Epidemic Strategies in Delay Tolerant Networks from an Energetic Point of View: Main Issues and Performance Evaluation

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***Abstract*— In this work we investigate Epidemic novel strategies called SNPS and EAER-SNPS applied to a DTN Network. These strategies extend the approach of the basic epidemic routing by using the node density estimation and the nodes energy levels; they adopt the forwarding scheme of the n-Epidemic routing. However, differently from n-Epidemic, it applies a dynamic forwarding scheme based on nodes density, that is able to reduce energy consumption and increase message delivery probability. A deep campaign of simulations was carried out in order to verify the effectiveness of the SNPS and EAER-SNPS. Simulation campaigns were conducted to evaluate the message delivery ratio, the average hop count, the average end-to-end delay and the average residual energy. Different mobility scenarios have been considered through the Working Day mobility model and by simulating pedestrians, buses and cars, in order to see how the performance can degrade on the basis of mobility and nodes characteristics.**

***Keywords*— DTN; Energy efficient; Epidemic routing; n-Epidemic; DTN routing; DTN;**

I. INTRODUCTION

The field of ad-hoc routing was inactive throughout the 1980s and the widespread use of wireless protocols rapidly grew in the 1990s, when Mobile Ad-hoc NETworking (MANET) became an area of critical interest, resulting in more advanced communications architectures, like VANETs [1], and routing protocols for mobile scenarios [2]. Mobile wireless ad-hoc networks were first studied under the assumptions of moderate node mobility and sufficient density to ensure end-to-end connectivity. Both conditions are necessary for traditional MANET approaches, be they proactive or reactive. Recently, there has been an effort to classify the various types of mobile ad-hoc networks [3]. One can characterize the relevant routing paradigms in mobile wireless networks along the two main parameters of node density and node mobility. In sparse networks, nodes have very few, if any, neighbors within their transmission ranges. The topology eventually splits into several non-communicating connected components. This is typically the realm of Delay Tolerant Networking[4]. A Delay-Tolerant Network (DTN) [5], defined as a “network of regional networks”, represents an Ad-Hoc Network which supports long delay, intermittent connectivity, asymmetric data rate and high error rate by using “Store&Forward” message switching. The DTN architecture implements such methodology by overlaying a new protocol layer, called bundle layer. The interest for DTN has rapidly grown, as well as for the Quality of Service (QoS) optimization in classic ad-hoc and delay-tolerant networking environments [5], [6], taking into account some new factors such as security and reliability. For example, DTNs can be employed in interplanetary networks (when communication between satellites is characterized by long delay and intermittent connectivity) [7], battery powered sensor networks (the consumption of which causes deactivation of the nodes and consequently the fall of the related links), as shown in fig. 1, and military ad-hoc networks (when nodes are in constant motion and are liable to be destroyed). Routing in DTNs plays an important role and, in this paper, our attention is focused on Epidemic Routing (ER) [8]: the choice of using it as routing protocol for the exchange of data allows us to have high probability to deliver a packet to its destination. In an ideal case, where there is no energy consumption by nodes, an ER protocol can be considered very efficient from the Packet Delivery Ratio (PDR) point of view. Unfortunately, in real environments, where nodes consume energy in the activation, transmission and reception phases, the ER protocol does not maintain the same performance as in the ideal case, because its “modus operandi” causes excessive energy consumption and, thus, a more frequent death of the nodes within the network (a large number of deactivated nodes causes the lowering of the delivery probability). To overcome this problem we can consider the n-Epidemic methodology: the source node uses a broadcast channel as a communication channel between itself and destination nodes. In this way, there is a unitary consumption of energy for each message transmitted on the broadcast channel (transmitting only one packet instead of n ones), obtaining a considerable energy saving, a limit on the energy consumption, a lower number of disabled nodes and, consequently, a higher delivery probability. In this paper, we propose an enhancement of the n-Epidemic methodology, introducing three different heuristic approaches as extensions of the n-Epidemic routing scheme: our approach, called Energy-Aware Epidemic Routing (EAER), provides a dynamic and scalable management of the n parameter, with the aim of increasing the overall system performance, especially in terms of PDR. The paper is organized as follows: section II gives a detailed description of the existing works on the considered topic, section III describes the main issues for ER, then in section IV the proposed idea is presented and simulation results are presented in section V; sections VI and VII conclude the paper.

II. RELATED WORK

There are many routing protocols for DTNs proposed in literature. One of the simplest approaches is to let the source, or a moving relay node, carry the message to the destination. A faster way to perform routing in DTN is ER [8]. Epidemic routing was proposed as a robust routing scheme for such a network, adopting a "store-carry-forward" paradigm: every node acts as a relay for other nodes. Multiple copies of the same message flow in the network and all nodes have the same messages in their buffers. In this way, all messages are spread in the network to all the nodes including the destination in an epidemic (like disease) manner. Due to a large number of redundant messages in the network, this protocol has significant demand on both bandwidth and buffer capacity. The algorithm is essentially flooding with some variations to reduce overheads. Resource Allocation Protocol for Intentional DTN (RAPID) [9] treats DTN routing as a resource allocation problem. It uses a utility function that: (i) assigns a value based on the metric being optimized to every packet and (ii) first replicates packets that increase the utility function. In RAPID, forwarding operations are based on a particular metric which takes into account the trend of some utility functions. A Probabilistic Routing Protocol using History of Encounters and Transitivity (PRoPHET) [10] is a variant of the epidemic routing protocol for intermittently connected networks that operate by pruning the epidemic distribution tree to minimize resource usage while still attempting to achieve the best case routing capabilities of epidemic routing. It is intended for use in sparse mesh networks where there is no guarantee that a fully connected path between the source and destination exists at any time, rendering traditional routing protocols unable to deliver messages between hosts. Before sending a message each node calculates a probabilistic metric called "Delivery Predictability" for each known destination, that indicates the probability of successful delivery of a message from the source node to the destination node. This metric is calculated on the basis of the history of encounters between the nodes or the history of their visits to certain locations. When two nodes meet, they exchange their Delivery Predictability with each other. Two nodes have a higher value of Delivery Predictability to each other if they have often encountered. A node will forward the message to another node only if it has a higher value of Delivery Predictability than the destination node [11]. Contact Graph Routing (CGR) [12] is a dynamic routing system that computes routes through a time-varying topology composed of scheduled, bounded communication contacts in a DTN network. The basic strategy of CGR is to take advantage of the fact that, since communication opportunities throughout the network are planned in detail, the communication routes between any pair of bundle agents in a population of nodes that have all been informed of one another's plans can be inferred from those plans rather than discovered via dialogue, which is impractical over space links with long one-way light times. Spray and Wait [13] is a quota-based protocol where an upper bound on the number of replicas allowed in the network is fixed during message creation. It provides an improvement over the Epidemic routing protocol by controlling the level of flooding. Spray and Wait breaks routing into two phases: a spray phase, where message replicas are disseminated, and a wait phase, where nodes with single-copy messages wait until a direct encounter with the respective destinations. The performance of this protocol depends on the value of L. The smaller value of L makes it similar to the Direct delivery protocol and a larger value of L makes it similar to the Epidemic protocol. A follow-up protocol called Spray and Focus [13] uses a similar spray phase, followed by a focus phase, where single copies can be forwarded to help maximize a utility function. While both Spray and Wait and Spray and Focus succeed in limiting some of the overhead of flooding-based protocols, their delivery ratios suffer.

