Enhancements of Epidemic Routing in Delay Tolerant Networks from an Energy Perspective

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***Abstract*— In last years, the challenge of providing end-to-end service where end-to-end forwarding paths do not exist is faced by the new emerging approach of Delay Tolerant Networks (DTNs), that support interoperability of "regional networks" by accommodating long delay between and within regional networks, such as space communications, networking in sparsely populated areas, vehicular ad-hoc networks and underwater sensor networking. The common issue of these environments consists in the absence of guarantees about the existence of continuous end-to-end paths between source and destination nodes. In this paper we consider epidemic schemes to solve this problem, proposing an extended approach aimed at the routing optimization in terms of energy consumption and message delivery probability. The performance of our idea have been evaluated through a deep campaign of simulations, verifying that the proposed extended epidemic approach leads the system to an overall enhancement.**

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

I. Introduction

A Delay-Tolerant Network (DTN) [1], defined as *"network of regional networks"*, 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. For example, DTNs can be employed in interplanetary networks (when the communication between satellites is characterized by long delay and intermittent connectivity) [2], sensor networks powered by battery (the consumption of which causes deactivation of the nodes and consequently the fall of the related links) 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) [3]: 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 receiving 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; section VI concludes the paper.

II. Related Work

There are many routing protocols for DTNs proposed in literature. One of the simplest approach 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 [3]. The basic idea of this protocol consists in the continuous relying of the message to each node that has still not got a copy of it, with the aim that the message is surely delivered. The advantage of this protocol consists in its simple philosophy, which requires a simple network configuration. If a link between source and destination node exists, all messages are correctly delivered, without any configuration. The only disadvantage in real (and not ideal) cases is that the protocol is not effective/efficient from the energy point of view. Spray&Wait [5] is a simple but effective protocol. It decouples the number of generated copies of the message, so the number of transmissions to be performed. There are two phases: the spray phase (for each message generated from source node, L copies are forwarded to L distinct nodes) and wait phase (if destination node has not been identified in the spray phase, each of the L nodes perform a direct transmission, i.e. forward message to its destination). In [7] the authors propose a new Resource Allocation Protocol for Intentional DTN (RAPID): in this context, routing operations are modeled as a driven service aimed at the resolution of a resource allocation problem; multiple copies of a packet are forwarded until one of them reaches the destination node. In RAPID, forwarding operations are based on a particular metric which takes into account the trend of some utility functions. The Contact Graph Routing (CGR) protocol [6] has been proposed to solve the messaging problem of interplanetary communications, exploiting networks where nodes exhibit deterministic mobility. With CGR, nodes construct transmission opportunities and the contact graph on the basis of mobility and bandwidth information: the main disadvantage of this protocol is the necessity to plan all the active connections before the beginning of the transmission, without the chance to use the opportunistic contacts. Another protocol used for DTNs is PRoPHET (Probabilistic Routing Protocol using a History of Encounters and Transitivity) [4]. It uses an algorithm which tries to exploit non-randomness of real meetings, storing a series of probability of successful delivery to best known destinations, replicating messages to nodes, which do not already have the message. This protocol is completely autonomous, available links between nodes are discovered dynamically and future transmissions are planned on past knowledge.

Our proposal is based on the n-Epidemic paradigm [9], 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 three new heuristics, all based on the dynamic setting of the ***n*** parameter, in order to obtain 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;
- Increasing of packet delivery probability, by the reduction of the node-deactivation phenomenon.

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 ensure message delivery, leads to the maximization of 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. 1. ER bases its operations on transitive distribution of messages.

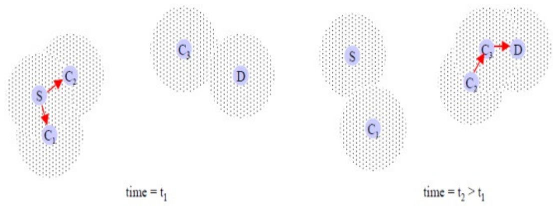

Figure 1. An example of ER operations.

