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An Energy-aware Routing Scheme in Delay Tolerant Mobile Sensor Networking

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Abstract: In Delay Tolerant Mobile Sensor Networking (DTMSN), mobile sensor nodes are usually limited to their energy capacity, one important concern in routing design of DTMSN is energy consumption. This paper presents a number of variations of the Epidemic Routing Protocol (ERP) to extend the DTMSN lifetime. It introduces the analytical model for ERP, after introducing the concepts behind the Target Delivery Probability and Minimum Delivery Probability, it defines the network lifetime. In this paper, it firstly studies many variations of the Epidemic Routing Protocol to extend the lifetime of the DTMSN. Secondly, based on the Epidemic Routing Protocol, three schemes are introduced. Those schemes rely on the limiting the times of message allowed for propagation (LT scheme), directly controlling the number of the copies (LC scheme), split the copies to the residual energies of the nodes (LE scheme). Finally, with the experiment and the validation of the simulation, the LE scheme can significantly maximize the lifetime of DTMSN, because it minimizes the number of copies and that shifts the generation of the copies to the nodes with larger residual energy. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Energy aware routing, Residual energies, Limited energy target delivery probability, Minimum delivery probability, Epidemic routing protocol.

1. Introduction

Delay Tolerant Mobile Sensor Networking (DTMSN) is one of occasionally-connected networks that may suffer from frequent network partitions. DTMSN provides still some services despite long end to end delays or infrequent connectivity. One fundamental problem in DTMSN is routing messages from their source to their destination [1]. DTMSN differ from the Internet in that disconnections are common cases instead of the exception. Representative DTMSN includes sensor-based networks using scheduled intermittent connectivity, terrestrial wireless sensor networks that cannot ordinarily maintain end-to-end connectivity, satellite networks with moderate delays and periodic connectivity, underwater acoustic networks with moderate delays and frequent interruptions due to the environmental factors, and vehicular networks with cyclic but nondeterministic connectivity.

These have something in common with more and more devices incorporating computing and networking technology in less traditional networking environments. Challenged networking in such environments is faced with some new challenges and new techniques and protocols are required, and all these challenges can be characterized as follows [2].

1.1. Intermittent Connectivity: if there is no end-to-end path between source and destination, the end-to-end communication using the traditional TCP/IP protocols does not work, so some new protocols to support the communications without an end-to-end path must be provided.

1.2. Long or Variable Delay: In addition to intermittent connectivity, long propagation delays among nodes and variable queuing delays at each node contribute to end-to-end path delays that can defeat the Internet protocols and applications that rely heavily on quick arrivals of acknowledgements or data.

1.3. Asymmetric Data Rates: The Internet supports moderate asymmetries of bi-directional data rates for users with cable TV or asymmetric DSL access. However, if asymmetries are significantly obvious, conversational protocols will not work.

1.4. High Error Rates: Bit errors over transmission links require error correction or retransmission of the entire packet, which might result in more network traffic. For a given link-error rate, fewer retransmissions are needed for hop-by-hop rather than for end-to-end retransmission.

Furthermore, mobile nodes are usually limited to their energy capacity, one consideration in the design of delay tolerant mobile sensor networking is energy consumption, which is the goal of extend the lifetime of network. One approach that reduces energy consumption is to limit the node transmission power, and accordingly to limit the transmission range, copies of the network nodes. When the networking topology is sparse, nodes remain often disconnected from the rest of the other nodes. One approach to routing packets in such network is for packets to be carried by network nodes until such time as the mobile node can create a forwarding link to another node in the network. This is referred to as store-carry-forward paradigm. Some routing protocols for DTMSN are derivatives of Epidemic Routing Protocol (ERP), where a packet is replicated in every node that comes occasionally in contact with the node that has not the packet. This paper will propose an energy aware routing method to extend the network lifetime of ERP.

2. Routing Issues in Sparse DTMSN

In some communication cases when the transmission range is too short or the node density is too low, connectivity between the nodes can be intermittent. When lack of connectivity happens frequently, on the average, so that a node sees, less than one neighbor, it is referred to such communication environment as sparse networks.