MaxProp [14] does not assume any prior knowledge about the network connectivity and uses the local information and mobility of nodes to select the next best-hop for message delivery. It was designed for vehicle-based disruption-tolerant networks. It forwards the message to any node in the network having maximum probability of delivering the message towards the destination. It is based on the prioritizing of the schedule of the packets sent to other nodes, and the schedule of the packets to be deleted from the buffer. Is divided into three parts: Estimating delivery likelihood, where an optimal delivery path is found by constructing a directed graph of nodes connected by edges towards the destination, using Dijkstra's algorithm; Complementary mechanisms, that describe the priority order in which the different type of messages are exchanged between two nodes when they discover each other; Managing buffers, where an acknowledgment scheme for delivered messages is used that helps in flushing the redundant messages rom the network when the buffer space is almost full.

Our proposal is based on the n-Epidemic paradigm [15], but we introduce some enhancements in terms of energy consumption and packet delivery probability. In particular, the main contributions of this paper are:

- The extension of the n-Epidemic protocol through the proposal of a new heuristic based on the dynamic setting of the ***n*** parameter, in order to obtain the best performance in terms of energy consumption and packet delivery probability;
- Energy consumption reduction for the overall system, through the capability of the nodes of choosing the best variant of n-Epidemic, basing their behavior on the knowledge of network conditions or on the individual energy level;
- Extensive simulation under the Working Day Mobility model where heterogeneous mobility scenarios with pedestrians, bus and car movements have been accounted for.

III. EPIDEMIC ROUTING

Due to power limitations, the advent of short-range wireless networks and the wide physical conditions over which ad hoc networks must be deployed, in some scenarios the assumption for which a connection from a source to a destination always exists is often invalid. Introducing the ER, where random pair-wise exchanges of messages among mobile hosts ensures message delivery, leads to the maximization of the message delivery rate, minimization of message latency, and minimization of the total resources consumed in message delivery. Now an overview of ER in its basic and extended versions is given.

A. *Basic version*

ER protocol supports the delivery of messages, to an arbitrary destination, based on minimal assumption on topology and network connectivity. Only a regular pair connectivity is required, in order to ensure the delivery of message, as show in fig. 2. ER bases its operations on the transitive distribution of messages.

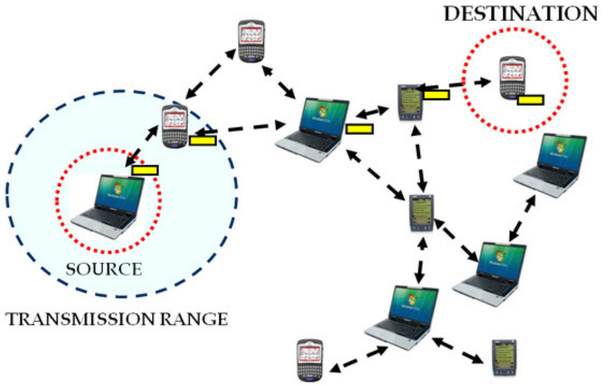


Figure 1. An example of Delay-Tolerant Network.

For example, in fig. 2 it is possible to observe how the source node S delivers a copy of the message destined to D to all its neighbors, in order to increase the probability that one of its neighbors meets the destination, terminating the transmission.

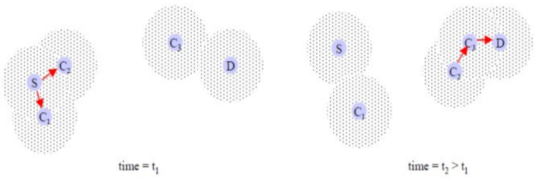
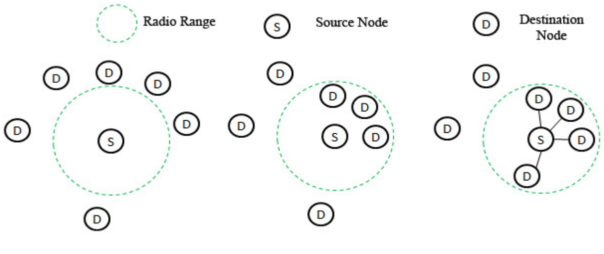


Figure 2. An example of ER operations.

Each host has a buffer for the storage of created and received messages destined to the other hosts. In order to obtain an efficient management of messages, they are indexed in a hash table. In addition, each node has an array of bit, called "summary vector", which indicates how many entries are stored in the hash table. When two hosts are in the communication range of each other, the host with the lowest *id* starts an "Anti-Entropy Session" with the host with the highest *id*, through which the messages are forwarded. To avoid redundant sessions, each host has a list of nodes with which a connection has recently occurred, in such a way as not to re-initialize a new Anti-Entropy Session, with a host contacted within a configurable period of time. As previously mentioned, the use of ER in real scenarios, does not allows us to obtain satisfactory results regarding delivery probability. Let us start to analyze a variant of epidemic protocol.

B. *n-Epidemic Routing*

Considering mobile nodes and assuming that they are powered by batteries, it is not so easy to perform battery recharges and, in the considered scenario, the battery level for each node is a primary and important constraint. If a node transmits a packet every time it meets another node, the battery will be used frequently and unsuccessfully. For this reason, we tried to optimize the possibility of sending messages from the node to its neighbors (when the node enters in the transmission range of another node, then it can be considered as a neighbor of the latter.), taking into account a new scheme, called n-Epidemic Routing (n-ER) [15], for which it is assumed that a node can start to transmit only when it has at least ***n*** neighbors. The steps of the algorithm are shown in fig. 3.



(a) n = 0 (b) n = 3 (c) n ≥ 4

No transmission No transmission S sends packet to nodes

Figure 3. The n-Epidemic Algorithm with n=4.

