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Spray and Wait Routing Protocol for Mobile and Delay-Tolerant Wireless Sensor Networks

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Abstract— Intermittently connected mobile networks are wireless networks, where, often, there is no complete path between the source and destination nodes and, the network is considered as a set of disconnected groups. This definition is related to Delay Tolerant Networks (DTN). Thus, several studies have been performed to design routing protocols that consider substantially delay tolerance constraint. In this paper, we investigate the projection of spray and wait routing protocol, which is dedicated to DTNs environments, in Wireless Sensor Networks (WSNs). The obtained results from the intensive performance evaluation of our proposal prove obviously the efficiency of spray and wait protocol in WSNs.

Keywords— Wireless Sensor Networks, routing protocol, Spray and Wait protocol, Delay Tolerant Networks.

I. INTRODUCTION

Wireless Sensor networks consist, in general, of thousands of low cost tiny nodes, often randomly deployed in hostile and inaccessible areas. Sensor nodes have the ability to collect information about dynamic characteristics of the deployment zone. The low energy reserves, as well as, the computational and memory scarce represent the main limiting constraints. Data routing in this type of networks is an important functionality that allows constraints-aware communication of sensed data from source sensor nodes to the base station, in many to one forwarding scheme. Current researches [1] show that conventional routing protocols are not enough appropriate to WSNs in real environments, especially due to specific radio conditions such as noise, interferences, collisions and the volatility of the neighborhood. This led undoubtedly to a significant degradation in network performances. In order to remedy to this problem in WSNs, researchers have proposed many protocols and techniques.

WSNs are useful in a large scale of application domains (military, healthcare, industry, home automation and so on). In fact, some applications require the mobility of sensor nodes to reduce the number of nodes deployed, which involves a lower investment cost. However, the risk of data loss when the mobile communicating devices diverge, presents a major drawback.

In this work we study some protocols that support sensor nodes and/or base station mobility in WSNs, and exploit node mobility to be connected to isolated groups (sparse network). These protocols face a set of challenges as the discovery and the detection of mobile nodes.

The remainder of this paper is organized as follows: in section II, we present routing in WSNs, as well as, the related features and constraints. We present also, many relevant routing protocols. In section III, we highlight mobility in WSNs and its main challenges. Then, we give a review of proposed protocols for routing in mobile WSNs. Thereafter, DTN environment is presented with the corresponding protocols. In section IV, we give performance evaluations and simulation results of Spray and Wait protocol in the context of WSNs. Finally, we summarize and conclude our work.

II. ROUTING IN WSN

Routing is by definition, a forwarding technique of messages generated from a source node towards a given destination. Each type of network has its proper routing policies and protocols. In this section, we highlight routing in WSNs context.

A. Routing issue in WSNs

Since radio range of sensor nodes is relatively short, the direct communication between sensor nodes and the base station is, in most cases, impossible. For this reason, the communication is carried in cooperative scheme including intermediate nodes, in what is known by multi-hop forwarding.

The most evident techniques that might be used to route data without any routing protocol are: flooding and gossiping techniques. In flooding technique, the sender sensor node disseminates data to its neighbor nodes, and the same process is repeated recursively with the set of all nodes that receive data, until the base station is reached. Although this technique is simple and guarantees a reduced latency and communication reliability, it causes important energy dissipation, with the risk of creating loops. Consequently, sensor nodes batteries are rapidly depleted. The second technique is called gossiping. Its main goal is to remedy to the problems raised in the flooding technique. To do this, each sensor node selects randomly one of its neighbors to transmit its data messages (or messages it receives). Despite the reduction of the total energy consumption in the network, this technique does not consider the level of remaining energy of relay nodes, which may be insufficient to perform data forwarding, leading to data loss. From there, it was deduced that the introduction of routing protocols based on the objective of energy-saving, while assuring efficient data forwarding in WSNs is highly recommended. However, this is not a trivial task, regarding the various constraints in such networks [2].

B. Routing constraints in WSNs

Routing in WSNs is a constrained task. The most important constraints are summarized in the following points [3]:

- It is not possible to form a global addressing system for extended WSNs.
- Multiple resources and unique sink : WSNs applications require to gather measurements from multiple resources. The final destination of all network flow is the base station.
- Data redundancy: dense sensor nodes can report the same data.
- Limited resources: routing protocols should give a special care to resources scarce [4].

