Evaluation of the Performance of Message Routing Protocols in Delay Tolerant Networks (DTN) in Colombian Scenario

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Abstract. Certain vehicles need to send information to their monitoring stations constantly, this information is usually sent by the vehicles, through the cellular network. The use of these wireless networks depends on coverage that it is not usually available in all geographic areas. This is the case of road segments where the coverage of data service of cellular networks is partial or zero, making transmission impossible. A particular case is the roads between the municipality of Juan de Acosta and the city of Barranquilla in Atlántico department (Colombia). As a solution, Delay-Tolerant Networks (DTN) emerge, which allow the transmission of data to the monitoring stations when there is no cellular network coverage. In this work, a simulated evaluation of the performance of some message routing protocols for DTN is performed, in the Juan de Acosta – Barranquilla scenario. Using *"The Opportunistic Networking Environment",* we determined the performance of these message routing protocols. The results show that the *first contact* message routing protocol, presents the highest rate of delivery messages *(delivery rate)* and the lowest delivery latency *(delivery latency).* In addition, the *Spray and Wait* protocol presents better results in System message overload (*overhead*) than the first one. *The Opportunistic Networking Environment* simulator, the performance of these message routing protocols was determined in this scenario. The results show that the *Firstcontact* message routing protocol presents the highest rate of delivery *(deliveryrate)* and the *lowest delivery delay (deliverylatency).* In addition, the *Spray and Wait* protocol has a better result in system overhead than the first one.

Keywords: Routing protocols · Delay Tolerant Networks (DTN) · Direct delivery · Epidemic · First contact · Spray and wait

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1 Introduction

Networks are groups of computing devices connected each other that allow the accomplishment of a task. Additionally, a group of networks can form a network, as is the case of “internet” which is a network of networks. To have several interconnected devices, it is necessary to ensure the transmission of messages from the sender to the destination. In some networks, an information package may pass through several intermediaries before arriving at its destination. The assurance of this transmission is made by means of routing algorithms [1].

According to the mode of communication, networks can be classified into: infrastructure networks in which there is an access point or base station through which the communications are made, or the AD hoc type, in which two Devices communicate directly with each other without any intermediary [1]. Cellular networks (*GSM, Global System for Mobile communications*) are that type of infrastructure, as all communications between devices pass through the base stations distributed by the connection area. In places where there are no base stations, or they are out of reach of wireless devices, information exchange is not possible.

Connections in infrastructure networks (such as the Internet, which uses *Transmission Control Protocol/Internet ProtocolTCP/IP* for message routing) have characteristics such as: established and constant bidirectionality between sender and receiver, delay in Milliseconds when requesting and receiving information and low loss or corruption data [2, 3]. However, there are networks that not accomplish with the aforementioned characteristics. In such networks, protocols such as TCP/IP does not work. These networks are known as Delay-Tolerant and Disruption Networks (DTN) [4]. Finally, the reliability of transmission is low in DTN networks, unlike those using TCP/IP [4].

DTN networks consist of nodes that seek to communicate in scenarios in which the connection between them fails or is null. A particular case of DTNs is the *VehicularDTN* (*VDTN*). In this type of networks, the vehicles are used to retransmit messages moving in the network, and to collect messages from origin nodes [5]. Indeed, DTNs can be used in several application. For example, Montoya *et al*. [6] have implemented a monitoring system for agriculture. This study does not implement a DTN but it can be a solution in zones with poor coverage.

In a system of vehicles monitored by GSM, it is necessary to have a connection between the nodes and the base stations to have knowledge of the vehicle information (position, speed, acceleration, fuel levels and oil). In cases where there is no base station, it is not possible to know the status of the vehicles, generating uncertainty in the monitoring operation, until by its displacement, the vehicle re-enters a coverage area of a base station *GSM* and it can deliver the information to its supervisory center.

The VDTN architecture is presented as a solution to a system as described above. With the help of the message routing protocols, it is possible to maintain communication with the monitoring center. However, according to the scenario, some protocols present better performance than others, in terms of the probability of message delivery, the time it takes the message to go from node to node, and the number of messages to be transmitted so that there is successful delivery to the destination.

For the evaluation of performance in routing protocols, several authors are developing hardware implementations called testbed, these allow to demonstrate and evaluate applications of VDTN and validation of the results of simulated evaluations [7]. Developed a prototype of a testbed VDTN in the laboratory using robotic cars, combining LEGO MINDSTORM NXT, desktop computers and laptops. On the other hand in [8] a testbed is presented using real cars developed with the objective of validating technical concepts in a controlled environment. Finally [9] presents a routing protocol called RAPID and for its evaluation are used simulations and a testbed. The testbed consists of 40 buses that travel in an area of 250 square kilometers.

