IJICTR
International Journal of Information & Communication Technology Research

Volume 11- Number 3 – Summer 2019 (9 -16)

Multi-Objective P- Epidemic Forwarding Method in Heterogeneous DTNs Using NSGA-II

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Received: 23 Feb 2019 - Accepted: 10 June 2019

Abstract—**Due to the increasing use of wireless communications, infrastructure-less networks should be highly considered. Delay Tolerant Network (DTN) as such networks does not have the end to end path between the source and destination nodes. Consequently, routing in DTN as an open issue needs to be studied. Many replication protocols such as epidemic routing are proposed in these challenging wireless environments. The main idea of epidemic routing is to send a copied message to each node without that message. The replication process consumes a high amount of network resources such as energy.**

In this work, a probabilistic epidemic (p-epidemic) forwarding scheme is suggested that minimizes the energy consumption and maximizes the message delivery probability within the heterogeneous sets of nodes using Non-dominated Sorting Genetic Algorithm II (NSGA-II). Current research considers all the nodes of the network with the equal transmission radii and the network is assumed homogeneous. In our work, the nodes have two different amounts of available energies and two different transmission radii. The radius of each node is chosen according to the current energy of that node. The node energy has a significant role in successfully delivering the messages. Regarding the node energy, the lower transmission radius the node has, the lower its chance to send the message with the lower probability. The node with the higher transmission radius sends the message with a higher probability. The optimal transmission probabilities are obtained by NSGA-II. The front of optimal solutions according to these probabilities for delivery probability and energy consumption are observed.

Keywords-Delay Tolerant Networks, Node Current Energy, NSGA-II, Probabilistic Epidemic Forwarding, Transmission Probability

I. INTRODUCTION

Delay Tolerant Networks (DTNs) are designed to provide the communication services in many wireless networks which are mostly known for their path failures between the sender and receiver nodes. Vehicular ad-hoc networks [1]-[4], sparse sensor networks [5], deep-space interplanetary networks [6] and mobile social networks [7] are examples of Delay Tolerant Networks. In such networks, the popular ad-hoc routing protocols such as Ad hoc On-Demand Distance Vector (AODV) or Dynamic Source Routing (DSR) which offer a frequently available connected path are not useful [8].

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Because of the uncertainty in the communication among DTN nodes, the routing protocols should consider the store and forward approaches [9]-[11]. A message needs to be stored in a node's buffer, carried and transmitted to the other available node.

Establishing an end to end path is difficult in DTN; therefore, a specific routing algorithm replicates the message to provide many copies of it and sends them to the different nodes. It is hoped that at least one message is delivered to the destination. Epidemic Routing (ER) as a simple algorithm sends many copies of a message to all the neighboring nodes when they are available [12]. Although ER has a high message delivery probability, it wastes the valuable network resources such as energy. Therefore, many researchers suggested probabilistic forwarding algorithms which attempt to limit the number of possible copies of a message such as Two Hop Routing (2HR) [13], gossip forwarding [14] and spray routing [15] algorithms. In these algorithms, a specific delivery probability is achieved when the energy is not limited. As a matter of fact, the energy of the nodes is limited in DTN nodes and it is important to design the energy-efficient forwarding algorithms to manage the energy consumption.

[42] formulated an energy-efficient probabilistic epidemic forwarding method of heterogeneous sets of nodes having two different transmission radii as well as two different amounts of available energies. In this paper, a probabilistic epidemic forwarding method for the heterogeneous DTN is suggested. The message transmission probability of a node is controlled according to the current energy of that node. In a real network, different nodes have different transmission radii based on their current energies. We considered two different transmission radii with two different transmission probabilities for the heterogeneous nodes. The optimal transmission probabilities are founded with Non-dominated Sorting Genetic Algorithm II (NSGA-II) by solving the multi-objective optimization problem which maximizes the message delivery probability and minimizes the energy consumption. NSGA-II is an algorithm for multiple objective function optimizations. The target of the NSGA-II algorithm is to adapt candidate solutions to a Pareto front constrained by a set of objective functions. The algorithm uses an evolutionary process [41].

In the following, a short overview of some related work is given in Section 2. The proposed method for DTN is discussed in Section 3. Simulation of the proposed p-epidemic forwarding scheme in the heterogeneous network is performed in Section 4. A conclusion in Section 5 puts an end on the paper.

II. Related Works

First, Within the last few years, many routing protocols and forwarding algorithms were suggested to improve the performance of DTN routings. Epidemic routing as such protocols, duplicates and transmits a message to every available node that does not have that message. Unfortunately, this protocol wastes lots of energy and produces a high amount of overhead due to all the copied messages.

