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A SOCIAL SPRAY-AND-WAIT ROUTING PROTOCOL BASED ON SOCIAL NODES IN DELAY TOLERANT NETWORKS (DTNS)

EL MASTAPHA SAMMOU
Cadi Ayyad University, Faculty of Science and Technology, Department of Computer Science, Marrakesh, Morocco
Email: sammou.elmastapha@yahoo.fr

ABSTRACT

In this article we will discuss the problem of routing in delay tolerant networks (DTNs). The major problem in DTN networks is to find an end-to-end communication path between a source node and a destination node. This situation occurs because of several factors, namely: Disruptive and intermittent connectivity, high mobility of nodes, sparse network in several areas, highly dynamic network, etc. Among the classic routing protocols designed to overcome routing problems in the DTN network is the spray and wait routing protocol, and despite all the efforts made by researchers in recent years to improve the performance of this protocol but it still suffers from several shortcomings. Most of the researchers' proposals to improve the performance of the spray-and-wait routing protocol are based primarily on either mobile similarity and/or social similarity. Indeed, these proposals of the researchers prove ineffective in certain scenarios in which the movement of the nodes is completely random and when the nodes show non-social behaviors. To solve routing problems and effectively improve the performance of the wait phase of the Spray-And-Wait protocol, we propose a routing approach called SSW (Social Spray-and-Wait) based on mobile attributes and social attributes between nodes by exploiting the similarities (mobile and social) of the nodes as well as the probability of delivery and the probability of visit to improve the delivery rate and reduce the delivery delay as well as minimize the resources consumed in the DTNs networks. Our SSW approach proposes a strategy of selecting appropriate relay nodes to ensure successful delivery of messages in the wait phase of the spray-and-wait protocol. This strategy is based on the selection of special nodes called social nodes having higher activities and can play the role of relay nodes in the network. In other words, the social nodes are selected preferably as relay nodes to increase the delivery rate. The simulation results show that, our SSW approach significantly improves the delivery rate, and reduces the delivery time, compared to the spray and wait protocol and also shows good performance in terms of resources consumed in the network.

Keywords: *Routing, Delay Tolerant Networks, DTN, Social Spray-And- Wait, SSW, social node, Simulator*

1. INTRODUCTION

Delay-tolerant networks have different characteristics than classic mobile networks [1]. These characteristics mainly include intermittent connectivity, relatively wide delivery times and limited resources at the nodes. Routing in delay-tolerant networks is insufficient despite significant research efforts in this area. The main reasons are due to high node mobility, low node density, or when the network is partitioned into multiple areas, which makes it difficult to establish and maintain communication links between a source node. and a destination node. classic routing protocols originally designed for delay-tolerant networks are ineffective in these situations where its performance degrades sharply, especially if it is nearly impossible to find a communication path between a source node and a destination node. In recent years, several DTN routing approaches have been proposed by researchers to overcome routing problems in DTN networks. Among the classic approaches we can cite the Epidemic routing protocol [2] based essentially on the duplication of copies of the same message and on the epidemic flooding strategy. The Prophet routing protocol [3] based on the encounter history of mobile nodes to calculate the delivery probability. The Spray-and-Wait routing protocol [4] based on a strategy allowing to pre-limit and limit the number of copies of the messages circulating in the network. However, the classic routing approaches listed above have several problems. For example, the Spray-and-Wait approach which does not take into account the social relations between the nodes and does not take into account the mobility of the nodes during the transfer of the messages. The Spray-and-Wait approach only uses a strategy based on pre-limiting the number of copies of a message in the spray phase and naively waiting for the destination in the wait phase. the Spray-and-Wait approach does not take into account the possibilities and opportunities to meet with other nodes. With the development of wireless communication technology and with the heterogeneity of communication equipment, researchers have proposed several improvements on the Spray-and-Wait routing protocol [4] to overcome the routing problems that arise in environments where the establishment of communication is not enough such as, the Internet of Things (IoT), drones, smart cities, etc. Most of the proposals of the researchers to improve the performance of the spray-and-wait routing protocol are based essentially on a single factor or two factors to select an adequate relay node in order to make the right routing decisions, these factors can be either the mobile similarity [9] [13] and/or social similarity [6], etc. Indeed, the researchers' proposals to improve the performance of the spray-and-wait protocol prove ineffective in certain scenarios in which the nodes show non-social behaviors or when the movements of the nodes are completely random. To overcome all these problems, we propose a routing approach called SSW (Social spray and wait) uses a strategy based on several factors at the same time to select the adequate relay nodes (Social Nodes) and to make the right routing decisions. Among these factors we can mention: the mobile similarity and the social similarity of the nodes as well as the probability of delivery, the probability of visit and the residual energy. All these factors are used to improve the performance of the spray-and-wait protocol in terms of the delivery rate and the resources consumed in the network. The main contributions of this article are summarized below:

- We propose an SSW (social Spray-and-Wait) routing approach to improve the wait phase of the spray-and-wait protocol, the SSW approach is based on a strategy allowing to select the appropriate relay nodes (social nodes) to take the good routing decisions and ensure successful delivery of messages in the wait phase of the spray-and-wait protocol.
- Nous définissons des nœuds sociaux (nœuds relais adéquats) ayant des activités plus élevées dans le réseau. Ces nœuds sociaux sont de préférence sélectionnés comme nœuds relais pour garantir la livraison des messages et augmenter le débit de livraison. Les nœuds sociaux sont des nœuds qui se caractérisent par une plus grande similitude mobile et sociale ainsi qu'une forte probabilité de livraison et de visite, par conséquent, les nœuds sociaux peuvent avoir une plus grande chance de se rencontrer et de transmettre avec succès des messages entre eux.
- In accordance with the simulation results in the environment of our simulator, our SSW approach significantly improves the delivery rate and also shows good performance in terms of resources consumed in the network compared to other routing approaches: spray-and-wait, PSW (Probabilistic Spray-and-Wait) and SC-AMSW.

