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Data fusion prolongs the lifetime of mobile sensing networks

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ABSTRACT

Mobile sensing accelerates the integration of physical world and virtual space by using the pervasive portable devices with sensing and communication abilities. Since the smart devices are often battery powered, prolonging the network lifetime in mobile sensing becomes very important. Previous works forward packets individually, resulting in a large amount of redundant copies. They therefore consume much energy. We notice that in many applications of mobile opportunistic networks, the sensory data are spatial-temporal correlations. The correlated data can be aggregated in the forwarding process, thus reducing the number of copies and saving energy. Considering this fact, we propose two forwarding schemes by integrating data fusion: Epidemic with Part Fusion (EPF) and Epidemic with Complete Fusion (ECF). The part fusion scheme is responsible for aggregating raw correlated data, and the complete scheme can fuse any type of correlated data (raw or fused data). We give the closed form of the dissemination law of raw data and fused data, respectively. The scaling law theoretically guarantees that the two schemes achieve better tradeoff between mean delivery delay and energy consumption. We evaluate the fusion scheme with synthetical and real traces. The experimental results demonstrate that the EPF can save energy by 55%, and the ECF reduces energy consumption by 80% compared with the non-fusion scheme.

1. Introduction

Due to the continued popularity of portable devices with sensing and communication abilities, such as smart phones, the first decade of the century witnessed a surge of mobile applications. Examples range from the physical environment monitoring (e.g., SensOrchestra (Cheng et al., 2012), SignalGuru (Koukoumidis et al., 2011)) to social activity detection (such as Medusa (Ra et al., 2012) and RockamRing (Packer et al., 2012)). This type of application has generally been called mobile/opportunistic sensing (Ganti et al., 2011; Lane et al., 2008). Mobile sensing brings ample opportunities to perceive the real world as shown in Fig. 1 (Ma et al., 2014). People and vehicles with smart devices form a mobile opportunistic network to collaboratively sense the things around them, and forward the sensory data for the purpose of sharing local contents of interest or improving global awareness of issues, etc.

Since the smart devices are often battery powered, prolonging the network lifetime in mobile sensing is a key problem. This constraint requires a lightweight data forwarding scheme, so as to reduce energy consumption. In the past few years, many opportunistic forwarding schemes (e.g., Epidemic (Vahdat et al., 2000), PROPHET (Lindgren et al., 2004) and BUBBLE (Hui et al., 2011)) have been proposed to transmit packets among mobile users. However, all of them route packets individually, resulting in a large amount of redundant copies and consuming much energy. Therefore, existing schemes cannot be applied in large-scale, long-term mobile sensing scenarios (Zhao et al., 2013; Yuan and Ma, 2013), due to their poor scalability and short lifetime.

Data fusion is a wise choice for meeting the long-term data collection demand of mobile sensing. In many practical applications, the sensory data gathered within close space and time period are highly correlated. Take a snapshot of GreenOrbs (Liu et al., 2013) project for instance. In their recent experiment lasting 10 h at night (Wang et al., 2012), they observed that the temperature readings of nearby sensors kept linear decreasing in the first 4 h, and then grew stable in the next 6 h. In addition, it is sometimes unnecessary to collect the total sensory data, such as reporting the highest/average/lowest temperature in a specified area. People may be interested only in the aggregated results, instead of the raw data. By aggregating the raw data in the forwarding process, the number of packets can be considerably reduced, thus saving energy and prolonging the network lifetime.

Motivated by these observations, we improve opportunistic routing performance with data fusion. More specifically, we propose two fusion schemes: Epidemic with Part Fusion (EPF) and Epidemic with Complete Fusion (ECF). The part fusion scheme is responsible

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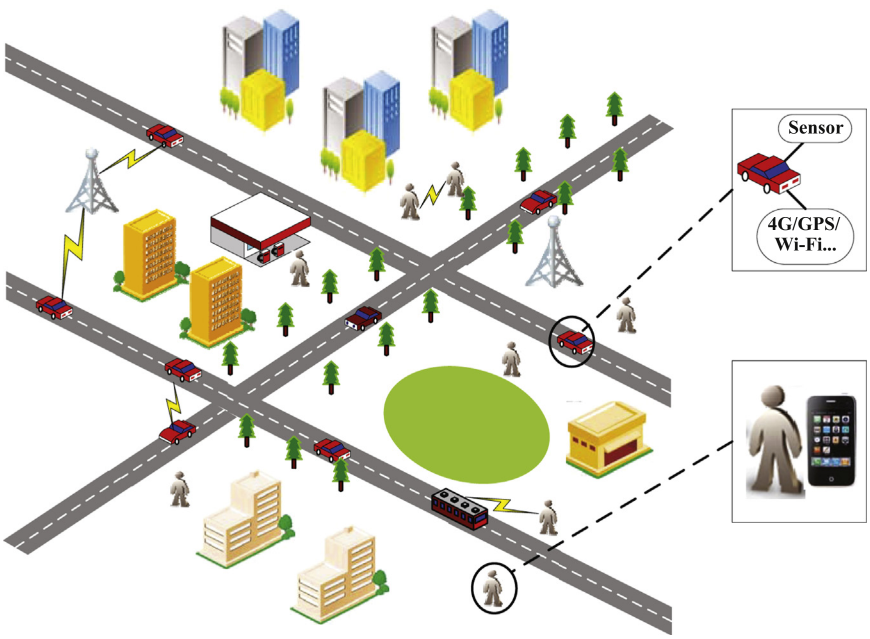