For example, in fig. 1 it can be seen 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.

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 an 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 highest *id*, through which the messages are forwarded, as we can see in fig. 2. To avoid redundant sessions, each host has a list of nodes with which a connection has occurred recently, in such a way as not to re-initialize a new Anti-Entropy Session, with host contacted within a configurable period of time.

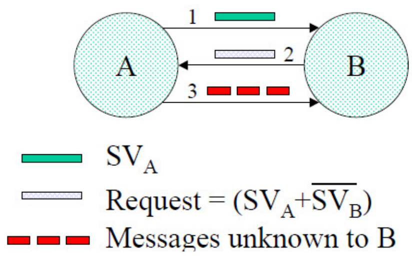

Figure 2. Anti-Entropy Session between host A and host B.

As previously mentioned, the use of ER in real scenarios, does not allows us to have 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, battery will be used frequently and unsuccessfully. For this reason, we tried to optimize the possibility of sending messages from node to its neighbors (when 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) [9], 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.

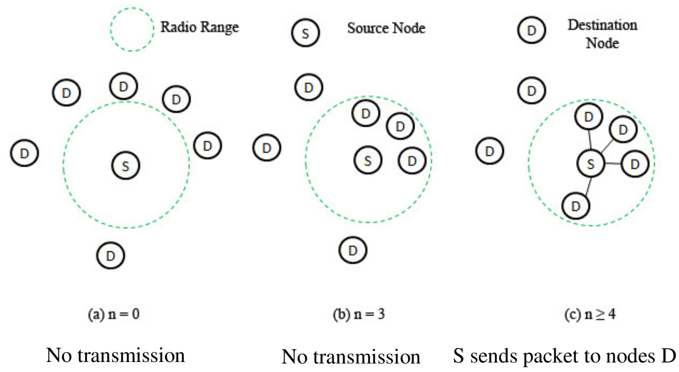

Figure 3. The n-Epidemic Algorithm with n=4.

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, destination node has a low probability of receiving it. In the other case, if the value of ***n*** is too low, 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 figure 3 (where ***n*** is assumed equal to 4). From the treatment of [9] it can be noticed that the forwarding rate of n-ER scheme is lower than the forwarding rate of ER scheme. In addition, in [9] 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 source node and ***n*** nodes within 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 delivery of packet at destination. In the transmitting phase, energy consumption is related to packet size and 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 also an energy consumption related to the normal operations of the mobile device.

A. *Energy-Aware Heuristic*

We propose an heuristic with the goal of dynamically manage 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 about the possibility to dynamically manage it. In our case, instead, we considered a dynamic ***n***-parameter based on energy considerations and nodes 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 Current Neighbors Nodes (*CNN*), for a particular node. That is to say ***n*** is chosen on the basis of the interval that the current value of *CEL* or *CNN* is belonging to: $thr_i<CEL<thr_j$ or $thr_i<CNN<thr_j$. In these terms we can write that $\boldsymbol{n} = f_H(CEL,CNN)$. 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:

- *Prevalence Strategy*: this heuristic manages the value of ***n*** firstly based on *CNN*, and subsequently based on *CEL*.

- *Prevalence Strategy (PS)*

This strategy we considered manage dynamically a value of ***n*** parameter considering the energy consumption and neighbors nodes for a particular node. Particularly, considering the *CNN* of each node when the battery level is higher than 2000 mAh (in particular between 2000 mAh and 4000 mAh), and considering the *CEL* when the level battery is lower than 2000 mAh. As shown in table III, we considered two functions f_{H1} and f_{H2} for *PS*, on the basis of the *CEL* values.

Table III. THR Set for PS strategy

	thr_1	thr_2	thr_3	thr_4
	0	400	1200	2000
n	7	6	5	

IF CEL≤2000

thr_1	thr_2	thr_3	thr_4
0	3	4	∞

n	2	4

IF CEL>2000

V. Performance Evaluation

Our simulations were performed using ***ONE*** (Opportunistic Network Environment) simulator [10]. We made a comparison between theoretical epidemic routing and proposed routing protocol called *Energy Aware Epidemic Routing* (EAER) or "prevalence" based routing performance, focusing on delivery probability and energy consumption.