2. PRELIMINARY DTN

2.1. Bundle layer

To succeed in delivering the messages, the DTN architecture [1], implements a modification of the usual protocol stack. This change is to add an additional layer called the Bundle layer, whose main role is to store messages until an opportunity to transmit them arises. In the protocol stack, the Bundle layer is placed between the application layer and the network-specific layers (Transport, Network, link and physical). The Bundle layer intervenes to ensure interoperability between the lower layers of the different regions to be interconnected by the use of an intermediate sub-layer called Convergence Layer. The Bundle Protocol is the protocol used in the Bundle layer to gather the data in the form of a message called "Bundle" and it is responsible for transmitting it.

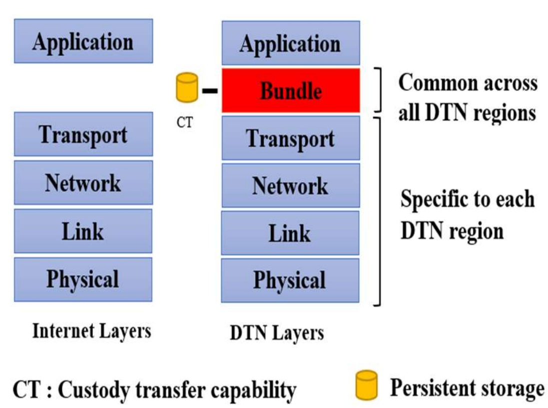

Figure 1: Bundle protocol layer

2.2. Store-and-Forward Mechanism

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This technique is the basis of most routing protocols that have been proposed for DTN networks. For DTN networks, each DTN node is equipped with a storage unit at which it can keep a message. A DTN node that finds itself disconnected from the rest of the network will have to keep a given message in its storage unit for a long time until an opportunity to transmit it arises.

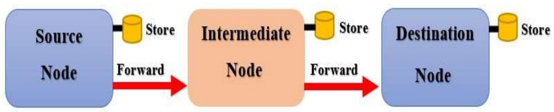

Figure 2: Store and forward mechanism

3. ROUTING PROTOCOLS FOR DTN NETWORKS

3.1 Epidemic routing Protocol

Epidemic Protocol [2]: is essentially based on the duplication of a fairly sufficient number of copies of the same message to the nodes of the network. The copy of the message is stored until it is delivered to the destination regardless of latency and regardless of storage space. This approach ensures that the message reaches its destination as much as possible, but it also wastes a lot of resources on unnecessary message forwarding.

3.2 Prophet routing protocol

The Prophet protocol [3] is a probabilistic routing protocol which uses the encounter history of mobile nodes to calculate the probability of delivery (Delivery Predictability). Message delivery probabilities are calculated based on encounter frequency. Prophet introduces the probability of delivery, P (A, B) ∈ [0, 1]. This metric is calculated by each node A of the DTN network, and this for each known destination B and it will be used to decide which messages to exchange each time two nodes meet. Our SSW routing approach also uses contact information to achieve social similarity.

3.3 Spray and Wait routing protocol

The Spray and Wait routing protocol [4]. This is a simple routing protocol based on the messages replication. Spray and Wait routing decouple the number of copies generated per message, and therefore the number of transmissions performed, from the network size. It consists of two phases:

- **Spray phase**: for every message originating at a source node, L message copies are initially spread – forwarded by the source and possibly other nodes receiving a copy – to L distinct relays.
- **Wait phase**: if the destination is not found in the spraying phase, each of the L nodes carrying a message copy performs direct transmission (i.e. will forward the message only to its destination).

Spray-and-Wait combines the speed of epidemic routing with the simplicity and thriftiness of direct transmission. It initially "jump-starts" spreading message copies in a manner similar to epidemic routing. When enough copies have been spread to guarantee that at least one of them will find the destination quickly, it stops and lets each node carrying a copy perform direct transmission.

3.4 Probabilistic Spray-and-Wait (PSW)

3.4.1. PSW Routing protocol presentation

The authors in [5] propose a probabilistic Spray-and-Wait (PSW) routing algorithm based on two metrics:

- Node Interest Preference (NIP): based on social attributes of nodes and used to measure the likelihood of nodes becoming friends
- Probability of delivery (DP): based on node encounter history usually both NIP and DP metrics are used to select the relay node.

3.4.2. PSW Routing Problem

- The PSW approach does not take into account the management of conflicts of interest of the nodes, Therefore, when selecting a relay node, if the message is forwarded to a node with a lower NIP value than the destination node, it is more difficult to transfer the message.
- The routing problem also arises when a source node of a message has a very low adaptive probability of delivery (DP) for the destination, in this case it will transmit this message to all the nodes it meets until until this message is deleted by the queue. Which takes up a lot of resources.
- The PSW approach does not take into account certain scenarios where the movement of the nodes is completely random. And also, the case of nodes that show non-social behaviors.

3.5 SC-AMSW Routing protocol

3.5.1 SC-AMSW Routing protocol presentation

The authors of [6] propose social circle-based multiple spray-and-wait adaptive routing algorithm (SC-AMSW), SC-AMSW is divided into spray phase and wait phase.

- In the spraying phase, the authors introduce a social circle-based (SC-SS) spraying strategy to improve the spraying phase of Spray-and-Wait. SC-SS selects the next hop based on the social circle of the nodes in the spray phase, instead of setting the initial number of copies.
- In the waiting phase, the SC-AMSW algorithm selectively sputters messages multiple times in the waiting phase and determines an appropriate number of redundant message copies based on the predictability of delivery.

