A Unicast Tree-Based Data Gathering Protocol for Delay Tolerant Mobile Sensor Networks

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Abstract

The Delay Tolerant Mobile Sensor Networks (DTMSNs) distinguish themselves from conventional sensor networks by means of some features such as loose connectivity, node mobility, and delay tolerability. It needs to be acknowledged that traditional end-to-end routing protocols cannot be applied usefully in such challenging network conditions because of intermittent connections and/or long delays. Hence, this research is intended to propose a Unicast Tree-based Data Gathering protocol (UTDG) to resolve this problem. A UTDG includes 3 phases: tree formation phase, data collection and data transmission phase, and finally the updating phase. The proposed protocol constructs a tree in each community on the basis of transmission ranking, contact probability and the link expiration time. The selection of the next-hop node is based on the tree structure rather than forwarding the message to the neighbor node directly. Each node unicasts the data to its parent in the related community, and the root of the tree successively sends the data to the sink node. The authors contend, based on the simulation results of the study, that the proposed protocol can gain significantly higher message delivery rates with lower transmission overhead and also lower delay in data delivery than the other existing DTMSNs routing protocols in some applications.

Keywords: Delay-Tolerant Mobile Sensor Networks (DTMSNs); Unicast Tree-based Data Gathering protocol (UTDG); Transmission Ranking; Contact Probability; Link Expiration Time.

1. Introduction

Many routing protocols have been proposed for wireless sensor networks (WSNs) in the related literature in recent years. Although traditional routing methods are appropriate for many sensor applications, they cannot be applied to those scenarios with intermittent and low connections because of sensor nodes mobility, sparse network density, and energy limitation [1-3]. Two practical instances of this scenario are monitoring pervasive air quality and tracking flu virus. In order to obtain the most precise and effective measurement in these examples, wearable sensors that adapt themselves to human activities have been bound. As a result, the connection among the mobile sensors is poor; therefore, it can be concluded that establishing a well-connected mesh network to transfer data through end-to-end connections between sensor nodes and the sinks is hard.

Delay Tolerant Mobile Sensor Networks (DTMSNs) have been proposed in order to solve this problem. DTMSNs are considered as the subset of Delay Tolerant Networks (DTNs) which have many features such as node mobility, delay tolerance, frequent and prolonged communication interruption between nodes, and resource limitations. DTN is a subject that absorbs lots regards and studies have examined many DTN application domains [4]. At the earliest, it was offered to resolve the problem of interplanetary Internet communications through establishing a new network model in space system. This new model could encounter data transmission and other communication needs on the business in the space communications [5, 6]. The considered DTMSN in this paper contains two types of nodes, the wearable sensor nodes and the sink nodes. The former are attached to people (or other mobile objects) which collect information and establish a loosely connected mobile sensor network for information delivery. The second type of nodes are the high-end nodes (e.g., personal digital assistants with sensor interfaces or mobile phones), which are used as the sink nodes to receive data from wearable sensors. Sink nodes are employed are deployed at strategic positions with a high visiting probability or they are carried by people.

In this paper, the authors have a Unicast Tree-based Data Gathering protocol (UTDG) for Delay Tolerant Mobile sensor networks. The proposed UTDG has 3 phases: tree formation phase, data collection and data transmission phase, and the updating phase. In the tree formation phase, the UTDG builds a tree for each community based on the location of nodes, contact probability, transmission rankings and link expiration time; all routing decisions are made according to the formed tree. In the second phase, the next hop node is selected based on the tree structure and also the data

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which is unicast to the parent node in the tree. In the final phase, the tree in each community is updated at each time slot. UTDG can improve the network performance with reduce the cost of transmission overhead by means of elaborately selecting the next hop node to forward the data messages.

The rest of the paper is organized as follow: section 2 describes the related work of the literature. Section 3 describes the system architecture and also introduces the proposed Unicast Tree based Data Gathering algorithm. Section 4 reports the simulation results and reports the discussion of the results and the findings. Finally, Section 5 concludes and sums up the whole paper.

2. Related Work

The routing protocols for traditional networks [7-11] would fail in the DTN scenario because these protocols were intended to be deployed in a network with end-to-end connectivity. So many significant research studies have been conducted with regard to DTN architecture in the related literature and there seems to be a consensus on the general DTN architecture [12]. DTN routing algorithms can be referred to as an example of the consensus on DTN architecture. There has been wide research on routing in delay-tolerant networks. The purpose of these research studies was to gain high data delivery rate with low transmission overhead and respectably short delivery delays. A simple and basic routing protocol named direct transmission has been presented in [13]. In this protocol, whenever the sensor meets a sink, it transmits the data messages in its queue to the sink. A sensor does not receive or transmit data messages of the other sensors. This protocol has lower transmission overhead but undesirably longer delivery delay. Moreover, since it depends on the contacts of the sensor nodes and the sink node, and if there would be few sink nodes or the network is very sparse, as a result, it will have very low delivery rate. Epidemic routing [14] protocol has been proposed to increase the data delivery rate in partially connected networks. According to this protocol, a node copies its message to all those nodes with which it has contact. On the other hand, undoubtedly flooding the network with messages will consume network resources such as node energy, bandwidth, buffer, etc. If the resources are scarce and limited, the performance level might decrease [15]. Several methods have been proposed to control the flooding [16-21]. An alternative to epidemic routing is to spread copies of a message to a limited number of nodes. Spray-and-Wait is an approach that “sprays” a number of copies into the network, and then “waits” until 1 of these nodes meets the destination [22]. Moreover, spray-and-Focus [23] is very similar to Spray-and-Wait. This scheme distributes a small number of copies to a few nodes. However, instead of waiting to deliver a message to its destination by itself, each relay node can forward its copy to more nodes using a scheme based on the single-copy utility.

