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Efficient techniques for time-constrained information dissemination using location-based social networks

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ABSTRACT

Social networks have undergone an explosive growth in recent years. They constitute a central part of users' everyday lives as they are used as major tools for the spread of information, ideas and notifications among the members of the network. In this work we investigate the use of location-based social networks as a medium of emergency notification, for efficient dissemination of emergency information among members of the social network under time constraints. Our objective is the following: given a location-based social network comprising a number of mobile users, the social relationships among the users, the set of recipients, and the corresponding timeliness requirements, our goal is to select an appropriate subset of users so that the spread of information is maximized, time constraints are satisfied and costs are considered. We propose LATITuDE, our system that investigates the interactions among the members of the social network to infer their social relationships, and develop scalable dissemination mechanisms that select the most efficient set of users to initiate the dissemination process in order to maximize the information reach among the appropriate receivers within a time window. Our detailed experimental results illustrate that our approach is practical, effectively addresses the problem of informing the appropriate set of users within a deadline when an emergency event occurs, uses a small number of messages, and consistently outperforms its competitors.

1. Introduction

Recently, we have observed the explosive growth of social networks such as Facebook [1], Twitter [2] and Google+ [3], that enumerate large amount of subscribers. For instance, Google+ has reached over 1.6 billion active users, while Facebook follows with over 1.2 billion users and Twitter with more than 600 million users.[1] These networks have been utilized as major tools for the spread of ideas, information and notifications among their members. Studies reveal that social networks can be exploited not only for "viral marketing" [4] (*i.e.*, promote products to targeted sets of users that further propagate them through the word-of-mouth effect to reach a larger audience), but also for discovering emergent topics [5] and for emergency events alerting, management and public safety [6]. For example, people located in the vicinity of earthquakes share via Twitter, a well known social service for exchanging short text messages, anecdotal information related to the dissemination of seismically activity, that earthquake alerts lag behind firsthand notification [7,8]. Studies reveal that depending on the size and location of the earthquake, scientific alerts can take between 2 and 20 min to publish, while using Twitter's notification capabilities people were notified about the occurrence of the earthquakes shaking within seconds of their occurrence. Recently, Facebook, one of the most popular social networks, announced the release of a tool, *Safety Check*, to be

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[1] https://en.wikipedia.org/wiki/List_of_social_networking_websites

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used by users in the proximity of a disaster zone to notify their loved ones about their safety during emergency situations. The application has been developed based on observations of user activity in the network in Japan during the tsunami of 2011.[2]

The use of social networks during emergencies and their efficiency in communicating important information, even when traditional communication medium fail, has been verified in numerous disastrous events in the recent years. As reported by the administrator of the US Federal Emergency Management Agency [9] with respect to the catastrophic 2010 Haiti earthquake, even when an area's physical infrastructure was completely destroyed, the cellular tower bounced back quickly, allowing survivors to request help from local first responders and emergency managers to relay important disaster-related information via social media sites.

Thus, social networks (*i.e.*, Google+, Facebook, and Twitter) can play a major role in effective emergency notification due to their ability to (1) effectively reach millions of users, especially family and friends, (2) become alternative communication mediums when the wireless and telecommunication networks are overloaded during emergencies, and (3) provide cost-effective solutions since they are able to reach large amounts of social users without additional infrastructure costs. Furthermore, the study of social relationships and interactions in social networks may provide important insights for gathering information and planning evacuations during rescue efforts, as demonstrated in [10]. However, adopting location-based social networks as an effective communication medium for emergency alerting raises considerable challenges. Challenges lie in the level of availability and responsiveness expected from these infrastructures in delivering notifications under *time constraints* to reach all recipients interested in receiving the information (these can be people located in the area of the event *i.e.*, students in a campus, as well as their relatives and friends).

In this paper we study the problem of using location-based social networks for efficient dissemination of information under time constraints. Specifically, we examine how efficiently a location-based social network, such as Twitter, can be deployed for emergency notification. Twitter has the ability to broadcast and forward messages to users and is primarily used via mobile devices, allowing users to be informed at anytime, anywhere, as long as they can access the network. We have chosen the network of Twitter over other Online Social Networks as it is indisputably one of the most widely adopted social network with more than 80% of its users being active mobile users, and over 500M tweets published daily on Twitter,[3] as opposed to Facebook that presents 55M status updates per day[4] and Google+ that, despite its growth, 90% of the users have never published a post.[5] Consequently, we consider Twitter to be the most appropriate network for emergency related information propagation, since users on Twitter are more actively engaged to the network. Albeit we focus on the network of Twitter, we note that other social networks may be exploited to infer users' relationships and propagate emergency information.

Our objective is stated as follows: Given a location-based social network comprising a number of mobile users, the social relationships among the users, the set of recipients, and the corresponding timeliness requirements, our goal is to select an appropriate subset of users to propagate the information such that (1) the expected spread of information among users related to the event is maximized, (2) time constraints in the dissemination of the information are satisfied, and (3) costs are considered. Cost is defined as the amount of messages exchanged among users. Thus, it could be either monetary (for an SMS) or resource allocation cost. Our primary focus is on information that needs to be propagated under time constraints, such as emergency information, where the notification about the event needs to be propagated under strict time constraints.

We approach the problem in two phases. First, we use a crawling phase where User Profiles are built, social relationships are inferred and effective dissemination paths among the users of the social network are computed. In the second phase, namely reaction phase, we aim at reducing the search space by considering only users in the social network that are interested in the event (*i.e.*, users related to the event) since the event may not be of interest for all users in the network. Then, we select a small number of seed users that will allow us to efficiently disseminate the emergency information to all interested recipients during the emergency event. Reduction of costs is accomplished by avoiding push-based broadcasts, which is important in emergency events as communication is typically over-utilized in such scenarios [8].

Existing information dissemination techniques are not adequate to solve these problems. The problem of maximizing the spread of influence in social networks has been addressed in [11–14], but none of these works consider time constraints. Only recent efforts recognize that time plays an important role in the influence spread [4,15]. However, contrary to our approach, these efforts assume that the influence flow is known and aim at maximizing the influence in the entire network rather than identifying and informing an appropriate subset of users that would be most interested in the information. Furthermore, both works study cases of viral marketing campaigns or voting systems, rather than emergency response situations that have to operate under tight time deadlines and resource savings. In [16] an approach is proposed to maximize the influence in a subset of users, rather in the entire network, while minimizing the number of users involved in initiating the propagation process. However, time constraints are ignored.

Emergency response outside social networks has also been studied. The use of geographical notification systems has been considered in [17]. The purpose of the presented system is to construct overlays that support location-based regional multicasting while they also consider issues of providing reliable storage of social information under extreme regional conditions. Traditional approaches such

[2] http://time.com/3513016/facebook-safety-check/
[3] https://about.twitter.com/company
[4] https://blog.kissmetrics.com/facebook-statistics/
[5] https://www.stonetemple.com/real-numbers-for-the-activity-on-google-plus/

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