C. Performance criteria of routing protocols in WSNs

Routing protocols performances are measured according to several criteria [5], the most important are:

- Energy consumption: energy reserves of each sensor node are very limited and, generally insufficient to perform highly complex tasks. Therefore, routing protocols have to be energy-aware.
- Low overhead: the memory footprint of routing protocols should be as reduced as possible. Moreover, the amount of signaling packets that a routing protocol generates to setup and update routes shouldn't be important.
- Scalability: scalability is an important factor in wireless sensor networks. The network is not always static, it can be extended according to the user needs. Routing protocols designed to WSNs should consider this feature, while maintaining their performance.

D. Routing goals in WSNs

Routing functionality in WSNs is closely dependent on application services. In some cases, we only need an efficient and energy-aware messages routing between a source node and the base station. However, there are certain applications that require other services, such as real-time or secure message delivery [6]. Routing goals in WSNs are:

1) *Reliability:* As sensed data are generally sensitive, ensuring their delivery is essential in routing protocols. This means that the protocol must always be able to find a path linking the sensor nodes with the base station.
2) *Real-time deliverance:* Some applications impose that data messages must be communicated within a specified delay, otherwise information become obsolete. In such a case, the main objective of a routing protocol is to respect that real-time issue.
3) *Extended network lifetime:* This feature is highly recommended in networks where the application must be running for a long time on constrained sensor nodes. Routing protocols should balance between the need for lower energy consumption and an efficient routing. However, the metric used to determine the lifetime of the network is also related to the application. Most protocols assume that each node is as important as all the other ones, and continue to be operational until the first node dies, as a metric. Otherwise, the protocol considers as a metric, the operational time until the last nodes (or nodes of the highest priority) die.

III. MOBILITY IN WSNS

Monitoring a large area requires an important number of sensor nodes. This definitely implies a prohibitive cost. An alternative approach consists in the use of mobile nodes, where one mobile node can replace a set of stationary nodes. Hence, the co-existence of both fixed and mobile nodes in a mixed zone can be considered.

In this section we present an overview of mobile WSNs and their main characteristics and challenges.

A. Mobile Wireless Sensor Networks

In order to deeply understand the specific characteristics of wireless sensor networks with mobile elements (WSN-ME), we first present the network architecture, which is detailed according to the role of MEs. The main components of a WSN-ME are [7]:

1) *Regular sensor nodes:* Regular sensor nodes are the sources of information. Their main task is event detection and monitoring. They can also relay messages in the network according to the adopted communication policy.
2) *Sinks (base stations):* Sinks are the destinations of information. They collect sensed data, either directly (from the effective source nodes) or indirectly (through intermediate nodes).
3) *Special support nodes :* Acting as intermediate data collectors, or as mobile gateways, the nodes of this type are neither the sources nor the destinations of messages. However, they exploit mobility for assisting data collection functionality in the network.

We note that in a WSN-ME sensor nodes may be mobile and sink(s) may be static, and vice versa. In any case, we define a WSN-ME as a network where at least one of the components listed above is mobile.

The presence of the support nodes in a WSN-ME is optional. When the network includes only the regular nodes, the resulting WSN-ME is called homogeneous or flat. On the other hand, when the support nodes are also present, the WSN-ME is heterogeneous.

Furthermore, in contrast of ordinary network architectures of WSNs, which are generally restricted to be dense, a WSN-MEs may be dispersed.

4) *Mobility impact:* According to whether the movement state of the ME is autonomous or not, we distinguish two main modes of uncontrolled mobility: deterministic and random.

The deterministic mobility scheme is characterized by the regularity of the ME‘s contacts, typically periodic. On the other hand, the random mobility model is characterized by irregular contacts, but with a probability of distribution. In general, a given node should perform constantly the discovery so that it can increase the probability of finding contacts. However, when a little knowledge on the mobility context of nodes is available, the node may limit discovery to the moment when the probability of the existence of a near ME is relatively high.