In this case, a node cannot transmit packets randomly as theoretical ER, and the value of ***n*** has to be fixed carefully, after many considerations. If the value of ***n*** is too high, the probability of having so many nodes within transmission range is low, as the possibility to relay a packet. If a packet cannot be distributed widely, the destination node has a low probability of receiving it. In the other case, if the value of ***n*** is too low, the source node has a high probability of having so many neighbors within its transmission range, then a high possibility of transmitting packets, involving an increasingly fast consumption of energy. The key step of n-ER is the discovery of the right values for the variable ***n***. According to the scheme of theoretical ER, when a node meets another node, it transmits the information to the latter, while according the scheme of n-ER, a node can transmit information only when in its transmission range there are at least ***n*** nodes, as previously shown in fig. 3 (where ***n*** is assumed equal to 4). From the treatment of [15] it can be noticed that the forwarding rate of the n-ER scheme is lower than the forwarding rate of the ER scheme. In addition, in [15] the energy consumption is considered only in the transmission phase: as presented in next section, we removed this hypothesis, giving to the proposed idea a more real and practical utilization.

IV. ENERGY-AWARE EPIDEMIC ROUTING (EAER)

The proposed protocol is based on the n-Epidemic methodology and considers energy consumption of mobile nodes in the following cases: a) transmitting phase 1 (related to the size of the packets), transmitting phase 2 (related to the distance between connected nodes, i.e. transmission range), functioning phase (related to the operation on the mobile device), receiving phase (related to the size of the packet to be received). Packet transmissions between the source node and ***n*** nodes within the radio range (transmission range) use a broadcast channel: in this way, the source node transmits the message (or messages) only once, and it is subjected to the transmission energy consumption only for one message, through the use of broadcast channel, from which the ***n*** nodes can withdraw the message (or messages). Without the use of broadcast channel, the source node will be subject to a consumption of energy ***n*** times greater, which leads source nodes to a faster deactivation, with negative consequences on packet delivery at the destination. In the transmitting phase, energy consumption is related to the packet size and the distance between linked nodes, while in the receiving phase energy consumption is only related to the size of the packet which will be received. Obviously, there will be an energy consumption related to the normal operations of the mobile device.

A. *Energy-Aware Heuristic*

We propose a heuristic with the goal of dynamically managing the ***n*** parameter of n-Epidemic protocol. In the basic version of n-Epidemic a static value of ***n*** has been adopted and just a general idea has been provided regarding the possibility of dynamically manage it. In our case, instead, we considered a dynamic ***n***-parameter based on energy considerations and node density.

Let ***THR*** be a set of thresholds $\{thr_1, \ldots, thr_K\}$ with $\|\boldsymbol{THR}\|=K$. In our approach each $thr_k \in \boldsymbol{THR}$ represents, for example, a particular energy level or a number of neighbor nodes. The idea of heuristic *H* is to choose a value for ***n***, on the basis of the Current Energy Level (*CEL*) or Average Neighbors Nodes (*ANN*), for a particular node. That is to say ***n*** is chosen on the basis of the interval that the current value of *CEL* or *ANN* is belonging to: $CEL_i<CEL<CEL_j$ or $thr_i<ANN<thr_j$. In these terms we can write that $\boldsymbol{n} = f_H(CEL,ANN)$. On the basis of the proposed heuristic we want to reduce the number of nodes involved in the data diffusion, reducing the energy consumption but maintaining a good delivery ratio during the time. The proposed heuristic is called *Smoothed Neighborhood based Prevalence Strategy (SNPS)*. It manages the value of ***n*** firstly based on *ANN*, and subsequently, if the residual energy decreases under a minimum threshold it considers the forwarding strategy based on *CEL*.

B. *Smoothed Neighborhood based Prevalence Strategy (SNPS)*

This considered strategy dynamically manages a value of ***n*** parameter considering the energy consumption and neighbor nodes for a particular node. Particularly, considering the *ANN* of each node when the battery level is higher than a energy threshold and considering the *CEL* when the level battery is lower than minimum residual energy threshold. In the proposed dynamic forwarding strategy, the criteria based on the node density adopts an average value of the number of neighbors in order to avoid a ping-pong effect in the *n* value assignment due to network dynamic. The proposed scheme, concerning the neighborhood parameter, works as follows:

1. Each node, in a distributed way and locally, computes the number of nodes in its neighborhood. This computation is made on a periodical basis;
2. The vector v_i related to each node *i*-th is filled with the current neighbor nodes number computed;
3. The average number of neighbors to a specific node is computed as:

$$n_{avg} = \frac{\sum_{p=1}^{|v_i|} v_i[p]}{|v_i|} \tag{1}$$

After the computation of n_{avg}, the tables as explained below are considered to dynamically assign the *n* parameter.

Two sets of thresholds are considered in our proposal:

- The first simulation campaign considers six thresholds and three possible *n* values to be assigned to the dynamic forwarding scheme. In table I the thresholds and the *n* values assigned to each sent message are presented:

TABLE I. THR SET FOR SNPS STRATEGY

thr_1	thr_2	thr_3	thr_4	thr_5	thr_6
0	1	2	7	8	∞
n	2	4		6	

The second simulation campaign considers seven thresholds and a higher number of *n* values to assign on the basis of these thresholds. In table II the set of thresholds and *n* values adopted in the simulations are presented:

TABLE II. THR SET FOR SNPS STRATEGY

thr_1	thr_2	thr_3	thr_4	thr_5	thr_6	thr_7
0	1	2	4	6	8	∞
N	2	4		6	8	10

As shown in table III, we considered two functions f_{H1} and f_{H2} for *SNPS*, on the basis of the *CEL* values.

Strategy Pseudocode: THR Set for EAER+SNPS strategy

```
IF CEL>2000mAh {
    If $thr_1 \leq n_{avg} \leq thr_2$ n=2
    else if $thr_3 \leq n_{avg} < thr_4$ n=4;
    …….
    else if $thr_5 \leq n_{avg} < thr_6$ n=8;
    else if $n_{avg} > thr_6$ n=10; }
ELSE IF CEL<2000 {
    If $CEL_1 \leq CEL < CEL_2$
        If fp>0,3 apply SNPS strategy
        otherwise no message forwarding
    else if $CEL_2 \leq CEL < CEL_3$
        If fp>0,6 apply SNPS strategy
        otherwise no message forwarding
    else $CEL_3 \leq CEL < CEL_4$ }
        If fp>0,8 apply SNPS strategy
        otherwise no message forwarding }
```

where *fp* (*forwarding probability*) is a randomly selected number uniformly generated in the interval [0,1]. This approach probabilistically allows the reduction of the number of messages forwarded on the network when node residual energy is reducing.

V. PERFORMANCE EVALUATION

Our simulations were performed using ***ONE*** (Opportunistic Network Environment) simulator [16]. We made a comparison between n-Epidemic routing and proposed routing protocol called *Energy Aware Epidemic Routing* (EAER), focusing on delivery probability, average hop count, data delivery delay and energy consumption.