Other endeavors aiming to improve the performance of the DTMSN routing include [24,25]. In [24], an efficient replication-based data delivery (RED) protocol is presented on the basis of erasure coding technology. RED consists of two key components for data transmission and message management. The first component makes the decision on when (time) and where (location) to transmit data messages according to the delivery probability. The second component makes the decisions about the optimal erasure coding parameters based on its current delivery probability. The second component makes these decisions in order to achieve the desired data delivery rate and also to minimize the overhead. This history-based method is not effective and cannot have the actual ability that a node needs to deliver data to the sink nodes. In [25], the authors proposed the Message Fault Tolerance-Based Adaptive Data Delivery Scheme (FAD) to increase the data delivery rate in DTMSN. The FAD approach employed the fault tolerance feature of a message which indicates the importance of the messages. The decisions on message transmission and message dropping are made based on fault tolerance in order to minimize the transmission overhead. The system parameters are carefully tuned on the basis of thorough analyses to optimize the network performance. However, this protocol still has a high overhead.

Yong Feng et al. in [26] proposed a Distance-aware Replica Adaptive Data Gathering protocol (DRADG). This protocol uses a self-adapting algorithm to cut down the number of redundant replicas of the messages based on the distance between sensor nodes and the sink node and uses the delivery probabilities of the mobile sensors as the main routing metrics.

Also, traditional tree based routing algorithms [27-47] are not much robust in the challenged networks which suffering from frequent disruption, sparse network density and limited device. Several tree based approaches have been adopted in such challenged networks.

Two tree based algorithms are designed in [48], which are Static Tree Based Routing (STBR), Dynamic Tree Based Routing (DTBR). Regarding DTBR and STBR approaches, the message is forwarded along a time varying based end-to-end path from the source node to destination and replicated at the branch nodes which have more than one sub branches. STBR is based on the shortest path between the source node and destination and uses the link state information adopted in [49]. However, STBR cannot be dynamically adaptive to the large variation of network topology in DTNs, since the message would be constantly kept by its carrier until the connectivity is available, even if the message carrier is within the group membership of destinations. Motivated by this shortcoming, DTBR updates the path towards destination on receiving the message from previous hop.

In [50], the authors proposed an on-demand situation-aware multicast (OS-multicast) approach. Initially, a source-rooted tree is constructed in the similar way as STBR [48]. When a node receives a bundle, it will dynamically rebuild the tree rooted at itself to all the destinations based on the current network conditions. Their simulation results showed that OS-multicast can achieve smaller delays and better message delivery ratios than DTBR [48].

These tree based approaches are multicasting algorithms. With respect to multicasting in DTNs, the large variation of network topology limits the scalability of the tree based approaches, since it is difficult to maintain and update the multicast tree using partially historical information. Note that the destinations of the multicast message are a set of nodes using Unicast Based Routing (UBR). In contrast, there is only a unique destination for unicast message performed by the unicast algorithms instead, UBR attracts more research attention by borrowing from the research activities of existing unicast algorithms in DTNs, of which to distribute the multicast destinations [51] is interesting. Then, we proposed the Unicast Tree-based Data Gathering Protocol for Delay Tolerant Mobile Sensor Networks which is described in the next section.

3. Proposed Protocol

Our protocol is a route forwarding protocol designed for delay tolerant mobile sensor networks. The major contribution of this protocol is to build a tree in each community and to select the next-hop based on the tree structure. The proposed protocol is intended to guarantee high performance. In this section, the network model is first described and then 3 important protocol parameters are introduced; after that, the proposed protocol is explained in detail.

3.1 Network Model

Initially, the authors assumed that all the *N* sensor nodes are randomly deployed in a square area of *A*. All the sensor nodes are homogeneous and have a unique ID number. A node, e.g., node *i*, maintains the table as its local information. As shown in Fig. 1, the table consists of 8 fields.

Node_ID	Sink Position	Home_ID	Level of tree	Parent Node_ID	Contact Probability	Link Expiration Time	Transmission ranking

Fig. 1. Format of node header

Each entry in the table is for a node ever met by the Node *i*. The maximum transmission range of all the sensor nodes is fixed to *R*.

As shown in Fig. 2, the mobility of all the sensor nodes is assumed to follow the community-based Mobility model depicted in [52,53] where the whole area is divided into several non-overlapped cells, a public gathering place (G) (e.g., in reality it could be a buffet in a university), and communities (C) (e.g. faculty departments of a university where each node belongs to a home community and most of the time it stays there, for example this node could be a student that belongs to a faculty department. Each node's movement accords to the Random Way Point Model [54] in each home community. Nodes randomly choose a destination and move to their destination by the specified speed v. Upon arrival at the destination, the node pauses for a while and then chooses a new destination. The destinations are selected in a way that if a node is at home, there is a high probability that it will go to the public gathering place (but it is also possible for it to go to other places), and if it is away from home, it is very likely that it will return home. Each sensor node can compute its location by means of the GPS (Global Positioning System) [55] or other GPS-less technique. The sink node is immobile and it is located at the G location which is known to all sensor nodes.