Unlike the first case, the controlled mobility exploits nodes that can actively change their place, as they can control their trajectory and speed. As a result, the movement becomes an additional factor that can be effectively exploited to develop protocols for collecting specific data in WSN-MEs. It should be noted that controlled mobility can generate certain issues related to the collection of less relevant data.

B. Mobility challenges

The most important mobility challenges in WSN-ME are summarized in the points below [7]:

- Contact detection: since communication is possible only when the nodes are in the communication range of each other, it is necessary to correctly detect a mobile node.
- Mobility & energy management: In some cases, it is possible to employ knowledge about the mobility model, in order to optimize the detection of mobile nodes. In fact, if the visit times are known or can be predicted with some accuracy, the sensor nodes can be awake only when they expect that the ME is in their transmission range.
- Reliable data transfer: As the available contacts can be really few, there is a great need for maximizing the number of messages transferred to the sink. Furthermore, the message exchange process must be aware of mobility.
- Mobility Control: when the movement of mobile nodes can be controlled, a policy of visiting nodes in the network should be established to define the path, the speed and the residence time of mobile nodes in order to improve network performance.

C. Advantages of nodes mobility

Sensor nodes mobility in WSNs is useful for various reasons [8] :

- Connectivity: mobile elements can monitor efficiently the isolated areas.
- Reduced cost: Since fewer nodes can be deployed, the cost of network deployment gets reduced in mobile WSNs.
- Reliability: It is recognized that the rate of packet loss increases with a large number of hops in fixed networks. Moving elements in WSN-ME can route data directly through single-hop transmissions. This not only reduces collisions, but also the loss of messages.

  In WSNs with stationary elements, nodes that are closer to the sinks are more overloaded than others and are subject to rapid energy consumption. In contrast, mobile nodes move and visit different regions in the network, and make the energy consumption more uniform.

D. Comparison between routing approaches based on mobile elements

In the following table, we compare the different routing approaches based on MEs, according to specific criteria.

TABLE I: COMPARISON OF APPROACHES FOR ROUTING TO MES. [7]

Solution	ME Role	Nbre of MEs	Network type	Mobility model	Metric
EARM [9]	MS	Single	Dense	linear	Energy
WEDAS [10]	MS	Single	Dense	random	Energy
HLETDR [11]	MS	Single	Dense	random	Energy
OLSR+ [12]	peer	Multiple	Dense /Sparse	random	Reliability
MASP [13]	MS	Multiple	Dense /Sparse	linear	Reliability
DD+ [14]	MR	Single	Sparse	fixed	Energy
SEAD [15]	MS	Multiple	Dense	random	Energy
DEED [16]	MS	Multiple	Dense	random	Latency
TTDD [17]	MS	Multiple	Dense	random	Energy
MobiRoute [18]	MS	Multiple	Dense	fixed	Reliability
[19]	MS	Multiple	Sparse	fixed	Reliability

E. DTN (Delay Tolerant Networks) environments

DTN networks refer to networks that ensure end to end information transmissions, even when the network is not continuously connected. The figure below shows an example of DTN.

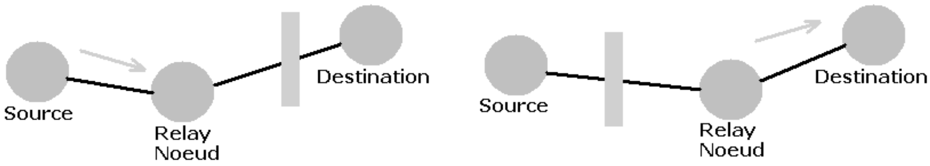


Fig. 1 Information transfert in DTN environnements

Depending on its current position, the relaying node is either connected to the source node, or it is connected to the destination, but not to both simultaneously. Consequently, there is no end to end connection. Some protocols (for example TCP/IP protocols) do not work in these conditions.