On the other hand, the evaluation by simulation of different routing protocols is a resource used by several authors through the use of simulation software such as *NS-2* (Network Simulator), *NS-3* u *ONE* (*The Opportunistic Networks Environment*) [10], And few authors use real scenario maps with these tools. [11] uses the NS-2 software to evaluate the performance of a routing protocol based on probabilistic gradients. In [12] the NS-3 software is used to evaluate the design of a new routing protocol in a map of the city of Valencia comparing with existing protocols. Another way to evaluate the performance of different routing protocols is through the use of grids, although these do not provide realistic or very frequent scenarios as is the case [13, 14]. In [15] synthetic maps are used for the evaluation of *Epidemic* y *Spray and Wait* routing protocols.

The simulator ONE is a discrete event simulation engine where the main agents of the simulation are the nodes that move on a map. Each node generates, transmits, and delivers messages to other nodes when come into contact For protocol performance evaluation, many authors use the map that loads by default ONE (a portion of the city of Helsinki - Finland), as is the case of [15] that compares the performance of the routing protocols *Epidemic*, *Spray and Wait*, *Prophet* y *Maxprop*. [16] evaluates the performance of the protocols, such as *Epidemic*, *First contact*, *Direct delivery*, *Prophet*, *Spray and Wait* y *Maxprop*. [17] proposes a scheme to avoid nodes which not forward messages and/or delete messages received. Performs a simulation using the *Spray and Wait* routing, improving with its proposal the probability and reducing the overhead in the network. [18] proposes a mobility model that represents the movement of vehicles and population after a disaster that affects the network of transport. Finally [19] proposes two routing protocols based on contact information between nodes, these are compared with protocols such as *Maxprop*, *Prophet* y *Spray and Wait*.

Few authors have performed real scenario mapping in ONE such as [20], which evaluates the performance of the *Epidemic*, *Spray and Wait* y *Maxprop* routing protocols on the map of the city of Tirana, capital of Albania.

The work presented in this article is carried out with the objective of determining the characteristics of the message routing protocols in *VDTN* in the Juan de Acosta – Barranquilla route and that could serve as an alternative for the monitored vehicles that transit it, seeking to reduce the uncertainty about its status in areas where *GSM* coverage is not available. It is organized in the following way, in the first section a definition of the delay-tolerant networks, the routing protocols used in this evaluation and the evaluation metrics is made. This is followed by defining the software used in this simulation and the used methodology. Finally, simulation results and conclusions are presented.

2 Delay-Tolerant Networks (DTN)

Delay Tolerant Networks or *DTN* are those that experience intermittent or often zero connections and have a delay in delivering long information. DTNs were proposed as part of the interplanetary network, where satellites do not have a constant line of sight between them or the earth.

In DTNs the senders and receivers of messages are nodes. Nodes can represent vehicles, cell phones or any device that could wirelessly exchange messages, information processing, and storage space. The DTNs base their operation on "routing" a message through a series of nodes, being stored and forwarded by each one. The operation is performed when two nodes are within their communication ranges, until the message reaches the destination node. This process is known as "*store, carry, forward*" [21].

In recent years, the use of DTNs has been of interest to researchers since they allow communication in adverse environments where there is no constant connection between nodes [8]. For this reason, the current applications of DTNs include satellite communications [22], deep space communications [23], submarine communications [24], communications in emergency and disaster situations [11] and communications for Vehicular networks [25].

2.1 Routing Protocols

The development of new routing protocols is a constant activity, in the review of the literature of this article we found numerous routing protocols. They base their operation on the "*store, carry, deliver*" paradigm, however they can be grouped depending on (a) the way make such copies, based on the information known by the nodes and (b) the number of copies it generates. For the first group, there are stochastic and deterministic protocols [26]. The stochastic routing protocols assume that the behavior of the nodes is totally random and is not possible to determine the future encounters of a node in this way when delivering a copy to a node operating under one of these protocols is done without regard if the node has a high probability of delivery.

On the other hand, deterministic protocols assume that future encounters of a node can be predicted based on factors such as the history of encounters, geographical location, among others, making possible to copy messages only to nodes that have a certain probability of to meet the destination node to increase the message delivery rate. On the other hand the routing protocols can generate a single copy of the message, a certain number of copies or an unlimited number of messages; however as more messages are generated, more resources will be used, for example, storage space. Following are the routing protocols that were evaluated are detailed, all these are stochastic protocols that generate different numbers of copies.

2.2 Direct Delivery

It is a protocol that handles a single copy of the message in the whole network, it bases its operation in that the node that generates the message only transmits it when it comes in contact with the destination node. *Direct delivery* is characterized by not excessively occupying the storage space, however, it can make the delivery time of the messages variant, depending on the location of the sending and receiving node. The operation of *Direct delivery* is represented in Fig. 1.

