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# Distance and Energy Aware Routing Protocol for Delay Tolerant Mobile Sensor Networks

*Zeynab Mottaginia, Somaiyeh Dabaghipoor and Ali Ghaffari*

Department of Computer Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran

**Abstract:** Delay Tolerant Mobile Sensor Networks (DTMSNs) are a category of emerging networks that experience frequent and long-duration partitions. Compared with the conventional networks, the distinct characteristic is that there is no end-to-end connectivity between source and destination. The network topology may change dynamically and randomly. This characteristic and non-existence of an end-to-end path poses a number of challenges in routing in DTMSNs. So, Utilizing multi-replica schemes to improve the routing performance is reasonable. Most of the presented multi-replica approaches distribute many copies of the messages into the network for increasing the packet delivery rate. This operation consumes a large amount of constrained resource of DTMSNs. To solve this problem we propose a Distance and Energy-Aware Routing protocol (DER), which cut down the replicas based on the distance between the sensor nodes and sink node and the residual energy of the sensor node. The packet delivery probability is based on sink meeting frequency and nodes movement direction. Then we improve our protocol by using multiple sink called Multi-Sink Distance and Energy Aware Routing protocol (MSDER). Simulation results indicate that our proposed protocol achieves higher message delivery ratios with lower transmission overhead and data delivery delay than existing DTMSNs routing protocols.

**Key words:** Delay tolerant mobile sensor networks · Routing protocols · Multi-sink

## INTRODUCTION

In recent years, many routing protocols have proposed for wireless sensor networks (WSNs). Traditional methods of routing are suitable for many sensor applications, but they cannot be applied to the scenarios with intermittent and low connections because of sparse network density, sensor nodes mobility and energy limitation. Two practical examples of this scenario are pervasive air quality monitoring and flu virus tracking. In these examples for the most accurate and efficient measurement, wearable sensors that adapt to human activities has been bound. AS a result, the connection between the mobile sensors is poor and thus forming a well connected mesh network to transfer data through end-to-end connections between sensor nodes and sinks is difficult.

In order to deal with this problem, Delay Tolerant Mobile Sensor Networks (DTMSNs) [1-5] has been introduced. DTMSNs are the subset of the Delay Tolerant Networks (DTNs) [6-12] which have many features such as node mobility, frequent and prolonged communication interruption between nodes, delay tolerance and resources limitations. A DTMSN under our consideration consists of two types of nodes, the wearable sensor nodes and sink nodes. The former are attached to people (or other mobile objects), collecting information and forming a loosely connected mobile sensor network for information delivery. A number of high-end nodes (e.g. mobile phones or personal digital assistants with sensor interfaces) which serving as the sinks to receive data from wearable sensors, are deployed at strategic locations with high visiting probability or carried by a subset of people.

One of the methods of data gathering in DTMSNs, are multi-replica schemes that generate multiple replicas for each message. Distributing a message to a large number of nodes will increase the probability of packet delivery rate. For a DTMSN that has limited resources, duplicate messages will increase traffic overhead, collision, delay and energy consumption of mobile nodes.

**Corresponding Author:** Zeynab Mottaginia, Department of computer engineering, Tabriz branch, Islamic Azad University, Tabriz, Iran.

In recent years, several multi-replica routing protocols [13-17] have been presented to increase the data delivery rate. These protocols can be divided into two categories: a) flooding-based approaches b) quota-based approaches. In flooding-based approaches, the nodes send copies of a message to all neighbor nodes, while, in quota-based approaches, the nodes send fixed and limited number of copies of a message and have better efficiency than flooding-based approaches. In this paper we have tried to present a replica adaptive routing protocol for DTMSNs.

The rest of the paper is organized as follow: Section 2 discusses related work. Section 3 presents the proposed protocol. Section 4 discusses proposed protocol with multi sink. Section 5 presents simulation results. Finally, Section 6 concludes the paper.

**Related Work:** There has been wide research on routing in DTMSNs. The work dates back to before the term "delay-tolerant" was extensively used. The adjectives "intermittently-connected", "sparse" and "disconnected" are also used to explain networks without constant end-to-end connections. One of the categories of routing schemes is multi-replica methods. A majority of existing multi replica routing protocols, such as epidemic [13], are flooding-based. Epidemic protocol is attempts to give all nodes a copy of every message, through random exchanges between nodes. If it is provided infinite bandwidth and buffer resources, it could achieve a high data delivery rate and low data delivery delay. It has more overhead and energy consumption that increases packet dropping and retransmission. Different from flooding-based routings, quota-based protocols such as Spray-and-Wait [17] and Spray-and-Focus [18] use fixed number of replicas. Spray-and-Wait "sprays" a number of copies into the network and then "waits" until one of these nodes meets the destination. Spray-and-Focus is very similar to Spray-and-Wait. This scheme distributes a small number of copies to a few nodes. Though, each relay node can forward its copy further using a single-copy utility-based scheme, instead of waiting to deliver it to the destination itself.