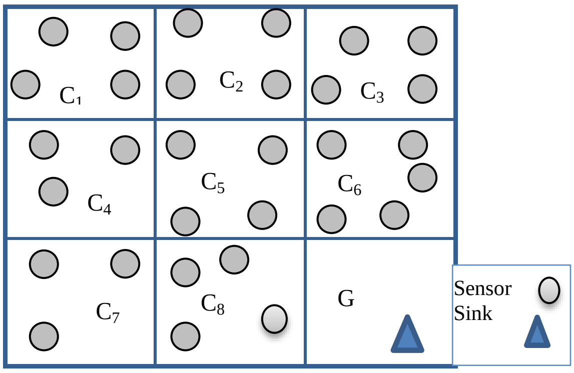


Fig. 2. Community-based mobility model [25]

3.2 Parameters of the Proposed Protocol

The proposed protocol is based on 3 important parameters, namely, contact probability, transmission ranking and Link Expiration Time which are described separately below.

3.2.1 Contact Probability

Contact probability indicates the degree of likelihood that a sensor node will communicate with its neighbors. We adopt a simple approach, namely exponentially weighted moving average (EWMA) [56] to calculate the contact probability. In this approach, Node *i* retains a list of contact probabilities ξ_{ij} for everyother node j, which it has met before. ξ_{ij} is initialized with zero. ξ_{ij} is updated in every time slot according to the following rule:

$$\xi_{ij} = \begin{cases} (1-\alpha)\left[\xi_{ij}\right] + \alpha & , \quad \text{imeetsj} \\ (1-\alpha)\left[\xi_{ij}\right] & , \quad \text{otherwise} \end{cases} \qquad (1)$$

In Eq. (1), $\alpha \in (0,1)$ is a constant parameter, and $\left[\xi_{ij}\right]$ is the old contact probability. Evidently, this is a dynamic process, and thus $\xi_{ij}$is not essentially equal to the actual contact probability p_{ij}. However, according to the following theorem p_{ij} converges to ξ_{ij}.

Theorem 1: If p_{ij} is a probability of Nodes *i* and *j* which should be met in each time slot, ξ_{ij}converges to p_{ij}.

Proof: Consider a sequence of time slots and let $\xi_{ij}(t)$ indicate ξ_{ij} in the time slot *t*. we have:

$$E(\xi_{ij}(1)) = (1-\alpha)\xi_{ij}(0)+p_{ij}\alpha$$

$$E(\xi_{ij}(2)) = \xi_{ij}(0) + p_{ij}(\alpha)[1 + (1-\alpha)]$$

$$\ldots.$$

$$E(\xi_{ij}(t)) = (1-\alpha)^t\xi_{ij}(0) + p_{ij}(\alpha)[1 + (1-\alpha) + \cdots + (1-\alpha)^{t-1}]$$

When $t \to \infty$, we arrive at:

$$\lim_{t\to\infty} E(\xi_{ij}(t)) = \alpha.\, p_{ij}.\frac{1}{\alpha} = p_{ij},$$

Which is independent of the parameter α and the initial value $\xi_{ij}(0)$.

3.2.2 Transmission Ranking

Transmission rankings indicate the degree of likelihood that sensor nodes will communicate with the sink node. Generally, the more likely a node is to communicate with the sink node, the higher the transmission ranking attached to it. Let p_i denote the transmission ranking of sensor *i*. As depicted in [57] Due to the randomly moving characteristic of sensor nodes, p_i is a variable related to speed, current moving direction and the distance with the sink node. Based on the Random waypoint model, the process of calculating p_i of node *i* can be categorized into the following 4 cases:

If node *i* is in the transmission range of the sink node, its transmission ranking p_i is equal to 1, and hence it can communicate with the sink node directly. This is because the node *i* can directly communicate with the sink node at that time.

If the current moving path of node *i* intersects the communication range of the sink node, we let $p_i = 1$. Since node *i* is moving towards the sink node, hence, it will soon communicate directly with the sink node.

If the above-mentioned conditions cannot be held, we can calculate the current transmission ranking p_i of the node which is larger when the line is closer to the sink node.