2.1. Routing Approaches

The basic routing paradigm for effective mobility-based routing in DTMSN is to use the store-carry-forward approach, where intermediate nodes keep the message until new links come up in the path to the destination [3]. It is to rely mainly on the mobility of the nodes and the likelihood of the creation of temporary links among the network nodes. While packets are forwarded from one node to another, the current receiving node might not have the ability to forward the packet on immediately after the packet reception. Thus the current receiving node has to carry the packet for a variable period of time before it encounters another node, where the packet could be forwarded on. This routing paradigm leads to an increased end-to-end packet delivery delay and might not be a desirable approach when delivery delay and delay jitter are of important concern.

Sparse mobile networks are an important type of DTMSN and have applications in battlefield, disaster recovery and wide surveillance. Nodes are mobile and distributed sparsely such that network partitions occur frequently and may last for a long period of time. Because of the lack of end-to-end paths, routing algorithms designed before cannot be simply suitable for sparse mobile networks. Based on observation, many mobility models that assist data delivery schemes have been proposed, which utilize node mobility to carry and deliver data. They may be generally classified as reactive schemes or proactive schemes. In reactive schemes, applications rely on node movement that is inherent in the devices themselves to facilitate deliver packets. While in proactive schemes, devices move proactively and specifically in order to meet and communicate with others.

They are characterized by sparse network topologies, often as a result of short transmission range relative to the diameter of the networks, where the limited transmission range is a result of the restricted capacity of the energy sources of the network nodes and the necessity of preserving energy to extend the network lifetime.

2.2. Energy Concerns

In some mobile communication environments, nodes are equipped with limited power such as batteries. So it is very important to conserve energy to prolong the network lifetime. There has been extensive research in the field of energy and power design for DTMSN. Measurement studies show that the idle energy consumption would be the dominant factor in the overall energy consumption. A number of schemes have been proposed to turn off radios when need to save energy. For example, there are some researches that exploit node redundancy in sensor networks to minimize idle energy used for connectivity. In the investigation, the upper bound of network lifetime due to the cell-based energy consumption has been extended. The study in this paper proposes to further reduce idle energy consumption by switching aggressively nodes into sleep mode, then trading off latency for energy saving.

Power management is also an important issue for sparse mobile networking where nodes need to discover each other for communication. This is especially important when contact opportunities between nodes may occur irregularly and last for a very short period of time. Some researchers develop a power management framework that allows a node to save energy while missing few encounter opportunities. It depends on the extent to which that message is available, different mechanisms are proposed to turn off nodes for energy saving. In some approaches, a low power radio will wake up for discovery the nodes or detecting other nodes nearby. Another work develops some algorithms to control dynamically the wakeup intervals and attempts to optimize networking performance based on observed traffic information.

There is another work concerning on conserving energy by use of mobility. For example, it may consider node mobility to minimize energy consumption for packet delivery in mobile sensor networks. The message ferrying scheme, which utilizes special nodes to deliver data, can also reduce energy consumption on regular nodes. This is mainly because of the fact that all data are forwarded using message ferries. So nodes may not need to discover each other or relay data. In addition, through utilizing sufficiently information about message ferry movement, regular nodes may be put into sleep state for a longer period of time, thereby reducing greatly energy consumption.

This paper focuses mainly on the problem of how to decrease energy consumption for every node by controlling the packet flow to extend the lifetime in delay tolerant mobile sensor networking that adopts ERP. What is noteworthy is that maximizing the network lifetime is not necessarily equal to minimizing the amount of the copies of a packet in DTMSN. For example, replicating abundant copies of a packet by nodes having rich energy, when even minimally reducing the number of copies produced by nodes equipped with poor-energy will still extend the lifetime, aiming for an overall increase in the number of copies.

3. Model

3.1. Epidemic Routing Protocol

Becker were the first to introduce a bio-inspired routing protocol for intermittently, opportunistically connected mobile ad hoc networks called Epidemic Routing [4]. This protocol relies on the theory of epidemic algorithms [5] by doing pair-wise exchange of messages between nodes as they get contact with each other to eventually deliver messages to their destination. Epidemic routing protocol is a kind of routing protocol which exerts the shortest end-to-end delay in intermittently connected mobile sensor networks. It floods messages into the network. The source node sends a copy of the message to every node that it meets. The nodes that receive a copy of the message also send a copy of the message to every node that they meet. Eventually, a copy of the message arrives at the destination of the message. This protocol is simple, but may consume a significant amount of resources. Too excessive communication overheads may drain each node's battery quickly. Moreover, since each node keeps a copy of each message, storage capacity cannot be used efficiently, and the capacity of the network is limited. Each node can only transmits some messages after some amount of time or stop forwarding them after a certain number of hops. After a message expires, the message will not be transmitted and will be deleted from the storage space of any node that holds the message.