A. *Simulation Scenario*

We consider two forwarding strategies: SNPS and EAER-SNPS . Nodes movement is restricted to an area of 4500m x 3400m. The number of nodes varies from 10 to 200 and each of them has a radio range of 100 meters, with movement speed varying from 0.5 m/s to 1.5 m/s. The size of the created message varies from 500kB to 1MB and each message is created every 25/35 seconds. The TTL is equal to 300 minutes. The transmission speed is equal to 250 kbps and the buffer size of each node amounts to 50MB. If we consider the energy consumption, the initial energy of each node varies from 1000 mAh to 4000 mAh, with the activation consumption of 0.005 mAh per second, the transmission consumption of packets of 0.03 mAh per 10kB, the radio range consumption of 0.006 mAh per meter and the consumption of received packet of 0.04 mAh per 4kB. The value of the ***n***-parameter, which identifies the minimum number of nodes that the source nodes must have into the radio coverage to start the transmission, varies from 2 to 10. Simulation parameters are resumed in table III.

TABLE III. SIMULATION PARAMETERS

Transmission Speed	2Mbps
Transmission Range	100 meters
Buffer Size	50 MB
Nodes speed	(0,5 - 1,5) m/s
Time To Live (TTL)	300 minutes
Initial Energy	(1000 - 4000) mAh
Activity Energy	0,005 mAh per minute
Packet Transmission Energy	0,03 mAh per 10 kB
Radio Transmission Energy	0,006 mAh per meter
Packet Receiving Energy	0,04 mAh per 4 kB
Packet Size	(500 kB - 1MB)
CEL_1, CEL_2, CEL_3,CEL_4	2000,1200,400,0 mAh
thr_1, thr_2, thr_3, thr_4, thr_5, thr_6, thr_7	0,1,2,4,6,8,10

Performance parameters considered in the simulation are the following:

a) Delivery Probability: It is useful to evaluate the effectiveness in terms of packets delivered to the destinations.

b) Average Hop Count: it considers the path length to evaluate the number of nodes involved in the diffusion strategy

c) Average Delay: it evaluates the end-to-end delay to arrive at destination.

d) Average Energy Consumption: it is important to see how much energy is spent and to estimate the network lifetime.

B. *Mobility Model: Working Day Model*

We considered this mobility model because it allows the definition of three transportation submodels: pedestrian, bus and car. These submodels are useful to create heterogeneous mobility scenarios useful to our purpose to evaluate the effectiveness of the epidemic strategies. During the initialization, a configurable percentage of nodes in each group are set to use a car for transportation between activities. Nodes not moving by car will use the bus or walking submodel. Nodes moving by car only use the car submodel for all transportations. The three basic submodels are briefly reported below:

- *Walking submodel:* Nodes that walk use streets to advance with a constant speed towards the destination. Dijkstra's algorithm is used for finding the shortest path to the destination.
- *Car submodel:* Nodes owning a car can travel at a higher speed between different locations. Otherwise it does not differ from walking. Within an activity submodel, car owners behave like the other nodes.
- *Bus submodel:* Nodes without a car can use buses to travel faster. There are pre-defined bus routes on the city map. The buses run these routes according to a schedule. Buses can carry more than one node at a time.

Each node that does not own a car knows one bus route. It can use any bus driving that route. The nodes make the decision to take the bus if the Euclidean distance from the node's location to the nearest bus stop summed with the Euclidean distance from the destination to the nearest bus stop is shorter than the Euclidean distance between the node's location and the destination. Otherwise, it walks the whole distance. If the node decides to take the bus, it uses the walking submodel to the closest bus stop and waits for the bus. When the bus arrives, the node boards it and travels until the bus comes to the bus stop nearest the destination. Then it switches back to the walking submodel to reach the destination.

C. *Data Delivery Evaluations of Energy-aware Heuristics on n-Epidemic Routing*

The performance with SNPS is better than n-Epidemic with a fixed n value. In fig.4 it is possible to see how SNPS performs worse than n-Epidemic with n=7. This is due to the bad selection of thresholds to attribute a dynamic n-value. This means that the thresholds range is a critical point in the proposed approach and it needs to be tuned. However, with five ranges such as expressed in tab. I, the SNPS performs better than n-Epidemic for a lower number of nodes (<200).

The same performance is depicted in fig.5 where the average hop count is higher in SNPS than n-Epidemic with n=7. However, concerning the average delay in fig.6, the SNPS performs better obtaining a lower delay in the data delivery. This is due to the higher number of messages sent on the network in comparison with n-Epidemic. Thus, in the case of three thresholds, SNPS reaches a higher delivery probability (about 65%) than n-Epidemic but just for a number of nodes lower than 200. On the other hand, SNPS behaves like n-Epidemic with n=4 for higher number of nodes.

We observed a high occurrence of the application of n=4 in the dynamic management of the parameter. This means that the benefits of our proposal cannot be evident when the granularity of the ranges in the node density is high. However, by increasing the number of node density range considering more thresholds, it is possible to observe how the overall performance improves significantly.

In fig.7 the graph of data delivery probability is shown. In this case, EAER-SNPS performs better than n-Epidemic because the higher granularity in the node density allows a fine management of the message forwarding through the selection of the most appropriate n value. In this case, the dynamic management outperforms the n-Epidemic in any situation because it has the capability to adapt to network conditions and to changing node density.

In this case, EAER-SNPS with a higher threshold number, reaches a peak value in the delivery probability of 77,01% with 200 nodes and overcomes the n-Epidemic of 50% in the maximum value. After the best nodes number of 200, its performance degrades but it maintains a better performance in comparison with n-Epidemic with n=7.

When a scenario with a light mobility is considered, a slightly different performance results in the delivery probability. EAER-SNPS is better than n-Epidemic until 300 nodes. Its performance degrades slightly for a higher number of nodes and n-Epidemic with n=7 performs better because it is more conservative preserving buffer space and increasing the delivery probability. However, EAER-SNPS performs better than n-Epidemic with n=4. This means that a conservative strategy when node density increases can be suitable to preserve buffer resource reducing packet dropping in the intermediate nodes.

The same advantage of n-Epidemic with n=7 is maintained in the other scenario in fig. 6 where there are 50% pedestrians and 40% buses.

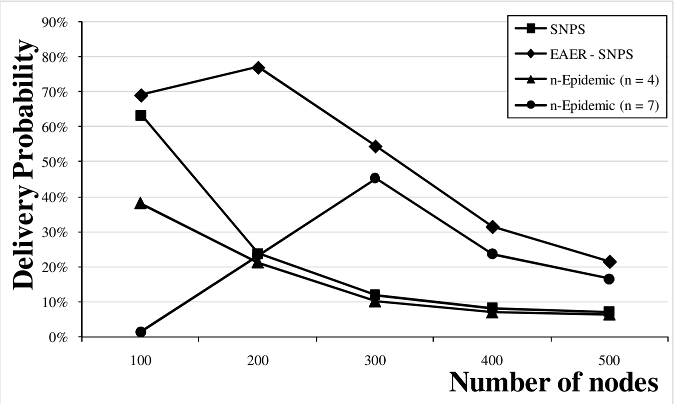


Figure 4. Packet delivery probability of EAER-SNPS heuristic (with 7 thresholds) and n-Epidemic (with energy consumption) with 100% pedestrians.

