Efficient Data Transmission in Delay Fault Tolerant Mobile Sensor Networks (DFT-MSN)

Yu Wang, Feng Lin, and Hongyi Wu

I. Introduction

Pervasive information gathering plays a key role in many applications. One typical example is flu virus tracking, where the goal is to collect data of flu virus in the area with high human activities in order to monitor and prevent the explosion of devastating flu. Another example is air quality monitoring for tracking the average toxic gas taken by people everyday. The aforementioned applications share several unique characteristics. First, the data gathering is *human-oriented*. More specifically, while samples can be collected at strategic locations for flu virus tracking or air quality monitoring, the most accurate and effective measurement shall be taken at the people, making it a natural approach to deploy wearable sensing units that closely adapt to human activities. Second, we observe that delay and faults are usually tolerable in such applications, which aim at gathering massive information from a statistic perspective and to update the information base periodically.

In this research, we study a *Delay and Fault Tolerant Mobile Sensor Network (DFT-MSN)* for pervasive information gathering. A DFT-MSN consists of two types of nodes, the wearable sensor nodes and the high-end sink nodes. The former are attached to people, gathering target information and forming a loosely connected mobile sensor network for information delivery. With short sensor transmission range and nodal mobility, the connectivity of DFT-MSN is very low, where a sensor connects to other sensors only occasionally. A number of high-end nodes (e.g., mobile phones or personal digital assistants with sensor interfaces) are either deployed at strategic locations with high visiting probability or carried by a subset of people, serving as the *sinks* to receive data from wearable sensors and forward them to access points of the backbone network.

After carefully studying related work in the literature (such as Data Mule [1], ZebraNet [2], Habitat Monitoring [3], Delay Tolerant Networking [4], etc.) and analyzing two simple data delivery schemes, namely the direct transmission and flooding [5], we propose an efficient DFT-MSN Data delivery scheme tailored specially for DFT-MSN.

Yu Wang and Hongyi Wu are with the Center for Advanced Computer Studies, University of Louisiana at Lafayette, P.O. Box 44330, Lafayette, LA 70504. Email:{yxw1516,wu}@cacs.louisiana.edu.

Feng Lin is with the Computer Science School, Sichuan University, China, and is currently a visiting scholar at University of Louisiana at Lafayette. Email:linfeng@cs.scu.edu.cn.

II. Proposed DFT-MSN Data Delivery Scheme

A. DFT-MSN Parameters

The proposed data delivery scheme for DFT-MSN is based on the nodal delivery probability and the message fault tolerance, as discussed below separately.

1) Nodal Delivery Probability: The delivery problity indicates the likelihood that a sensor can deliver data messages to the sink. Let ξ_i denote the delivery probability of a sensor i. ξ_i is updated as follows,

$$\xi_i = \begin{cases} (1-\alpha)[\xi_i] + \alpha\xi_k, & \textit{Transmission happens} \\ (1-\alpha)[\xi_i], & \textit{Timeout happens}, \end{cases} \tag{1}$$

where $[\xi_i]$ is the delivery probability of sensor i before it is updated, ξ_k is the delivery probability of node k (a neighbor of node i), and $0 \leq \alpha \leq 1$ is a constant employed to keep partial memory of historic status.

2) Message Fault Tolerance: The fault tolerance of a message is defined to be the probability that at least one copy of the message is delivered to the sink by other sensors in the network. Let's consider a sensor i, which is multicasting a data message j to Z nearby sensors, denoted by $\Xi = \{\psi_z \mid 1 \leq z \leq Z\}$. The message transmitted to sensor ψ_z is associated with a fault tolerance of $\mathcal{F}^j_{\psi_z}$,

$$\mathcal{F}^j_{\psi_z} = 1 - (1 - [\mathcal{F}_i^j])(1 - \xi_i) \prod_{m=1,\ m \neq z}^{Z} (1 - \xi_{\psi_m}), \tag{2}$$

and the fault tolerance of the message at sensor i, denoted as $\mathcal{F}_i^j$, is updated as

$$\mathcal{F}_i^j = 1 - (1 - [\mathcal{F}_i^j]) \prod_{m=1}^{Z} (1 - \xi_{\psi_m}), \tag{3}$$

where $[\mathcal{F}_i^j]$ is the fault tolerance of message j at sensor i before multicasting.