Many algorithms were designed to decrease epidemic routing overhead [3], [10], [14], [15]–[18]. Haas et al. proposed a gossip-based routing [14] which considered a specific probability to forward the routing messages in ad-hoc networks. Spray & Wait as a simple and effective protocol confined the number of copied messages and limited the number of transmissions [15]. Burgess et al. [3] proposed MaxProp protocol to define which message should be transmitted, and which message should be dropped. To measure the probability, different metrics were proposed in many methods which are based on opportunistic forwarding, such as time elapsed since the last meeting [17], social similarity [16], and geometric distance [18]. Minimum average delivery delay and maximum average delivery probability were the goals of an efficient optimal forwarding schedule algorithm that was suggested by Krifa, et al. [19], [20]. Hay et al. [21] studied the optimal time-independent graph-based algorithms according to the contact time among the nodes which is known in nonrandom and centralized DTN. The aim of Liu et al. [22] was to provide an optimal forwarding protocol to maximize the delivery probability according to information of the network.

The performance evaluation of epidemic routing in a homogenous DTN was studied by the authors in [13] using the pure-birth continuous-time Markov chain model with the absorption state. In another suggestion, authors in [23] considered Ordinary Differential Equations (ODEs) to evaluate the performance of epidemic routing in a homogenous DTN. DTN researchers also considered many heterogeneity forms in their model. The authors in [24] considered the network with heterogeneous devices such as mobile handhelds, vehicles, and sensors. Because of such heterogeneity, they studied the heuristic methods and they found that the special relay nodes in the network apply considerable improvement in the routing performance, [15], [25], [26]. Authors in [27] studied the cost-performance trade-off of a heterogeneous network including the base stations, meshes, and relays. DTN with different velocities for the nodes was considered in [28] where the network consists of two types of nodes called the normal nodes and high-speed nodes. Performance evaluation for epidemic routing in this heterogeneous model was also studied with two-dimensional continuous-time Markov chain.

The authors in [29] studied the routing protocols of Vehicular Delay Tolerant Networks (VDTN). Because of having different interfaces, all the nodes were proposed to be heterogeneous. The heterogeneity of the nodes contributed to design the smart cities. In [30], the authors reported the spraying routing protocol for DTN with the heterogeneous probabilistic model. Based on that model, the contact rates among the nodes were different. The result showed that the old spraying routing protocol was improved using much fewer copied messages and hop counts.

The authors in [31] proposed a Hybrid protocol using the advantages of two protocols namely epidemic and Probabilistic Protocol using History of Encounters and Transitivity (PRoPHET). Epidemic routing ensured to find the best available path for message transmission and PRoPHET utilized the node's energy efficiently.

The authors compared three important DTN routing protocols in [32] in terms of energy consumption under three different mobility models. The routing protocols were epidemic, PRoPHET, and Spray & Wait.

The issue in [33] investigated the energy consumption of the nodes in DTN. It compared several existing routing protocols in terms of the average remaining energy and the number of the dead nodes using shortest path map based mobility model. Epidemic, Spray & Wait, PRoPHET, and MaxProp were compared.

The work in [34] investigated epidemic novel strategies which extended the basic epidemic routing by estimating the node density and the nodes energy levels. However, it applied a dynamic forwarding scheme based on nodes density that reduced energy consumption and increased the message delivery probability.

In [35], the authors proposed an energy-aware epidemic routing protocol for DTNs to reduce the energy consumption of the nodes in the network. The results showed that the performance of the proposed routing protocol was better than the original epidemic routing protocol in terms of energy consumption, message delivery probability, and overhead ratio.

The authors in [36] proposed a framework to evaluate the performance of the epidemic routing when both the message hop count and maximum forwarding times were limited. The framework was based on the ODE model. The results showed that the message hop count and forwarding time have an important impact on the performance of epidemic routing in terms of the average delivery probability. The authors in [37] modeled the performance of the epidemic routing in scenario sets of the multiple communities with the social selfishness using ODEs. They proposed an energy-efficient copy-limit-optimized algorithm. The results demonstrated the energy-efficiency improvement of the proposed protocol.

The work reported in [38], studied the optimal forwarding method, assuming that all the nodes are with the equal transmission radii and energies. In other words, they worked on a homogenous network. Therefore, all the nodes send their message with the same transmission probability. In [42], the authors extended that work on the heterogeneous DTNs. With the help of the later work, we consider the probabilistic epidemic forwarding method in a network having nodes with two different transmission radii according to the current energy of the node.