Other endeavors aiming to improve the performance of DTMSN routing include [19, 20]. In [19], a replication-based efficient data delivery (RED) protocol based on erasure coding technology is presented. RED consists of two key components for data transmission and message management. The first makes decision on when and where to transmit data messages according to the delivery probability. The second decides the optimal erasure coding parameters based on its current delivery probability, in order to achieve the desired data delivery rate while minimizing overhead at the same time. This history-based method is not effective and cannot denote the actual ability that a node delivers data to sink nodes. In [20], the authors propose a Message Fault Tolerance-Based Adaptive Data Delivery Scheme (FAD) to increase the data delivery rate in DTMSN. The FAD approach employs the message fault tolerance, which indicates the importance of the messages. The decisions on message transmission and dropping are made based on fault tolerance for minimizing transmission overhead. The system parameters are carefully tuned on the basis of thorough analyses to optimize network performance. That protocol still has a high overhead. Yong Feng *et al.* in [21] proposed a Distance-aware Replica Adaptive Data Gathering protocol (DRADG), which uses a self-adapting algorithm to cut down the number of redundant replicas of messages according to the sensor nodes' distance and sink node and leverages the delivery probabilities of the mobile sensors as main routing metrics. Creating message copies without considering the sensor nodes' residual energy maybe cause the faster sensor nodes' energy consumption and it cause hole problem in the network and reduce the network life time.

**Distance and Energy Aware Routing Protocol:** As is described above, DER dynamically calculates the number of copies of each message based on two parameters: a) the distance between the sensor node, that generates message and the sink nodes. b) Residual energy of the sensor node. Residual energy of sensor node consideration in determining number of replicas, reduce energy consumption and prevent the creation of holes in the network. Also, DER computes the delivery probability of every mobile node according to its frequency of meeting with the sink node and its movement direction. In this section, we will explain the proposed protocol in detail.

**Network Model:** We assume initially all the N sensor nodes randomly deployed in a square area of A. All the sensor nodes are homogeneous. The maximum transmission range of all the sensor nodes is fixed to R.

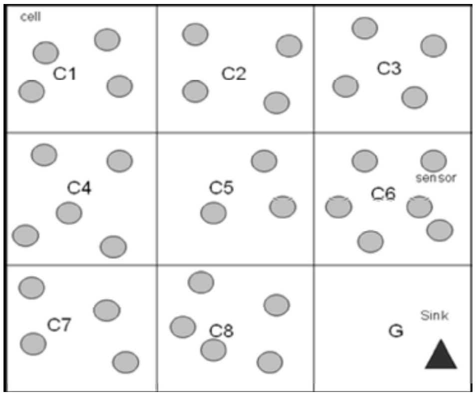



Fig. 1: Community-based Mobility Model

The mobility of all sensor node is assumed to follow the community-based Mobility model depicted in [22,23] where the whole area is divided into several non-overlapped cells, one gathering place (G) and communities (C). Each sensor node has one home community which it is more likely to visit than other communities. Nodes randomly choose a destination and a speed and move there. Upon arrival at the destination, \the node pauses for a while and then chooses a new destination. The destinations are selected such that if a node is at home, there is a high probability that it will go to the gathering place (but it is also 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 GPS (Global Positioning System) [24-26]. The sink node is immobile and it is located at G. its location is known to all sensor nodes.

**Message Replica Number Calculation:** According to the DRADG, replica number of each message calculated based on the distance between the sensor nodes which generates the message and sink node. In this paper to increase the efficiency of this protocol, DER decides the replica number of each message according to residual energy of the sensor which generates the message in addition its distance with sink node. In the header of each message there is a field of integer type that holds the number of its replica ticket. For example, when $n_i$ generates a new message M, value of $d_i$ that is the current distance between node $n_i$ and the sink node equals:

$$d_i = \sqrt{(x_{sink} - x_i)^2 + (y_{sink} - y_i)^2} \tag{1}$$

Where the location of node $n_i$ is $(x_i, y_i)$ and the location of sink node is $(x_{sink}, y_{sink})$.

