Energy-Aware Probabilistic Epidemic Forwarding Method in Heterogeneous Delay Tolerant Networks

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Abstract- **Due to the increasing use of wireless communications, infrastructure-less networks such as Delay Tolerant Networks (DTNs) should be highly considered. DTN is most suitable where there is an intermittent connection between communicating nodes such as wireless mobile ad hoc network nodes. In general, a message sending node in DTN copies the message and transmits it to nodes which it encounters. A receiving node, if it is not the destination of the message, stores the message and transmits a copy of the message to nodes it meets. This process continues until the message reaches its destination or its lifetime expires. Various DTN routing protocols have been proposed to reduce the number of copies and improve the message delivery probability. However, very few of them consider the energy constraint of mobile nodes in routing protocols. Mobile nodes especially smartphones and tablets are powered by batteries with limited energy. It is essential to consider energy constraint while designing routing protocols for DTNs. Moreover, most studies focus on homogeneous networks having nodes with equal transmission radii. At this paper, a probabilistic epidemic (p-epidemic) forwarding scheme is suggested which aims to improve both the energy consumption and the message delivery probability within the heterogeneous sets of nodes. The nodes have two different amounts of available energies and two different transmission radii. Based on this proposed p-epidemic method, the transmission radius and the transmission probability of each node are chosen according to its current energy. The performance of the method is evaluated through many simulations.**

Index Terms- Delay Tolerant Networks, Node Current Energy, Probabilistic Epidemic Forwarding, Transmission Probability

I. INTRODUCTION

Delay Tolerant Networks (DTNs) are designed to send messages in wireless networks which are mostly known for their intermittent connectivity between the sender and receiver nodes. In other words, there is a very low probability that an end-to-end path exists between a given pair of nodes at a

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given time, so the message transmission shows unpredictable performance due to the dynamic network topology. 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 frequent connected path are not useful [8]. These protocols establish a complete route and forward the messages. However, when establishing an end-to-end path is difficult or impossible, routing protocols must switch to a store, carry and forward method [9]-[11]. In store, carry and forward routing protocols, mobile nodes act as buffer between the source and the destination. Nodes store a message, carry and transmit it to a new node when it is in the range. Similarly, the message reaches to its destination.

Establishing an end to end path is difficult in DTN, so the essential of the routing protocols such as Epidemic Routing (ER) is to forward a copy of a message to a node which comes into contact [12]. The node which receives the copy of the message will repeat the process until the message reaches to its destination or the message's lifetime expires. Although store, copy and forward nature of DTN routing protocols increases the message delivery probability to destinations, many copies of messages are stored in many nodes consuming nodes' resources such as buffer, energy. Therefore, many routing protocols try to optimize resources consumption of nodes and improve the message delivery probability such as Two Hop Routing (2HR) [13], gossip forwarding [14] and spray routing [15] algorithms. However, the majority of well-known routing protocols do not consider energy constraints of mobile nodes. As a matter of fact, the energy of the nodes is limited and it is important to design the energy-efficient forwarding algorithms to manage the energy consumption.

In this paper, a probabilistic forwarding method for the heterogeneous DTN is suggested and the trade-off between node energy consumption and message throughput is considered. 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, and the number of transmitted messages versus the message delivery probability is investigated. According to simulation results, high value of message delivery probability is observed. Therefore, this method increased the message delivery probability with limited energy consumption.

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 WORK

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 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 the 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 a message transmission and PRoPHET utilized the node's energy efficiently.

The authors compared three important DTN routing protocols in [32] in terms of the 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 in a DTN network. The strategies 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 the 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 the 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 ODE model. The results showed that the hop count and forwarding time of a message have 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 authors in [38] proposed an Energy-Aware epidemic (EA-Epidemic) routing algorithm to improve energy efficiency of epidemic routing in DTNs. They considered remaining energy and available free buffer of nodes for making decision to forward copies of the messages. The results showed that EA-Epidemic not only extends the network life by making nodes to consume less energy, but also increases the delivery of messages in the network.

The work in [39] investigated the performance of four routing protocols in DTNs in terms of energy consumption according to the number of unavailable nodes in the network using shortest path map based mobility model. The results showed that the varying number of nodes, message size, message generation interval, and the speed of nodes affects the performance of the routing protocols.