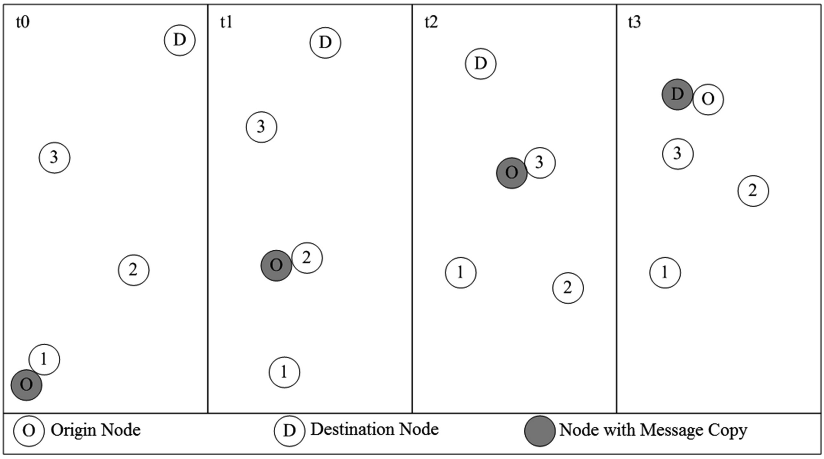

Fig. 1 Direct delivery protocol. Based in [26].

2.3 Epidemic

It was the first proposal for DTN networks made by [27]. Each node in generating a message creates an ID to each message, when two nodes come in contact, exchange the list of IDs to determine which messages are common between the two nodes and which are not. When detecting the non-common messages, the messages are copied so that at the end of the transmission both nodes have the same messages, if the node receiving the new copies of a message has the space to store those copies. In this way, it is sought to create copies of a message on all the nodes to ensure that one of them is delivered to the destination.

However this proposal makes an excessive consumption of storage space making it ideal to use when there is a storage space of considerable size. The following, is the pseudo code of the Epidemic protocol at the moment two nodes come into contact:

```
Procedure Name: OnContact
Input: node a, node b, integer ContactDuration
DropExpiredPackets(a,b) /* Drop packets with their
lifetime expired in both nodes */
ExchangeSummaryVector(a,b)
if ContactDuration > 0 then
      pkt=GetPacket(a)
      if pkt then
            if NotReceivedBefore(pkt,b) then
                  if IsDestination(pkt,b) then
                        SendPacket(pkt,a)
                        ConsumePacket(pkt,b)
                  else
                        SendPacket(pkt,a)
                        StorePacket(pkt,b)
                  end if
                  ContactDuration=ContactDuration-
size(pkt)
            end if
      end if
end if
```

Algorithm 1. Epidemic Pseudocode [27].

2.4 Firstcontact

This routing protocol bases its operation on delivering a copy of the message to the first node with which it has contact. After the transfer is made the message is deleted, maintaining a single copy in the network. The process is repeated until the message reaches its destination. This process not ensure the delivery of the messages in all cases, since the transference can be made to a node that is not in the path of the destination node. The operation of *Firstcontact* is shown in Fig. 2.

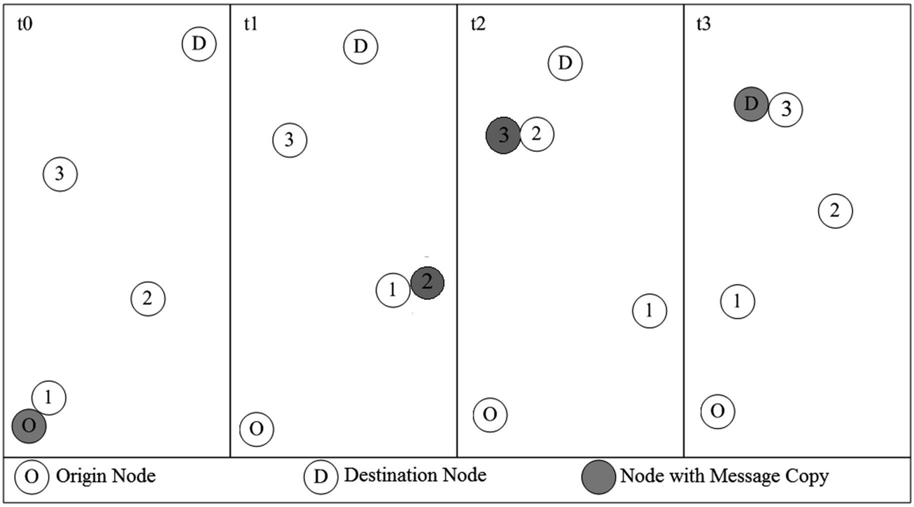

Fig. 2 First contact protocol based in [27].