The value of the ticket that denotes the upper bound of replica number defined as follow:

$$ticket_M = \left[ a * \left( \left[ k * T_{max} * \sqrt{\frac{d_i}{D_{max}}} \right) + (1-a) * \frac{EN_i}{EN_{max}} \right] \right] \tag{2}$$

Where k and $\alpha$ are constant parameters between 0 and 1; $T_{max}$ is the maximum value of the ticket; $D_{max}$ is the distance between farthest sensor node and the sink node in the network; $EN_i$ is residual energy of node $n_i$; $EN_{max}$ is the initial energy of each node that it is equal for every sensor node. From Equation 2, it can be found that the number of message replica is high in the node which is closest to the sink and has the highest level of remaining energy. This approach, decrease the message redundancy when sensor nodes and sink node are close to each other and the poor performance when they are far from each other. In addition, it cause energy efficiency and avoid problem of hole in the network.

**Node Delivery Probability Calculation:** In this protocol, we establish a probabilistic metric called delivery Probability, $p_i$ at every node *i.* This parameter indicates how this node will be able to directly deliver a message to the sink node. The calculation of the delivery Probability has several parts. Each sensor node calculates its delivery probability in accordance to its frequency of meeting with the sink node and its movement direction and sends the message to nodes with high delivery probability. The first thing to do is to compute the meeting frequency of $n_i$ in the most recent interval of $\tau$, denoted as $freq_i$ by Equation 3 as follows [21]:

$$freq_i = \begin{cases} \frac{Num_i}{Num_{th}} & Num_i < Num_{th} \\ 1 & Num_i \geq Num_{th} \end{cases} \tag{3}$$

Where $Num_i$, is the meeting time of node $n_i$ with the sink node in the latest interval of $\tau$, $Num_{th}$ is the threshold value that should be varied based on the application. Then, we calculate $F_i$ as follow:

$$F_i = freq_i * \frac{dist_{i,sink} - dist_{j,sink}}{dist_{i,sink}} \tag{4}$$

Where $dist_{i,sink}$ and $dist_{j,sink}$ are the distance between node *i* and sink and node *j* and sink, respectively.

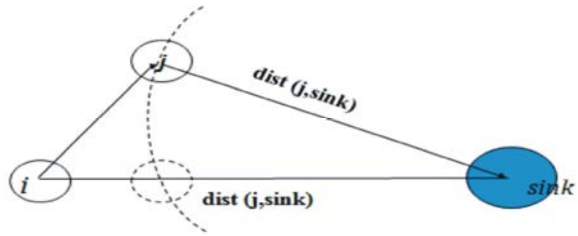



Fig. 2: Location of sensor nodes on the way to sink node

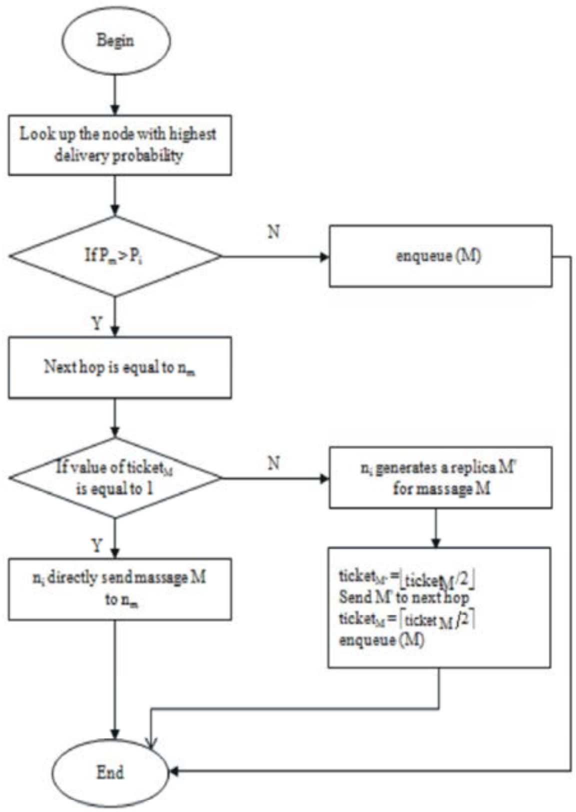



Fig. 3: Flow chart of data delivery algorithm

The movement direction of the sensor nodes is also impressive in node delivery probability. As shown in Figure 2, if the sensor node moves towards the sink node, it is likely to encounter sink node in a future period of time.

We can calculate the packet delivery probability, $P_i$ as follow:

$$P_i = \beta * F_i + (1-\beta) * P_{i(old)} \tag{5}$$

Where, $\beta$ is weight parameter.