The authors in [40] extended the approach of the basic epidemic routing using the node density estimation and the node energy level. The proposed method applied a dynamic forwarding scheme based on nodes density which reduces energy consumption and increases message delivery probability. The work reported in [41] mathematically characterized the fundamental tradeoff between energy conservation and Quality of Service measurement as a dynamic energy-dependent optimal control problem. They showed that in the mean-field regime, the optimal dynamic forwarding decisions follow simple threshold-based structures in which the forwarding threshold for each node depends on its current remaining energy.

In the work [42], the authors studied the opportunistic routing protocols for networks comprising heterogeneous nodes. The results showed that choosing the relays carefully, improve the performance of routing protocols in heterogeneous settings.

The work reported in [43], 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 contrast and in this paper, we tried to extend their work on the heterogeneous DTNs. We consider the probabilistic 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 probabilistic epidemic (p-epidemic) routing for heterogeneous DTNs which the number of redundant messages is decreased due to the 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 r1, otherwise, it is r2 where r1< r2, 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

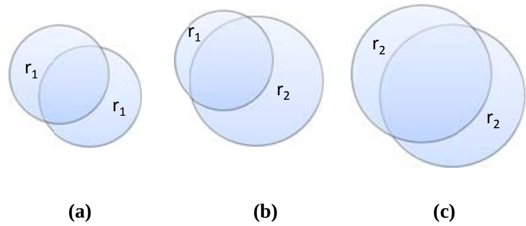

Fig. 1. Two nodes contact with the Inter-Meeting Rate λ_{11} in (a), two nodes contact with the Inter-Meeting Rate λ_{12} or λ_{21} in (b), and two nodes contact with the Inter-Meeting Rate λ_{22} in (c)

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 the 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 [44]:

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

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 r1 as well as those with the transmission radius of r2 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 to Fig.1c. On the other hand, the IMR of nodes with the different transmission radii is calculated by [44]:

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

where λ12 is the IMR for the case in which a sender node with the transmission radius of r1 communicates with the other node with the transmission radius of r2. Also, λ21 is defined similarly.

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

The total number of transmitted messages in the network at time t is defined by a random process Y(t). The amount of energy which is consumed for delivering a message to the destination node is related to the expected number of transmissions in the message lifetime. Communication energy consists of the transmitting and receiving energy, [43]. Therefore, it can be represented by:

$$E(Y(T)) \leq \psi \tag{3}$$

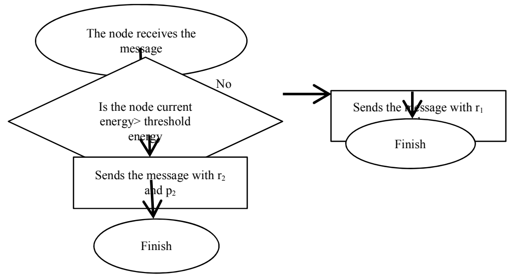

Fig. 2. The flowchart of each node operation

where E(Y(T)) is the expectation operator of Y(T).

It is observed from (3) that the message is delivered with E(Y(T)) as the number of transmissions that is limited by ψ as the energy, moreover F(t) is assumed as the delivery probability of the message to the destination node at time t [43].

This paper proposes p-epidemic as a scheme for delivering a message to its designated destination. It strives to increase the delivery probability while satisfying message lifetime constraint. To achieve this aim, we suggest the probabilistic epidemic forwarding 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 for the cases that transmission radius of sender node are r1 and r2, are represented by p1 and p2, respectively. A threshold for the nodes current energy is considered. If the current energy of each node is higher than the threshold, the r2 radius is chosen and otherwise, the node transmits the message with the radius of r1.

In this scheme, p1 and p2 are network parameters that are selected in such a way that F(T) is maximized under limited energy consumption and lifetime constraint. As mentioned earlier, F(t) is defined as the delivery probability of the message to its destination node at time t. The flowchart of each node operation is drawn in Fig. 2.

As a result of proposed scheme, the number of transmitted messages diminishes; thereby the total consumed energy throughout the network is reduced. This is reflected in (3).

