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Copy limited flooding over opportunistic networks ☆

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ABSTRACT

Mobile devices with local wireless interfaces can be organized into opportunistic networks which exploit communication opportunities arising from the movement of their users. For some occasions, such as tracking wild animals and communications at rural areas, opportunistic networks are a practical way to disseminate information. It is important to investigate message dissemination over opportunistic networks to maximize the potential of those networks. Traditional flooding is an optimal mechanism to disseminate messages over opportunistic networks if resource consumption is not considered. To overcome the weakness of traditional flooding, in this paper, we considered k-Copy Limited Flooding (k-CLF) over opportunistic networks where a node can forward no more than k copies of a message to its neighbors. To achieve this goal, we proposed a network model called Markov and Random graph Hierarchic Model (MRHM), where a node transfers among different Main-areas (places frequently visited by nodes according to the Markov rule), and two different nodes in the same Main-area can establish a connection with a certain probability. This model is able to reflect the social characteristics of nodes to some extent. We theoretically analyzed the performance of CLF over MRHM in terms of delivery ratio, buffer and energy consumption. Our extensive simulation results over synthetic and real traces show that if the buffer space and initial energy of nodes are sufficient, the performance of the 3-CLF algorithm is very close to that of traditional flooding, or else the 2-CLF algorithm performs best among all the schemes in terms of delivery ratio and resource consumption.

1. Introduction

Delay Tolerant Networking (DTN) is an approach to computer network architecture that seeks to address the technical issues in heterogeneous networks that may have only intermittent network connectivity (http://en.wikipedia.org/wiki/Delay-tolerant_networking). Pocket switch networks, vehicle and pedestrian networks (Liu et al., 2013) and human contact networks are the most appropriate examples to illustrate how DTNs change our life. Because of the close relation with our daily life, this field has become a hot research area since DTN was first proposed. Most DTNs consist of mobile devices (e.g., smartphones and iPads) equipped with local wireless network interfaces. With the fast development of wireless communications technology, recent years have witnessed mobile devices equipped with wireless network getting cheaper, smaller and faster, which significantly boosts the research and application of DTNs (Xiong et al., 2009).

Opportunistic networks are similar to DTNs, while underlining the characteristic that the links between nodes are not stable. Due to the unstable links between the nodes, the delay of opportunistic networks is unpredictable and varies greatly. From this point of view, all opportunistic networks are DTNs. Although there are already some proof-of-concept applications based on opportunistic networks, such as ZebraNet (Juang et al., 2002), CarTel (Hull, 2006), there is still big room for them to be developed and evolved if some key problems could be solved in future. Moreover, in some special scenarios, utilizing opportunistic networks is the most suitable choice and sometimes the only choice (Mart-Campillo et al., 2013). For example, after the earthquake at Wenchuan County in Sichuan Province, the public cellular networks were severely damaged. In such a situation, opportunistic networks may be a proper choice for people in such a scenario to communicate.

Opportunistic networks are highly dynamic as a result of nodes' mobility and the sparse distribution of nodes (Pirozmand et al., 2014). Hence, messages cannot reach their destinations by a continuous end-to-end path from the source node in most cases. In order to exploit the mobility of nodes, opportunistic networks usually adopt the "store-carry-forward" paradigm to disseminate

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messages, which consequently leads to an unpredictable delay due to the uncertainty of communication opportunities. Moreover, interference, collision and channel fading occur frequently in wireless channels. Therefore, providing reliable and energy efficient communication in opportunistic networks is still a big challenge, which stymies widespread adoption of opportunistic networks in daily life.

Epidemic Routing (ER) (Vahdat and Becker, 2000) is the most robust and optimal routing protocol in terms of message delivery ratio and delay, but impractical due to high resource consumption and ineffective message delivery in reality. To achieve a tradeoff between delivery ratio and energy cost, researchers have already proposed many limited flooding protocols to address the drawbacks of ER. For example, Vojnovic and Proutiere (2011) analyzed the hop-limited flooding over dynamic networks. Baumann et al. (2009) investigated the time-limited flooding in dynamic graphs.

In this paper, we shift our focus to the k-Copy Limited Flooding (k-CLF) algorithm over opportunistic networks, where a node can only forward the same message to no more than k other nodes in the network. As far as we know, this work is the first one to theoretically and empirically investigate k-CLF over opportunistic networks.

To evaluate k-CLF, we propose a novel network model, Markov and Random graph Hierarchic Model (MRHM), to portray the node movement patterns in opportunistic networks. MRHM is motivated by the facts that humans follow simple reproducible patterns (Gonzalez et al., 2008) and that there is potentially a 93% average predictability in human mobility (Song et al., 2010). As the performance of the “store-carry-forward” paradigm strongly depends on the mobility pattern of nodes (Chaintreau et al., 2007), we pay special emphasis on analyzing the performance of the k-CLF using this model.