III. Proposed Method

As mentioned earlier, epidemic routing demands a significant amount of energy to generate many redundant copies of the original messages. Hence, this paper proposes p-epidemic routing for heterogeneous DTNs which the number of redundant messages is decreased due to the two different transmission probabilities.

A. System Model

It is assumed that each DTN node supports two transmission radii. If the current energy of a node is smaller than a predefined threshold, the transmission parameters are set in such a way that the transmission radius is r_1, otherwise, it is r_2 where $r_1 < r_2$, according to Fig. 1. As a result of the movement, a node meets another node when this node is situated in its transmission radius. This paper supposes that the movement of the nodes takes place in a 2-D area according to the Random Way Point (RWP) mobility model. In RWP, a node stays in a location for a specific time. Once the time elapses, the node moves to a random location with a random velocity that is uniformly distributed between the minimum and maximum speeds. The RWP mobility model is mainly characterized by the Inter-Meeting Time (IMT) of two nodes. It is defined as the duration between two successive meetings of two nodes. Accordingly, Inter-Meeting Rate (IMR) is defined as the rate that two specific nodes encounter each other. The distribution of IMT is exponential in the RWP mobility model when the node transmission radius is smaller than the network dimension [28]. The parameter λ (IMR) with the exponential distribution is obtained by [39]:

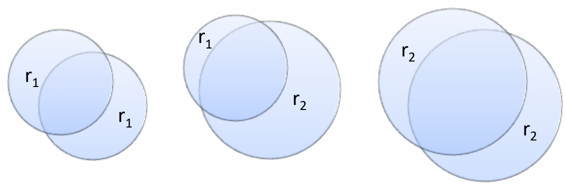
$$\lambda \approx \frac{8\omega r \upsilon}{\pi L^2} \tag{1}$$

ω is constant and it is 1.3683, L is the side of the area, υ is the velocity of a node, and r is the communication radius of that node. Accordingly, the IMR between the nodes with the transmission radius of r_1 as well as those with the transmission radius of r_2 are calculated by (1) and they are denoted as $\lambda_{11} = \frac{8\omega r_1 \upsilon}{\pi L^2}$ and $\lambda_{22} = \frac{8\omega\, r_2 \upsilon}{\pi L^2}$, respectively in Fig.1a and Fig.1c. On the other hand, the IMR of nodes with the different transmission radii is calculated by [39]:

$$\lambda_{12} = \lambda_{21} \approx \frac{8\omega \min(r_1, r_2)\upsilon}{\pi L^2} \tag{2}$$

Where λ_{12} is the IMR for the case in which a sender node with the transmission radius of r_1 communicates with the other node with the transmission radius of r_2, Fig.1b. Also, λ_{21} is defined similarly.

In the network, a message is generated at time 0 by the source with the lifetime of T. Therefore, that message is discarded by all the nodes after T. Hence, the message should reach to the destination before T.



(a) (b) (c)

Figure 1. Two nodes contact with the Inter-Meeting Rate λ11 in (a), two nodes contact with the Inter-Meeting Rate λ12 or λ21 in (b), and two nodes contact with the Inter-Meeting Rate λ22 in (c).

This paper proposes p-epidemic as a scheme to deliver a message to its designated destination. The goal of the scheme is to maximize the delivery probability and minimize energy consumption. The delivery probability is the ratio of the delivered messages to the created messages. The consumed energy of the network is the total consumed energy in each node. To achieve this aim, we suggest the probabilistic epidemic forwarding method as follows:

B. Probabilistic Epidemic Forwarding Method

A node sends a message by using either its lower or its higher radius. When a node carrying a specific message is encountered with another node which does not possess that message, it forwards the message to that visited node according to a specific probability. The forwarding probabilities are represented by p_1 and p_2 for the cases that the transmission radius of the sender node are r_1 and r_2, respectively. A threshold for the nodes current energy is considered. If the current energy of each node is higher than the threshold, the r_2 radius is chosen and otherwise, the node transmits the message with the radius of r_1.

In this scheme, p_1 and p_2 are the network parameters and the optimal transmission probabilities are optimized using NSGA-II in such a way that the delivery probability is maximized and the energy consumption is minimized. The operation flowchart of each node is drawn in Fig. 2.