IV. SIMULATION SETUP

In our simulations, the performance of the proposed p-epidemic forwarding method is studied based on both the delivery probability F(T) and the consumed energy ψ. These parameters are

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 UNIT
AVAILABLE ENERGY OF 100 NODES	1300 UNIT
ENERGY THRESHOLD FOR RADIUS CHANGE	825 UNIT
FIRST RADIUS DATA RATE	2 MBPS
SECOND RADIUS DATA RATE	10 MBPS
SIMULATION TIME	22500 TIME UNIT

evaluated with different sets of forwarding probabilities, p1 and p2. Opportunistic Networking Emulator (ONE) as a Java-based simulation tool is used [45]. Table I 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 r2 radius is chosen and otherwise, the node transmits the message with the radius of r1.

The important parameters of simulation are p1 and p2 according to the probabilistic epidemic forwarding scheme.

It is assumed that $r_1 < r_2$, p1< p2 and we begin with p1 = 0.1 using different p2. The simulations are conducted 100 times for each possible sets of p1 and p2 to find F(T) versus T, and F(T) under different ψ. As mentioned, F(T) is the delivery probability of the message within T time. Also, ψ is the energy consumption to deliver the message.

Figs. 3-7 show the delivery probability of F(T) versus the message lifetime of T. It is shown that the maximum value of F(T) for all different sets of p1 and p2 is between 0.3 and 0.45. When the simulation begins, the available energy of all nodes is more than 825. All nodes' radius is 35m and two nodes meet each other with this radius. They send the message with the probability of p2. When time passes, the available energy of some nodes decreases and it gets lower than 825. Once two nodes contact, one of them may choose the radius of 10m and the other node may choose the radius of 35m. The node with the lower energy than 825, sends the message with the probability of p1 and the other node sends the message with the probability of p2. Finally, the energy of all nodes decreases and the transmission radii of them are set to 10m. Two nodes contact and they send the message with the probability of p1. By using these probabilities, the number of transmitted messages decreases and the

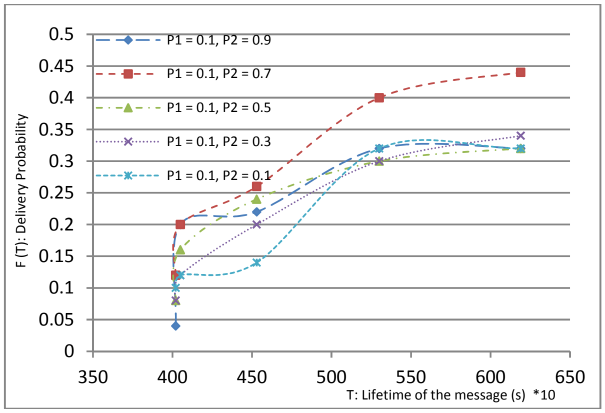

Fig. 3. F(T) versus T for different transmission probabilities.

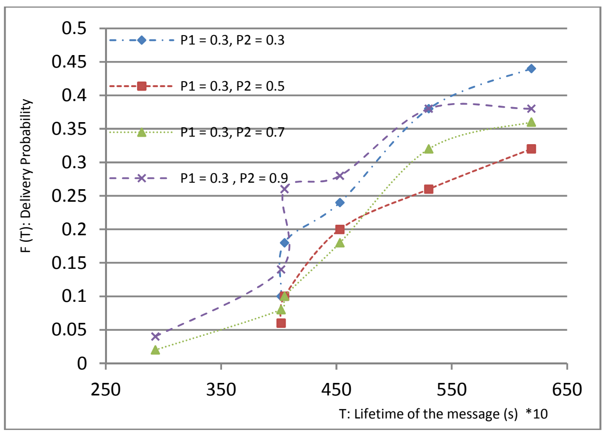

Fig. 4. F(T) versus T for different transmission probabilities.

delivery probability of F(T) reduces. According to Figs. 3-7, the minimum values of F(T) are between 0.05 and 0.3 when T has the low values between the 2500s and 4500s. It means if T is low, all nodes meet each other with low opportunities and when T is high, i.e. over 4500s, the nodes have enough time to contact with other nodes and F(T) increases from 0.3 to 0.45. To get the high value of F(T), the network should tolerate the high amount of T.

Fig. 3. shows the message delivery probability F(T) versus the message lifetime T for p1= 0.1 with different values of p2. It can be noticed that the transmission probability F(T) increases with the message lifetime T. Moreover, even when T is longer than 6000s, F(T) is still lower than 0.35 for all values of p2. Just for p2= 0.7, F(T) gets the maximum 0.45 after T> 6000s.

Fig. 4. shows the comparison of F(T) for p1= 0.3 with different values of p2. The transmission probability F(T) increases with the message lifetime T. It is observed that the maximum F(T) for different values of p2 is between 0.3 and 0.45 for T> 5500s.