According to the characteristics of nodes mobility, we distinguish three categories of DTN:

- Nodes are fixed, or few nodes are mobile [20,21]

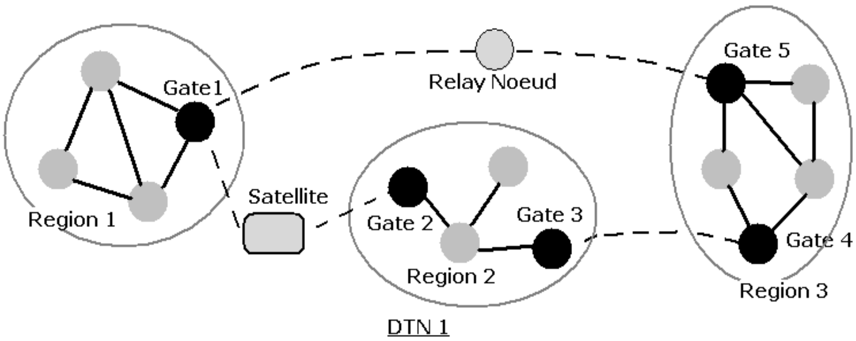


Fig. 2 Semi-static DTN

In Figure 2, we can see three main regions. Internal connections within each region are reliable (wired or wireless). However, the intra-connections between regions are not reliable. They can be provided by satellite links (between Gate1 and Gate2), nodes moving between two regions (relay node between Gate1 and Gate5), or may radio links of low quality (between Gate3 and Gate4). For example, a bus circulating between two villages or an elevator between the attic and the basement of a building.

• All nodes are mobile, they communicate through wireless links as in ad hoc networks, but the network has a heterogeneous density [22,23].

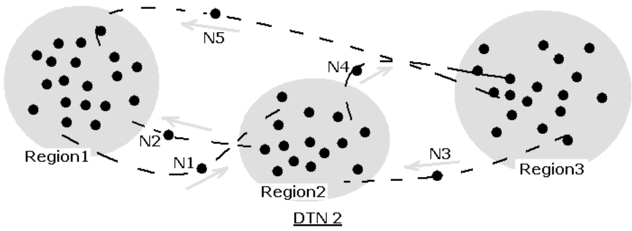


Fig. 3 Dynamic DTN

In the scenario shown in Figure 3, the density of nodes is enough important in the three regions. The connectivity of each internal region is guaranteed. However, there is no permanent connection between two regions, the communication between two areas depends only on the movement of some nodes. For example, Region 1 may be a campus library and Region 2 a conference room. A person (N1) which moves from the library to the conference room can ensure the delivery of a certain volume of data. We assume that a node that frequently moves between two regions has a high probability of re-doing so.

• All nodes are mobile, but the density of the nodes is very low. Furthermore, there are no permanent end to end connections and, message routing is done by movement of nodes. When two nodes meet, they exchange the messages they have to forward.

1) Routing algorithms in DTNs

In traditional networks, routing is to find the best path to the destination, based on specific metrics. In DTN networks, concepts of path and topology are different, because the contacts may be intermittent due to nodes mobility. For this reason, the topology is variable in time. Consequently, traditional routing protocols are not suitable for DTNs.

In DTN networks, routing goals are:

- Reducing packet loss and/or forwarding errors rates.
- Reducing the end to end delay.
- Minimizing as much as possible the total number of mandatory retransmissions for the transmission of a given packet.

The primary goal of routing mechanism is to provide an efficient deliverance of the packets from their source to the destination. Therefore, the rate of loss is always the most important routing parameter.

However, for some applications, a packet that arrives too late is useless. Hence, the end to end delay should be reduced, which is a very difficult and challenging task. Most DTN networks are wireless networks, that is to say that the links are unreliable, bandwidth links is low, the queues sizes are not important and, nodes must save energy. Thus, to improve system performance, we have to reduce the total number of packet transmission, as well as, the number of copies of each packet. Thus, the overhead related to the signaling information that should be exchanged is required to be as reduced as possible.