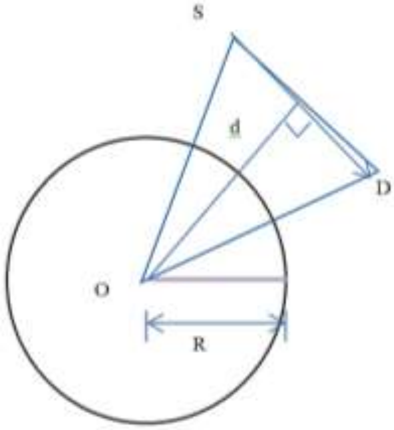


Fig. 3. The sketch map for calculating the transmission ranking [57]

As shown in Fig.3, triangle ΔOSD is composed of the sink node $O(x_o, y_o)$, the start point $S(x_s, y_s)$ and the destination point $D(x_d, y_d)$. SD, OD and OS are denoted for sub-tenses of the angles O; S and D respectively. *d* is denoted for the distance between O and SD. Half circumference of the triangle ΔOSD is denoted by *p*, and acreage of the triangle ΔOSD is denoted by St, then the value of *p* is shown in Eq.(2) as below:

$$p = \frac{1}{2}(\|SD\| + \|OD\| + \|OS\|) = \frac{1}{2}\Big[\sqrt{(x_s - x_d)^2 + (y_s - y_d)^2} + \sqrt{(x_o - x_d)^2 + (y_o - y_d)^2} + \sqrt{(x_o - x_s)^2 + (y_o - y_s)^2}\,\Big] \tag{2}$$

And the average St is shown in Eq. (3) as follows:

$$S_t = \frac{1}{2}\big|\|OS\|\big|.\big|\|SD\|\big|.\operatorname{Sin} S = \frac{1}{2}\|SD\|.d = \sqrt{p(p - \|OS\|)(p - \|OD\|)(p - \|SD\|)} \tag{3}$$

According to Eq. (3), the distance *d* is shown in Eq. (4) as follows:

$$d = 2\sqrt{p(p - \|OS\|)(p - \|OD\|)(p - \|SD\|)} \,/\, \|OS\| \tag{4}$$

We can get the value of *d* since it can be calculated by means of using p and d, as it is shown in Eq. (5):

$$d = \sqrt{\|OS\|^2 - \left(\frac{\|SD\|^2 + \|OS\|^2 - \|OD\|^2}{2\|SD\|}\right)^2} \tag{5}$$

In addition, if $R/d < 1$ and $d<\|OS\|<\|OD\|$ or $d <\|OD\|<\|OD\|$, we ought to set $p_i = {}^{R}\!/_{\|OS\|}$ or $p_i = {}^{R}\!/_{\|OD\|}$. In the end, we can get the transmission probability formula as it is shown below [57].

$$p_i = \begin{cases} 1 & , \frac{R}{d} \geq 1 \\ R \Big/ \sqrt{\|OS\|^2 - \left(\frac{\|SD\|^2 + \|OS\|^2 - \|OD\|^2}{2\big|\|SD\|\big|}\right)^2} & , \frac{R}{d} < 1 \\ \frac{R}{\|OS\|}, \frac{R}{d} < 1 \text{ and} d < \|OS\| \leq \|OD\| & \\ \frac{R}{\|OD\|}, \frac{R}{d} < 1 \text{ and} d < \|OD\| < \|OD\| & \end{cases} \tag{6}$$

3.2.3 Link Expiration Time

In this section the authors introduce the expiration time of the link that is formed between the two nodes whose locations are included in the transmission range of each other. Based on our assumption, each mobile node can learn its location by GPS or other GPS-less technique and all the sensor nodes have synchronized clocks. Thus, each mobile node can calculate its speed and direction, and hence broadcast the parameters to its neighbors by the periodic hello messages. Assume that the two nodes *i* and *j* are within the transmission range of each other at time *t*. As described in [58], we can calculate the link expiration time between the nodes *i* and *j*, which is denoted T_{ij} as follow:

$$T_{ij} = t + \frac{-(ab+cd) + \sqrt{(a^2 + c^2)r^2 - (ad-bc)^2}}{a^2 + c^2} \tag{7}$$

In Eq. (7), the locations of the nodes *i* and *j* are represented by (x_i,y_i) and(x_j, y_j), the speeds by v_i and v_j, and the moving directions by θ_i and θ_j ($0 \leq \theta_i, \theta_j \leq 2\pi$), respectively; a= $v_i \cos\theta_i - v_j \cos\theta_j$, b= $v_i \sin\theta_i - v_j \sin\theta_j$, c=$x_i - x_j$, d=$y_i - y_j$.

3.3 UTDG Algorithm

The system model, that is, a Unicast Tree-based Data Gathering protocol (UTDG) as shown in Fig. 4 has the following properties. The nodes in each community build a tree with different levels. The distance between the two levels is equal to the radio range of the sensor node.

The UDTG algorithm for delay tolerant mobile sensor networks has been proposed in this paper. This algorithm works in 3 phases: Tree formation phase, data collection and transmission phase, and finally updating phase.

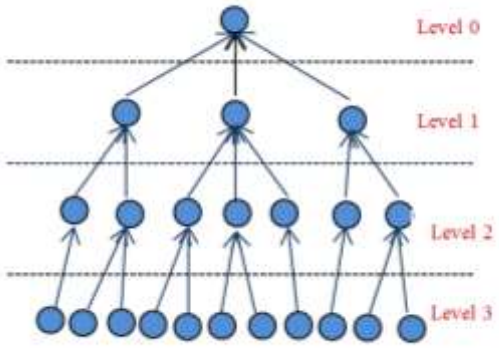


Fig. 4. System architecture

a. Tree formation phase:

All the nodes have their clock synchronized by using the NTP or the GPS clock itself. We set their clocks before deploying them in the area and at a certain time they will begin to build a tree in each home community. Our unicast tree-based protocol requires the warm-up period to construct trees in each home community. In the tree formation phase, the number of levels is calculated using the Eq. (8) as follows:

$$\text{number of levels} = \left[\frac{1}{\beta}\right] + 1 \tag{8}$$

Where $\beta \in (0,1)$ is a constant value and should be defined based on the application, the number of levels shows the number of the levels in each community.