An optimization to reducing the communication cost is to transfer index messages before transferring any data message. The index messages derive from messages that a node currently holds. Thus, by examining the index messages, a node only transfers messages that are not yet obtained by the other nodes. Hosts buffer received messages even if at the time of reception they have no path to the destination. A so-called summary vector is kept by the nodes to index the buffered messages. When two nodes meet they exchange summary vectors. Thus, each node can determine if a newly identified neighbor node has new messages. In such a case, these new messages are requested. In this way, as long as there is buffer space available, mobile nodes “infect” each other with the new messages. So replication of packets in ERP increases the probability of packet delivery via maximizing the number of nodes carrying packets.

However, ERP increases the usage of network resources, such as the energy consumption on the transmissions, because they may be not useful for delivering the packet to the destination node. Moreover, ERP reduces the capacity of network, which may be a bottleneck, as the encounter time are typically short and a link capacity is limited. In some communication environment the amount of energy stored in the batteries of a node becomes a major drawback of ERP.

In ERP, each message must clearly contain a globally unique identifier to determine if it has been previously seen. Besides the obvious fields of source and destination addresses, messages also contain a hop count field. Similar to the TTL field in IP packets, the hop count determines the maximum number of hops that a message can be forwarded on, and can be used to limit the resource utilization of the epidemic protocol. Messages with a hop count of one will only be transmitted by the source directly to their final destination, “infecting” no other nodes. The resource usage of this scheme is thus regulated by the hop count set in the messages, and the buffer capacity set at the nodes. If these are correctly set to sufficiently large values, the messages may eventually propagate throughout the entire network. Vahdat and Becker have, however, have shown that by choosing an appropriate maximum hop count, delivery ratios can still be kept high while the resource utilization is lower in the scenarios used in their evaluation.

3.2. MaxProp Routing Protocol

MaxProp [6] has been developed at the University of Massachusetts. If a contact is discovered, all the packets that the contact has not held would be attempted to be copied and transferred. The novelty of MaxProp comes in determining which messages should be transmitted first and which messages should be dropped first. That is about the priority of transmitting or discarding packets. So, MaxProp maintains an ordered queue based on the hop count of each message as well as the estimated likelihood of a future transitive path to that destination.

To obtain the path likelihoods, suppose that there exists the number of n node in a mobile sensor network, every node maintains a vector with the size of n-1 consisting of the probability that the node has encountered each of the other nodes in the network. Each element in the vector is equally likely to meet other node. But the entire vector is normalized such that the sum of all entries should be 1. When two nodes encounter, they will exchange their estimated node meeting likelihood vectors firstly. Ideally, every node will have an up-to-date vector from each other node. With these n vectors at hand, the node can then compute a shortest path via a depth-first search where path weights indicate the probability that the link does not occur. These path weights are summed to determine the total path cost and computed over all possible paths to the destinations desired. The path with the least total weight is chosen as the cost for that particular destination. The messages are then ordered by destination costs, and transmitted or dropped in that order.

MaxProp allows for many complementary mechanisms to enhance the message delivery ratio in common. Firstly, acknowledgment messages can be injected into the network by the nodes that have successfully received a message. These acknowledgements are 64-bit hashes of the message that are flooded into the network. The nodes can be instructed to delete the extra copies of the message from their buffers. It will help to free storage space so that outstanding messages will not be dropped too often. Secondly, messages with lower hop-counts will be given higher priority. It helps promote initial rapid message copies to give new messages a head start. Without the head start, newer messages can be quickly starved by older messages since there are generally fewer copies of new messages in the network. Finally, each message maintains a hop list indicating the nodes that have been previously visited, to prevent the visit of a node twice.

3.3. Markov Chain Model

The process of Epidemic Routing is very similar to the process of a virus spreading in epidemiology [7]. During epidemic routing, the number of nodes carrying a packet copy (it is referred to as “infected nodes”) increases every time an infected node encounters an uninfected node (it is referred to as a “susceptible node”).

In a network with finite number of nodes, especially in the sparse network, as the number of infected nodes increases, the number of susceptible nodes decreases, so that the infection rate saturates when the number of infected nodes is equal to the number of susceptible nodes.