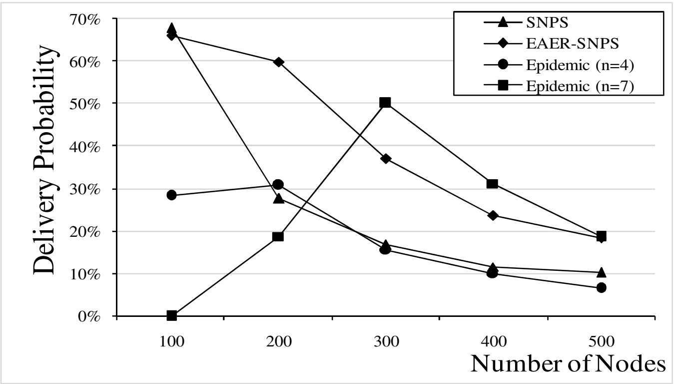


Figure 5. Delivery Probability of SNPS, EAER-SNPS heuristics and n-Epidemic with 80% pedestrians, 10%buses, 10% cars.

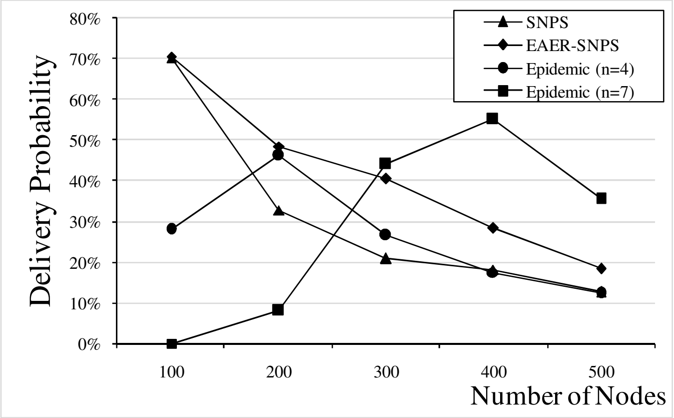


Figure 6. Delivery Probability of SNPS, EAER-SNPS heuristics and n-Epidemic with 50% pedestrians, 40%buses, 10% cars.

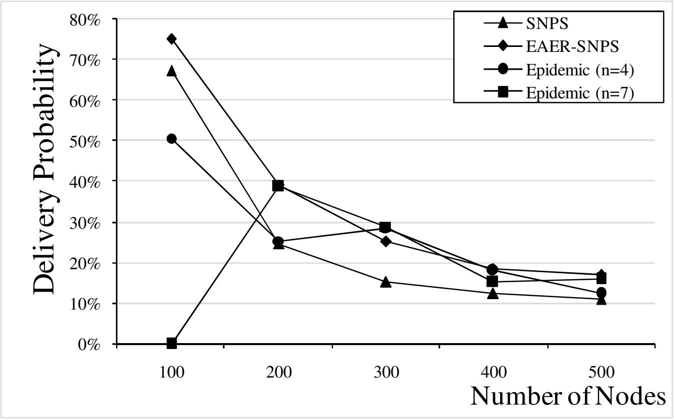


Figure 7 Delivery Probability of SNPS, EAER-SNPS heuristics and n-Epidemic with 20% pedestrians, 40%buses, 40% cars.

Also in that case, after 300 nodes, the most conservative version of n-Epidemic is better than EAER-SNPS. This is due to the partially stable scenario of pedestrians and the mobility of buses where the diffusion strategy of data becomes more effective. However, when node mobility becomes too high as in fig.7, also the conservative Epidemic (with n=7) degrades its performance and EAER-SNPS performs in a similar way for higher node numbers and always performs better for lower numbers of nodes.

D. Path Evaluation of Energy-aware Heuristics on n-Epidemic Routing

Concerning the average hop count in fig. 8, it is possible to see how EAER-SNPS significantly reduces the path length. Also n-Epidemic with n=7 performs well while n-Epidemic with n=4 increase the hop count because it forwards a high number of messages in the networks involving mores nodes between sources and destinations. Also the average data delay is better performing in the proposed scheme, obtaining a delay in the range [40-80] min.

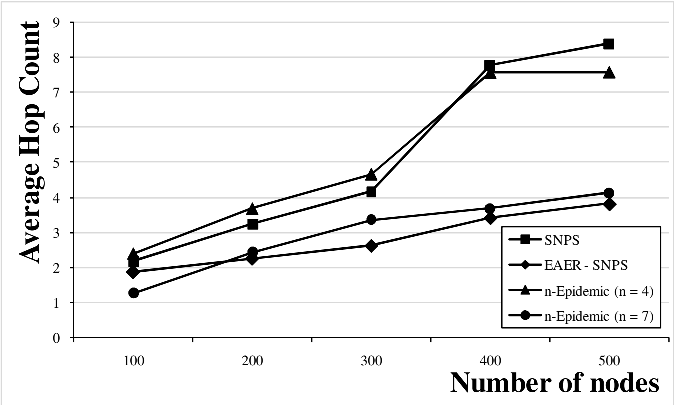


Figure 8. Average hop count of EAER-SNPS heuristic (with 7 thresholds) and n-Epidemic (with energy consumption) with 100% pedestrians.

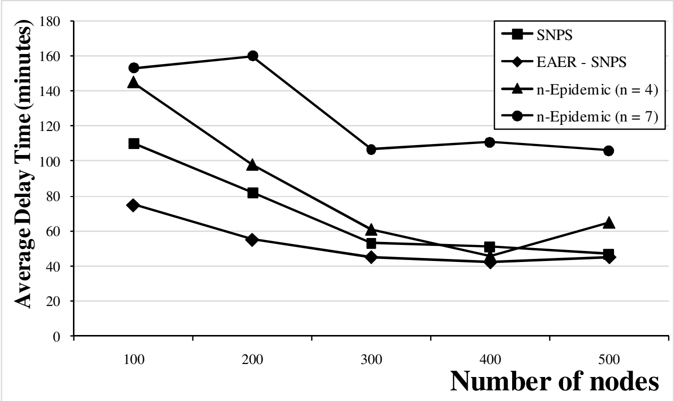


Figure 9. Average delay time of EAER-SNPS heuristic (with 7 thresholds) and n-Epidemic (with energy consumption) with 100% pedestrians.