2) Examples of routing protocols in DTN environment

a) Epidemic Routing

Epidemic Routing [18] is the most famous and the simplest algorithm in DTNs. In this protocol, each node maintains a single queue, where messages generated from the local node and other nodes are inserted into the same queue. Each node creates a summary using a hash function. This summary contains a list of all messages owned by that node. When two nodes A and B meet (ie. they can communicate directly), they initiate a session called Anti-Entropy. During this session, they exchange their summary. Upon a summary reception, each node compares its own one with the received one so that it finds new messages.

b) Probabilistic Routing Protocol using History of Encounters and Transitivity (PRoPHET)

The main principle of PROPHET [17] protocol is similar to the epidemic routing. When two nodes meet, they exchange their state vectors which, in this case, contain information about the prediction of message deliverance. This information is used to update the vector of internal deliverance predictability. Therefore, the information stored in the state vector is used to determine the node to which the message will be transmitted, based on a given transmission strategy.

c) Spray and Wait :

The Spray and Wait routing protocol [26] oeuvres in core of spraying a few message copies into network and then waiting for them to get in contact with target node in concord to its name. In general, the Spray and Wait spreads a scare amount of message packets into the network and waits for a bounded amount of time until one of the nodes in the network get in contact with the destination node.

The Spray and Wait [27] outstrips the other traditional routing schemes with its average message delivery ratio, number of transmission hops to reach the destination on packet delivery and the overall routing performance. The implementation complexity of Spray and Wait |] is undemanding and it also can be heightened to pull off the performance in certain. It is palpable that this routing scheme limits the amassed number of transmissions per message packet without conciliation with the performance.

The Spray and Wait protocol holds two phases namely the Spray phase and Wait phase.

- 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”.
  Figure 4 depicts the L message copies initially spread to L distinct nodes. It means that the source node hand over all the packets that were generated in it to the node that it has encountered within its radio range.

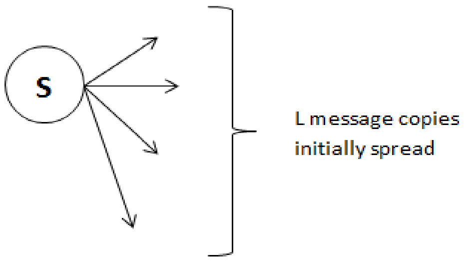


Fig. 4 L message copies sprayed

- 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. In our present work we’re interested in this routing protocol.

IV. SIMULATION & RESULTS

In this section, we present our performance evaluation of the protocol Spray and Wait in WSNs and DTNs environments. For this end, we have used the network simulator NS-2.

A. The evaluation parameters

To evaluate the performance of Spray and Wait routing protocol, we have considered three main parameters: the number of received packets, the end to end delay and the number of lost packets.

1) Number of received packets

The data transferred from sensor nodes to the base station are often sensitive. For this reason, efficient routing protocols minimize the number of lost packets. In other words, these protocols should guarantee an important rate of received packets.

2) End to end delay

The average end to end delay is the time between the moment of sending a packet by the source and the time of its reception by the destination. It includes the latency consequent from route discovery, the time of residing in the queues of the intermediate nodes and the transmission time at each hop. We measure the end to end delay over all received packets during the simulation. Thereafter, we calculate the average. This parameter represents the efficiency of the protocol in terms of response time and in terms of choosing optimal paths.

3) Lost packets:

The network topology changes due to node mobility, which causes an increased probability of packets loss. This obviously affects the performance of the routing protocol.

B. Simulation results

In this section, we present the evaluation results of the spray and wait protocol regarding several criteria.

The Spray and Wait routing protocol has been evaluated using NS2 simulator. The parameters set are the basic NS2 simulator, environ parameters are given in Table 2.

TABLE III: SIMULATION PARAMETERS

Simulation period	100
Number of nodes	150
Deployment area (m^2)	100×100
Transmission power (dbm)	3
NS Version	NS2.35
Buffer	100
Max speed	50

The figure "Fig. 5" presents the results the end-to-end delay estimation in regarding different network load levels.