A. Simulation Scenario

We consider two main scenarios: one in which nodes are not subject to energy consumption and the other one which considers the energy consumption. 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 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 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 7. Simulation parameters are resumed in table IV.

TABLE IV. 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)

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

The obtained results are very satisfactory for the proposed strategy. Figure 4 shows the packet delivery probability for the Prevalence strategy and the n-Epidemic versus the number of nodes. The graphs demonstrate how the *PS* strategy is the most satisfying one, because it has a linear trend compared to the *n*-Epidemic. The *n*-Epidemic with ***n*** = 4 presents good performances, reaching the peak with a number of hosts equal to 200 with a delivery probability of 34,66%, but this value decreases with the increase of hosts.

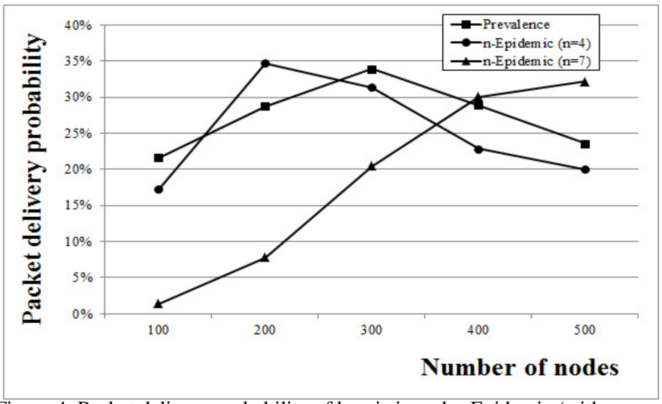

Figure 4. Packet delivery probability of heuristic and n-Epidemic (with energy consumption)

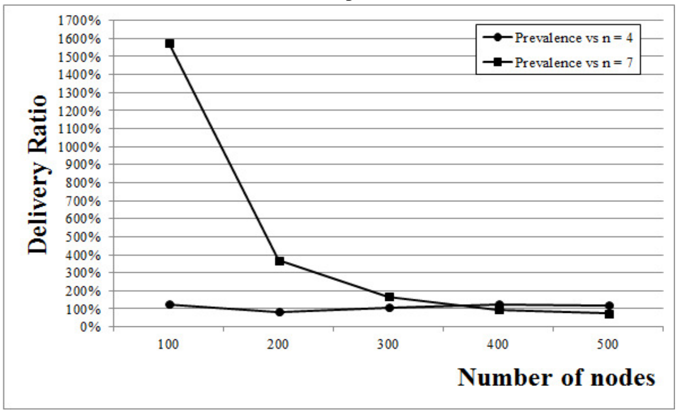

Figure 5. Packet delivery ratio of heuristic and n-Epidemic (with energy consumption)

Observing the curve for *PS*, it is shown that there are a good and linear performances, reaching the peak with a number of hosts equal to 300 with a delivery probability of 33,90%, while the *n*-Epidemic with ***n*** = 7 presents a poor performances until number of hosts is equal to 400, reaching a peak for 500 hosts with a delivery probability of 32,17%; Figure 5 represents the delivery ratio for *EAER* with ***n*** = 4 (best case) and ***n*** = 7 (worst case). Considering the delivery ratio for the worst case, *PS* strategies is maintained above the threshold of 100% initially, but goes down for a number of nodes ≥ 400. Considering the delivery ratio in the best case, the Prevalence strategies is maintained above the threshold of 100% for a number of nodes < 200 and ≥ 300, but goes down for a number of nodes equal to 200. Prevalence strategy and *n*-Epidemic present similar trend, but the proposed strategy results efficient under the energetic profile. *PS* consumes less energy than n-Epidemic Routing, and this fact allows to have good delivery probability as shown in fig. 4.