Also the average delay time in fig.9 is lower for EAER-SNPS. This is due to the better distribution strategy that is able to dynamically adapt the diffusion spread. This better performance for EAER-SNPS is maintained for all the other scenarios. However, it is possible to observe a reduction of the path length for all epidemic strategies when mobility increases. This suggest how under mobility there is a natural data diffusion with general benefits in the node selection strategy. Moreover, also the average delay time is better for EAER-SNPS. This means that the dynamic strategy is able to better preserve the buffer space reducing the queuing delay. The delay of n-Epidemic is worse than EAER-SNPS of about 30-40 minutes.

The main difference in the considered scenarios is in the average hop count observed. In the last scenario where few pedestrians are considered and an equal amount of buses and cars (40% and 40%), the path length is about 4 for 500 nodes. This means that the use of a transportation system allows the user to reach more users (aggregation of users due to the group mobility) reducing the number of nodes involved to reach the destinations.

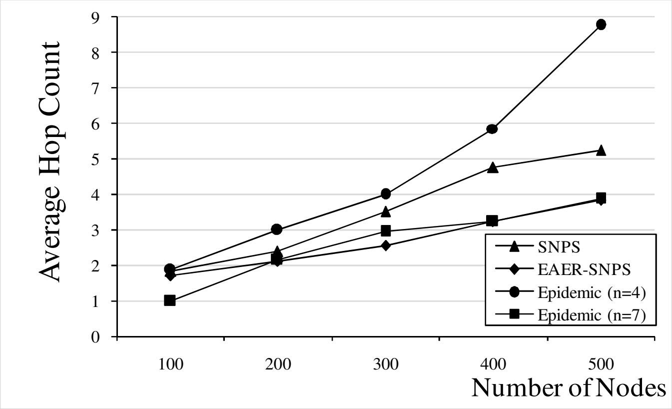


Figure 10 Average Hop Count of SNPS, EAER-SNPS heuristics and n-Epidemic with 80% pedestrians, 10%buses, 10% cars.

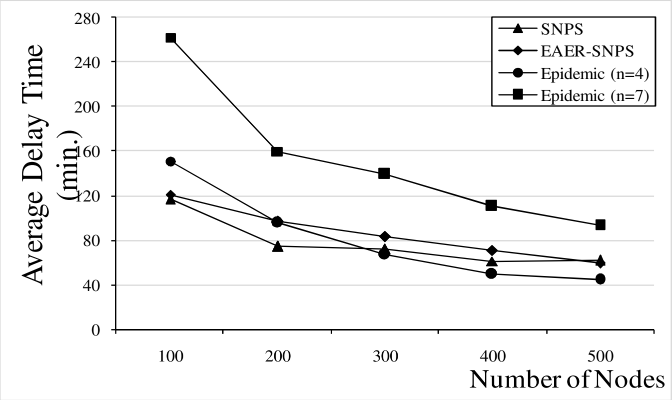


Figure 11. Average Delay Time of SNPS, EAER-SNPS heuristics and n-Epidemic with 80% pedestrians, 10%buses, 10% cars.

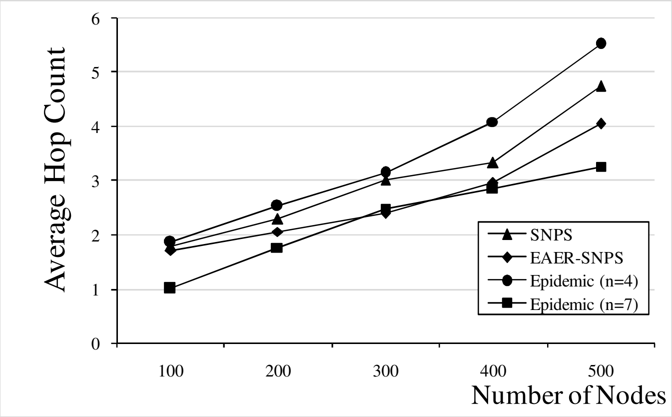


Figure 12. Average Hop Count of SNPS, EAER-SNPS heuristics and n-Epidemic with 50% pedestrians, 40%buses, 10% cars.

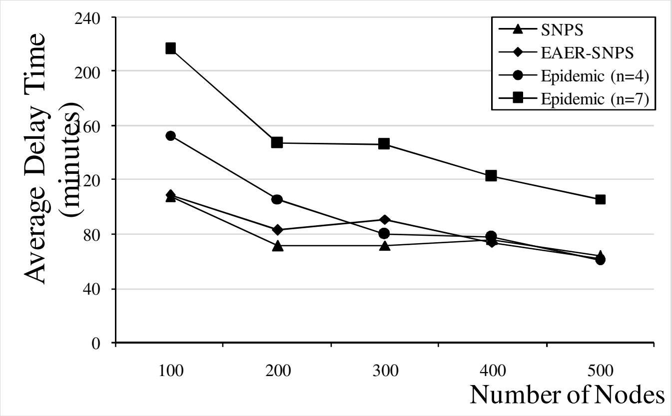


Figure 13. Average Delay Time of SNPS, EAER-SNPS heuristics and n-Epidemic with 50% pedestrians, 40%buses, 10% cars.

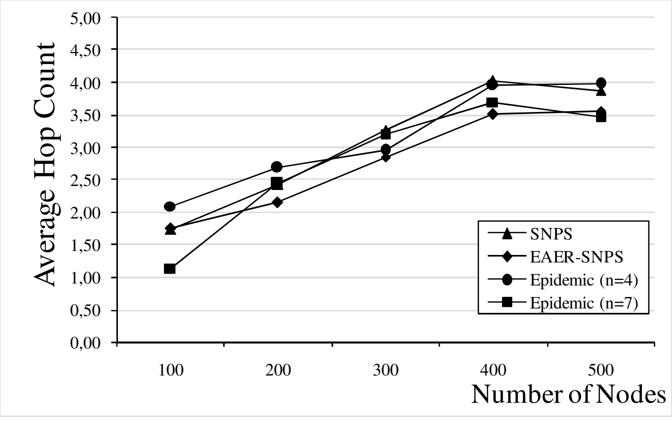


Figure 14. Average Hop Count of SNPS, EAER-SNPS heuristics and n-Epidemic with 20% pedestrians, 40%buses, 40% cars.

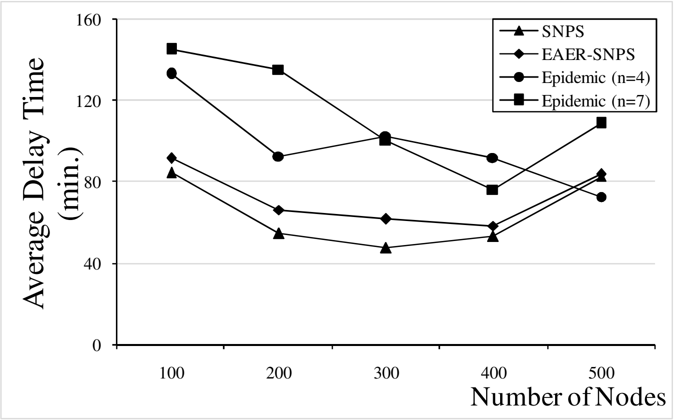


Figure 15. Average Delay Time of SNPS, EAER-SNPS heuristics and n-Epidemic with 20% pedestrians, 40%buses, 40% cars.