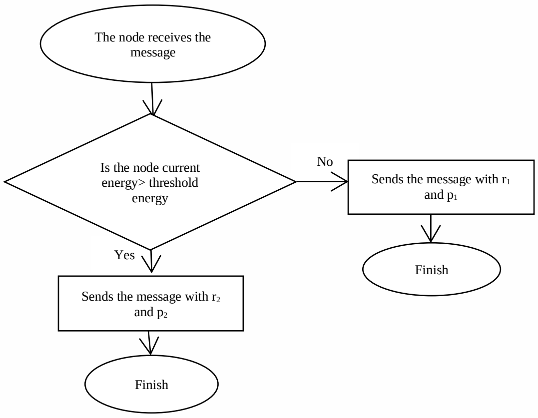


Figure 2. The flowchart of each node operation.

IV. SIMULATION SETUP AND IMPLEMENTATION OF NSGA-II

After In our simulations, the performance of the proposed p-epidemic forwarding method is studied based on both the delivery probability and the consumed energy. Opportunistic Network Emulator (ONE) as a Java-based simulation tool is used [40]. Table 1 shows the simulation parameters. The network with 200 nodes having two different r_1 and r_2 radii is considered. A threshold for the nodes current energy is defined. If the current energy of each node is higher than the threshold, the r_2 radius is chosen and otherwise, the node transmits the message with the radius of r_1.

TABLE I. THE SIMULATION PARAMETERS.

Parameter	**Value**
Total Nodes	200
Area Size	4500*4500 m^2
Velocity of Nodes	1-20 m/s
Buffer Size	5 MByte
Movement Model	RWP
TTL	255
First Transmission Radius of the nodes - r_1	10 m
Second Transmission Radius of the nodes - r_2	35 m
Available Energy of 100 Nodes	1500 energy unit
Available Energy of 100 Nodes	1300 energy unit
Energy Threshold for Radius Change	825 energy unit
First Radius Data Rate	2 Mbps
Second Radius Data Rate	10 Mbps
Simulation Time	22500 time unit

The important parameters of the simulation are p_1 and p_2 according to the probabilistic epidemic forwarding scheme. It is assumed that $r_1 < r_2$ and $p_1 \leq p_2$. The values of p_2 are between 0 and 1. Also, the auxiliary variable of a, is chosen between 0 and 1. The values of p_1 are computed by $p_1 = p_2 * a$, to get the $p_1 \leq p_2$ constraint. The simulations are conducted 100 times in ONE for each possible set of p_2 and p_1 to find the energy consumption and delivery probability of the network.

The results of simulation in ONE are imported to Matlab and the function of F_1, the degree 5 polynomial, is fitted for the delivery probability:

$$F_1(p_2, a) = -0.1927 + 5.044 * p_2 + 7.998 * a - 31.93 * p_2^2 + 2.49 * p_2 * a - 40.84 * a^2 + 79.34 * p_2^3 - 4.302 * p_2^2 * a + 1.591 * p_2 * a^2 + 86.14 * a^3 - 84.67 * p_2^4 - 2.188 * p_2^3 * a + 3.639 * p_2^2 * a^2 - 4.713 * p_2 * a^3 - 81.08 * a^4 + 32.49 * p_2^5 + 6.83 * p_2^4 * a - 10.7 * p_2^3 * a^2 + 9.12 * p_2^2 * a^3 - 1.623 * p_2 * a^4 + 28.56 * a^5$$

The coefficients are computed with 95% confidence bounds.

The curve of Fig. 3. is constructed by curve fitting with two variables of p_2 and a, for the delivery probability. The parameters of R-square and adjusted R-square for the goodness of fit are 0.9098 and 0.8896, respectively. The R-square shows how well data points fit a curve. Adjusted R-square also defines how well data points fit a curve but adjusts for the number of data points in a model.

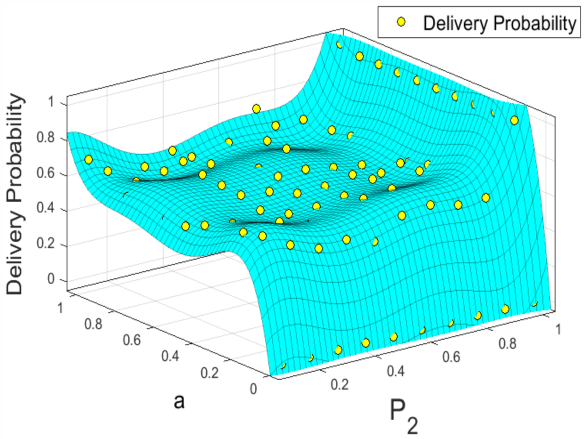


Figure 3. Curve of delivery probability vs. a, and the transmission probability of p2.