3.5.2 SC-AMSW routing problem

Although the approach can work well in scenarios based on the social attributes of the nodes, however the approach does not take into account some scenarios in which the nodes show non-social behaviors and the motion of the nodes is completely random.

3.6 MobySpace routing protocol

3.6.1 MobySpace routing protocol presentation

The MobySpace routing protocol [9]: is a geographic routing approach based on the mobility of nodes and frequency of node visits for each possible location in the network by using a high-dimensional Euclidean space, which we call MobySpace, built on schemas of mobility of the nodes. The basic idea is that the nodes have the most similar motions have a greater probability to meet. For example, two people with similar mobility patterns are more likely to meet so they can communicate. MobySpace, is seen as a tool to help nodes make routing decisions. These decisions are based on the notion that a node is a good carrier of a packet if it has a mobility profile similar to that of the destination of the packet. Routing is done by forwarding packets to nodes that have mobility patterns that are more and more similar to the mobility model of the destination. In MobySpace, the mobility model of a node provides its coordinates, called its MobyPoint, the routing is done by transmitting pqauets towards nodes which have their MobyPoint closer and closer to the destination MobyPoint. For each of the nodes, there is a definite probability of finding this node at each of the n locations. This set of probabilities corresponds to the mobility model of a node and described by a MobyPoint in a n-dimensional MobySpace. For every node "i", we have:

$$M_i = (C_{1i}, C_{2i}, \dots C_{ni}), \quad \sum_{k=1}^{n} C_{ki} = 1 \qquad (1)$$

M_i is the mobility pattern of the node "i".
C_{ki} is the probability of node "**i**" to visit location k.

The distance between two nodes i and j in this space of n dimensions is calculated by the following formula:

$$\boldsymbol{d(M_i, M_j) = \sqrt{\sum_{k=1}^{n} (C_{ki} - C_{kj})^2}} \qquad (2)$$

In MobySpace, the message is always sent to the node that is closer to the destination.

3.6.2 MobySpace routing problems

MobySpace routing protocol has several disadvantages, namely: The obligation to update the location history for all network nodes; The path indications obtained are only probabilities; A source that transmits a message to a destination is not sure to be able to reach it.

4. ROUTING PROBLEM OF SPRAY AND WAIT

The "Spray and Wait" routing protocol has two phases: in the first phase it distributes a fixed number of copies to the first relays encountered, and in a second phase each of these relays waits until it encounters the destination itself. The spray and wait protocol have many problems, namely:

- The protocol does not take into account the performance of the relay node when transferring messages
- When the source node is far from the destination, the message will be difficult to send to the destination so that the transition to the Wait phase is done very quickly
- The protocol does not take into account the possibilities of meeting other nodes in the wait phase
- All message copies are only taken by nodes in the neighborhood of the source node.
- When nodes encounter a node that has a very high probability of delivery, it cannot send the message if they are in a waiting phase. So, these nodes have to wait to be in direct contact with the recipient to send the message to them.

5. MOBILITY MODELS IN DTN NETWORKS

A mobility model is a model that expresses the behavior of nodes and how their position, velocity and acceleration vary with time.

5.1. Random Walk Model

The Random Walk model [10] is one of the mobility approaches where the movement of nodes is completely random and independent of old positions. the parameters taken into consideration in this model are the direction and the speed of movement. When a node moves from one point to another, it first chooses a direction angle between 0 and 2π. Then, it must choose a random speed between two values Vmin and Vmax. When the node has reached its destination after a time t or a distance d, it may change the values of these two parameters.

5.2. Radom Waypoint model

In this model [11] each node chooses randomly, as destination, a point of coordinates (x, y) in the simulation surface and a speed between V_{min} and V_{max}. The node travels to the chosen destination with the chosen speed. Upon arrival, the node takes a rest period before choosing a new destination and a new speed again to repeat the same process.

5.3. Restricted Radom Waypoint Model

The idea of this mobility model [12] is inspired by the movements of a real population where the simulation area contains rectangles representing cities connected by highways. Each node uses the Random Waypoint to move through one of the cities a number of times specified by a parameter, before traveling to another city where it will move for a certain time and so on.

6. ROUTING PROBLEMS IN SPRAY-AND-WAIT APPROACHES AND PROPOSED SOLUTIONS

With the rapid development of new communication technologies, the classic spray-and-wait routing protocol becomes ineffective in making routing decisions and transmitting messages between nodes and especially in environments where communications between devices must be increasingly reliable and robust. Therefore, it is desirable to improve the performance of the spray-and-wait protocol so that it becomes feasible and more suitable for the new application range. To improve the performance of the spra-and-wait protocol, researchers have proposed several approaches based mainly on one factor or two factors to make the right routing decisions. These approaches present several routing problems, namely:

- Routing approaches based on the social attributes of nodes [5][6] can only work in scenarios where nodes have social relations between them, however these approaches do not take into account certain scenarios in which nodes show behaviors non-social and the movement of the nodes is completely random. In these routing approaches, the social relations between the nodes represent the main factor with which the node can make a routing decision.
- Routing approaches based on the mobile attributes of the nodes [9][13] can work in certain scenarios where the nodes are characterized by mobile similarities and mobility habits, however these routing approaches do not take into account the scenarios where the movement of nodes is completely random. These routing approaches are based on one or two factors which are: mobile similarity and mobility habits to choose a relay node and make the right routing decisions.
- Routing approaches based on delivery probabilities [5][7][8] and visit probabilities [16] do not take into account the relationships between nodes, they are based only on the delivery probability of a message and/or the probability of visiting the geographical location of the destination, this probability is the main factor with which each node decides, individually to which relay node should deliver the message. However, other secondary factors may also be taken into consideration during the relay node selection process, such as residual energy. This type of approach generally makes it possible to obtain an increase in the delivery rate and a reduction in the number of messages exchanged.