C. 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. 6 it is possible to see the average energy consumption during the simulation of PS and *n*-Epidemic with ***n***=4. It is possible to see as our strategy is more performing in time 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 such as emphasized in the previous section. We considered just the *n*-Epidemic with ***n*** = 4 and *PS*, as shown in the average energy consumption evaluation in fig. 8. It is possible to see the better load balancing of nodes for *PS*. This is due to the dynamic management of ***n***-parameter that allows to distribute the data dissemination among nodes that present the higher residual energy.

On the contrary, *n*-Epidemic, with its static ***n***-value, does not discriminate among nodes with low energy levels and nodes with more energy and this leads to the draining of energy, reducing the network lifetime.

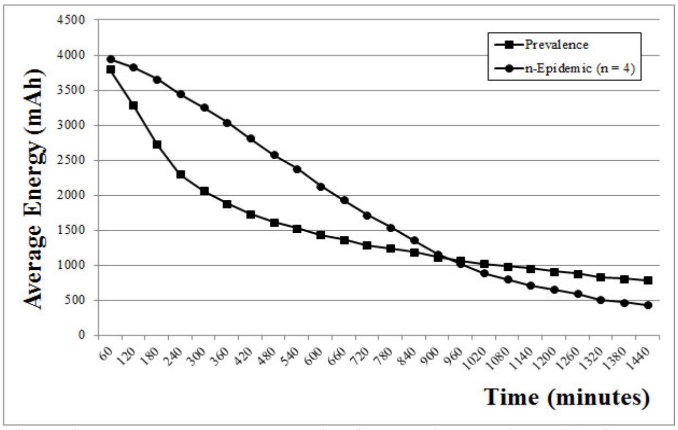

Figure 6. Average Energy Consumption for Prevalence and n-Epidemic (n=4)

VI. CONCLUSIONS

In this paper a novel strategy to dynamically adjust the ***n***-parameter are proposed. This strategy account for the energy dissipation of mobile nodes and nodes 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 shown, a more scalability of the prevalence strategy is offered and the ***n***-parameter is increased when the residual energy of nodes 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 verified also, as the ***n***-parameter can be increased when an high nodes degree is present in the network, because the delivery probability can be preserved reducing the energy wastage.

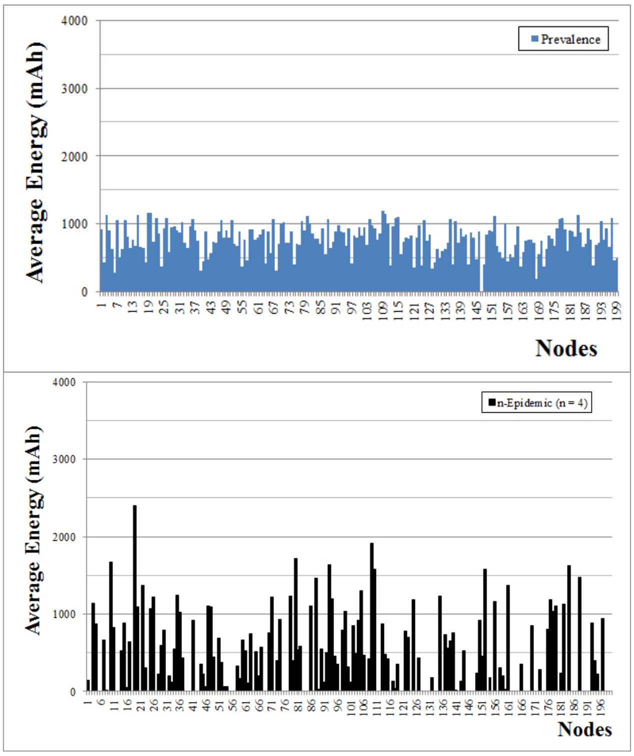

Figure 7. Average Energy Consumption for a) Prevalence; b) n-Epidemic vs nodes

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