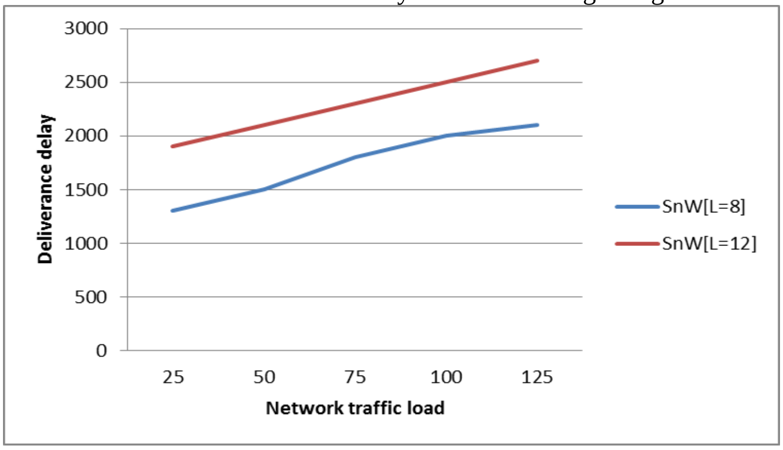
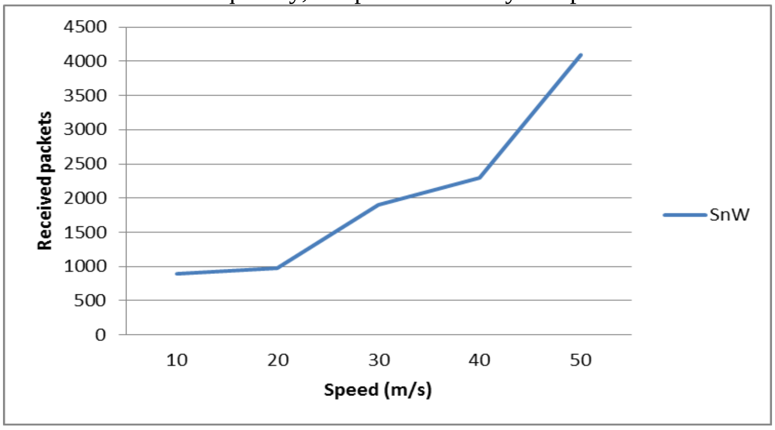
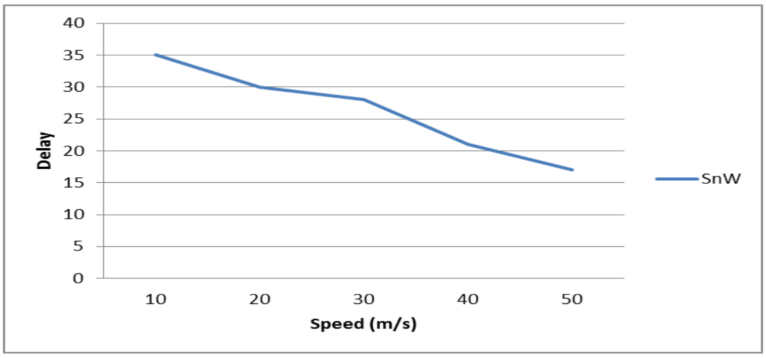


Fig. 5 end to end delay over network load

We can see that the deliverance delay increases as the network traffic load rises. We also note that the number of message copies generated in Spray and Wait protocol, affects the end to end delay; with more copies we have more possible paths to reach the destination. Consequently, the packet delivery is rapid.



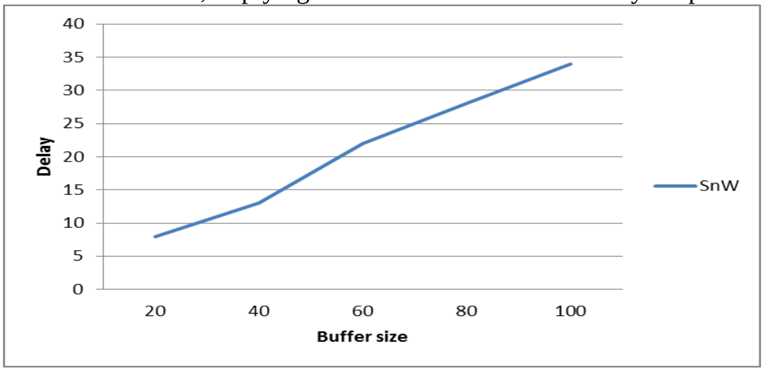
(a)