To solve all these routing problems, this work proposes an SSW routing approach exploiting several factors both to choose the adequate relay nodes (Social Nodes) and also to make the right routing decisions. Our SSW approach is mainly based on:

- The multiple and total similarity (social similarities and mobile similarities) of nodes in DTN networks. This strategy uses the social attributes of the nodes (Social relations between the nodes) and the mobility history of the nodes to determine the degrees of similarity between them in order to make good routing decisions.
- The multiple and total probability (The probability of delivering a message and the probability of visiting different network locations). This strategy uses the contact history between nodes and the visit history of different places in the network to determine

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the probability of reaching the geographical area of the destination and the probability of successfully delivering the message to the destination.

Our SSW routing approach makes it possible to combine the advantages of several routing approaches, namely: routing approaches based on social attributes [6] and routing approaches based on mobile attributes [9] [13] as well as probabilistic routing approaches based on the frequency of encounters between nodes [7] [8] and probabilistic routing approaches based on the frequency of visits to different network locations [16].

7. OUR APPROACH TO ROUTING: SSW

Table 1: Notation of abbreviations

Notation	Explanation
SW	Spray-and-Wait
SSW	Social Spray-and-Wait
PD	Probability of Delivery
PV	Probability of visit
MS	Mobile similarity
SS	Social Similarity
RE	Residual Energy

7.1. SSW Routing approach presentation

To effectively improve the performance of the wait phase of the spray-and-wait protocol, we propose an SSW routing approach that distributes a small number of copies to a few relays in the Spray phase. Then each relay can then transmit its copy using a probabilistic approach based on the selection of social nodes as relay nodes in the wait phase. This approach takes all the advantages of spray and wait controlled replication, but also able to identify appropriate forwarding opportunities that might deliver the message faster. To select an appropriate relay node among neighbors. Researchers propose several algorithms based on node mobility [9], mobile node similarity [11] and based on node social attributes [5][6]. The similarities of the nodes proposed by the previous algorithms do not take into consideration a large number of similarity factors, but rather only one. Our routing approach (SSW) proposes a strategy to select appropriate relay nodes based on several similarity factors (mobile and social similarity) by defining special nodes called social nodes as relay nodes to ensure successful delivery of messages. Social nodes are nodes that exhibit greater mobile and social similarity, and therefore they may have a higher chance of meeting and successfully passing messages between them. Social nodes introduce a variety of attributes:

- Traces and mobile trajectories of nodes
- The encounter history of network nodes and zones
- Mobile similarity and social similarity
- High frequency of access to different areas and network location
- The high frequency of node encounters

7.2. Social node selection

The selection of a social node is defined as the essential part of the wait phase of our SSW routing approach. The social node selection problem is also defined as a complete NP problem [14]. In our SSW approach, the selection of a node is done according to several criteria, namely:

a) The probability of delivery (PD): The probability of delivery [7][8] is the probability that a message arrived at the destination via a given social node. Each node maintains a list of all known destinations with associated delivery probabilities. To calculate the probability of delivery according to the destinations, our SSW approach uses a probabilistic routing strategy based on the history of the encounters of the nodes in order to make the right routing decisions. To increase routing efficiency in DTNs, we introduce delivery probability to measure the ability that a social node can deliver messages to the destination. The probability of delivery of a social node is affected according to the state of the network and also according to the state of the node.

b) Probability of visit (PV): The Visit Probability [16] is used to define the visit frequency of different network areas and locations. The routing strategy used by our SSW approach is also based on the visit history of the geographical areas of the network to calculate the probability of visit. The probabilities of visit are calculated according to the frequency of visit of the geographical areas of the network. The probability of visit is the probability that a social node (relay node) arrives at the geographical area of the destination. Each node in the network maintains a list of all known geographic areas in the network with associated visitation probabilities. The visit probability also makes it possible to determine the geographical area of the destination node. SSW uses a strategy based on both the encounter history of the nodes and the history of visits to the geo-graphical areas of the network by the social nodes. These two metrics are used to calculate the total probability (probability of delivery

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and probability of visit) in order to make the right routing decisions.

c) Residual energy [RE: Residual energy] and battery life [15]: Our SSW routing approach proposes battery life and residual energy as criteria for the selection of a social node. The node that has the greatest battery life can be considered a social node. Among the main challenges of DTNs networks lies in the limited energy resources that constrain the nodes to store, transport and transfer messages. Existing DTN routing approaches do not consider available energy resources when making routing decisions. This limit both delivery probabilities, node mobility and network performance in terms of lifetime. We propose the SSW approach which takes into account the available energy to achieve an efficient use of node energy during routing decision making and also to extend the network lifetime. The majority of previous works [15] show that energy is a decreasing resource, and therefore, our SSW routing approach is designed in such a way to take into account the energy consumption and the available energy of each node of the DTN network for making the right routing decisions.

d) Mobile similarity (MP): The mobile similarity is constructed from information on the mobility habits of nodes [9] [13]. For example, if two nodes having similar mobility habits have a great chance of meeting and therefore of being able to communicate in a DTN manner. In DTNs, several researchers have proposed routing approaches based on mobile node similarity to improve the delivery rate, such as [9][13]. The higher the mobile similarity between two nodes, the higher the probability that they will meet in the future as well. Sometimes human beings behave in a way that repeats the same moving path every day. For example, two students who move from their residences to the school and vice versa (inversely), this means that there is a high probability that the same students will meet every day. In other words, two nodes can meet frequently if there is a high degree of mobile similarity between them, which indicates that message-carrying nodes can decide when and where they can forward messages to the appropriate relay nodes. Therefore, DTN network nodes are able to exploit the mobile similarity between nodes to improve their routing performance and also to guarantee message delivery. Indeed, the mobile similarity is based both on the geographical trajectories of the nodes and also on temporal information. For example, two nodes visiting the same places with the same frequencies, but at different times. In this situation the two nodes having a very high degree of mobile similarity however the probability that they meet in the future will be very low.

e) Social similarity (SS): Each node uses contact and position information to define the social similarity between a pair of nodes [6]. The social attributes of the nodes (the social relations between the nodes) can form an important basis for choosing a relay node among all neighboring nodes. Research shows that nodes with high social similarity [6] belong to the same social circle. Social circles of nodes are composed based on historical records of encounters. A node in the same social circle as the destination node is preferably selected as a relay node. Therefore, there is a great opportunity for communication and delivering the message to ensure the successful delivery of messages.