The simulation results of the energy consumption in ONE leads to fit the degree 5 polynomial of F_2 as:

F_2 (p_2, a) = (1.132e+05) + (2.814e+04) * p_2 + (2.187e+04) * a – (1.556e+05) * p_2^2 + 8699 * p_2* a – (1.23e+05) * a^2 + (3.661e+05) * p_2^3 – (1.598e+04) * p_2^2 * a – 1533 * p_2* a^2 + (2.784e+05) * a^3 – (3.821e+05) * p_2^4 + (2.641e+04) * p_2^3 * a – (3.084e+04) * p_2^2 * a^2 + (1.565e+04) * p_2* a^3 – (2.774e+05) * a^4 + (1.455e+05) * p_2^5 – (1.068e+04) * p_2^4 * a + 9656 * p_2^3 * a^2 + (1.019e+04) * p_2^2 * a^3 – 9522 * p_2* a^4 + (1.004e+05) * a^5

The coefficients are computed with 95% confidence bounds.

By curve fitting with two variables of p_2 and a, the curve of Fig. 4. is observed for energy consumption. The parameters of R-square and adjusted R-square are 0.725 and 0.6632, respectively.

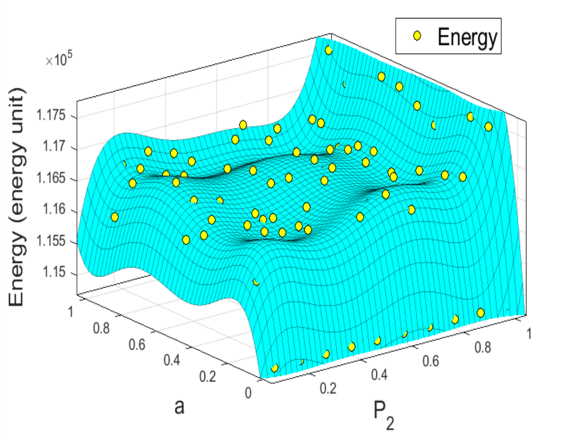


Figure 4. Curve of energy consumption vs. a, and the transmission probability of p2.

Up to this point, F_1 (p_2, a) and F_2 (p_2, a) as the objective functions of the delivery probability and energy consumption are fitted. NSGA-II is implemented in Matlab to minimize energy consumption and maximize the delivery probability. The selection policy of NSGA-II is roulette-wheel selection. The aim of the selection operator is to emphasize good solutions and eliminate the bad solutions in a population while keeping the population size constant. The probability of choosing an individual in roulette-wheel selection depends directly on its fitness. Also, uniform crossover and uniform mutation are chosen as the control parameters of NSGA-II. The uniform crossover provides the uniformity in combining the bits of both parents. The uniform mutation operator changes the value of the chosen gene with the uniform random value selected between the user-specified upper and lower bound for that gene.

A set of the optimal transmission probabilities of NSGA-II algorithm for p_2 and p_1= p_2 * a, are shown in table 2. These probabilities are set points to minimize the energy consumption and maximize the delivery probability of the network.

The first front of the non-dominated solutions obtained by NSGA-II is shown in Fig. 5. It indicates the trade-off between energy consumption and delivery probability. It also shows that NSGA-II is able to find the optimal transmission probabilities of p_1 and p_2 with high delivery probability and low energy consumption.

The plot shows that the non-dominated solutions obtained have good diversity with a large spread in the objective space.

In this figure, the contradiction between the optimization of energy consumption and delivery probability is also shown. In such a way, with the optimization of energy consumption, the delivery probability goes to non-optimality and vice versa. By obtaining this Pareto front including non-dominated solutions; the decision makers have several choices to choose the optimal policy based on their needs.

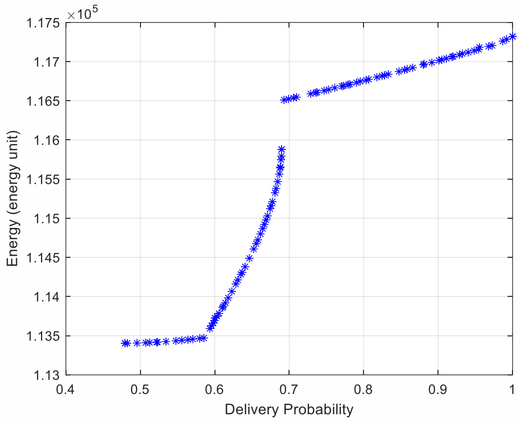


Figure 5. The first front of the optimal solutions for the delivery probability and energy consumption.