Finally, due to the node mobility, each node calculates the delivery probability periodically and broadcast the value to its neighbors by hello messages.

**Forwarding Strategies:** In DER, each sensor node has a dynamic list of its neighbor that updates it by receiving hello messages. When node $n_i$ has a message M to forward, first of all it looks up the node with highest delivery probability in its neighbor list, denoted as $n_m$. As shown in Figure 3, if $P_m$ is greater than $P_i$ then $n_m$ is next hop. Secondly, if the value of $ticket_M$ is equal to 1 then $n_i$ directly forwards M to $n_m$; if else, $n_i$generates a replica of M, denoted as M', set $ticket_{M'}$ as [$ticket_M$/2], forwards M' to $n_m$ and finally updates $ticket_M$ as [$ticket_M$/2] and stores message M into its routing queue.

**Queue Management:** In challenging networks like DTMSNs, multiple message replicas may be generated and buffered by different sensors, resulting in redundancy. In order to achieve effective data delivery rate and enhance network performance, queue management scheme is essential. The main idea of the queue management scheme is employing both survival time and giving more priority to important message.

**Message's Survival Time:** We assume each data message has a field that records its survival time. For example, the survival time of massage m in the queue of sensor j, denoted as $\xi_n^m$. When a message is generated, its survival time is initialized to be zero. When node j deliveries a message m to single hop neighbor nodes, such as node n, the time required for transmission be ignored and the node inserts the message to its queue without any changes on amount of the survival time. Therefore, the initial value $\xi_n^m$ is the same amount of $\xi_j^m$ before transmission. If a source message has transmitted to its next hop and it is inserted into node's queue again, its survival time is also assumed to be equal to the value before transmitting. Furthermore, for messages in the queue buffer, their survival time should be updated with the time clock.

**Massage's Priority:** Each sensor node maintains a list of the messages in its buffer that come from the following sources:

- After the sensor nodes sense a data, it generates a message and inserts it into its data queue. (b) When a sensor node receives a message from other sensor nodes, it may insert it to its buffer. (c) After the sensor node sends the data message from its buffer to other destination except the sink, if the message is generated by the source node itself, it may insert the message again, because there isn't any guarantee to deliver the messages to the destination. Messages in the first classification have highest priority and messages belonging to the second and third class are have middle and the lowest priority level respectively.

**Implementation of Queue Management Scheme:** Implementation of the queue management scheme is based on two parameters, the massage priority and the data message survival time. Messages are sorted in the queue based on a descending order of the priority, if two messages have the same priority level, then they are sorted based on ascending order of survival time, indeed the massage that its survival time is less has a higher priority. The massage will be dropped from the queue in the following two occasions: a) the message survival time exceeds the network's delay tolerant threshold (maximum message delay value). b) When the queue is full and a new message arrives, its priority level is compared with the priority level of the message at the end of the queue and one with less priority level is dropped among them. Otherwise if the priority levels are equal, then the one with a longer survival time is eliminated. This condition has been set to reduce energy consumption, given that the messages are delivered to the destination with the highest priority or the massage be declared invalid.

**Multi-Sink Distance and Energy-Aware Routing Protocol :** Due to the battery resource constraints, saving energy is a critical issue in DTMSNs, particularly in large DTMSNs. One possible solution is to deploy multiple sink nodes simultaneously. Having multiple sinks in the network gives networks compared with single sink sensor networks as follows:

- They are more reliable because of the fact that invalidation of a sink node will drag down the whole network in single sink networks.
- Usually there exists a serious node energy bottleneck (around sinks) if a single sink masses reports from too many sensors.
- They mitigate the unbalanced energy consumption.
- They suggest more adaptable functional applications and communication cooperation. In some applications, different users (sinks) may require different environmental variables (temperature, humidity, light intensity, *etc.*) or data formats (image, sound, video, *etc.*). In this time, all nodes need to cooperate with each other during the communication process.

The work presented in this section is mainly motivated by partly stationary, multi-sink deployments of DTMSNs such as real-time surveillance and city pollution monitoring applications. Multiple sinks deployed in the network and each sensor node knows the location of all \the sensors. The sensor node that generates a data message, calculate distance between itself and sink nodes according to Equation 6 as follows:

$$d_{si} = \sqrt{\left(x_{sj} - x_i\right)^2 + \left(y_{sj} - y_i\right)^2} \text{ For i= 1 ... n} \qquad (6)$$

Where $d_{si}$ is the distance between $n_i$ and the sink nodes.