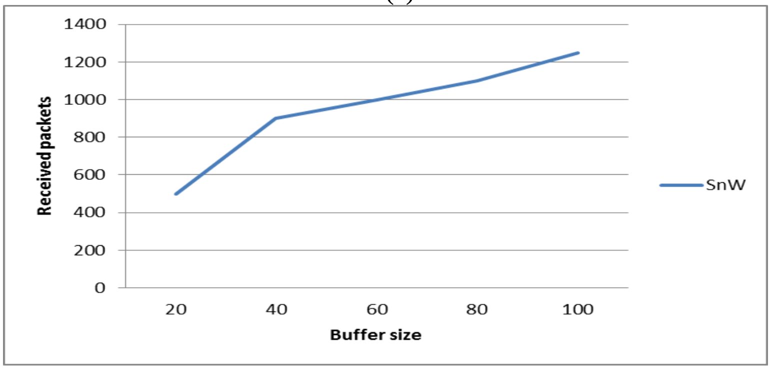
(b)

Fig. 6 Number of received packets and the delay over the mobility speed of nodes.

By analyzing the results depicted in Fig. 6, we find that there's a proportional relationship between the speed of mobile nodes and the amount of received packets. This is justified by the fact that the probability of meeting another node is high, so the number of packets received increases, implying that there is a reasonable delay for packets forwarding.



(a)



(b)

Fig. 7 Delay and received packets over buffer sizes

The Fig. 7 clearly shows that there's a proportional relationship between the size of the buffer and delivered packets, and the delay as well. Obviously, we consider only the delivered packets in the estimation of the end to end delay. Thus, the obtained results in Figure (a) are logic, as with an increasing number of the buffered packets, the deliverance delay increases too. Also, in the figure (b) shows that the number of delivered packets is important when the size of the buffer is sufficiently important. This is explained by the fact that the rate of lost packets gets reduced with an increasing size of buffer.

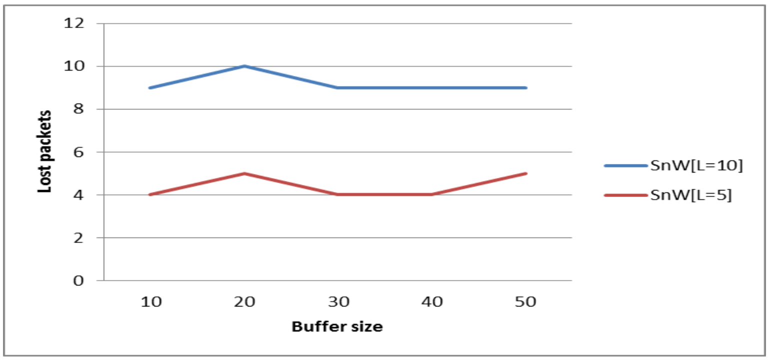


Fig. 8 Number of lost packets over buffer size and the number of message copies

If a source sends *N* packets to its neighbors, at the end of the simulation we expect to have a number of *n* or *n-1* lost packets, so this is the explanation of the results depicted in the Fig. 8, which represent a stable number of lost packets whatever the buffer sizes in the neighboring nodes, and also regardless of the number of packet copies generated in the network.

From the overall simulation results, we can deduce that the performance of Spray and Wait protocol can be affected by the following parameters:

- The mobility speed of mobile nodes.
- The size of the buffer.
- The rate of transmitted packets.

Usually when the network includes a high number of mobile nodes, the protocol Spray and Wait seems sufficiently efficient, especially in terms of the total number of received packets and communication delay. Unfortunately, this is not the case when the mobility is limited, or when the local mobility is predominant.

V. CONCLUSION

WSNs have become a vital research area. Different aspects have been intensively highlighted in the last decade. However, some issues remain inefficiently resolved. Mobility issue is one of most known examples. In this paper, we have addressed the routing issue in mobile WSNs in the context of DTNs. We have discussed the adoption of Spray and Wait protocol that exploits the mobility feature in data routing. The simulation results have proved that Spray and Wait protocol can be efficiently applied in mobile WSNs (even though if the mobility is frequent), especially, in terms of communication delay, lower congestion and lightness. Although its various advantages, Spray and Wait presents a drawback which is performance degradation in the case of localized and limited mobility.

As a future work, we aim to optimize Spray and Wait protocol so that it will be able to improve the end to end delay and reduce the amount of lost packets in the network. We intend also to compare it with other routing protocols supporting DTN environments.

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