A node assigns a level to itself according to the value of p_i (Transmission Ranking). A node with maximum transmission ranking is selected as the trees' root. If the other nodes have the transmission rankings $(1 - \beta x_{n-1}, 1 - \beta x_n]$, they will assign the level n to themselves. In other words, we can assign different levels of the tree to sensor nodes in the tree with *n*+1 level according to Eq. (9) as follows:

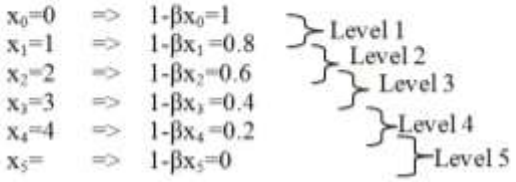
$$\begin{cases} \text{level} = 1, p_i \in [1 - \beta x_0, 1 - \beta x_1] \\ \text{level} = 2, p_i \in \ (1 - \beta x_1, 1 - \beta x_2] \\ \text{level} = 3, p_i \in (1 - \beta x_2, 1 - \beta x_3] \\ \quad\quad . \\ \quad\quad . \\ \text{level} = n, p_i \in (1 - \beta x_{n-1}, 1 - \beta x_n] \end{cases} \tag{9}$$

Where p_i is the transmission ranking of the node i; the level of the node in the tree will be as follows:

$x_j = j; j = 0, \dots, (\text{number of levels} - 1)$; $0 \leq 1 - \beta x_j \leq 1$.

In fact, nodes with greater transmission ranking will be placed at higher levels of the tree. For example, if β is equal to 0.2, we have:

$$\text{number of levels} = \left[\frac{1}{\beta}\right] + 1 = 6$$



The node with the highest transmission ranking is placed at the zero level; if the transmission ranking of a node (p_i) is within [1, 0.8] then its level will be equal to 1. If p_i is within the interval [0.8, 0.6], then, it will be placed at level 2; if p_i is within the interval [0.6, 0.4], the level will be 3; and finally if (p_i) is within the interval (0.2, 0], the node will be at level 5

After assigning a level to the nodes, we use contact probability (ξ_{ij}) and link expiration time (T_{ij}) for connecting children to their parents. (The node that has higher T_{ij} and $\xi_{ij}$is selected as the parent) If the node *i* is at the level of x, the variable x will be reduced count by 1, and then will broadcast a hello message which contains the value of x-1. Each node which is located at the x-1 level and receives a hello message will send an RTR (Ready to Receive) message which contains node's ID. The node *i*, with reference to its table, calculates ξ_{ij} and T_{ij} and it gets the probability of being a parent, according to Eq. (10) as follows:

$$\text{parent}_i = \gamma \xi_{ij} + (1 - \gamma)\ T_{ij} \tag{10}$$

Where in Eq. (10), γ is weight parameter; parent_i is probability of being parent.

The node *i* becomes the child of the node that sends its RTR message earlier and has higher parent_i. it sends a message to its parent node to be aware of its presence. The parent node keeps the ID of its children in a table called children table. These steps are repeated until the whole tree has been constructed.

b. Data collection and data transmission phase

After the tree formation phase, like CSMA/CA each node asks its parent to send data by means of an RTS (Ready to Send) message. Since our network is unreliable, we will have several modes:

The child node sends the RTS message and the parent node is in the IDLE mode:

Parent nodes send CTS (Clear to Send) messages to their children nodes; these messages contain ID of the node which has sent the RTS message. By means of this message parent nodes inform their other children to go to the sleep mode and save energy until the time data transmission is finished. Then, the child will start unicasting data. If the parent node receives the message, it will send the ACK message. If the child does not get any ACK messages from its parent, then it will send the data again (Because the network is intermittently connected). The child node sends the RTS and the parent node is in BUSY mode:

Children do not receive any messages from their parents; therefore, they must wait a random amount of time and then resend the RTS message. It is probably the case that the parent has no response to the RTS message due to the disconnection. So the child node refers to its table and sends the hello message to those nodes that have higher contact probability. Each node that receives the hello message will send an ACK message with its ID and level. Consequently, the node which has higher contact probability and lower level becomes the new parent of the child node and the child node sends its data to it. The root of each tree that has been formed in communities sends the received data to the sink node.

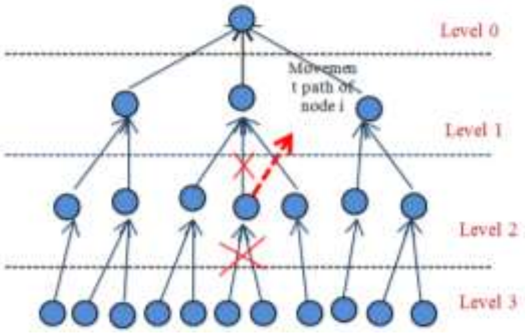


Fig. 5. Movement of the node

c. Updating phase

In each time slot, the values of ξ_{ij}, p_i and T_{ij} will be updated according to Eq.s 1, 6 and 7, respectively. When a sensor node moves from 1 location to another location in its home community, as shown in Fig. 5, there will be 2 possibilities regarding the movement of the node. The node moves either within the same level or to a higher or lower level. The node re-calculates its level according to p_i. If the level of a node does not change, then the node will check that if it is within the range of its father or not; if it is within the range of its parent node, then there is no need to re-join the tree; otherwise, the node chooses its father according to parent_i, as shown in Fig. 6.