Then it determines number of hops towards each sink by Equation 7:

$$d_{si} = \sqrt{\left(x_{sj} - x_i\right)^2 + \left(y_{sj} - y_i\right)^2} \text{ For i= 1 ... n} \qquad (7)$$

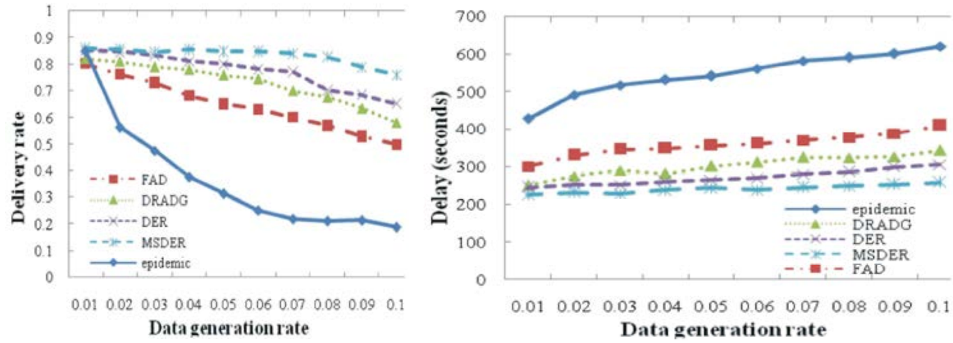
Where $h_i$ is the hops between $n_i$ and the sink nodes; r is the transmission range of each node that is fixed.

Each node chooses the sink that has minimum hops to it as a management sink.

Rest of the algorithm is like the DER algorithm that is described in section 3.

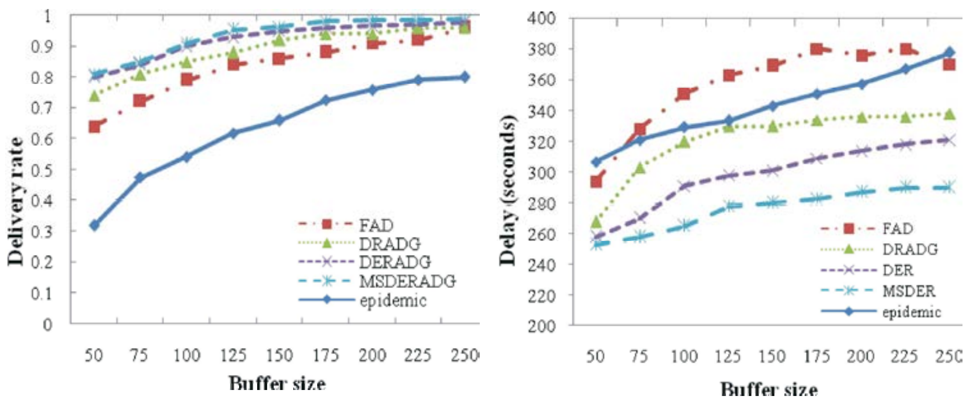
**Simulation:** In this Section, we provide simulation results on the performance of the DER, MSDER, DRADG, FAD, epidemic routing protocols in matlab. We evaluate our scheme under different conditions. In our experimental environment, the whole area is divided into 9 non-overlapped cells; 8 comminute and one gathering place. Other simulation parameters and their default values are summarized in Table 1. The performance metrics we used in our simulations are: Data Delivery rate, Data Delivery Delay and Network lifetime.

**Impact of Data Message Generation Rate:** In the simulation, we suppose the data generation of each sensor follows a Poisson process with an average arrival interval from 10 s to 100 s. we observe the impact of varying data generation in Figure 4. As we can seen in Figure 4(a), MSDER achieves the highest delivery rate and DER have lower delivery rate than multi sink protocol. But the other 3 protocol due to creating more message replicas and consumption of much energy, have lower delivery rate. Figure 4(b) demonstrates that the average delay of all protocols go up when the data generation rate increases. In our protocol, because the algorithm chooses next hop based on nodes' delivery probabilities and its movement direction, it efficiently decrease data delivery



