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Data delivery scheme for intermittently connected mobile sensor networks

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ABSTRACT

In mobile sensor networks, connectivity between nodes is intermittent due to blockage of radio and nodal mobility. Consequently, the efficient delivery of packets requires nodes communicate while connectivity is reliable and delay during other times. In such cases, the challenging issue is setting delay duration at each node. In this paper, we aim to provide a reliable data delivery scheme for mobile sensor networks with an enhanced delaying technique. In the proposed scheme, nodes estimate connectivity and expect inter-encounter time with sink nodes. Connectivity is estimated based on ratio of past and present connections. When the connectivity is unreliable, nodes delay the transmission for the remaining inter-encounter duration or per-hop lifetime. Since packets are forwarded if the connectivity reaches a reliable threshold before delay time expires, delivery latency is significantly reduced. Our scheme adopts receiver-based opportunistic forwarding to reduce delivery cost. To this end, we analyze the connectivity estimation and optimal delaying technique via theory and simulation. The proposed protocol deals well with network partitioning and indefinite link disconnection, which often arises in mobile sensor networks, and satisfies the requirement for delivery latency. Simulation results show that the proposed protocol outperforms other protocols in terms of packet delivery and per packet delivery cost.

1. Introduction

Convergence of mobile devices and wireless sensor networks has recently motivated an emerging research area in mobile sensor networks (MSNs) [1]. Mobile sensor networks have unique characteristics due to node mobility and unreliable wireless links. In particular, shaky connectivity has a stronger effect on the communication characteristics than mobility. Although nodes move as fast as a walking or running human, packet propagation is much faster than node movement. The movement of nodes does not cause rapid topology change. However, intermittent connectivity commonly experienced in MSN makes reliable delivery impossible, even for one-hop communication. Therefore, novel communication techniques for mobile ad hoc sensor networks are required.

Consider a health and environment monitoring scenario in hospitals or houses for the elderly. Elderly people or patients may carry sensor devices equipped with electrocardiography, humidity and temperature sensors, by which the patient's environment and health are monitored. Reports, i.e. sensor readings, are periodically sent in small packets to responsible persons via multiple hops. We assume reports should be delivered before a predetermined delivery deadline; in other words, delivery of reports may be delayed for a few seconds. In this setup, individuals are typically involved in various activities throughout their daily life, so the communication environment tends to change dynamically depending on factors that affect communication characteristics. Analyzing all these factors at runtime is simply not feasible. An obvious technique to achieve good delivery would be to establish communication only when strong connectivity is available and delaying packet delivery during other times. However, a critical issue is to set delay duration appropriately, because a long delay would miss the packet delivery deadline and a short delay would cause extra message overhead due to the repeated request. Particularly in intermittent and partitioned networks, packets may never reach their intended destination due to excessive delaying.

Although there has been active research on data delivery techniques for sensor networks, most of the previous work does not address the problem of intermittent connectivity and mobility. Those which have addressed mobility issues have mainly focused on sink mobility and prolongation of network lifetime [2–5]. Yet these protocols are vulnerable to the change of network topology caused by node movement. Some research adds redundancy to improve reliability while taking overhead injection as a tradeoff [6,7]. These approaches may increase packet delivery rate but are not sufficient to guarantee delivery to the sink node against network partition or temporary disconnection.

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Issues on intermittent connectivity and partitioned networks have been widely addressed in Delay-Tolerant Networks (DTNs) [8–19]. These schemes use a store-carry-forward mechanism to achieve reliable delivery over intermittent connectivity. However, the schemes need to perform handshaking before actual data transmission, which requires reliable links for communication. On the other hand, communication links are very unreliable in the sensor networks. Consequently, the selection of next hop is important in the first system, while the decision on when to transmit is more important in the sensor network. In the delivery process of sensor networks, a packet is broadcasted to one-hop neighbors, and nodes which receive the packet independently decide whether to carry the packet or not.

Our research aims to design a packet-delaying technique that satisfies delivery deadlines while achieving a high delivery rate and lower delivery cost under intermittently connected and partitioned networks. To achieve reliable delivery against intermittent connectivity, we propose a delivery scheme with three features: opportunistic routing using implicit acknowledgement; reliable communication using connectivity estimation; and delay estimation based on the Levy–Walk mobility model [20]. The proposed scheme includes a policy to decide whether to transmit received packets immediately or delay the transmission when a node receives packets. Delay duration is efficiently estimated using inter-encounter time and a latency limit provided by the application. The simulation results show that the proposed scheme outperforms previous schemes in terms of delivery ratio and per packet energy consumption. The key contributions of our work are outlined as follows:

- We have identified and addressed the main reasons for shaky connectivity in mobile sensor networks.
- We applied store-carry-forward routing as delayed transmission for intermittently connected mobile sensor networks.
- We have provided a light-weight and practical routing solution for intermittently connected mobile sensor networks.