7.3. SSW transmission strategy

Our SSW approach is to spread the copies as quickly as possible at the start, then forward them to the social nodes according to the following routing metrics:

- Probability of Delivery (PD)
- Probability of visit (PV)
- Degree of mobile similarity (MS)
- Degree of social similarity (SS)
- Residual energy (RE) and battery life

This strategy makes it possible to strictly limit the number of copies of a message and the number of message carriers circulating in the network and it makes it possible to optimize the use of network resources.

- The spray phase of the SSW routing protocol limits the number of copies of a message circulating in the network
- The wait phase of the SSW protocol limits the number of bearers of a message.

Therefore, the SSW routing protocol limits both the number of copies of a message circulating in the network and also the number of bearers of a message. Thus, the SSW approach maximizes the chances of reaching the destination through the use of social nodes and minimizes the resources consumed in the network, which involves fewer copies of a message and fewer message bearers. The SSW routing protocol is used to limit the number of copies of messages circulating in the network but also to limit the number of message carriers. When a node sends a message, two phases occur:

- **Spray phase of SSW**: a phase of random (epidemic) routing; For each new message that has just been generated by a source, this phase ensures that L copies of the latter will be propagated Epidemically in DTN network, so the message will be present in L different relays.
- **wait phase of SSW:** this phase uses a social probability based on several metrics to select the relay nodes or more exactly the social nodes. The social probability is based on: the social similarity and the mobile similarity of the nodes, the probability of delivery and the probability of visit as well as the residual energy of the nodes.

Generally, in the wait phase of our SSW approach, the message is sent to a social node having:

- A high probability of delivery (PD)
- A high probability of visit (PV)
- Increasingly similar mobility to that of the destination (MS)
- Similar social attributes of the destination (SS)
- High residual energy and sufficient battery life.

There are situations where nodes are not allowed to forward messages to a social node. When the movement of the nodes is completely random and does not show any social or mobile similarity, the message is sent to a node that has a high probability of delivery and/or has a high probability of visit.

8. DTN SIMULATOR

To implement our approach SSW, we developed a DTN simulator written in Java language consistent with the architecture of the DTN network. Our DTN Simulator contributes a graphical environment that allows users to evaluate and improve routing protocols designed for Delay-Tolerant Networks. The simulator is able to visualize simulation results in real time via an interactive graphical user interface.

8.1. General simulator design

The simulator is composed of three main units:

a) Input unit: is a unit that allows the simulation parameters to be defined, namely: Routing protocols, the speed of nodes, the number of nodes in the network, the size of the simulation area, the energy level of each node, the communication range of each node.

b) Processing unit: is the unit that groups the basic functionalities of the simulator, namely:

- **Receive and analyze routing information**: each time two nodes meet; they prove to broadcast the routing information they hold in order to decide which message has the best chance of reaching the destinations while respecting the routing protocol used.
- **Movement of nodes**: is the functionality that allows defining the mobility models used by the nodes.
- **Contact of the nodes**: the contact represents the functionality which makes it possible to define the beginning and the end of the contact.
- **Duration of contact**: is the functionality which allows to define the two timers, Time-To-Acknowledge (TTA) and Time-To-Live (TTL)
- **Behavior of nodes**: is the functionality that allows defining the routing protocol used by the nodes of the network,
- **Connection**: is the functionality that makes it possible to establish connections between mobile nodes

c) Output unit: is responsible for outputting the following processing results:
Number of packets transmitted in the network, number of packets received by destination, number of packets not transmitted, total energy consumed in the network, Amount of memory used in the network. The figure below shows the general design of the simulator.

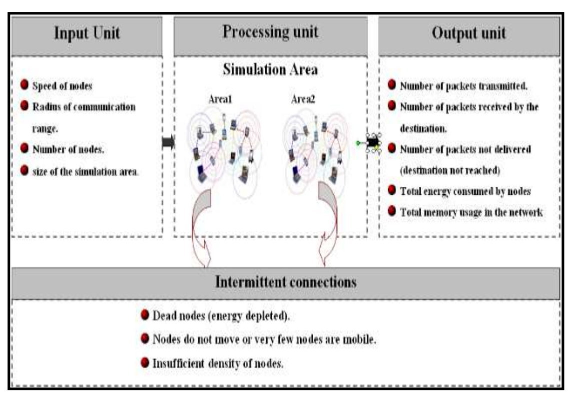

Figure 3: General simulator design

8.2. Domain structural model

Structural UML diagrams are used to model the static structure of our DTN simulator. Among these diagrams, we have focused on the class diagram which shows both the behaviors and the functionalities of each class.