In order to evaluate the number of packet copies in the network at some certain time while the epidemic routing is employed, we first analyze the packet flooding mechanism by use of the time interval while nodes encounter. The basic assumption is that the number of encounters between two specific network nodes follows the Poisson distribution, so that the time interval between two consecutive encounters has exponential distribution with rate λ.

In a mobile network with the total of n nodes, while the number of infected nodes is i and the number of susceptible nodes is $n-i$, the encounter rate between infected nodes and susceptible nodes is $i(n-i)\lambda$. Whenever an infected node encounter a susceptible node, then number of infected nodes increased by 1 and number of susceptible nodes decreased by 1. So with the number of infected nodes increases, the encounter rate between the infected node and susceptible node increases until the value of i reaches the value of $n/2$, and might finally decreases to the value of $(n-1)\lambda$.

Using the encounter rate between the infected nodes and the susceptible nodes, it derives a Markov chain model, in which the states in the Markov chain denote the number of copies in the networks, as is shown in Fig. 1.

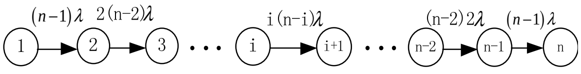

Fig. 1. Markov chain model for number of copies.

By using this Markov chain model, it derives the probability of having i copies of the packet among n nodes at time t, $P_i(t)$:

$$\begin{aligned} &P_i(t) = \int_0^t P_{i-1}(x)(i-1)\{n-(i-1)\}\lambda e^{-i(n-i)\lambda(t-x)}dx \quad (i>1) \\ &P_1(t) = e^{-(n-1)\lambda t} \quad (i=1) \end{aligned} \tag{1}$$

By Formula (1), it derives the average number of copies as a function of time t.

$$E_j(\mathrm{t}) = \sum_{i=1}^{n} iP_i(\mathrm{t}) \\ = \mathrm{e}^{-(\mathrm{n}-1)\lambda\,\mathrm{t}} + \sum_{i=2}^{n} i\int_0^t P_{i-1}(\mathrm{x})\{n-(\mathrm{i}-1)\}\lambda\,\mathrm{e}^{-i(\mathrm{n}-i)\lambda(\mathrm{t}-\mathrm{x})}\,dx \tag{2}$$

As is show in Fig. 2, it compares the number of the copies in the network as a function of time obtained by the Equation (2) with the number of copies obtained by the simulation. As is expected, it shows that the rate of increase of the number of copies is largest when the number of copies is to 30, which is the half of the total number of nodes.

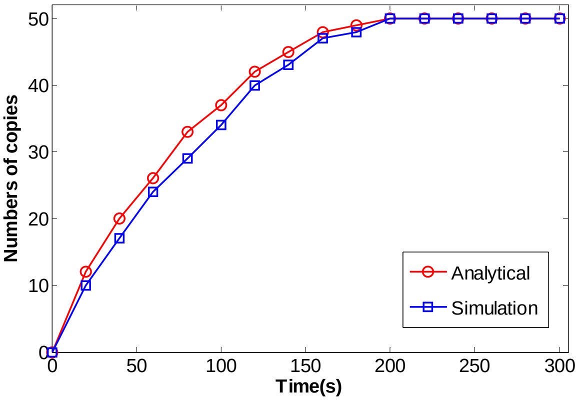

Fig. 2. Result of average number of copies.

In this simulation, there are $n = 60$ mobile nodes, in addition to one destination node. The transmission range is 25 meter. The scenario environment is a square area of $900m \times 900m$. Every node in mobile network determines its velocity independently. The time between velocity changes is distributed random with average value of 0.2 s. The speed is uniformly distributed at 20-65 m/s. The rate of encountering is $\lambda = 0.00125$. This type of random mobility model and the encounter rate will be used throughout this paper.

Now turn our attention to on delay tolerant mobile networking, there exists usually a single special node to which all the packets in the network are to be delivered, this special node is referred to as a sink node.

From the analysis above, the only difference between these is the encounter rate between the sink node and the other network nodes. Sink nodes do not transmit data packets, but only receive packets from other network nodes. With the exception of the sink node, all other network nodes do not know whether a data packet was received by the sink node. So, the data packets are erased from the nodes only based on the value of the TTL. The initial TTL value is determined according to the calculated probability of a sink receiving the copy of a packet by some time (t) and some agreed-upon level of confidence that the packet is to reach a sink before it is erased from the network node buffer storage. In this paper, we have used one simplification to make the discussion more understandable, that is, we consider only a single mobile sink node, with the same transmission range and mobility pattern as the other network nodes.

