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Fast track article

Hotspot-entropy based data forwarding in opportunistic social networks

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ABSTRACT

Performance of data forwarding in opportunistic social networks benefits considerably if one can make use of human mobility in terms of social contexts. However, it is difficult and time-consuming to calculate the centrality and similarity of nodes by using solutions of traditional social networks analysis, this is mainly because of the transient node contact and the intermittently connected link. In this paper, we are interested in the following question: Can we exploit some other stable social attributes to quantify the centrality and similarity of nodes? Aggregating GPS traces of human walks from the real world, we find that there exist two types of phenomena. One is public hotspot, the other is personal hotspot. Motivated by this observation, we propose Hotent (HOTspot-ENTropy), a novel data forwarding metric to improve the performance of opportunistic routing. First, we use the relative entropy between the public hotspots and the personal hotspots to compute node centrality. Second, we utilize the inverse symmetrized entropy of the personal hotspots between two nodes to evaluate their similarity. Third, we integrate the two social metrics by using the law of universal gravitation. Besides, we use the entropy of personal hotspots of a node to characterize its personality. Finally, we compare our routing strategy with the state-of-the-art works through extensive trace-driven simulations, the results show that Hotent largely outperforms other solutions, especially in terms of packet delivery ratio and the average number of hops per message.

1. Introduction

With the pervasive of hand-held mobile devices, such as smart phones, there arises the requirement to share content (e.g., news, photo, music, video clips, etc.) among those devices [1–4]. Such contents can be the offloaded data from virtual space, or the sensed information from physical world as shown in Fig. 1. People download and replicate content when they enter the communication range of access point (AP). When they are out of the AP's coverage, they can request their interested contents from other peers. Thus, mobile devices form an opportunistic social network (OSN) [5–7], for example via WiFi, to exchange/share content by intermittent contacts.

In the above scenario, routing is the base of content sharing. It is also one of the most challenging problems, due to the lack of an end-to-end path between source and destination. This new feature leads to a considerable performance degradation for conventional wireless routing protocols such as AODV or DSR, since they are originally designed for stable scenarios. Hence, new data forwarding algorithms are desired for opportunistic scenarios.

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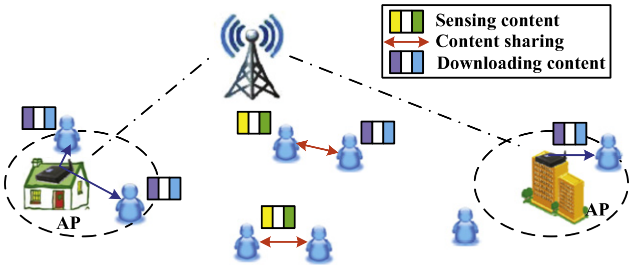

Fig. 1. A scenario of content sharing.

Several routing schemes (e.g., epidemic [8] and data MULEs [9]) have been proposed to deal with this problem in the past few years. Among them, the epidemic scheme seems to be a feasible solution to forward content from a sender to a potential receiver when nothing is known about the mobility of nodes, this is mainly because it tries to send content over all possible paths in the network. This scheme therefore achieves the optimal performance in terms of mean delivery delay (MDD) and packet delivery ratio (PDR), simultaneously, it requires more buffer space than other schemes, so as to store the large amount of redundant copies.

This deficiency has motivated researchers to develop other data forwarding algorithms, including PROPHET [10], CAR [11], MobySpace [12], Spray-and-Wait [13] and delegation forwarding [14], etc. For these algorithms, the contexts they used to estimate the relay nodes play a big role in routing performance. We notice that most existing schemes only take the physical contexts (e.g., contact number and duration) into account and neglect the impact of social contexts on network performance. In fact, the network performance depends heavily on human walks [15], since devices may lose connection when people move around. Hence, the social contexts acquired by mobility characterization techniques are of great importance on designing data forwarding metrics.

There exist a few works that explicitly consider some social contexts in opportunistic routing, for example SimBet [16] and Bubble [17]. The two schemes computed node's centrality/similarity by using traditional social network analysis technology [18], which is time consuming or even impractical in OSN [19]. For instance, SimBet has a high time complexity since it needs to calculate the cube of adjacency matrix [20]. Moreover, as we have shown later, SimBet exploits the growing time window to aggregate node contacts, resulting in a homogeneous issue. On the other hand, considering the fact that the shortest path for each source–destination pair may not exit or vary from time to time in OSN, betweenness centrality adopted in Bubble has to collect the shortest path in an off-line way, which makes it impractical in distributed scenarios. Considering these facts, we are interested in the following question: Can we explore some other stable social attributes to quantify the centrality and similarity of nodes? By analyzing GPS traces of human walks from the real world, we confirm that there also exist two known phenomena as the indications in [21]. One is that people always move around a set of well popular locations which are called public hotspots, instead of purely random motions. The other is that each people shows preference for some particular locations which are called personal hotspots in this paper. We believe that both kinds of hotspots are more stable than underlying social contexts mentioned above, as public hotspots are formed by superimposing personal hotspots together and personal hotspots/habits are stable over time and across situations [22].

Taking all above issues into account, we design data forwarding metric by exploiting hotspot distribution of nodes. In specific, we investigate the following two kinds of hotspots. (i) The public hotspots: this implies that there exists a bigger chance to meet the destination in these landmarks than other places. In other words, a node frequently wandering among these hotspots can reach more other nodes in the network, which is consistent with the nature of node centrality. Hence, we have to address how to identify these nodes with a higher centrality than others. (ii) The personal hotspots: this implies that if we can deliver content to one of the top k popular personal hotspots of the destination, the content will be quickly received by the destination. As such, we have to answer the problem of how to estimate the similarity between a potential relay and the destination. Besides, since each person has his/her unique mobile profile which we call node personality, we still need to incorporate this factor into the data forwarding process.

In this paper, we develop a novel data forwarding metric, called Hotent (HOTspot ENTropy), to address these challenges. We first use the *relative entropy* [23] between public hotspots and personal hotspots to evaluate centrality of nodes. Then we utilize the *inverse symmetrized entropy* [24] of personal hotspots of two nodes to characterize their similarity. Third, we use the *law of universal gravitation* to integrate the two social metrics. Furthermore, different from the related works, we integrate a new factor, personality, into the Hotent metric and exploit the *entropy* of personal hotspots to estimate node personality. We also propose a method to ascertain the optimized size of hotspot. Our main contributions can be summarized as follows:

- We observe that the hotspots are bursty and stability. The bursty feature implies that we can decrease the number of hotspots required to exchange, and the stability feature means we can reduce the update frequency of hotspots. Both of them make Hotent lightweight.
- We employ the information entropy theory to compute node's centrality, similarity and personality. Rather than exchanging neighbor's adjacency matrix [16] or counting the number of the shortest delay paths [17], we use hotspot entropy to quantify the centrality and similarity of nodes, which guarantees Hotent with a low time complexity.