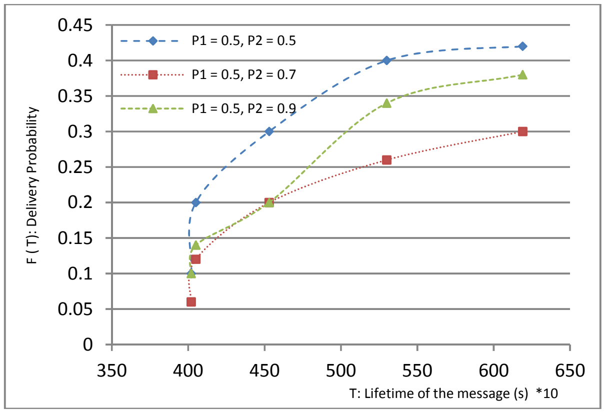

Fig. 5. F(T) versus T for different transmission probabilities.

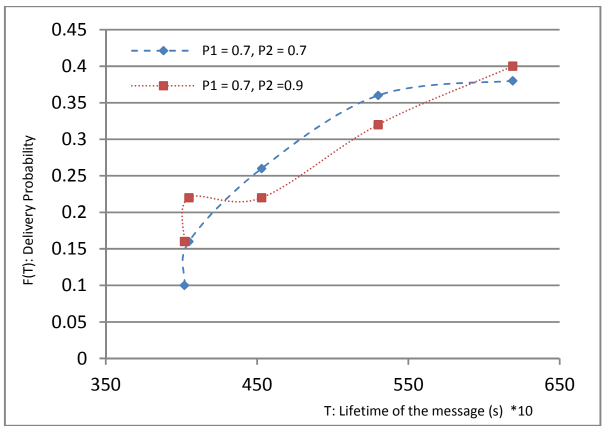

Fig. 6. F(T) versus T for different transmission probabilities.

Fig. 5. displays the message delivery probability F(T) according to the message lifetime T for p1= 0.5 with different values of p2. For p2= 0.5, F(T) tends to be 0.4 much closer to the maximum 0.45, even before T< 5500s.

Fig. 6. and Fig. 7. show the other different sets of p1 and p2 with the message delivery probability F(T) versus the message lifetime T. In these results, F(T) gets the lower values than the maximum 0.45.

It is observed in Figs. 3-7 that different sets of transmission probabilities control the number of transmissions in the network and even for the larger values of the message lifetime T, the message delivery probability of F(T) does not differ very much.

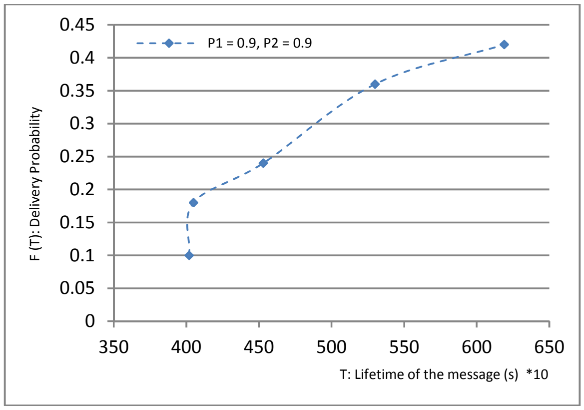

Fig. 7. F(T) versus T for different transmission probabilities.

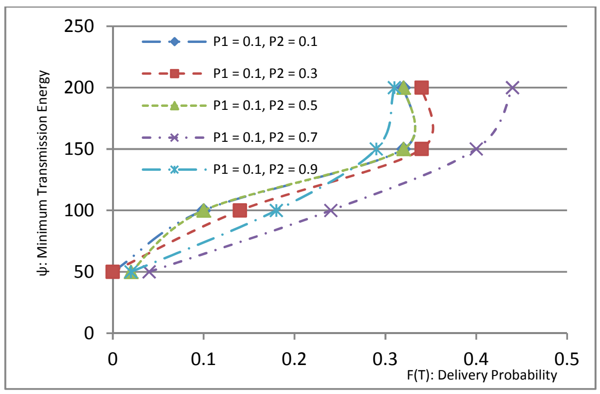

Fig. 8. ψ versus F(T) for different transmission probabilities.