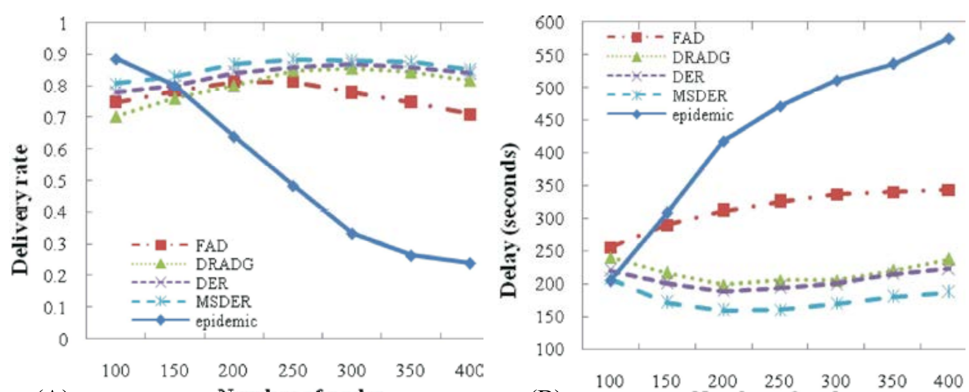

(A) (B)

Fig. 4: Impact of data generation rate. (a) Average elivery rate; (b) Average delay.




(A) (B)

Fig. 5: Impact of buffer size. (a) Average delivery rate; (b) Average delay.

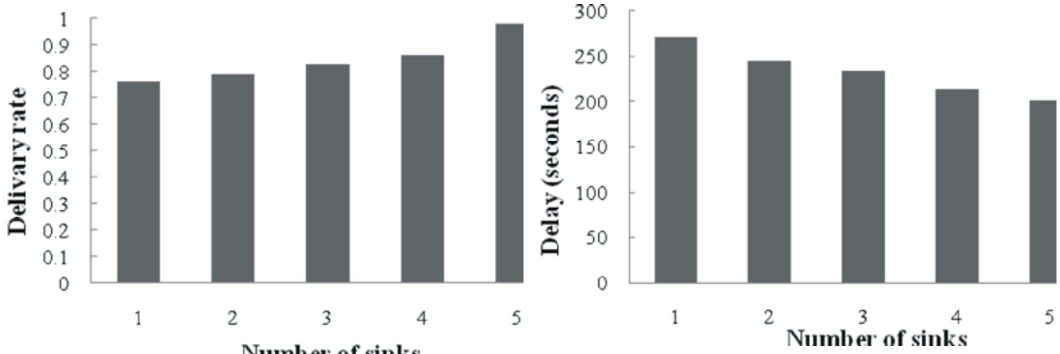



(A) (B)

Fig. 6: Impact of buffer size. (a) Average delivery rate; (b) Average delay.

delay. Our multi sink protocol can be forwarded messages to the sink nodes with fewer hops and then it has the shortest delivery delay.

**Impact of Buffer Size:** Looking at the graph of the delivery ratio over buffer size in Figure 5, we can immediately see that the buffer size has significant impact on the multiple copy delivery protocols. The buffer size here indicates the maximum messages the sensor can hold. As shown in Figure 5(a), with an increase of buffer size, the delivery rate increases for all protocols because the message can stay in the memory for the longer time before they are dropped. It is also noticed that our protocol achieves higher delivery rate than other protocols. Figure 5(b) depicts that the average data delivery delay increases with larger queue length while the delivery delay in the epidemic protocol is more sensitive to the variation of the queue length.




(A) (B)

Fig. 7: Impact of number of sink nodes. (a) Average delivery ratio; (b) Average delay.

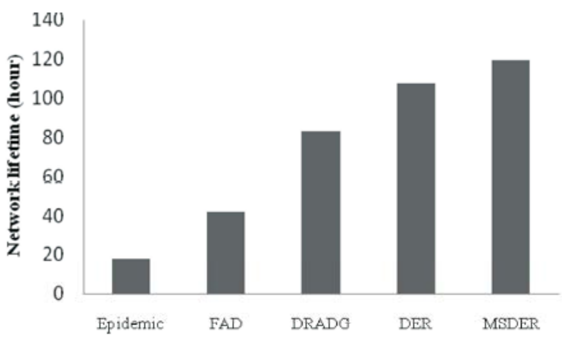



Figure 8: The network lifetime

Table 1: Simulation parameters

| Parameter | Default value |
|---|---|
| Network size ($m^2$) | 900 * 900 |
| Network cell size ($m^2$) | 300*300 |
| Number of sensor node | 200 |
| Radio Transmission *r* (m) | 50 |
| Speed of sensor node v (m/s) | 1~10 |
| Maximum buffer size of sensor (message) | 200 |
| Data message size (bytes) | 100 |
| Control message size (bytes) | 250 |
| Message generation ratio (message/s) | 0.01 |
| Maximum delay tolerant value (s) | 1,800 |
| Number of cells | 9 |
| Timer expiration value(s) | 180 |
| $Num_{th}$ | 2 |
| $\alpha$ value | 0.8 |
| *Tmax* value | 10 |