In order to evaluate the ERP performance, we need to consider three metrics: the number of packet copies in the network, the delay of the data packet, the probability of the sink node receiving a copy of the packet. It is shown on the above, the number of copies and the packet delivery probability are both increasing as a function of time.

When the network is in a state A_i, the sink node has not yet received a copy of the packet, and when the network is in a state B_i, the sink has received at least one copy of the packet. The constant i in A_i and B_i denotes the number of packet copies present in the network. When in a state A_i, the rate of transiting from state A_i to stateB_i is $i\lambda$, which is the encounter rate between any of the i nodes and the sink node.

The probability of having i packet copies in the network at time t, $P_i(t)$ is calculated by Equation (1). From the model in Fig. 3, we may calculate the probability $P_{A,i}(t)$ being in the state A_i at time t. The probability $P_{B,i}(t)$ being in the state B_i at time t, may then be calculated by subtracting $P_{A,i}(t)$ from $P_i(t)$.

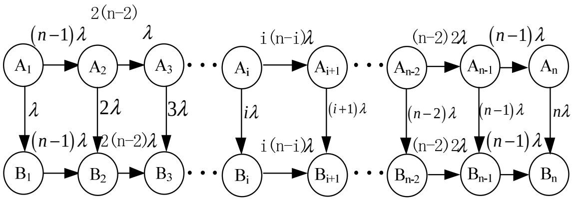

Fig. 3. Markov chain model for number of copies with destination.

$$\begin{aligned} P_{A,i}(\mathrm{t}) &= \int_0^t P_{A,i-1}(\mathrm{x})(\mathrm{i}-1)\{n-(\mathrm{i}-1)\}\lambda e^{-i(\mathrm{n}-\mathrm{i}+1)\lambda(\mathrm{t}-\mathrm{x})}dx \quad (\mathrm{i}>1) \\ P_{A,1}(\mathrm{t}) &= e^{-\mathrm{n}\lambda\mathrm{t}} \quad (i=1) \end{aligned} \tag{3}$$

$$P_{B,i}(t) = P_i(t) - P_{A,i}(t) \tag{4}$$

By using these probabilities derived from Equation (4), the packet delivery probability at time t, $D(t)$ is calculated as follows:

$$D(\mathrm{t}) = \sum_{i=1}^{n} P_{B,i}(\mathrm{t}) \tag{5}$$

The expected number of packet copies at time t is calculated by Equation (2), and since the infected nodes have not knowledge whether the sink node received the data packet or not, the average number of packet copies is independent of the packet delivery probability in Equation (5). Based on equations above the number of copies and the packet delivery probability are plotted as a function of time.

Above results show that if the packet propagation is left uninterrupted, the network will transit to one of B_i states. The transition to state B_i occurs when the value of i is closing to value n. Thus there are many redundant copies in the network at the time that the sink node receives the packet. If considering the energy consumption, one would like to have as few packet copies as possible while a copy is delivered to the sink node. The rates of transition could be made large for smaller value of i, this will allow us to terminate the packet propagation sooner. That is the idea behind selective transmissions, where the packet copy is replicated primarily on nodes that have larger probability of encountering the sink node.

4. Routing Schemes Based on ERP

The purpose of the novel routing schemes are to reduce the number of copies of a packet in the network to deliver a copy to the destination. A node may transmit only to the nodes with a larger delivery priority, in which a node's delivery priority may be based on the destination encounter history, the mobility pattern, and other information. However, the node mobility is totally random, the priority of all other nodes encountering the sink node will be the same. So reduction of the number of the copies may be achieved by a control algorithm, which is independent of the information of a particular encountered node [8].

In the following, the paper introduces three schemes to restrict the number of the copies in ERP. Those schemes rely on the limiting the time allowed for propagation (it is referred to LT scheme), directly controlling the number of the copies (it is referred to LC scheme), split the copies to the residual energies of the nodes (it is referred to LE scheme).