Figs. 8-12 show the minimum transmission energy ψ versus the delivery probability of F(T). The results show that the maximum value of F(T) is about 0.45 when the maximum consumed energy is 150, and afterwards no insightful changes in F(T) are observed. In other words, if the network needs to get high F(T), i.e. between 0.3 and 0.45, it must consume the high amount of energy. The energy consumption is controlled by p1 and p2 in all nodes which they also control the number of transmitted messages in the network. Therefore, every value of F(T) is between 0.05 and 0.45 for minimum transmission energy ψ between 50 and 150. After ψ> 150 and due to the p1 and p2, there are not more transmitted messages in the network and F(T) does not show any insightful change for 150<ψ<200.

Fig. 8 gives the performance comparison in terms of ψ versus F(T) for p1= 0.1 with different transmission probabilities of p2 which they are equal and higher than p1= 0.1. Based on the results, we can observe that the ψ needed by p2= 0.7 is lower than the ψ needed by other values of p2 for F(T)< 0.3. In particular, when 0.01<F(T)< 0.3, p2= 0.7 performs much better in ψ. After F(T)> 0.3, except p2= 0.7 which its F(T) increases to 0.45, F(T) does not change for the other values of p2 even with the increasing ψ.

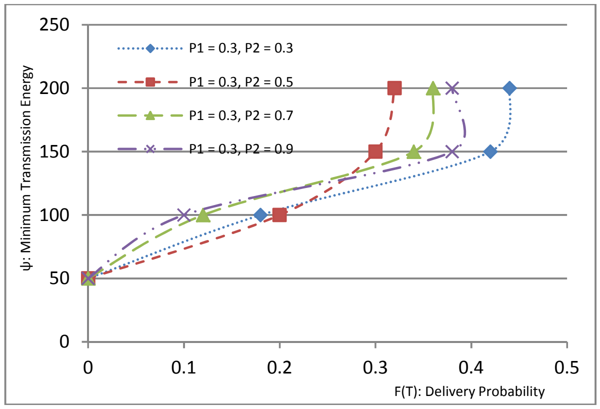

Fig. 9. ψ versus F(T) for different transmission probabilities.

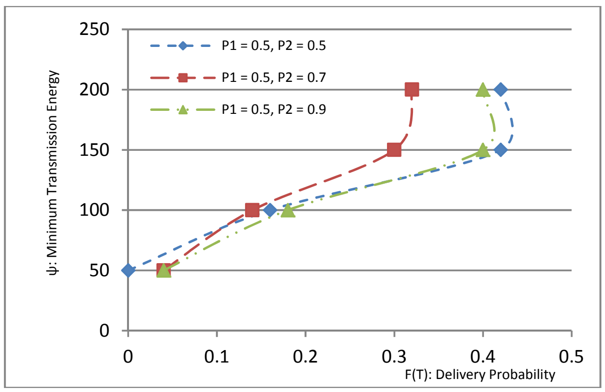

Fig. 10. ψ versus F(T) for different transmission probabilities.

Fig. 9. compares ψ versus F(T) for p1= 0.3 with different transmission probabilities of p2. Based on the results, it is observed that the ψ needed by p2= 0.3 is lower than the ψ needed by the other values of p2 for F(T) < 0.3. In other words, when 0.01<F(T)< 0.3, p2= 0.3 performs much better in ψ. When 0.3< F(T)< 0.4, F (T) does not have any change for p2= 0.5 and F(T) just differs a little for the three other values of p2. When F(T)> 0.3, except p2= 0.3 which its F(T) increases up to 0.42, the other values of p2 do not experience a lot of changes in F(T) even with the increasing ψ.

Fig. 10. gives the comparison of ψ versus F(T) for p1= 0.5 with different transmission probabilities of p2. Based on the results, the ψ needed by p2= 0.5 and p2= 0.9 is almost equal and it is lower than the ψ needed by p2= 0.7 when F(T) < 0.3. In particular, when 0.01<F(T)< 0.3, the p2= 0.5 and p2= 0.9 perform much better in ψ. After F(T)> 0.3, except for p2= 0.5 and p2= 0.9, F(T) does not differ for p2= 0.7 even with the increasing ψ up to 200.