When a node moves from 1 community to another community, it assigns a level to itself in the new community according to p_i.

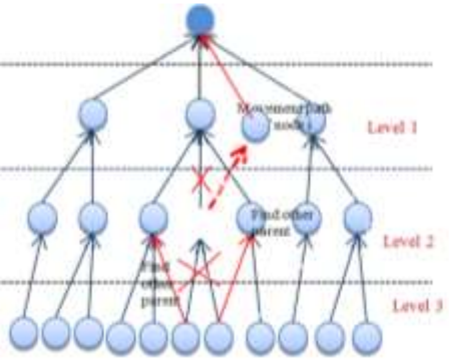


Fig. 6. New tree formation

d. Handling node invalidation

Child node invalidation: if the parent node does not get any response from any of its children in the data transmission process, hence, it will add this node in the list of invalid nodes and will wait for the maximum T_{ij} of its children. After this waiting time, the node which does not send any response will be inferred as an invalid child and as a result, the parent node will remove this node from the list of its children nodes.

Parent node invalidation: after the link expiration time between a child node and a parent node, the child node will remove the father node from the father list and will choose a new father according to a new ξ_{ij} and T_{ij}.

e. Handling energy constraints

There are 2 possible values for the energy level of a node: A node with an energy level higher than half of the original battery capacity and a node with an energy level lower than half of the original battery capacity. These energy limitation options of the nodes will be treated as follows:

If the sensor node energy level is lower than half of the original battery capacity but higher than the average energy level (Threshold value) then move the node to 1lower level and increase its level count by 1. Otherwise if the energy level of the node is lower than the threshold value, then move this node to the lowest level. If the leaf node energy level is higher than the battery capacity, then move this node to 1 higher level and decrease the level count by 1.

4. Simulation

In this section, we evaluate the performance of the schemes through MATLAB simulations. Each simulation is repeated 10 times. In our experimental environment, we assumed that the simulation area is a 1500 m × 1500 m region which was divided into non-overlapped subareas: one gathering place and eight communities. The sub-area at the left bottom is selected as the gathering place, and the sink node is positioned at the gathering place. The authors supposed that the data generation in each sensor follows a Poisson process with an average arrival interval from 10 s to 100 s. Other simulation parameters and their default values are summarized in Table 1 below.

We carried out the UTDG, OS-multicast, DRADG, FAD and epidemic routing protocols. The performance metrics used in our simulations are as follows:

Data delivery ratio, which is the ratio of the data received by the sink node to the sum of data generated by all the sensor nodes in the network.

Data delivery delay, which is defined as the duration from the very beginning of data generation time until it is received by the sink node.

Network lifespan, which is defined as the duration from the very beginning of the network operation until the time a half of all sensor nodes depletes their energy in our simulation.

Table 1: Simulation parameters.

Parameter	Value
Network size (m2)	1500 ×1500
Number of sensor nodes	150
Radio Transmission R (m)	105
Speed of sensor node v (m/s)	2~10
Maximum buffer size of sensor (message)	1000
Data packet size (bytes)	1000
Control message size (bytes)	250
Initial energy (J)	50
Packet generation ratio (packet/s)	0.01
Maximum delay tolerance value (s)	1000
Position of sink node (m)	(300, 300)
α	0.8

4.1 Impact of Message Generation Ratio

In the simulation which was conducted in this study, the authors changed the data generation rate in order to observe its impacts on the performance of the four protocols under different transmission loads. The performance of five protocols is shown in Fig. 7 and Fig. 8.

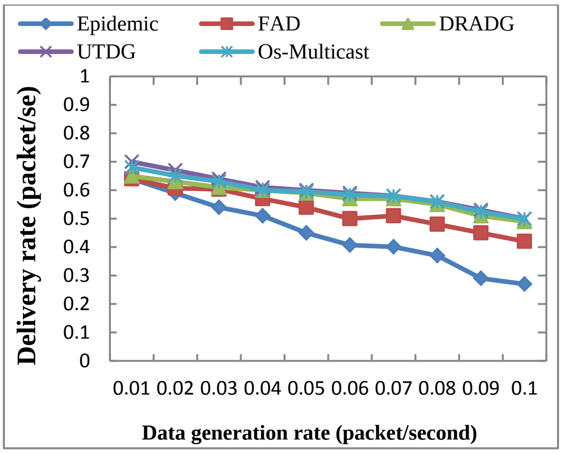


Fig. 7. Impact of data generation rate on packet delivery rate

As Fig. 7 shows, UTDG has the highest data delivery ratio in comparison with the other four protocols; the reason is that UTDG has less resource demands and can deal with high transmission loads through reducing the network traffic. Although OS-multicast tries to take advantage of the current available opportunistic links to push the data closer to the destination but the chance of network congestion also increases in this algorithm and redundant traffic has been created, so it has lower delivery rate than UTDG. The epidemic protocol will have the lowest data delivery ratio when the data generation rate is very low, but as the data generation rate increases, data delivery ratio will increase. This can be explained in view of the fact that since the epidemic protocol generates too many message copies; hence it leads to MAC layer collision and rapid exhaustion of the limited network resources. Moreover, FAD shows better performance than the epidemic routing. However, since DRADG has less resource demands than the other 2 protocols, as a result, it performs better than FAD and the epidemic protocols.