**Impact of Sensor Nodes Density:** Figure 6 presents the protocol performance by varying number of nodes. As shown in Figure 6(a), with the increase of sensor node density, the delivery rate of all the evaluated schemes increase. This reasonable because the number of neighboring sensors of each sensor node increases and more sensor nodes help relaying messages and messages have a better chance of reaching sink nodes. Meanwhile, we also notice that epidemic protocol achieves the highest data delivery rate when a low node density is deployed. Overall, DER has better performance when the node density is high. Figure 6(b) shows that due to the fact that proposed protocol generates much less message replicas than other 3 protocols, the delivery delay is lower than them.

**Impact of Number of Sink Nodes:** To evaluate the impact of number of sink nodes on the performance, we vary the number of nodes from 1 to 7. From Figure 7(a), we find that with more sink nodes present, the sensors exhibit a better opportunity to reach the sink nodes, therefore resulting in a higher delivery ratio. Figure 7(b), presents the average delivery delay. The delay decreases sharply with an increase in the number of sink nodes, since the sensor node select the closest sink to itself to forward and the message can be delivered to the sinks with fewer hops.

**Network Lifetime:** Network lifetime is one of the most important criteria for performance evaluation of routing protocols. We suppose that the network lifetime ends when over a half all sensors deplete their energy. We can see from Figure 8 that DER have longer network lifetime than other 3 existent protocols, since it uses a self-adapting algorithm that decreases the redundant replicas of messages based on nodes distance from sink node and its residual energy and reduce the consumption of nodes' energy. MSDER has longer network life time than single sink protocol. Obviously, with more sink nodes existing, the message can be transmitted with fewer hops, reducing energy consumption and saving much energy.

## CONCLUSIONS

This paper deals with efficient data transmission in the Delay-Tolerant Mobile Sensor Network (DTMSN).

By taking into consideration the unique characteristics of DTMSN, such as sensor node mobility, loose connectivity and delay tolerability, which distinguish DTMSN from conventional sensor networks, we have proposed a new routing approach called A Distance and Energy Aware Routing Protocol (DER) for DTMSN. In DER, replica number of each message calculated based on the residual energy of the sensor nodes which generates the message and its distance and sink node. DER makes routing decisions according to delivery probability. The experimental results show that our proposed DER protocol provide better performance at the cost of lowertraffic overhead and energy consumption and higher delivery rate than existing protocols. Furthermore, we improve DER by using multi-sink called MSDER, the simulation results show that with more sink nodes present, we have a higher delivery rate and lower delivery delay.