4.1. LT Scheme

In the LT scheme, packet propagation is the same as in ERP, but there is the time limit for the copies. To accomplish this scheme, a timer is introduced into Replication Time Limit (RTL), which is included within the data packet field. The nodes may replicate the data until the RTL expires, when the copies exist in the network. Assuming that no copies of the packet were prior to RTL; the packet delivery probability depends on the number of copies in the network at the time RTL. For $t \geq RTL$, the network follows a simple two-state Markov chain, it depends on whether at time $t = RTL$ the destination received a copy of the packet. For $0 < t < RTL$,

$$P_i(\mathrm{t}) = \int_0^t P_{i-1}(\mathrm{x})(\mathrm{i}-1)\{n-(\mathrm{i}-1)\}\lambda e^{-i(\mathrm{n}-\mathrm{i})\lambda(\mathrm{t}-\mathrm{x})} dx (\mathrm{i}>1) \quad (6)$$

$$P_{A,i}(t) = \int_0^t P_{A,i\text{-}1}(x)(i\text{-}1)\{n\text{-}(i\text{-}1)\}\lambda e^{\text{-}i(n\text{-}i+1)\lambda(t\text{-}x)} dx(i>1) \quad (7)$$

$$P_i(\mathrm{t}) = P_i(\mathrm{PTL})(\mathrm{i}>1) \quad (8)$$

$$P_{A,i}(\mathrm{t}) = P_{A,i}(\mathrm{PTL})\,\mathrm{e}^{i\lambda(\mathrm{t}-\mathrm{PTL})}(\mathrm{i}>1) \quad (9)$$

4.2. LC Scheme

In the LC scheme, there is an upper bound on the number of copies that the network is allowed to be replicated [9]. One way to limit the total number of copies is to determine a priori how many copies a node can create at the time when the node receives a copy of the packet. Another way to consider the scheme is to assume that upon a packet creation, all the possible replicas are created as well and from then on, the replicas are forwarded, but not replicated anymore.

In Fig. 4, n_i is the average number of nodes that can still propagate copies when there are i copies, and m is the maximum copies allowed in the network [10-13]. Every n_i may be calculated using the 2-D transition Markov chain.

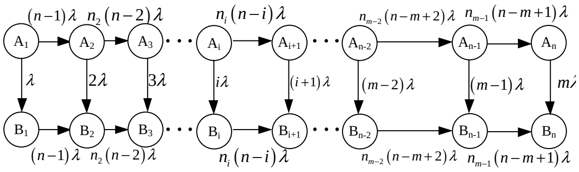

Fig. 4. Markov chain model for LC schemes.

By using the Markov chain model, the probability of i infected nodes without having a copy delivered to the destination is

$$P_i(\mathrm{t}) = \int_0^t P_{i-1}(\mathrm{x}) n_{i-1}\{n-(\mathrm{i}-1)\}\lambda e^{-n_k(\mathrm{n}-\mathrm{i})\lambda(\mathrm{t}-\mathrm{x})} dx \ (\mathrm{i}>1) \quad (10)$$

$$P_{A,i}(\mathrm{t}) = \int_0^t P_{A,i-1}(\mathrm{x})\,\mathrm{n}_{\mathrm{i}-1}\{n-(\mathrm{i}-1)\}\lambda e^{-(n_k(\mathrm{n}-\mathrm{i})+i)\lambda(\mathrm{t}-\mathrm{x})} dx \ (\mathrm{i}>1) \quad (11)$$

The expected number of copies in the network and the packet delivery probability for a given time t can be calculated by these equations. Because of the limited number of propagation nodes, the propagation rate in the LC scheme is smaller than the propagation rate in the LT scheme.

4.3. LE Scheme

4.3.1. Residual Energies

The performance of ERP is mostly depending on the number of active nodes in the networks. In order to obtain the ideal lifetime, all the batteries of all the nodes will be depleted at about the same time. So that needs some special mechanism implemented in the network. However, by the use of residual energy information, it is possible to achieve to control the energy consumption of each node. Such scheme needs each node to maintain its own residual energy information and transmit the information to the encountered node prior to transmitting the data packet [14-16].

It is supposed that at the encounter time of two nodes, the node shares their residual energy information [17]. A novel thing to do would be to allow the node with larger residual energy to create more copies in future encounters, as compared with the node with less residual energy.

Furthermore, the above-mentioned LC scheme is designed to allow for controlling the number of message copies that a node could spin off in its future encounters with other nodes. There is reason to believe that the LC scheme, if combined with the above energy control mechanism, could result in more uniform energy depletion among the network nodes.