The rest of this paper is organized as follows. Section 2 introduces the observation from preliminary experiments and describes intermittent connectivity problems. Section 3 presents an overview of the proposed delivery scheme, followed by detailed policy in Section 4. Section 5 evaluates the proposed scheme, using simulation results. Section 6 reviews related work. We conclude the paper and discuss future work in Section 7.

2. Preliminaries

Preliminary experiments were conducted to address the disruptive connectivity problem regarding mobile sensor networks. While nodes are deployed in static sensor networks considering node position and obstacles to achieve the best connection and coverage, sensor nodes in MSN individually move around and experience various motion activities during movement. The communication environment continuously varies and severely disrupts the ongoing communication. Through our preliminary experiments, we have confirmed that connectivity between nodes in MSN significantly differs from static sensor networks.

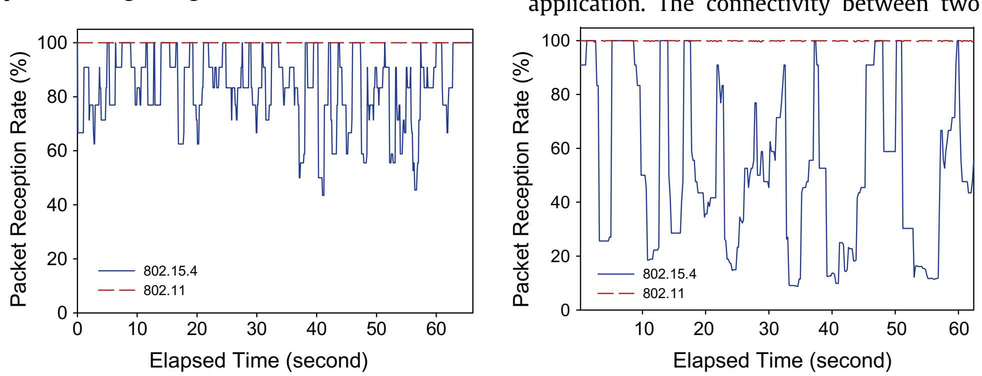
Fig. 1 shows the packet reception rate (PRR) between two nodes with a distance of 10 m in an outdoor environment. The TmoteSky hardware [21] and the HTC G1 smartphone [22], which have the IEEE802.15.4 and IEEE802.11 radio interface, respectively, were used for the experiments. The results in Fig. 1(a) were obtained in an ideal deployment situation where two nodes are statically positioned one meter above the ground and the line-of-sight is guaranteed between nodes. Fig. 1(b) shows the results with mobile environments where two persons communicate with sensor-equipped mobile devices while turning, putting the device in and taking it from a pocket, holding it to the ear, and so on. Although they stay in the same position, the connectivity between the IEEE802.15.4 equipped sensor devices is very unstable. On the other hand, connectivity between smartphones, which are equipped with the IEEE802.11 radio interface, is very steady. The experiment results indicate that the intermittent connectivity in mobile ad hoc networks is mostly caused by node mobility. In mobile sensor networks, the intermittent connectivity is caused by signal blockage and is more severe than mobile ad hoc networks that usually employ the IEEE802.11 radio interface. The disruptive results obtained in a single hop would conclude that multiple-hop packet delivery in mobile sensor networks is practically infeasible. Such challenges motivate us to design an efficient delivery scheme for MSN that considers intermittent connectivity caused by both signal blockage and mobility. In the following section we describe a proposed scheme to deal with the intermittent connectivity problem in mobile sensor networks.

3. Data delivery scheme

In this section we describe a data delivery scheme for intermittently connected mobile sensor networks. The section covers the protocol overview, and the key components are discussed. Detailed policy regarding each component is described in Section 4.

3.1. System overview

In the proposed scheme, a network node that needs to deliver packets to a sink node tries to forward packets if the connectivity of the node is above a threshold, which is typically provided by application. The connectivity between two nodes indicates the



(a) Packet Reception Rate (Static Deployment)

(b) Packet Reception Rate (Mobile Environment)

Fig. 1. Intermittent connectivity in mobile sensor networks.