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Optimizing social media message dissemination problem for emergency communication

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ABSTRACT

Social media is increasingly being used as a communication bridge between government, emergency responders and managers, and the general public in extreme events. Passing information through social media channels enables individuals to send and receive content in real-time and without limitation of location and geography. While the use of social media in extreme event situations has become prevalent, there is often little strategy involved in message dissemination and too little understanding of the effects that underlying online social networks have on message distribution. In this study, we introduce a formal model for social media message dissemination in social networks through time. Our proposed model includes emphasis on single and multiple message scenarios and examines key communication characteristics in the development of more intentional and targeted social messaging strategies. We present a detailed experimental design on randomly generated networks and real-world sub-networks of the Twitter social graph and discuss our findings. We also include a Tabu Search procedure for solving single-message problem and discuss its potential value for large-scale problems in real-world applications.

1. Introduction

Social media and mobile technology have quickly become a major influence in how people prepare for and response to extreme events. The access to information and individuals (friend, family) enabled through mobile devices creates a constant connection by which people can actively or passively learn in pre and post event. The real-time communication capability of social media has consistently been outpacing more traditional news outlets as well. The challenge faced by contemporary emergency managers is to understand these usage and capability characteristics and how social media and media technology can be exploited through policy to better prepare for, manage and response to extreme events.

In daily life, people read content posts in social media and share that content which they deem most interesting. Content gains popularity through increased visibility either from rephrasing and posting or from copying and reposting. Content sharing through social media is simple but powerful. In most social media outlets (e.g., Twitter, Facebook, Pinterest, Instagram, etc.), an individual's content post is observable by their entire friendship network immediately after posting. Even though the post may be read or received until a later time period, the sender's post becomes a part of the specific social media stream as soon as the sender distributes. Assuming that received/viewed content is relevant to an individual, he/she will likely repost, thereby increasing the visibility of the content to a new subset of the social media user pool. In this way, content can quickly reach more and more people in the social media network (this is often called 'going viral' in social media terms).

Inspired by this observation, we propose that emergency managers use a targeted message dissemination scheme in extreme events. By sending more personalized messages to a small subset of social media users, emergency managers can make their message more relevant to individual users and thereby are more likely to have their content reposted. Such targeting may also have indirect benefits like increasing trust between governmental representatives and the general public (a known challenge) (Crowe, 2010). Through targeted relevance, we hypothesize that emergency managers will have the chance to reach out to more people by establishing or maintaining connections with fewer but more critical social media users. On the other hand, social media users are more likely to receive, process, and act on messages received from their friends than they are with generic messages from emergency managers and government agencies. While select agencies begin to adopt such social messaging strategies, a majority

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continue to use social media only as another medium for one-way message dissemination (Centers for Disease Control and Prevention, 2012).

This paper introduces a network-based social media message dissemination model that determines message targeting strategies for emergency managers and government agencies. Adapting concepts from communication, multi-commodity flow, facility location and network optimization, we develop single and multi-message social media message dissemination (SMMD) models that identify communication policies for emergency management in extreme events. In particular, SMMD will identify small groups of key social media users such that having them receive and share alert messages sooner will contribute to the overall dissemination outcome. Accordingly, emergency managers may consider establishing reliable connections with these users in advance so that they could benefit in future events. In addition to the single-message model, our SMMD model is capable of handling scenarios where information from multiple messages are passed through the social networks and must be aggregated by a single user before that user can be considered as a receiver of information on the extreme event. In practice, this can be seen as a social media user choosing to evacuate from an impending extreme event after seeing relevant information of the event on Facebook, Twitter and via Text Message. Our strategic modeling goal is to show that selected targeting of a small subset of social media users is an effective and efficient way to disseminate messages to a large, connected population in extreme events.