TABLE II. THE SIMULATION PARAMETERS.

P_2	a	$P_1 = P_2 * a$
0	0.959543	0
1	0.319033	0.319033
0	0.959543	0
1	0.319033	0.319033
0.935009	0.419223	0.391977
0.087992	1	0.087992
0.028022	0.999992	0.028022
0.031844	0.999973	0.031843
0.943634	0.388952	0.367028
0.024652	0.999978	0.024651
0.015427	0.999978	0.015427
0.002974	0.999991	0.002974
1.20E-05	1	1.20E-05
0.938929	0.402105	0.377548
0.999463	0.348456	0.348269
0.976379	0.406326	0.396728
0.979866	0.399387	0.391346
0.065623	0.999973	0.065621
0.01317	0.999989	0.01317
1	0.402082	0.402082
0.018105	0.999907	0.018103
0.059105	1	0.059105
0.054189	0.999991	0.054188
9.87E-07	0.982754	9.70E-07
0.070339	1	0.070339
0.972876	0.401176	0.390295
0.984751	0.393841	0.387836
0	0.966954	0
0.03839	0.999995	0.038389
0.046892	0.999998	0.046892
0.019659	0.999823	0.019656
0.967906	0.384455	0.372117
9.44E-07	0.987589	9.32E-07
0.952355	0.379121	0.361057
0.06151	1	0.06151
0.035766	1	0.035766
0.050499	0.999978	0.050498
0.007854	0.999991	0.007854
0.982361	0.392677	0.385751
0.01145	1	0.01145
0.040817	1	0.040817
0.034116	1	0.034116
0.999513	0.33432	0.334157
0.994391	0.401473	0.399221
0.949865	0.393925	0.374176
0.998191	0.382797	0.382104
0.080107	0.999927	0.080101
0.042788	0.999996	0.042788
0.965113	0.383037	0.369674
0.962633	0.402082	0.387057
0.995711	0.399647	0.397933
0.953638	0.413928	0.394737
0.044938	1	0.044938
0.988523	0.393034	0.388523
0.992929	0.334607	0.332241
0.021779	0.999842	0.021776
0.082842	1	0.082842
0.022457	0.999993	0.022456
0.985879	0.382162	0.376766
0	0.990356	0
0	0.971973	0
4.16E-05	0.995264	4.14E-05
0.96109	0.372495	0.358001
0.009793	0.999992	0.009792
0.99208	0.398375	0.39522
3.69E-06	0.993158	3.66E-06
1.20E-05	0.998244	1.20E-05
0	0.961007	0
0.991355	0.373829	0.370597
0.935009	0.40122	0.375145
0	0.97419	0
0.979866	0.35721	0.350018
0.052051	1	0.052051
0.977369	0.397107	0.38812
0.958943	0.419223	0.402011
0.965626	0.398681	0.384976
0.977117	0.383125	0.374358
0.075035	0.999998	0.075035
0.087992	1	0.087992
0.946504	0.389911	0.369052
0.960162	0.400116	0.384176
0.003896	0.99998	0.003895
0.937536	0.402497	0.377356
0	0.978395	0
0.07444	1	0.07444
0.971097	0.403271	0.391615
0.987535	0.396367	0.391427
0.989875	0.387041	0.383122
0.006974	0.999754	0.006972
0.997216	0.409428	0.408288
0.004731	0.999991	0.004731
0.990465	0.402105	0.39827
0.010179	0.99999	0.010179
0.957849	0.39976	0.38291
0.971103	0.39375	0.382372
0.96109	0.417856	0.401597
0	0.977925	0
0.9484	0.412144	0.390877
0.005529	0.999993	0.005529
0.006454	0.999257	0.00645

V. CONCLUSION AND FUTURE WORK

In our paper, we investigated the probabilistic epidemic forwarding method in the heterogeneous DTNs. The curves of the message delivery probability and energy consumption based on the transmission probabilities are fitted. The optimal set of transmission probabilities for nodes is obtained by NSGA-II to achieve the optimal performance for the delivery probability and energy consumption.

The proposed p-epidemic forwarding scheme is evaluated by the simulations. We plan to develop analytically model for that scheme and compare its results with the simulation results. Moreover, we are going to consider energy consumption on each node. Also, we examine our method on a network with lots of nodes.

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