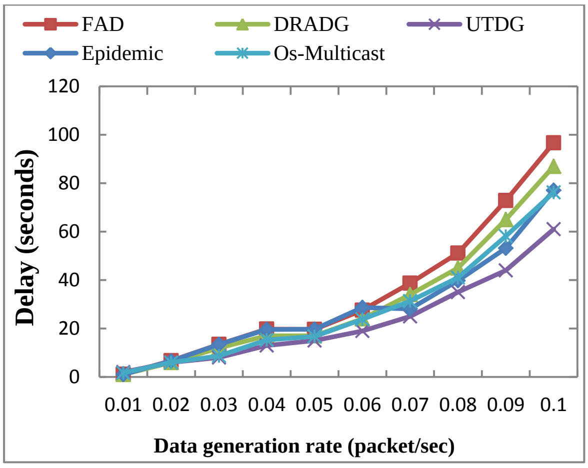


Fig. 8. Impact of data generation rate on delay

Just as Fig. 8 demonstrates, as data generation rate increases, the average delay of all protocols goes up. Obviously, the epidemic routing has the most increase in delivery delay among other protocols. It can be argued that inasmuch as UTDG efficiently cuts down the communication overhead as well as properly choosing the next hop based on nodes' delivery probabilities, hence, DRADG routing has shorter delivery delay than the epidemic routing and FAD. A lot of redundant traffic has been introduced by Os-multicast due to its nature of utilizing multiple currently available links; hence, OS-multicast has higher deliver delay than UTDG. Moreover, because in UTDG routing, sensors forward a data message for the node with the highest contact probability, and also because it can properly manage data traffic, hence, it has the shortest delivery delay among all the protocols .

4.2 Impact of Varying Sensor Node Density

The connectivity of DTMSN is related to the density of sensor nodes. The following experiments show the network performance of five protocols with different sensor node density. As shown in Fig. 9, as the density of sensor nodes goes up, the delivery rate of epidemic and FAD schemes decreases. This is logical since the number of collisions increases. The UTDG protocol almost achieves the upper bound of the data delivery rate when the node density is lower than 150 nodes, as the number of nodes becomes more than 150, the level of nodes in tree changes dramatically in UTDG routing scheme, which results in the reduction of the data delivery ratio. With the increment of number of nodes, the connectivity of the network is enhanced, and thus the performance of Os-multicast and DRADG improve. Overall, it can be concluded that UTDG has better performance than the other protocols in low node density.

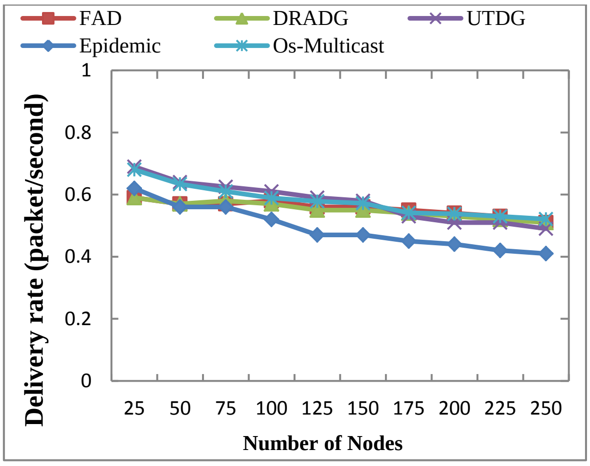


Fig. 9. Impact of varying sensor node density on average DDR

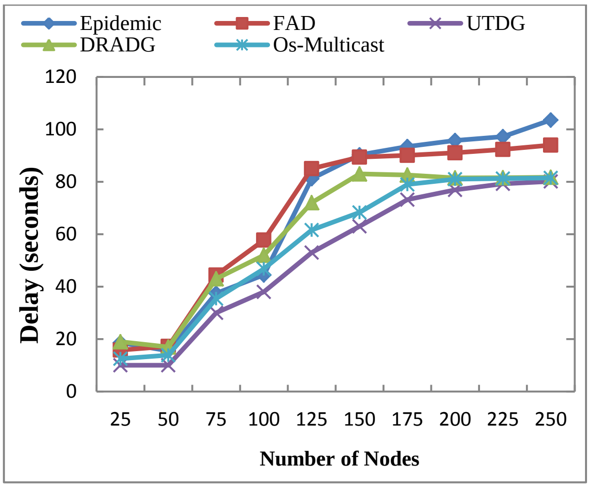


Fig. 10. Impact of varying sensor node density on average delay

4.3 Impact of Varying Buffer Size

In this section of the paper, we are evaluating the impact of buffer size on the performance (see Fig. 11 and Fig. 12). The buffer size here indicates the maximum number of messages a sensor can hold. As it is shown in Fig. 11, we can find out that as the buffer size increases, the delivery ratio also increases for all the protocols because in that case messages can stay in the memory for a longer time before they are dropped. Compared to the other evaluated protocols, the epidemic routing protocol is more sensitive to the buffer size since it generates many copies of the messages and hence needs more buffer size. It should also be noted that the UTDG protocol gains more than the other protocols with an increase in the buffer size. Fig. 12 depicts that the data delivery delay increases along with a larger buffer size; the reason for this is that when the node has larger buffer size, it exchanges more data message between the nodes; hence the chance of network congestion also increases.