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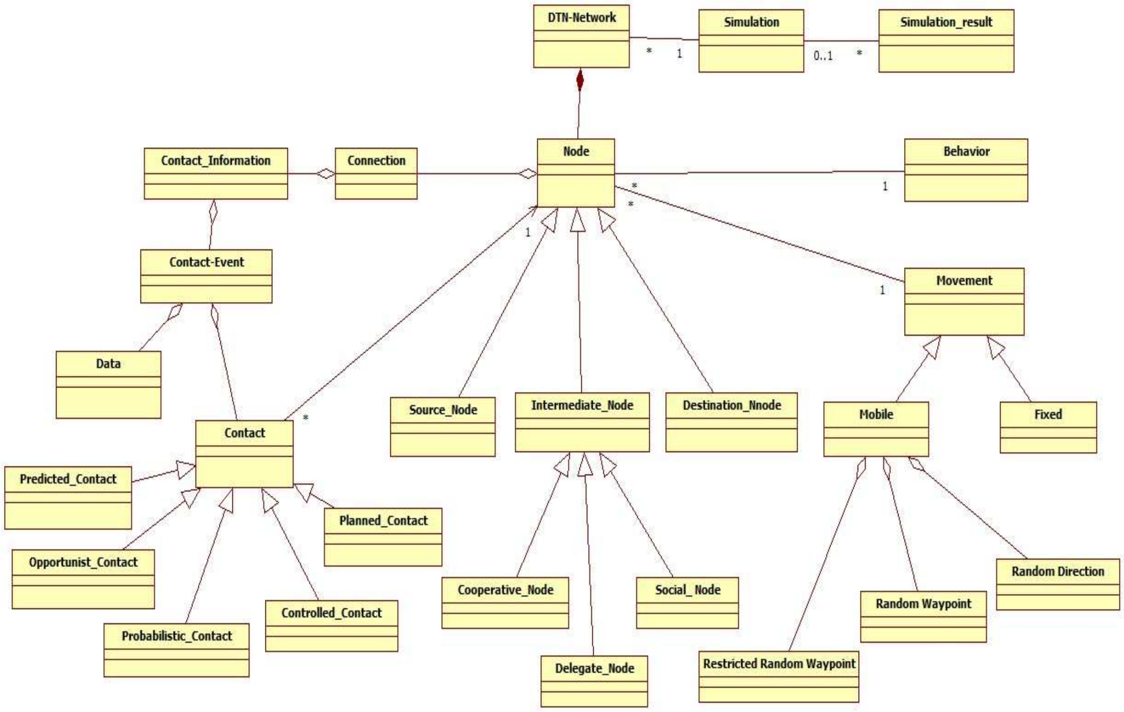

Figure 4: Class diagram

This diagram also shows the behavior of each class. It also includes key features and functionality:

a) **Receive and analyze knowledge**: at each meeting the nodes prove to disseminate the knowledge they hold in order to decide which message has the best chance of reaching the destinations while respecting the routing protocol used.

b) **Node:** The node class is the main design element. The role of the node is to: collect, store, transport, transmit and exchange data and routing information as well as contact events (Start of contact and End of contact). The node also has the role of analysing routing information and knowledge according to the routing protocols used in order to make the right routing decisions.

c) **Movement**: the nodes can be fixed or mobile, for the mobile nodes have the possibility of moving according to several models of mobility, Restricted Radom Waypoint, Radom Waypoint, Random Direction, etc.

d) **Contact**: is the functionality that allows you to define the start and end of the contact. In a DTN network, we can distinguish between five main types of contacts: Opportunistic contacts, Probabilistic contacts, Controlled contacts, scheduled contacts, Predicted contacts.

e) **Contact event**: represents the duration of contact generally a time interval [T1, T2], and the two timers, Time-to-Acknowledge and Time-to-Live.

- The Time-To-Acknowledge (TTA) is the time after which the bundle is sent to a new node
- The time-to-live (TTL) indicates the time during which the bundle must be kept before being rejected by a source node (Custodian).

f) **Behavior**: the behavior represents the application of a routing protocol which can be the PROPHET, MaxProp, Spray and Wait routing protocol or one of the enhanced routing protocols according to our routing approaches: The node selects the messages (bundles) to be sent according to one of the implemented routing protocols. For each selected message in a node, the content is transferred to the other node.

g) **Connection**: the connection is established when a node detects another node in its coverage area.

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8.3. DTN simulator graphical environment

Our DTN simulator is designed specifically to evaluate improvements in our routing approaches as well as routing protocols designed for DTN networks. It allows users to create scenarios based on:

1) The different mobility models,
2) The speed of nodes
3) The number of nodes in the network,
4) The size of the simulation area,
5) The energy level of each node
6) The communication range of each node.

The main window of the simulator allows users to visualize in real time the locations of the nodes, the connections between the nodes, the mobilities of the nodes, the speed of the nodes the number of nodes in the network, the size of the simulation zone, the energy level of each node and the communication port of each node as well as the nodes that can play the role of message carriers according to our routing approaches. The fig below shows the main window of our simulator.

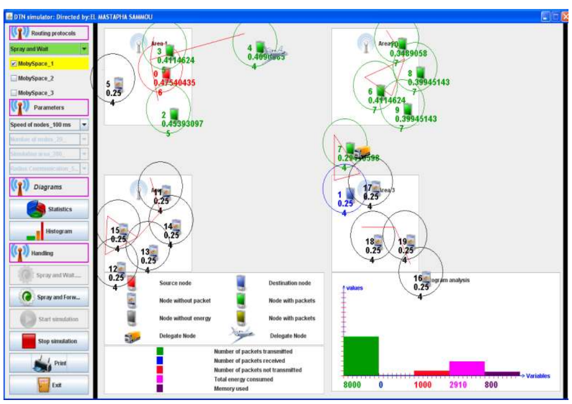

Figure 5 : The main interface of the application with four simulation zones

9. SIMULATION RESULTS ANALYSIS

9.1. First simulation scenario

We consider that the density of nodes is high in each simulation area. Internal connectivity of each simulation area is guaranteed, however connectivity between simulation areas exists but is not guaranteed. The table below summarizes the parameters of the first simulation scenario used to evaluate the performance of our SSW routing approach based on high node density. The other parameters such as the mobility patterns and the initial energy level of each node are considered constant and the buffer of each node is considered infinite for all simulations.