Our major contributions are as follows: (1) We propose a novel node mobility model (MRHM) for opportunistic networks, which can describe the patterns of human mobility to some extent; (2) We theoretically analyze the performance of the k-CLF over opportunistic networks, in terms of delivery ratio and resource consumption; (3) We empirically validate the performance of the k-CLF through extensive simulations over both synthetic and real human traces.

The rest of the paper is organized as follows. Section 2 surveys the related work. Sections 3 and 4 discuss MRHM and k-CLF, respectively. Section 5 provides the simulation results followed by the conclusions in Section 6.

2. Related work

In mobility management, the Random WayPoint (RWP) model (Johnson and Maltz, 1996) is a commonly used synthetic random model which portrays the movement pattern of independent nodes by simple rules. In RWP model, the mobile nodes move along a zigzag line from one waypoint p_i to the next p_{i+1}. The Random Walk model (RW) and the Random Direction (RD) model are variants of the RWP. These random-based mobility models ignore the fact that in most cases nodes have very different chances to encounter each other, i.e., the nodes in the same community may have higher probability to encounter each other than the nodes in different communities. This leads to the notion that distinguishing different types of connections (connections between nodes in the same community or different communities) can help greatly when forwarding data between two nodes. In Hui et al. (2005), the authors present their experiment measuring 41 users' mobility at the Infocom 2005 conference and found that nodes in real mobile traces are not equally active (some individuals are much more active in a group). Therefore, random-based mobility models may not portray correctly for nodes movement in some real situations. Some community based mobility models are introduced to reflect the social community structure of who meets whom. In the Time-Variant Community Model (TVCM) (Hsu et al., 2007), the authors define the communities for each node that are visited often by the nodes. Within each time period in TVCM, they randomly assign a community to each node. Node transitions between communities are governed by a 2-state Markov Chain. Nodes perform random waypoint trips inside and outside communities with probability $1-p$ of roaming and probability p of staying in the communities. The Community-based Mobility Model (CMM) (Musolesi and Mascolo, 2006) was another mobility model driven by social networks. In contrast to TVCM, the probability that a node performs a mobility trip towards community M depends on its social relationships towards nodes currently in community M. The Home-cell Community-based Mobility Model (HCMM) (Boldrini and Passarella, 2010) is an extension to CMM. The main difference between CMM and HCMM is that in HCMM, the transition probability to Location M no longer depends on nodes currently at that location but on the total weight of nodes assigned to Location M as their home location. Based on HCMM and TVCM, in Hossmann et al. (2011), the authors present an addition, called social overlay to help existing models to correctly reflect bridging links between communities.

Regarding the DTNs routing protocols, as is known to all that the obvious weakness of opportunistic networks is the uncertainty of latency. To address this weakness, the key point is to increase the copies of messages in the network and to relay messages as soon as possible. Therefore, several efficient routing protocols for DTNs have been proposed (Table 1). An implementation of this strategy is Epidemic Routing (ER) (Vahdat and Becker, 2000) which is one of the most representative routing algorithms in opportunistic networks. In brief, ER exploits flooding mechanism to disseminate messages in order to guarantee a shorter transmission delay and a higher data delivery ratio compared with other algorithms. Although ER is straightforward and robust, it is not a good choice in the real environment because the flooding mechanism could lead to high resource consumption and

Table 1
Comparison of DTN routing protocols.

Category	Feature description	Algorithm
Flooding based	Principle: A node copies its message to all the encountered nodes, provided the receiver does not have a copy of it already. Methods to control flooding: (1) Bounding the number of copies. (2) Embedding additional information.	2-Hop flooding (Grossglauser and Tse, 2002) ER (Vahdat and Becker, 2000) SW (Spyropoulos et al., 2005) SF (Spyropoulos et al., 2007)
History based	Principle: A node that has encountered the destination many times, is likely to encounter the destination again. Methods: Making routing decisions according to the history of encounters between nodes.	PRoPHET (Lindgren et al., 2003) MobySpace (Leguay, 2005) CAR (Musolesi et al., 2005) PER (Yuan et al., 2012)
Devices based	Principle: Utilize extra-facilities to enhance data forwarding. Methods: (1) Using stationary nodes to facilitate data forwarding. (2) Using mobile nodes to facilitate data forwarding. (3) Using social context.	Message Ferry (Zhao et al., 2004) Bubble rap (Hui et al., 2011) SimBet Routing (Daly and Haahr, 2007)