4.3.2. LE Strategies

Because the batteries in DTMSN nodes have a limited amount of energy, the nodes with depleted batteries are removed in effect from the network [18]. While time goes by, the number of active nodes gradually decreases to 0, does the packet delivery probability. So it might be concluded that the network will be useful only if the packet delivery probability is above some minimum level, which might be defined as the Minimum Delivery Probability (MDP). The lifetime of a network is therefore defined as the period of time during which the packet delivery probability is greater than or equal to the MDP level.

While MDP is set to 4/5 and for TTL of 150 s, the MDP lifetime is 36 packet intervals. This lifetime is facilitated by reducing the maximum achieved packet delivery probability. When the value of TTL is reduced from 150 s to 125 s, the maximum achievable packet delivery probability decreases from 93 % to 90 %. This shows the tradeoff between maximum packet delivery probability and the lifetime of the network.

Through appropriate reduction in the value of TTL, the MDP lifetime may be extended by decreasing the maximum packet delivery probability to the MDP level. But this may not always be desirable, as one would prefer the network to achieve packet delivery probability higher than the MDP level. The network should achieve packet delivery probability of some Target Delivery Probability (TDP) most of its lifetime, and only at the end of the network lifetime should be degrade to the MDP level, in which TDP > MDP. It is seen that, the MDP lifetime of the network may be extended at the cost of reducing the maximum packet delivery probability to TDP.

The ideal lifetime can be calculated simply by dividing the total energy in the network by the average energy consumed during a packet routing. It can be considered as the maximal possible extension of the MDP lifetime.

In the LC scheme, when a node transmits a copy to the other node, it divides to the number of copies and passes half of the load to the receiving node. So the two nodes will have the same number of copies to propagate the information. However, if the nodes may share their residual energy information, they will divide the number of copies in some relation to the residual battery energy. Such way to divide the load is to half the copies in proportion to the residual energy of the nodes. It is the LE scheme. We use the same method for the LC scheme, because we need to find the value of parameter that limits the total number of copies for the LE scheme. For example, the total number of copies that may be created would be limits to 38 copies. Then the ideal lifetime of the LE scheme is the same as that of the LC scheme, which almost is 9680s, as is shown in Fig. 5.

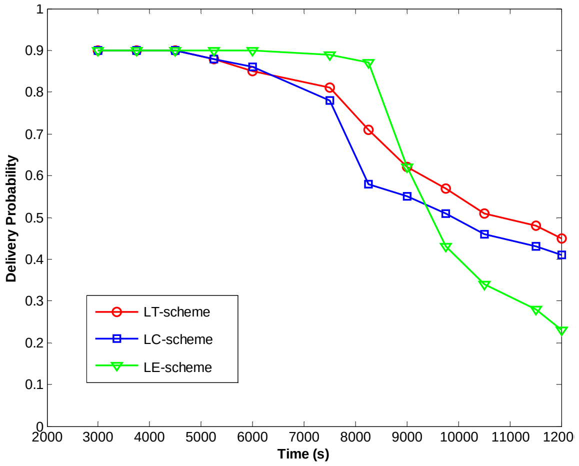

Fig. 5. MDP lifetime of ERP schemes.

The method used to extend the LC scheme to the LE scheme is difficult to be applying to the LT schemes, since this scheme cannot naturally control the number of transmissions of nodes in the future. In order to clarify this further, suppose that we extend the LT scheme by allowing a node to transmit to another node only when the first node has more residual battery energy than the second node. Then, if the source node has less residual battery energy than any nodes it encounters, the packet can be still propagated with the LE scheme. However, with the LT scheme, the only opportunity for the packet to reach the destination is for the source to deliver the packet to the destination itself.

However, we allow a node to transmit based on some probabilistic function of its residual energy. Then it would reduce the propagation rate, by decreasing the packet delivery probability below the TDP. So in order to satisfy the TDP, the number of copies has to be increased, reducing the effectiveness gained by extending the scheme to rely on the residual energy information.

5. Maximing the Life for DTMSN

In order to maximize the life of delay tolerant mobile networking that employs ERP based scheme, we show the comparison of the 80 % MDP lifetime for all the three schemes. As is shown in the Table 1, we can conclude that the lifetime of LE scheme is the most longer than the other schemes. The results in the table demonstrate that the LE scheme has the longest lifetime and that it is closer to the ideal lifetime than the other schemes. Although all the three variation schemes based on ERP have longer MDP lifetime than the ERP lifetime, the difference between the ideal lifetime and the MDP lifetime is larger for the RER schemes, compared with the ERP scheme. The only exception is the LE scheme, where the MDP lifetime is relatively close to the ideal lifetime. The results show that a large value of the coefficient of variation suggests a large difference between the MDP lifetime and the ideal lifetime.