E. Energy Evaluations of Energy-aware Heuristics on n-Epidemic Routing

In this paragraph, the energy evaluation of the proposed heuristic versus n-Epidemic routing is presented. In fig. 16 it is possible to see the average energy consumption during the simulation of SNPS and EAER-SNPS and *n*-Epidemic with ***n***=4 and n=7. In fig. 16, the scenario with only pedestrians nodes is considered. It is possible to see how EAER-SNPS is more performing in time than n-Epidemic with n=4 because after consuming more energy at the beginning, they reduce their transmissions on the basis of the energy level or of the nodes degree. This means that the dynamic setting of ***n*** parameter allows a higher scalability of the Epidemic protocol and reduces the energy consumption preserving the network lifetime. This result is reached without affecting the data delivery probability as emphasized in the previous section. On the contrary, n-Epidemic with n=7 is still better than SNPS and EAER-SNPS. This is due to the conservative forwarding strategy that avoids sending a message on the network if the density is low. Since there are 200 nodes in the network, it is rare to find at least 7 nodes as neighbors to send the messages. This situation changes in fig.17 where 500 nodes are considered in the networks. In this last case, the performance of EAER-SNPS are quite similar to n-Epidemic with n=7, but with the advantage of improving the other network performance parameters, such as data delivery probability, end-to-end delay and path length.

However, when the mobility scenario changes as in fig.18, more group mobility is exploited and the chance to reach more nodes in few steps is guaranteed, the n-Epidemic with n=7 is more performing in terms of energy saving. This means that the EAER-SNPS strategy is less conservative and more nodes are involved in communication draining more energy. If the number of nodes increases as depicted in fig.19, fig.21 and fig.23, the energy consumption is more severe and all protocols perform in a similar way. However, under higher mobility n-Epidemic with n=7 (conservative version) is more performing that other strategies. This suggests adopting a very conservative strategy when the node density is high and some mobility among nodes. The mobility seems to offer an advantage to the conservative version of n-Epidemic because there is a natural load-balancing and variety of nodes to reach distributing the buffer space (with packet dropping reduction) and the energy consumption.

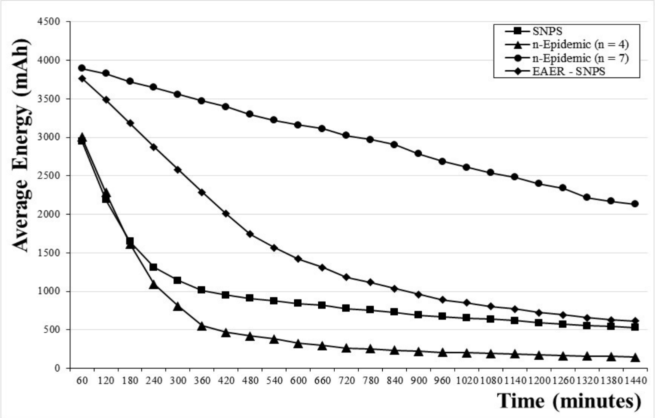


Figure 16. Average Energy consumption of SNPS, EAER-SNPS heuristics (with 7 thresholds) and n-Epidemic with 100% pedestrians and 200 nodes.

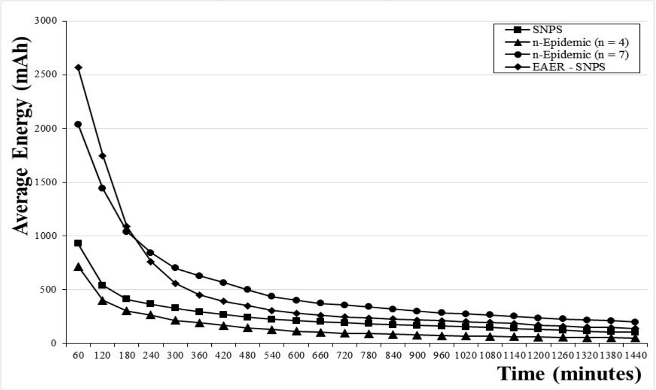


Figure 17. Average Energy Consumption of SNPS, EAER-SNPS and n-Epidemic with 100% pedestrians and 500 nodes.

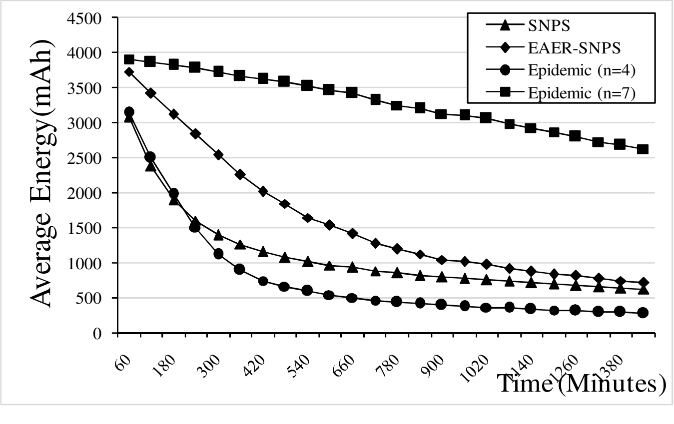


Figure 18. Average Energy of SNPS, EAER-SNPS heuristics and n-Epidemic with 80% pedestrians, 10%buses, 10% cars and 200 nodes.

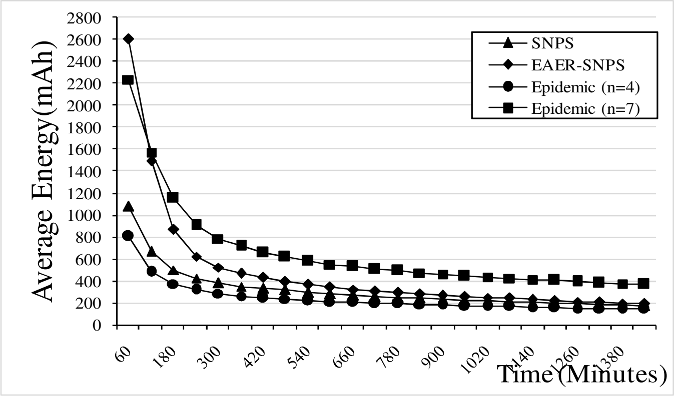


Figure 19. Average Energy of SNPS, EAER-SNPS heuristics and n-Epidemic with 80% pedestrians, 10%buses, 10% cars and 500 nodes.