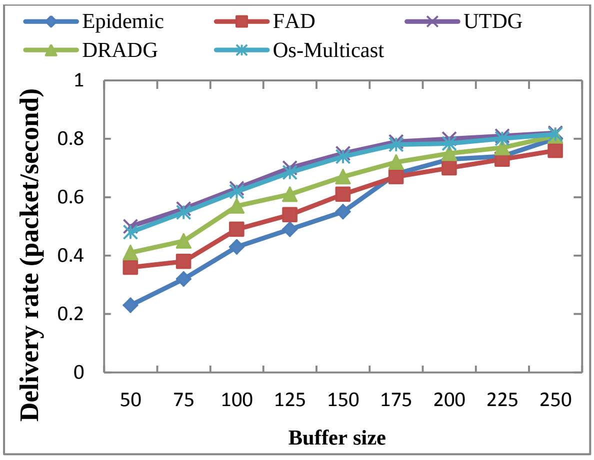


Fig. 11. Impact of varying buffer size on average DDR

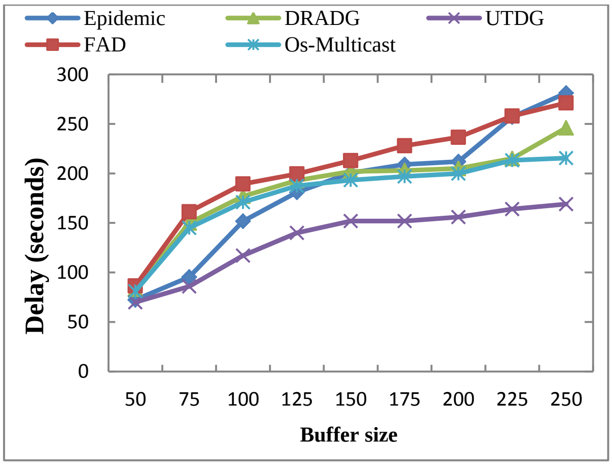


Fig. 12. Impact of varying buffer size on average delay

4.4 Analyzing Network Lifespan

Since sensor nodes are generally energy-constrained, therefore, network lifespan is considered as one of the most important metrics for DTMSNs. We can regard the network as dead when half of the sensor nodes exhaust their energy. The experiments show the network lifespan of the four protocols, and the results are shown in Fig. 13. It can be stated that because the epidemic routing sends and receives too many copies of the messages, it therefore depletes too much energy; so its network lifespan is deemed to be the shortest among the five protocols. Moreover, UTDG has much longer network lifespan than FAD, DRADG and Os-multicast. The reason is that UTDG, unlike the multiple-copy feature of FAD and DRADG, is a single-copy routing protocol, therefore it can reduce the transmission overhead. It also selects the best next-hop based on the tree structure, and also OS-multicast tries to utilize multiple paths to the receivers and multicasting data leads to more data message exchange between nodes, so it consumes more energy than UTDG. In addition, the total energy consumption in UTDG is significantly much less than Os-multicast, DRADG, FAD and the epidemic routing which is regarded as a great advantage for UTDG in terms of economizing energy.

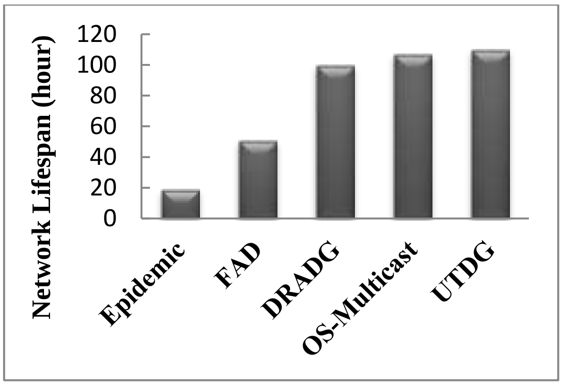


Fig. 13. Network lifespan

5. Conclusions

This paper dealt with the significant issue of efficient data transmission in the Delay-Tolerant Mobile Sensor Network (DTMSN). By taking into consideration the unique features of DTMSN such as sensor node mobility, loose connectivity, and delay tolerability which distinguish DTMSN from conventional sensor networks, we proposed a new routing approach, namely a Unicast Tree-based Data Gathering protocol (UTDG) for DTMSN. UTDG constructs a tree in each community based on 4 parameters: sensors location, transmission ranking, contact probability and link expiration time. The proposed protocol selects the next-hop to forward the data messages based on the tree structure. The simulation results showed that our proposed UTDG protocol performs significantly better than the other protocols with less traffic overhead and less energy consumption. Moreover, it has higher delivery rate than the other existing protocols in applications with 150 nodes or lower.

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