2.5 Spray and Wait

The routing protocol was proposed by [28] with the objective of ensuring the delivery of messages, creating a certain number of copies but controlling not consume resources such as storage space. It consists of two phases, first to spread (Spray) and then to wait (Wait), hence its name.

In the first phase the sending node creates a message from which a certain number of copies are generated. These copies are delivered to the first nodes with which contact is made. If the message is delivered to the destination in this phase, the route is terminated. If the delivery of the message to the destination is not met in the first phase, then each node maintains a copy of the message and retains it until it is delivered Direct to the destination node.

The two phases of *Spray* and *Wait* are in operation like *Epidemic* with a controlled number of copies and *Direct delivery* respectively. This routing protocol is also characterized by having two types of functions called *Vanilla* and *Binary* in their *Spray* phase. In the first mode, N copies are generated, and a single copy is delivered to the first N-1 nodes to be contacted (the sending node keeps a copy).

In *Binary* mode the first node delivers half of the copies to the first node it comes in contact with (N/2), then each of these nodes delivers at the next contact the half of copies with which it counts and so on until each node only retains a single copy of the message. The following is the pseudo-code of the *Spray and Wait* protocol in *Binary* mode, right in the moment the nodes come in contact:

```
Procedure Name: OnContact
Input: node a, node b, integer ContactDuration
DropExpiredPackets(a,b) /* Drop packets with their
      lifetime expired in both nodes */
ExchangeSummaryVector(a,b)
if ContactDuration > 0 then
      pkt=GetPacket(a)
      if pkt then
            if NotReceivedBefore(pkt,b) then
                  if IsDestination(pkt,b) then
                        SendPacket(pkt,a)
                        ConsumePacket(pkt,b)
                  else
                        NrOfCopies=GetNrOfCopies(pkt,a)
                        if NrOfCopies > 1 then
                              SendPacket(pkt,a)
                              StorePacket(pkt,b)
                              SetNrOfCopies(pkt,a,NrOfCopies/2)
                              SetNrOfCopies(pkt,b,NrOfCopies/2)
                        endif
                  endif
                  ContactDuration=ContactDuration-size(pkt)
            endif
      endif
endif
```

Algorithm 2. *Spray and Wait Binary* Pseudo-code [28].

2.6 Evaluation Metrics

When a new protocol is created or evaluated the performance of several existing protocols in a specific scenario, it is important to demonstrate which one is better. In this sense, to make this comparison, an evaluation metrics are necessary, here are some of the most used [19]:

Deliveryrate (*DR*) or "delivery index", specifies a quantity of delivered messages to their destination with respect to all created messages, is calculated by the following Eq. (1):

$$DR = \frac{N^\circ\ of\ delivered\, messages}{N^\circ\ of\ created\, messages} \tag{1}$$

The DR result is more favorable when it is equal to 1 (or 100% if it is represented by percentages), since the number of messages delivered should be as close as possible to the number of messages created.

Deliverylatency (*DL*) or "delivery latency", also known as *Averagedelay (AD*) or "average delay" [20]. It is calculated as the average time the delivered messages arrive at their destination using the following formula (2)

$$\mathrm{DL} = \frac{\Delta\ \mathrm{Delivery\ \ time}}{\mathrm{N^\circ\ of\ \ created\, messages}} \tag{2}$$

When comparing different protocols through its *DL*, a better result is obtained when approaching zero, since the delivery time of the messages should be the smallest possible.

Overhead (*O*), represents the overhead of the system and is calculated as the difference in total messages transmitted and delivered over the total delivered (messages transmitted are those that are copied between nodes) as shown in Eq. (3):

$$\mathrm{O} = \frac{\mathrm{N^\circ of\ created\ messages} - \mathrm{N^\circ of\ delivered\ messages}}{\mathrm{N^\circ of\ delivered\ messages}} \tag{3}$$

In the evaluation of *DTN*s routing protocols, *O* is expected to approach zero (or 0% if it is represented by percentages), since it represents the overload of messages that have been created but not delivered in the network and occupy resources such as storage space and energy. This metric is fundamental for the evaluation of *DTNs* since it can saturate quickly the network with message overload [20].

2.7 The Opportunistic Networks Environment

DTNs message routing protocols can be evaluated in a simulation before implementation, so software has been designed for this purpose has been developed. The simulator *ONE* (*The Opportunistic Networks Environment*) [9] is a discrete event simulation engine where the main agents of the simulation are the nodes. There are mobile and static nodes. A node represents an element that can fulfill the DTNs "store, carry, deliver" paradigm. Nodes have different characteristics to model the behavior of a real node. These characteristics can be the routing protocol, the storage capacity for messages, a communication interface, the communication range, the speed transfer speed on the communication interface, and others.