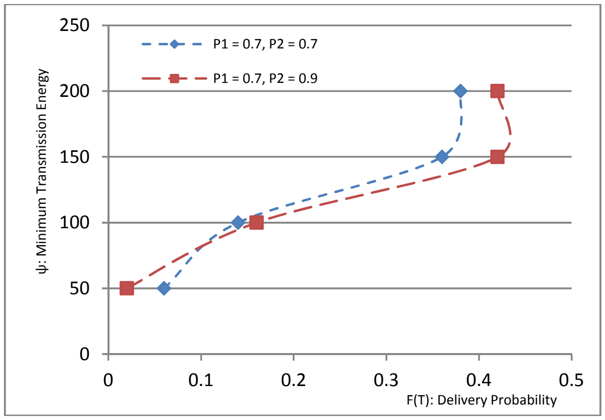

Fig. 11. ψ versus F(T) for different transmission probabilities.

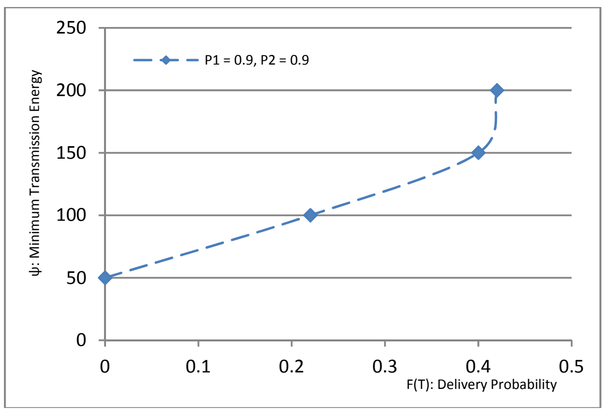

Fig. 12. ψ versus F(T) for different transmission probabilities.

Fig.11. gives the result of ψ versus F(T) for p1= 0.7 with different transmission probabilities of p2. It can be seen that the ψ needed by these sets of p1 and p2 are almost equal when F(T)< 0.35. After F(T)> 0.35, F(T) increases to 0.42 for p2= 0.9.

Fig. 12. shows the result for ψ versus F(T) for p1= p2= 0.9. From the different values of p2, just we choose p2= 0.9 because p2 should be equal or higher than p1= 0.9. It is observed that the maximum value of F(T) for this set of transmission probabilities is 0.4 and afterwards, F(T) does not increase even with increasing ψ.

Apart from the above results of the proposed method, Fig. 13 compares the result of the scheme with epidemic forwarding method in which p1= p2= 1. According to the results, it is observed that the number of transmitted messages in our method is less than 150 when F(T) tends to be 0.45. The number of transmitted messages in the epidemic forwarding method should be more than 150 to get the different values of F(T) while in our method, it is between 50 and 150. In other words, we save

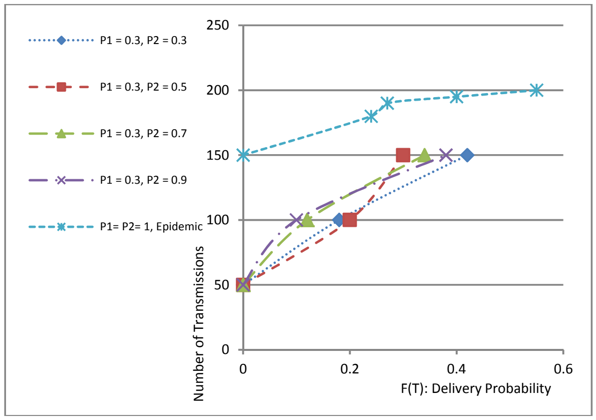

Fig. 13. Comparing the number of transmissions versus F(T) in different forwarding methods.

more energy than epidemic forwarding method, because of the lower number of transmissions in our scheme.

V. CONCLUSION AND FUTURE WORK

In our paper, we investigated the energy-efficient probabilistic forwarding method in the heterogeneous DTNs. We considered two transmission probabilities for nodes that achieved reasonable performance under limited energy consumption. The message delivery probability based on its lifetime is simulated. According to the different transmission probabilities, different message delivery probabilities are achieved and the energy consumptions are obtained for them. From the results, the high value of message delivery probability is observed. Also, the number of transmitted messages versus the message delivery probability is investigated. The proposed p-epidemic forwarding scheme is evaluated by the extended simulations. We plan to develop analytically model for that scheme and compare its results with the simulation results. Moreover, we are going to consider the energy consumption on each node. Also, we examine our method on a network with lots of nodes.

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