Fig. 1. A scenario of mobile sensing.

for aggregating raw correlated data, and the complete scheme can fuse any type of correlated data (raw or fused data). Both the two schemes enable a lightweight data forwarding protocol. Our main contributions can be summarized as follows:

- We design opportunistic forwarding scheme with data fusion. Although there are a large amount of related work in traditional WSNs (Al-Karaki et al., 2009; Luo et al., 2011), to the best of our knowledge, we are the first to investigate the impact of "data fusion" on performance of data forwarding.
- We give the closed form of the dissemination law of raw data and fused data, respectively. The scaling law theoretically guarantees that the fusion scheme achieves better tradeoff between mean delivery delay and energy consumption.
- We evaluate the fusion scheme with synthetical and real traces. The experimental results demonstrate that the EPF can save energy by 55%, and the ECF reduces energy consumption by 80% compared with the non-fusion scheme.

The remainder of this paper is organized as follows. Section 2 presents the related work. In Section 3, we propose two forwarding schemes with data fusion. Section 4 describes the simulation experiment and results. We finally conclude our paper in Section 5.

2. Related work

The related works include the following two aspects: data forwarding and performance evaluation. We introduce them in detail.

2.1. Data forwarding in mobile/opportunistic sensing networks

Routing is the base of data collection. Several routing schemes have been proposed in the past few years. On the basis of contexts they used, we classify them into the following two categories: (i) data forwarding with physical contexts and (ii) data forwarding with social contexts.

2.1.1. Data forwarding with physical contexts

Considering the heavy cost resulted from Epidemic algorithm, early works employed physical contact information of nodes to guide the data forwarding process. For example, Lindgren et al. (2004) proposed a probabilistic routing protocol for mobile scenarios. They exploited the past contact times between nodes to predict the future contact probability of node pairs. Leguay et al. (2005) presented MobySpace, a high-dimensional Euclidean space constructed by the contact locations of nodes. In addition, the authors of Erramilli et al. (2007) employed node contact frequency to select relays. Valerio et al. (2013) exploited messages' diffusion degree to design the data forwarding process. If an item belonging to a given channel of interest is spread enough, the item diffusion should be stopped in favor of other less diffused items.

2.1.2. Data forwarding with social contexts

A few recent works try to improve the opportunistic routing performance with social information encoded in human mobility. For example, SimBet (Daly and Haahr, 2009) exploited centrality and social similarity to differentiate nodes. Messages will be forwarded to such nodes with relatively big SimBet values, so as to increase the probability of finding proper relays to the final destination. ContentPlace (Boldrini et al., 2008) used nodes' social relationship to guide where to place the data items. ONSIDE (Ciobanu et al., 2014) selected relays by aggregating information about a nodes social connections, interests and contact history. Hui et al. (2011) proposed Bubble, which combined node betweenness centrality and community structure to make forwarding decisions. They assumed that each node had a global rank across the whole system and a local rank within its local community. When a message is out of the community of the destination, it is forwarded to the node with a high global rank, when it enters into the range of the destination community, the message is delivered to the node with a high local rank in that community. PeopleRank (Mtibaa et al., 2010) assigned higher weights to nodes if one or more of their neighbors play big roles in the network, which is inspired by the PageRank idea. Recently, Hug (Yuan and Ma, 2012) employed the static nodes placed in the system "hot region" to relay message. If the message entered into the "hot region", the static node sprayed one replica to any other node it encountered, otherwise, the copies of the message was sprayed in a binary way (Spyropoulos et al., 2008).

2.2. Performance evaluation in mobile/opportunistic sensing networks

Modeling the dynamics of Epidemic offers a fresh insight into the data forwarding process, on the other hand, it allows a network engi-