In *ONE* simulator to ensure communication and messages exchange between nodes, there are equal communication interfaces. A communication interface is determined by the name of the interface, the transfer rate and the communication range.

In addition, the nodes have mobility models, algorithms that define how each node moves on the map. Among the mobility models implemented by *ONE* are the "*Shortest Path Map Based Movement*" or *SPMBM* that chooses a random point on the map and moves to it using the shortest route established by the streets or map routes. There is also the *Stationary movement* model that is used when nodes without mobility are required.

In this article a simulated evaluation of a rural environment between a city and a municipality is carried out. It is a scenario that focuses on the road that communicates the two communities. The monitored vehicles that follow this route, suffer disconnection due to lack of GSM coverage, due to the shortage of base stations. The motivation of this work is due to the obvious need to provide connectivity to an area of low cell phone network coverage. It is a fairly busy municipal interconnection route and a work like the one proposed establishes a starting point for an implementation aimed at solving the problem. The evaluation will determine the performance of message routing protocols by changing the number of nodes and their storage capacity. The protocols to be evaluated are *Direct delivery*, *Epidemic*, *First contact* and *Spray and Wait*.

3 Materials and Methods - Description of the Evaluation

The present study arises due the necessity to track vehicles in rural areas where the lack of network coverage is a problem, then a simulation which recreate the conditions in a real road is necessary.

The first step to develop the simulation was the selection of the software to perform the evaluation. Meléndez *et al.* [29] has been used LabVIEW as software to simulate the process. Nevertheless, ONE was chosen [9] as a tool validated by the scientific community due the multiple jobs that are supported; consequently, Juan de Acosta – Barranquilla scenario is represented considering the following factors.

3.1 Juan de Acosta – Barranquilla Scenario

To use the Juan de Acosta – Barranquilla scenario map, the following procedure was performed:

- From the Open Street Map website, the area of interest in OSM format was selected and downloaded.
- Using the Java Open Street Map (JOSM) tool, filtering was performed, eliminating those elements that were not relevant such as mountains, peaks, lakes, etc., leaving only the vehicular routes of the Juan de Acosta – Barranquilla scenario.
- Finally, the OSM format is converted to a. WKT file to be used with ONE.

3.2 Generation and Reception of Messages

In the DTN there is sending and receiving messages between the nodes that compose it. For this test it has been established that mobile nodes (which pretend to be vehicles) are the message emitters. Also on the map are distributed static nodes that pretend to be base stations of cellular telephony, which will be the receivers of the messages. These base stations are distributed considering the location of the existing base stations that are in the evaluated scenario.

In establishing the nodes in this way, we seek to emulate the real-world behavior of supervised vehicles that consistently generate and send messages when there is coverage. In the simulation these messages are considered successfully sent when the vehicle finds coverage of a base station.

3.3 Mobile Nodes

In the simulation there are three groups representing mobile nodes, each with a minimum and maximum speed. These groups simulate different types of vehicles that travel on the map. The speeds of the groups are from 3 to 70 km/h, 50 to 100 km/h and 50 to 80 km/h.

Number of Mobile Nodes: The number of nodes in each of the three groups of nodes is set at 10, 20, 30 and 40 for a total of nodes in the simulation of 30, 60, 90 and 120.

Range of Communication Between Nodes: The mobile nodes have a single communication interface with a transfer speed set at 1 MB/s and a range of 100 mts. The static nodes or base stations have two communication interfaces, the first is the same used by the mobile nodes and the second with a transfer rate of 1 MB/s and a range of 35,000 mts.

3.4 GSM Communication Coverage

The objective of this work is to determine the performance characteristics of the protocols evaluated in an environment where due to the lack of coverage in the whole route that the nodes (vehicles) must meet, there are intermittences on communications. In the simulator *ONE*, a group of fixed nodes representing the base stations were established. The location of the base stations was determined by the following procedure:

- The OpenSignal application was installed available for Android and IOS devices. This application allows to determine the position of the base stations and the level of GSM communication coverage.
- Trips from the city to the municipality by the two main routes were made, in this process the application registered information of the state of the base stations. Parallel to this was a direct observation of the base stations that were visible from the route.

- Once the above steps were taken, it was determined that the coverage zones in the Juan de Acosta – Barranquilla route are in the urban centers next to the road where they have a base station. The coordinates of these base stations are obtained from the OpenSignal application.

The base stations were then located on the *ONE* map, representing the study scenario. The location of the base stations was adjusted to less than 100 meters of the route, because in the *ONE* simulator sending messages between nodes is possible if they have identically configured communications interfaces.

4 Consolidating Simulation Parameters

The application ran sixteen times for each of the following routing protocols: First contact, Direct delivery, Epidemic, and Spray and Wait. For the Spray and Wait protocol a number of copies were used in the first six phase of Binary type.