B. DFT-MSN Data Delivery

The proposed DFT-MSN data delivery scheme consists of two key components for queue management and data transmission, discussed below.

1) Queue Management: Each sensor has a data queue that contains data messages ready for transmission. Our proposed queue management scheme is based on the fault tolerance. More specifically, the messages in the queue are sorted with an increasing order of their fault tolerance. Message with the smallest fault tolerance is always at the top of the queue and transmitted first. A message is dropped at the following two occasions. First, if the queue is full, the message with the largest fault tolerance is dropped. Second, if the fault tolerance of a message is larger than a threshold, it is dropped, even if the queue is not full, in order to reduce transmission overhead, given that the message will be delivered to the sinks with a high probability by other sensors.

With the above queue management scheme, a sensor can determine the available buffer space in its queue for future arrival messages with a given fault tolerance. Assume a sensor has a total queue space for at most K messages. Let k_i^m denote the number of messages with a fault tolerance level of m in the queue of Sensor i. Then, the available buffer space at Sensor i for new messages with fault tolerance x is $B_i(x) = K - \sum_{m=0}^{x} k_i^m$.

2) Data Transmission: Data transmission decision is made based on the delivery probability. Without loss of generality, we consider a sensor i, which has a message j at the top of its data queue ready for transmission and is moving into the communication range of a set of Z' sensors. Sensor i first learns the neighbors' delivery probabilities and available buffer spaces via simple handshaking messages. Let $\Xi' = \{\psi_z \mid 1 \le z \le Z'\}$ designate the Z' sensors, sorted by a decreasing order of their delivery probabilities. Sensor i sends Message j to a set of neighbors with higher delivery probabilities (i.e., $\xi_i < \xi_{\psi_z}$), and at the same time, controls the total delivery probability of Message j (i.e., $1-(1-\mathcal{F}_i^{\,j})\prod_{m\in\Phi}(1-\xi_m)$) just enough to reach a predefined threshold γ in order to reduce unnecessary transmission overhead.

III. Experiments

To evaluate the performance of the proposed DFT-MSN data delivery scheme, small-scale experiments have been carried out. We have designed a test bed with 9 MICA2 nodes carried by students in the university library. Each sensor node collects the noise information once per minute and sends it back to the sink node, which is a laptop, using the proposed DFT-MSN data delivery scheme. As shown in Fig. 1, these nodes are initially scattered in three different areas, i.e., the reading area, the bookshelf area, and the computer service area. Each area has two boundaries, namely movement boundary and communication boundary. The former limits the nodal mobility in each area. The latter indicates the maximum radio transmission range of sensors in each area. The communication boundaries of any two areas partially overlap with each other. Note that, the nodes within transmission range may not always be able to communicate with each other because of the lack of line-of-sight (due to the bookshelves, computers, walls, etc.). Generally, a node only moves within the area where it is initially located, while periodically it may move out to another area with certain probability.

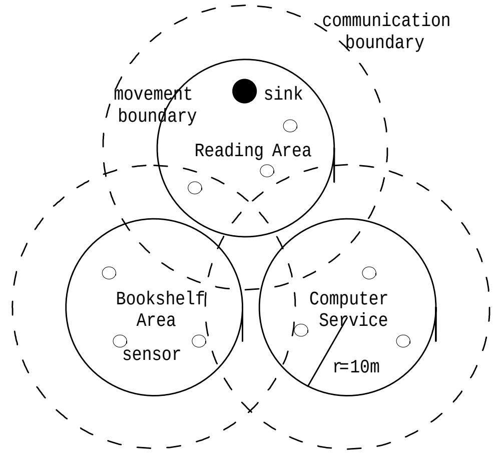

Fig. 1. Experimental Scenario. (The circular boundary is for illustration only. Actual boundary is irregular.)

To evaluate the performance of the proposed protocol, some performance information is recorded in each sensor node's EEPROM, such as the number of generated messages, the total number of transferred messages, and the number of buffer overflows. After our experiment, the information is then collected from each sensor to calculate the delivery ratio, delivery delay, and overhead. We run the experiment for 2 hours. Our results show that the proposed DFT-MSN data delivery scheme achieves a delivery ratio of 74%, with average delay of 3.8 minutes. Based on the small-scale experiments, a university-wide large-scale experiment will be carried out next.

References

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