## REFRENCES


1. Liu, N.B., M. Liu, J.Q. Zhu and H.G. Gong, 2009. A Community-Based Event Delivery Protocol in Publish/Subscribe Systems for Delay Tolerant Sensor Networks. Sensors, 9: 7580-7594.
2. Song, G.M., Y.X. Zhou, F. Ding and A.G. Song, 2008. A Mobile Sensor Network System for Monitoring of Unfriendly Environments. Sensors, 8: 7259-7274.
3. Wang, Y., F. Lin and H. Wu, 2005. Efficient Data Transmission in Delay Fault Tolerant Mobile Sensor Networks (DFT-MSN). In Proceedings of IEEE International Conference on Network Protocols (ICNP'05), Boston, MA, USA,
4. McDonald, P., D. Geraghty, I. Humphreys, S. Farrell and V. Cahill, 2007. Sensor Network with Delay Tolerance (SeNDT). In Proceedings of 16th International Conference on 2006 Computer Communications and Networks, ICCCN 2007, Dublin, Ireland,
5. Mainwaring, A., J. Polastre, R. Szewczyk, D. Culler and J. Anderson, 2002. Wireless Sensor Networks for Habitat Monitoring. In Proceedings of ACM International Workshop on Wireless Sensor Networks and Applications (WSNA). Atlanta, GA, USA,
6. Fall, K., 2003. A Delay-Tolerant Network Architecture for Challenged Internets. In Proceedings of ACM SIGCOMM 2003 Conference on Computer Communications, Karlsruhe, Germany,
7. Burleigh, S., A. Hooke, L. Torgerson, K. Fall, V. Cerf, B. Durst, K. Scott and H. Weiss, 2003. Delay-Tolerant Networking-An Approach to Interplanetary Internet. IEEE Communications Magazine, 41: 128-136.
8. Leguay, J., T. Friedman and V. Conan, 2005. DTN Routing in a Mobility Pattern Space. In Proceedings of ACM SIGCOMM'05 Workshop on Delay Tolerant Networking and Related Topics. Philadelphia, PA, USA,
9. Camp, T., J. Boleng and V. Davies, 2002. A Survey of Mobility Models for ad hoc Network Research. Wireless Communication & Mobile Computing (WCMC), 2: 483-502.
10. Warthman, F., 2010. Delay-Tolerant Networks (DTNs); DTN Research Group: March 2003. Available online: http://www. ipnsig. org/reports/ DTN_Tutorial11.pdf/ (accessed on 25 July 2010).
11. Neely, M.J. and E. Modiano, 2005. Capacity and Delay Tradeoffs for ad-hoc Mobile Networks. IEEE Transactions on Information Theory, 51: 1917-1937.
12. Partan, J., J. Kurose and B. Levine, 2006. A Survey of Practical Issues in Underwater Networks. In Proceedings of the 1st ACM International Workshop on Underwater Networks, Los Angeles, CA, USA, pp: 17-24.
13. Vahdat, A. and D. Becker, 2000. Epidemic Routing for Partially Connected ad hoc Networks; Technical Report CS-2000-06; Duke University: Durham, NC, USA,
14. Burgess, J., B. Gallagher, D. Jensen and B.N. Levine, 2006. MaxProp: Routing for Vehicle-Based Disruption-Tolerant Networks. In Proceedings of IEEE INFOCOM, Barcelona, Catalunya, Spain,
15. Ramanathan, R., R. Hansen, P. Basu, R. Hain and R. Krishnan, 2007. Prioritized Epidemic Routing for Opportunistic Networks. In Proceedings of ACM MobiOpp'07, San Juan, PR, USA,
16. Balasubramanian, A. and B.N. Levine, 2007. Venkataramani, A. DTN Routing as a Resource Allocation Problem. In Proceedings of ACM SIGCOMM, Kyoto, Japan, pp: 27-31.
17. Spyropoulos, T., K. Psounis and C. Raghavendra, 2005. Spray and Wait: An Efficient Routing Scheme for Intermittently Connected Mobile Networks. In Proceedings of ACM SIGCOMM Workshop on Delay-Tolerant Networking, Philadelphia, PA, USA, 26 August 2005.

18. Spyropoulos, T., K. Psounis and C.S. Raghavendra, 2007. Spray and focus: Efficient Mobility-Assisted Routing for Heterogeneous and Correlated Mobility. In Proceedings of IEEE ICPCC Workshop, Albuquerque, NM, USA, 2 April 2007.
19. Wang, Y. and H.Y. Wu, 2006. Replication-Based Efficient Data Delivery Scheme (RED) for Delay/Fault-Tolerant Mobile Sensor Network (DFT-MSN). In Proceedings of Fourth Annual IEEE International Conference on Pervasive Computing and Communications Workshops, Pisa, Italy, 27 March 2006.
20. Wang, Y. and H.Y. Wu, 2006. DFT-MSN: The Delay/Fault-Tolerant Mobile Sensor Network for Pervasive Information Gathering. In Proceedings of IEEE INFOCOM, Barcelona, Catalunya, Spain, pp: 23-29 April 2006.
21. Feng, Y., H. Gong, M. Fan, M. Liu and X. Wang, 2011. A Distance-Aware Replica Adaptive Data Gathering Protocol for Delay Tolerant Mobile Sensor Networks. Sensors, 11: 4104-4117.
22. Lindgren, A., A. Doria and O. Schelen, 2004. Probabilistic Routing in Intermittently Connected Networks. Lecture Notes in Computer Science, 3126: 239-254.
23. Spyropoulos, T., K. Psounis and C. Raghavendra, 2006. Performance Analysis of Mobility-Assisted Routing. in Proc. MobiHoc.'06: 7th ACM International Symposium on Mobile Ad Hoc Networking and Computing, 49: 60.
24. Cheng, X., D.Z. Du and L. Wang, 2011. TPS: A Time-Based Positioning Scheme for Outdoor Sensor Networks. In Proceedings of IEEE INFOCOM, Hong Kong, China, 7-11 March 2004. Sensors, 11: 4117.
25. Ruml, W., Y. Shang and Y. Zhang, 2003. Location from Mere Connectivity. In Proceedings of ACM MobiHoc, Annapolis, MD, USA, pp: 1-3.
26. Thaeler, A., M. Ding and X.Z. Cheng, 2005. iTPS: An Improved Location Discovery Scheme for Sensor Networks with Long Range Beacons. J. Parallel. Distrib. Comput., 65: 98-106.