The consolidation of the simulation parameters is shown in Table 1. For each run application the values of "storage capacity" and the number of mobile nodes where modified. The parameters for the simulation, were selected taking into account the previous works developed in this same subject.

Table 1. Simulation parameters.

Parameter	Value
Time	24 h
Simulation Map	Juan de Acosta – Barranquilla Route
Number of groups	4 (3 mobile groups and a group of base stations)
Number of nodes	30, 60, 90, 120
Storage capacity	5 Mb, 10 Mb, 15 Mb, 20 Mb
Mobility Models	SPMBM
Speed	3 km/h–100 km/h
Message lifespan	5 h
Message size	500 Kb–1 Mb
Generating time messages	60 s
Routing Protocol	Direct delivery, Epidemic, First contact, Spray and Wait.

5 Results

Due to the different metrics that are evaluated by varying parameters, the results are presented divided by metrics and from Presented from smaller to greater number of nodes (30 and 120); In each graph the storage capacity is varied. *Delivery rate* and *overhead* are presented in percentage, *delivery latency* is presented in minutes.

5.1 Delivery Rate Evaluation Results

According to Figs. 3 and 4 it is observed that *First contact* and *Spray and Wait* present greater *DR* in all the scenarios when the number of nodes is varied. In the case of *Spray and Wait*, a direct relationship between the storage capacity and the *DR* is observed, this is due to the number of copies generated by the *Spray* phase when there is a new message, causing it to occupy large storage space in the nodes and it is impossible for new copies to be received when they are filled out.

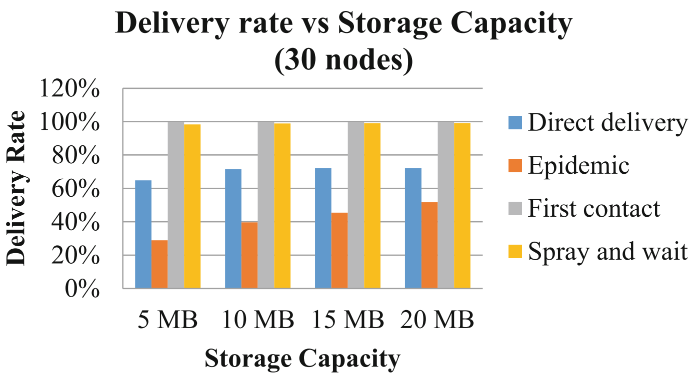

Fig. 3 *Delivery rate* of 30 nodes vs Storage capacity.

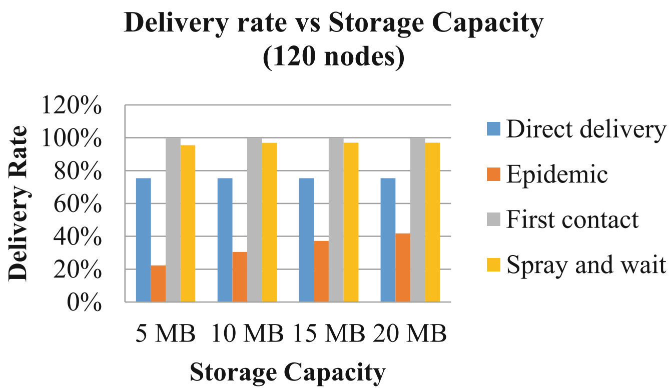

Fig. 4 Delivery rate of 120 nodes vs Storage capacity.

The Direct delivery protocol presents better results when the number of nodes increases. On the other hand, the *Epidemic* protocol presents the worst results in *DR*, although for each scenario of 30, 60, 90 and 120 nodes a better result is obtained as the storage capacity is increased, however the *DR* decreases as there are more nodes. This is due to *Epidemic* way of operating, which generates unlimited copies of the message, making it possible for more storage capacity to receive more copies, but there comes a point where copies of a message must be rejected because there is no storage capacity. In the same way, when the number of nodes increases, more messages are produced that saturate the network

5.2 Delivery Latency Evaluation Results

Based on Figs. 5 and 6 it is observed that the routing protocol with higher *DL* is *Direct delivery*, on the other hand *First contact* presents the lowest *DL*; Although both routing protocols are single copy, the transfer between several nodes of *First contact* favors the delivery time of the messages even increasing the number of nodes increases *DL*.