Table 2: First simulation scenario parameters

Simulation parameters 1	Values
Simulation time	1600s
Mobility models	Random Walk, Radom Waypoint, Restricted Radom Waypoint
Routing Protocol	SSW, Spray and wait
Number of nodes	50
Energy level of each node	1000
Radius of the focused communication	50 m
Maximum Speed	50 ms
Size of each area	500*500
Number of simulation zones	4
Initial probability of visit	0,25
Initial probability of delivery	0,75
β	0,25
ϒ	0,98
Parameter value L	4

9.1.1. Simulation results according to Spray-and-Wait

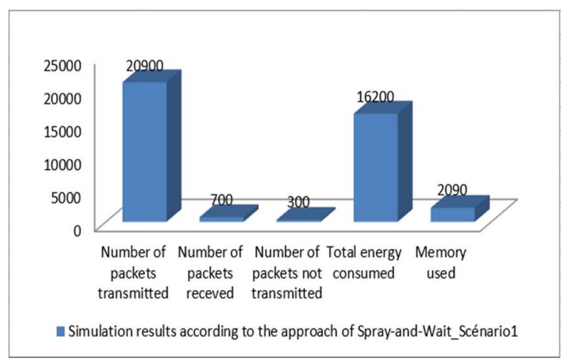

Figure 6 : Simulation results according to the Spray-and- wait

9.1.2. Simulation results according to SSW

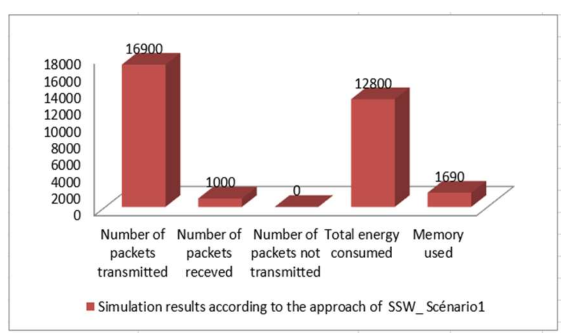

Figure 7 : Simulation results according to SSW

Figures 6 and 7 show the performance of our SSW routing approach compared to the spray-and-wait routing approach. In figures 6 and 7 we present [the number of packets transmitted, the number of packets received by the destination and the energy consumed in the network as well as the quantity of memory consumed in the network] according to the density of the nodes and the connectivity of the network. In figures 6 and 7 above, it can be noticed that the number of packets received by the destination using the SSW approach is greater than that of the routing approaches: spray-and-wat, PSW and SC-AMSW.

- For the SSW approach, all packets transmitted by the source node are 100% received by the destination node. In Figure 7, the 1000 packets transmitted by the source node are received by the destination node, which represents 100% of the successful delivery of packets and this result because of the social nodes which transport the messages to the destination. On the other hand, the SSW approach uses strategies based on the total similarity (the social similarity and the mobile similarity) of the nodes and also the total probability (the probability of delivery and the probability of visit) which makes it possible to guarantee the successful delivery of packets.
- For the spray-and-wait approach, the number of packets received by the destination does not exceed 70% of the set of packets transmitted by the source node. In Figure 6, the number of packets received by the destination does not exceed 700 packets. this result because of the absence of any opportunity for transmissions during the wait phase, and the relay nodes in this phase must naively wait for the meeting of the destination to deliver the packets.
- For the PSW and SC-AMSW routing approaches, the number of packets received by the destination [5][6] does not reach 100%, and this can be explained by the fact that the relations between the mobile nodes are not sufficient to guarantee the successful delivery of the packets, also these approaches do not take into account the non-social behaviors of the nodes and do not take into account the completely random mobility of the nodes.

Our SSW approach minimizes the resources consumed in the network such as energy, and the amount of memory compared to the Spray-and-Wait approach. In figures 6 and 7, our SSW approach consumes 12800 units of energy and 1690 units of memory to make 16900 possible transmissions in the network compared to the spray-and-wait approach which consumes more than 16000 units of energy and more than 2000 memory units to achieve more than 20000 possible trans-missions.

9.2. Second simulation scenario

We consider that the density of nodes is low in each simulation area. The internal connectivity of each simulation zone is not guaranteed. Connectivity between simulation areas does not exist and is not guaranteed. The table below summarizes the parameters of the second simulation scenario used to evaluate the performance of our SSW routing approach as a function of low node density. The other parameters such as the mobility patterns and the initial energy level of each node are considered constant and the buffer memory of each node is considered infinite for all simulations.

Table 3: Second simulation scenario parameters

Simulation parameters 2	Values
Simulation time	1600s
Mobility models	Random Walk, Radom Waypoint, Restricted Radom Waypoint
Routing Protocol	SSW, Spray and wait
Number of nodes	20
Energy level of each node	1000
Radius of the focused communication	30
Maximum Speed	50 ms
Size of each area	1000*1000
Number of simulation zones	4
Initial probability of visit	0,5
Initial probability of delivery	0,75
β	0,25
ϒ	0,98
Parameter value L	2

