [13] - is a routing algorithm that combines two social characteristics: *Similarity* and *Betweenness Centrality*. The Similarity is used to determine if a node belongs to a group of nodes and the Centrality is used to identify the relationship between groups. The algorithm computes locally the Centrality matrix for all network nodes. The nodes will calculate Betweenness Centrality value based on any equations from [13]. The node with the biggest Betweenness in the group will represent the central node in the group. Starting from the two social characteristics, the utility matrix will be computed in the SimBet algorithm. These values are between 0 and 1.

In order to send a message to a certain D node, the following calculation formulas for the Similarity and Betweenness are applied to node N compared to node M: $SimUtil_{\mathrm{N}}(D) = \frac{Sim_{\mathrm{N}}(D)}{Sim_{\mathrm{N}}(D)+Sim_{\mathrm{M}}(D)}$ and $BetUtil_{\mathrm{N}}(D) = \frac{Bet_{\mathrm{N}}(D)}{Bet_{\mathrm{N}}(D)+Bet_{\mathrm{M}}(D)}$

The utility values SimBet for node N are computed like this: $SimBetUtil_{\mathrm{N}}(D) = \alpha SimUtil_{\mathrm{N}}(D) + \beta BetUtil_{\mathrm{N}}(D)$, where α and β are parameters, and $\alpha + \beta = 1$.

This information is in [13] and [14].

Metric	Utility function per packet	Description
Minimize the average delay	U_i = - D(i)	Packages that reduce most the delay are replicated.
Minimize the deadline expired	U(i) = $\begin{cases} P(a(i) < L(i) - T(i)), & if L(i) > T(i) \\ 0, & otherwise \end{cases}$	L(i) is the package lifetime and T(i) is the time elapsed from the package creation. An expired package will have the utility value equal to 0.
Minimize the maximum delay	U(i) = $\begin{cases} -D(i), & if D(i) \geq D(j), \forall j \in S \\ 0, & otherwise \end{cases}$	Packages that increase most the delay are replicated.

Table 1: Routing metrics for RAPID algorithm

5 Personal remarks

DTN networks are increasingly used because nowadays contexts are such that a traditional network can hardly cope. It uses sensor networks to measure various meteorological phenomena, satellite networks in space (moving between various celestial bodies), networks that contain various mobile devices with a height range of mobility cannot always be in the signal coverage area. Considering these aspects, it is understandable that the resources used by such a network, which must operate under extreme conditions, are limited.

For example, signal transmitters and signal interception devices in the study of behavior and lifestyle of wild animals with a very high degree of movement can often come out of the coverage range or may remain free of electricity for quite long time periods. For this reason, the buffer space must be quite large, as important information can be recorded when the data capture devices are out of the network coverage area.

Also, routing algorithms need to be developed by taking into account the limitations imposed by such a network. If it is known that network nodes have a large storage capacity and the bandwidth can handle the frequency with which messages are transmitted, a routing strategy based on the scattering of multiple copies of the message in the network can be used, for increasing the chance that the message will reach the destination (for example, the database of the information stored on the field). On the other hand, if the nodes meeting schedule is known, or the frequency with which the source node meets the destination node is high, then a routing strategy based on the direct packet data transmission can be used, because it is a strategy with a fairly low cost in order to use only one copy of the message being transmitted.

However, it is difficult to compare two routing algorithms, since they were designed to serve different situations.

For example, in a satellite space network, given that their movement is based on a well-established timetable, it can pretty well approximate the moment when two satellites can come in contact. In such situations, a PRoPHET routing algorithm (Probabilistic Routing Protocol using History of Encounters and Transitivity) can be used. This protocol uses an algorithm that attempts to exploit the non-randomness of real-world encounters by maintaining a set of probabilities for successful delivery to familiar destinations in the DTN. This approach was first addressed in [6].

On the other hand, if we have a sensor network that monitors the migration of wild animals, entering the range of action of the sensor from which data is captured cannot be made according to a timetable. In this case, a more appropriate approach would be to use a Spray and Wait routing algorithm. When the animals monitored pass by a device that can capture information, the data packet is transmitted to this device. The device waits until it encounters the destination node or an intermediate node with the ability to transport the message to the destination.

Anyway, if they were to give priority to DTN performance criteria, routing protocols should give the highest priority to the message delivery rate, then the message transmission mode, and barely the third value to the delivery delay. It is less important that the algorithm contains a fast delivery strategy if the message delivery rate is low or if the network and buffer loading is so high that the messages are dropped and probably the number of messages that succeed in reaching the destination decreases.

One of the points of view regarding the storage capacity of the nodes would be that the routers must have buffer space compared to the message storage request. Another point of view would be that routing strategies should take into account the available buffering capacity when deciding to send a message. Each one comes with its advantages and disadvantages. The first point of view has the advantage that the routing protocol does not require too much processing to identify network traffic when a packet is to be transmitted. By reducing the number and type of processing, both power and device memory consumption will be reduced. The disadvantage is that not all devices are capable of holding large buffers. The second point of view increases the complexity of the routing algorithm, but it can work quite well with devices with low storage capacity.

This paper presented some routing algorithms with a brief description, but in their references there is a more detailed presentation and the results of their testing in concrete situations. In this way, we can observe the performances obtained behind the simulations of the algorithms presented. In literature there are several attempts to improve these classic routing protocols. For example, [15] tries to improve SimBet Routing using a human mobility model for nodes, [16] tries to improve ProPhet Routing by introducing a coefficient called α to improve the algorithm equations.

6 Conclusions

Many existing or potential communication media are not in line with the fundamental assumptions of the Internet network, because these environments are characterized by: intermittent connection, long delays and delay values that can vary consistently in the transmission of messages, asymmetric message transfer rates with a fairly high asymmetry which is unacceptable for the Internet communication protocols, high rate of errors during links corrupted bites on links involves correcting them, which implies more processing or even the retransmission of whole packet, resulting in more network traffic. DTN routing protocols may take into account these constraints, also aiming at improving network metrics. The routing protocols presented above are designed to improve different network performances, with different nodes movement and different social features.

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