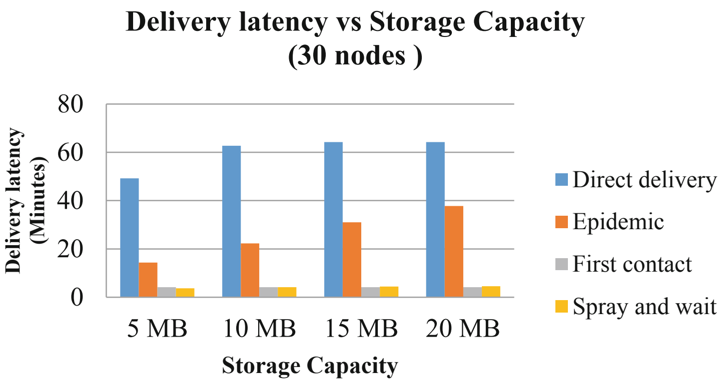

Fig. 5 *Delivery latency* of 30 nodes vs Storage capacity.

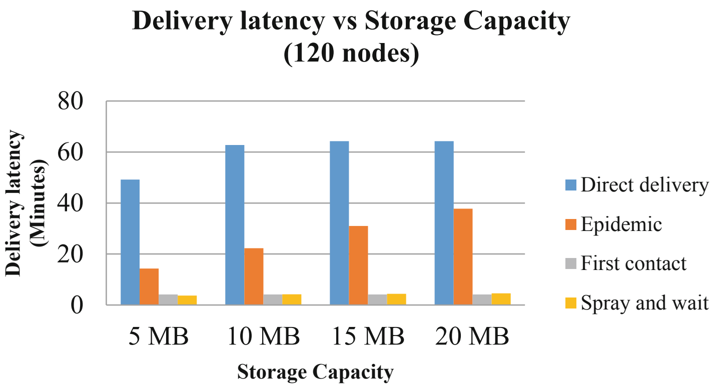

Fig. 6 Delivery latency of 120 nodes vs Storage capacity.

The *Epidemic* protocol presents a *DL* that varies depending on the number of nodes and the storage capacity. When observing its progress, it can be affirmed that *Epidemic* decreases *DL* when the number of nodes is increasing. On the other hand, *Spray and*

Wait although the scenario of smaller numbers of nodes and less storage capacity presents the lowest *DL* of all scenarios, this number increases when these two parameters increase. This is due to the *Spray* phase, which delivers a limited number of copies to the nodes which is contacted regardless.

5.3 Overhead Evaluation Results

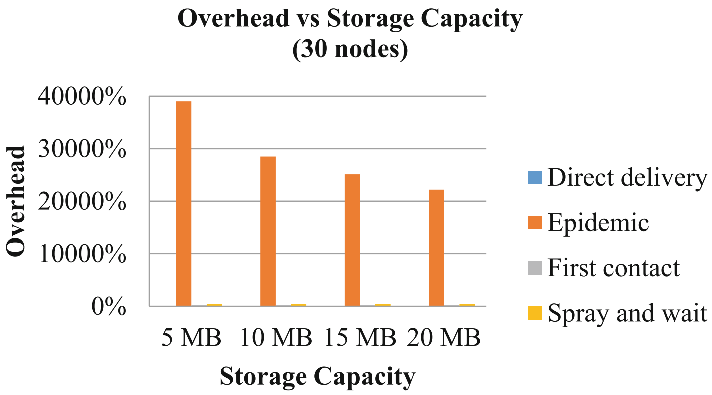

Fig. 7 *Overhead* of 30 nodes vs Storage capacity.

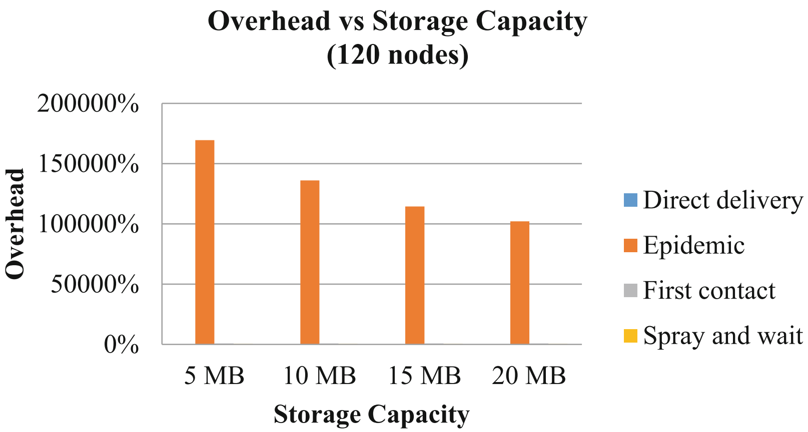

Fig. 8 Overhead of 120 nodes vs Storage capacity.

Figures 7 and 8 show that *Epidemic* is a protocol which generates overload in the system by creating unlimited copies of the message to all the nodes contacted, for this reason when increasing the number of nodes major tends to be *O*, Resulting in the highest value in all scenarios for all protocols. Because the value of *O* is significantly higher for the *Epidemic* protocol, making difficult the interpretation of the graph, the following images show the performance of the *First contact*, *Direct delivery* and *Spray and Wait* protocols.