Table 1. Ideal Lifetime and MDP Lifetime for Each Scheme.

Scheme	Ideal lifetime (s)	MDP (80 %) lifetime (s)
ERP	6500	5725
LT	8900	7250
LC	9680	7650
LE	9680	8765

The extension of the LC scheme to the LE scheme by including the residual energy information resulted in a significant MDP lifetime extension. This is important to the LE scheme. An interesting observation is that the packet delivery probability of the LE scheme decreases rapidly while it drops below the MDP level, when the packet delivery probability becomes lower than that of the and LT scheme. It suggests that for the LE scheme, most of the batteries of the nodes become depleted closer to the MDP lifetime and after this time most of the nodes become inactive. So, by comparing with the other schemes, the LE scheme lifetime better resembles the ideal lifetime. Lastly, we have the comparison of message delivery probability and average energy consumption of Epidemic routing protocol, MaxProp routing protocol and LE scheme.

The comparison of message delivery probability is shown in Fig. 6. With the time increasing, the delivery probability of all schemes is decreased above. When the time is to 12000 s, the probability of the MaxProp routing protocol is about 0.7, which is the most highest. It enhances the probability of message delivery ratio, because it transfers the message with priority and has some complementary mechanisms. But probability of the LE scheme is only 0.6.

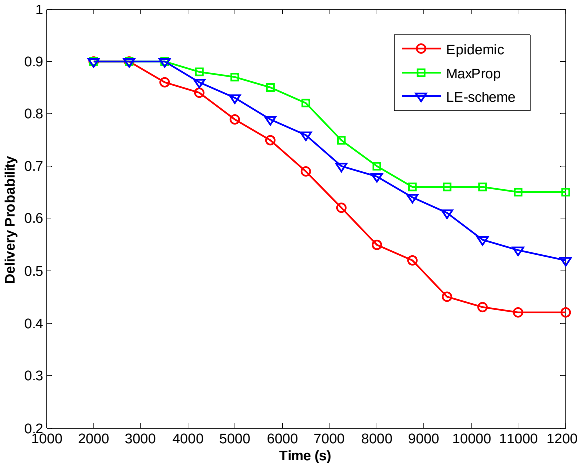

Fig. 6. Message delivery ratio.

The comparison of ratio of average energy consumption is shown on Fig. 7.

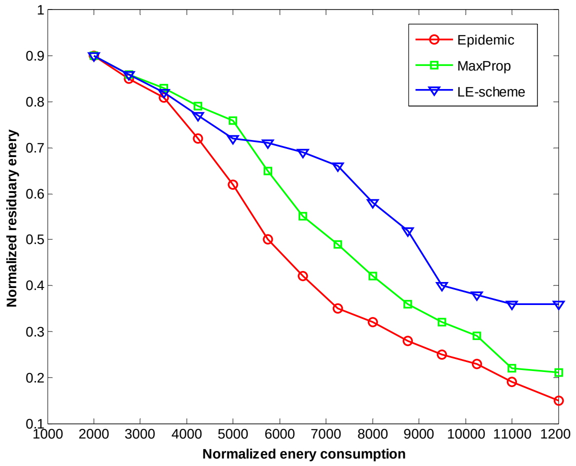

Fig. 7. Average Energy Consumption.

With the time increasing, the average energy consumption of all schemes is decreased above. When the time is to 9250 s, the energy of the LE scheme is about 0.4. When the time is to 12000 s, the energy of the LE scheme is still about 0.4, which is the largest than other schemes. It converse the energy, because it is not only merely reducing the number of packet copies, but also shift the production of the copies to the nodes with larger residual energy. But when the time is to 7800 s, the average energy of the MaxProp routing protocol is about 0.4. Indeed, the LE scheme has the longest lifetime and that it is closer to the ideal lifetime than the other schemes.

Conclusions

In this paper, the authors study three variations LT, LC, and LE of the Epidemic Routing Protocol (ERP) to extend the lifetime of the Delay Tolerant Mobile Sensor Networking (DTMSN). Here, an analytical model is proposed to obtain network lifetime. In the simulation, the LE provides the maximum lifetime of DTMSN.

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