9.2.1. Simulation results according to Spray-and-Wait

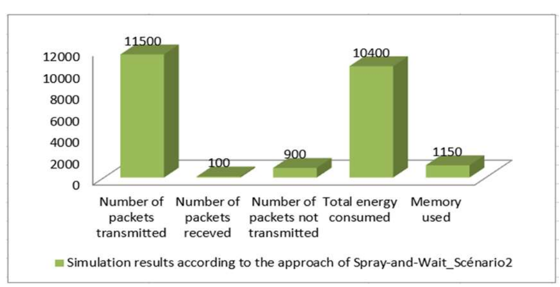

Figure 8: Simulation results according to Spray-and-Wait

9.2.2. Simulation results according to SSW

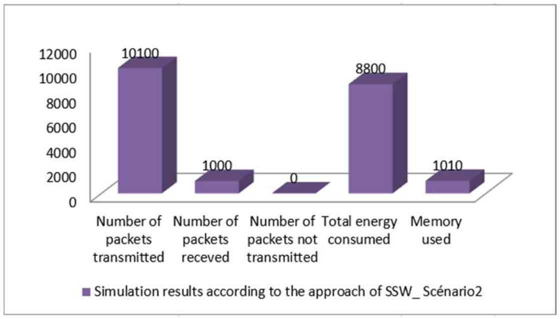

Figure 9:Simulation results according to SSW

Figures 8 and 9 show that our SSW routing approach outperforms the spray-and-wait routing approach in terms of packets successfully received by the destination and resources consumed in the network.

- For the SSW approach, figure 9, shows a total and successful delivery of all 1000 packets transmitted by the source node despite the low density of the nodes and the low communication range of the nodes, this because of the strategy used by the SSW routing approach based on total similarity and total probability.
- For the spray-and-wait approach, Figure 8 shows that the number of packets received by the destination represents 10% of the set of packets transmitted by the source node. This result is due to several reasons, namely: the low density of the nodes, the low communication range of the nodes but also because of the absence of relations between the nodes during the wait phase.
- For the PSW and SC-AMSW routing approaches, the percentage of packets received by the destination [5][6] does not manage to reach 100%, and this can be explained by the low density of the nodes but also by the behaviors unpredictability of some nodes that have no relations with other nodes

Our SSW approach in the second scenario also minimizes the resources consumed in the network compared to the Spray-and-Wait approach. From figures 8 and 9, our SSW approach consumes 8800 units of energy and 1010 units of memory to make 10100 possible transmissions in the network compared to the spray and wait approach which consumes more than 10000 units of energy and more than 1100 memory units to perform more than 11000 possible transmissions. On the other hand, the routing approaches: SSW and Spray-and-wait, PSW and SC-AMSW strictly limit the number of copies of each packet that circulates in the network.

9.3. Recapitulation and discussion

Our SSW approach consists in spreading the copies of a message as quickly as possible in the spray phase, then transmitting them to the social nodes having: A high probability of delivery, A high probability of visit, increasingly similar mobility of that of the destination, similar social attributes of the destination and very high residual energy as well as sufficient battery life. In the case of absence of any sort of mobile and social similarity and also the movements of nodes is completely random, copies of a message are sent to nodes which have a high probability of delivery and/or have a high probability of visit. This strategy makes it possible to strictly limit the number of copies of a message in the spray phase and to limit the number of message carriers circulating in the network in the wait phase and it makes it possible to optimize the consumption of network resources. The SSW approach maximizes the chances of reaching the destination through the use of social nodes and minimizes the resources consumed in the network, which involves fewer copies of a message and fewer message bearers.

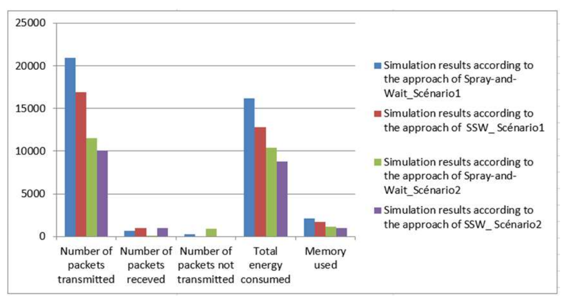

Figure 10: Simulation results of the "SSW" and "Spray and Wait" approaches according to the parameters of the first and second simulation scenarios

In the figures above, we present [the number of packets transmitted, the number of packets received by the destination, the energy consumed in the network, the amount of memory consumed in the network] according to the density and the connectivity of the network, by varying the number of nodes and the communication range. In the first scenario (scenario 1: the four zones are dense and connected) we can notice that the delivery rate (number of packets received / number of packets transmitted) of our SSW approach is greater than that of the Spray-and -Wait approach, as well as our SSW approach minimizes the resources consumed in the network such as energy, and the amount of memory compared to the Spray-and-Wait approach and this because of the reduced number of social nodes which transport the messages and also the reduced number of message copies circulating in the network. In the second scenario (scenario 2: the four zones are sparse and not connected), although both approaches show a low delivery rate due to the low density of the nodes, we can notice a small increase in the delivery rate of our SSW approach compared to the Spray-and-Wait approach as well as the resources consumed in the network by our SSW approach are reduced compared to the Spray-and-Wait approach. Our SSW approach has a significant impact on the number of packets transmitted and received in the network as well as the total energy consumed in the network and the amount of memory used in the network. From the results of the simulations performed, we can see that our SSW approach has a significant impact on the routing performance in DTNs compared to the Spray-and-Wait approach.

10. CONCLUSION

Delay-tolerant networks are wireless networks where disconnections occur frequently due to node mobility, low node density, or when the network spans long distances. In these situations, the spray-and-wait routing protocol that was developed to overcome routing problems in DTNs proves inefficient. To effectively improve the performance of the Spray-And-Wait protocol, we propose a routing approach called SSW (Social Spray-and-Wait) based on mobile attributes and social attributes between nodes as well as delivery and visit probabilities by exploiting special nodes called social nodes as relay nodes in the wait phase of the Spray-and-Wait protocol. Social nodes are nodes that exhibit greater mobile and social similarity as well as high delivery and visit probability. And therefore, they may have more chances to meet and successfully convey messages between them. From the results of the simulations performed, we can see that our SSW approach has a significant impact on the routing performance in DTNs networks in terms of delivery rate and resources consumed in the network compared to the Spray -and-Wait approach.

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