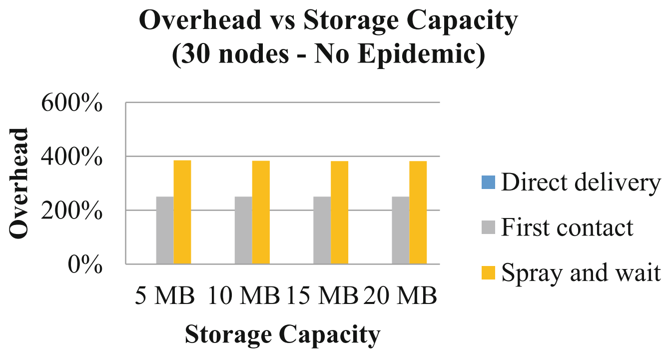

Fig. 9 *Overhead* of 30 nodes vs Storage capacity.

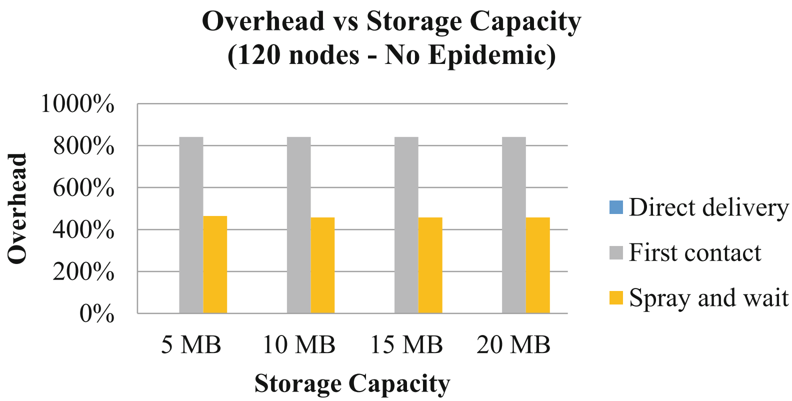

Fig. 10 Overhead 120 nodes vs Storage capacity.

Figures 9 and 10 show that *First contact* presents greater *overhead* when there are more nodes, this is because the message is delivered to any node no matter that it may or not be suitable to deliver the message to the faster receiver, in this way a single message can be delivered multiple times until it reaches to its destination. The *Direct delivery* protocol does not generate *overhead* because for each delivered message a single transfer is made to the destination node.

6 Conclusions

It is clarified that the base stations were not located in the actual positions on the map. This is because the simulator *ONE* does not allow the transmission of messages between nodes with communication interfaces of different characteristics. This prevents different communication ranges for the base stations representing the *GSM* communication coverage. However, the new location of the stations does not affect the results of the simulation, because they are placed in places close to the main roads and/or roads that serve to enter and exit urban centers, in this way the mobile nodes will have contact with the base stations and the message transfers will be made, if applicable. Since other *GSM* coverage services are not considered, the location of the base stations is adjusted for the simulation.

Based on a balance between the three metrics considered (*delivery rate*, *delivery latency* y *overhead*), and according to the performance results of routing protocols, it is stated that the protocol with better performance to be implemented in the *DTN* network in the Juan Acosta – Barranquilla scenario is *First contact*, followed by *Spray and wait*. It is clarified that the results of this evaluation correspond to values of the parameters "number of nodes" and "storage capacity" used in this article. In this way different results can be obtained by having a more crowded scenario than the one represented here or in the opposite case.

Non-probabilistic protocols were used in this article. For future work, it is desired to perform further evaluations with other types of protocols, in addition to adding protocols to the message feature to multiple destinations. Similarly, it was observed that the mobility model used does not allow the total emulation of a realistic rural environment and situations such as slowing down at mandatory stops, or accidents, detours or roadblocks, among others. Tables 2 and 3 show which protocol performs better in the selected metrics in each of the two scenarios (30 and 120 nodes).

Table 2. Scenario: 30 nodes. * No epidemic

	5 MB	10 MB	15 MB	20 MB
Delivery rate	First contact	First contact	First contact	First contact
Delivery latency	First contact	Spray and wait	Spray and wait	Spray and wait
Overhead*	Direct delivery	Direct delivery	Direct delivery	Direct delivery

Table 3. Scenario: 120 nodes. * No epidemic

	5 MB	10 MB	15 MB	20 MB
Delivery rate	First contact	First contact	First contact	First contact
Delivery latency	First contact	Spray and wait	Spray and wait	Spray and wait
Overhead*	Direct delivery	Direct delivery	Direct delivery	Direct delivery

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