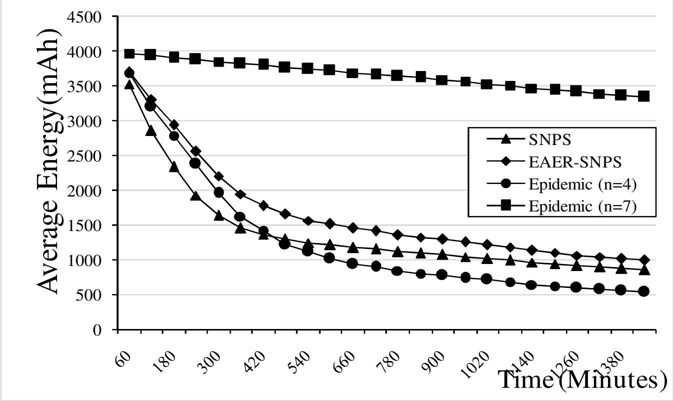


Figure 20. Average Energy of SNPS, EAER-SNPS heuristics and n-Epidemic with 50% pedestrians, 40%buses, 10% cars and 200 nodes.

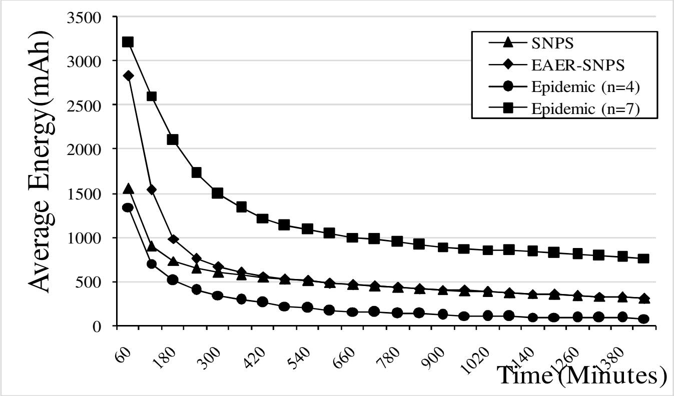


Figure 21. Average Energy of SNPS, EAER-SNPS heuristics and n-Epidemic with 50% pedestrians, 40%buses, 10% cars and 500 nodes.

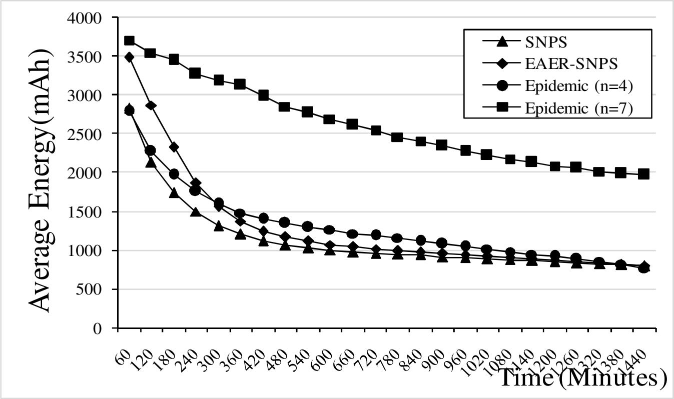


Figure 22. Average Energy of SNPS, EAER-SNPS heuristics and n-Epidemic with 20% pedestrians, 40%buses, 40% cars and 200 nodes.

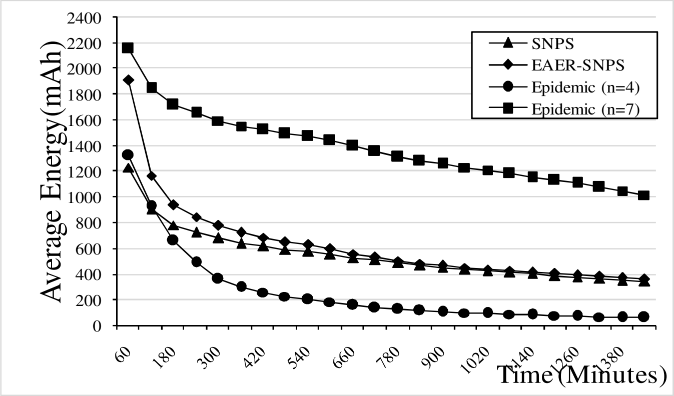


Figure 23. Average Energy of SNPS, EAER-SNPS heuristics and n-Epidemic with 20% pedestrians, 40%buses, 40% cars and 500 nodes.

EAER-SNPS, nevertheless is a dynamic tuning of n-parameter, which is not able to reduce the number of involved nodes. This means that some improvements in the number of threshold and in the energy levels needs to be designed in order to extend its operative range under different mobility scenarios.

VI. FUTURE DIRECTIONS

On the basis of the simulations proposed it is evident that epidemic strategies is a well known approach that can be significantly improved. Our SNPS and EAER-SNPS proposals are shown to be effective in some operative ranges. In particular for a number of nodes lower than 300 under mobility conditions or for a higher number of nodes in the case of pedestrians. This means that our approach can be further improved tuning the energy thresholds settings and the percentage of node density in a optimal way. The benefits of the proposed strategies can be evident in the lower energy consumption, higher delivery probability and lower path length. However, when the mobility scenario becomes more heterogeneous and other nodes are involved with the exploitation of more contacts and group dynamics, SNPS and EAER-SNPS are not able to estimate the node density and the n-parameter in an appropriate way in order to exploit the good trade-off between lower overhead and energy consumption and higher delivery probability. From simulation results, it is possible to observe that the benefits of EAER-SNPS are lost for higher nodes density and higher mobility. Future research directions can be focused on the improvement of the node density estimation also under more dynamic conditions and on the dynamic selection of the energy threshold under heterogeneous and group mobility. Moreover, some social criteria to account for contact frequency such as in PROPHET [17] and some distribution of the original message such as in Spray&Focus [18] will be accounted for in order to exploit a better data dissemination with lower overhead costs.

VII. CONCLUSIONS

In this paper a novel strategy to dynamically change the ***n***-parameter is proposed. This strategy accounts for the energy dissipation of mobile nodes and node density degree in order to increase or reduce the number of data dissemination in the network. We evaluated this technique against the classical n-Epidemic protocol in order to see the effectiveness of the dynamic management of the ***n***-parameter. As we have shown, with more scalability the prevalence strategy is offered and the *forwarding probability* is reduced when the node residual energy is low. On the contrary, when mobile nodes have good energy budget, more transmissions can be allowed and the transmission probability can be increased reducing the ***n***-parameter. Concerning the nodes degree, we also verified how the ***n***-parameter can be increased when a high nodes degree is present in the network, because the delivery probability can be preserved reducing the energy wastage.

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BIOGRAPHY

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