We test all variations of the SMMD model for computational performance and observe model trends by implementing an experimental design on randomly generated social networks. By systematically changing the SMMD input variables, we can identify how these variables influence the effectiveness of the optimal communication policy. We also build a small-scale test network by implementing a link-trace crawl on the online social network site Twitter. We run our single network model on this Twitter test case and compare our observations to the randomly generated experimental cases. We find that increases in the time horizon are directly and exponentially related to increases in computational time. We also find the initial selection of message recipients to be the most critical objective function value indicator and that the model is very insensitive to any message redistribution delay by emergency management.

The remainder of this paper is organized as follows. Section 2 provides a review of the literature in social media network analysis and extreme events, motivating both the relevance and need for this research. It also makes a distinction between our problem and some existing problems such as minimum cost network flow, gossiping, and broadcasting problems. Section 3 introduces the SMMD model and discusses its formulation. Sections 4 and 5 use the SMMD model in experimental and small scale, real-world testing networks, providing observations and discussion on objective function properties and model performance. Section 6 appends the computational discussions of the previous sections by connecting SMMD observations to emergency management policy. Section 7 introduces a Tabu Search implementation for single-message SMMD and discusses its potential value in dealing with large-scale problems. Section 8 concludes the paper.

2. Background on online social media networks

Online social networks (OSN) are highly distinct from other large-scale networks such as transportation, energy or health care networks. Offline social networks can be characterized by their power-law structure, show densification over time, and can often be separated into ‘strong’ (tightly clustered) and ‘weak’ ties, with strong correlations between friendship and geographic location (Gilbert & Karahalios, 2009; Leskovec, Kleinberg, & Faloutsos, 2005; Mislove, Marcon, Gummadi, Druschel, & Bhattacharjee, 2007; Shirky, 2003). Online social networks, in addition to these offline properties, have a high degree of reciprocity in directed user links (the online social network Twitter is an example of a directed user link network. Facebook, in contrast, is undirected) and contain a large and strongly connected core of high-degree nodes surrounded by many low-degree node clusters (Mislove et al., 2007). OSN are dynamic and their connectivity can be extremely different from hour to hour (or minute to minute).

In disaster scenarios, research shows that OSN serve as a back-channel for peer-to-peer communication and support, helping to raise national/state/local awareness during events while helping communities stay connected despite their geographic dispersal post-event (Shklovski, Palen, & Sutton, 2008; Sutton, 2010; Sutton, Palen, & Shklovski, 2008). The use of social media for emergencies and disasters may be conceptualized in two broad categories. First, social media can be used passively to disseminate information and receive user feedback via incoming messages, wall posts, and polls (FEMA currently utilizes online OSN in this way). Second, OSN can be used as a mechanism for emergency managers to actively engage with its OSN connections. Such usage might include using the medium to conduct emergency communications and issue warnings; using social media to receive victim requests for assistance; monitoring user activities to establish situational awareness; and using uploaded images to create damage estimates, among others (Sutton, Hansard, & Hewett, 2011). A subset of OSN literature describing such usage in extreme events is compiled in Table 1. Many of these applications remain speculative, while other uses are still in their infancy. Consequently, most emergency management organizations have confined their use of social media to the first category mentioned, passive dissemination of information (Sutton et al., 2011).

2.1. Composition and structure

Online social networks have been a very active research area for many years. A social network is a set of people (or organizations or other social entities) connected by a set of social relationships, such as friendship, co-working or information exchange (Garton, Haythornthwaite, & Wellman, 1997). Examples of OSN include YouTube, LinkedIn, Facebook, Twitter and Google+. While early research mainly focused on characterizing the properties of the social graph, researchers are becoming more interested in how to use these basic properties to explain observed online human behavior, including human mobility, privacy, security, user activity, population of online services as well as profile characterization (Faloutsos, Karagiannis, & Moon, 2010). Additional works were included with prior references in Table 1.

With the rapid growth in the number of OSN users, more and more researchers and practitioners have realized that OSN can also play an important role in the preparedness and management of extreme events. While almost all the papers show how OSN have been used in such a context and confirm the positive role that OSN have been playing, they focus on different facets or applications of using OSN in the management of extreme events. Jaegera et al. (2007) analyze the importance of OSN in developing community response grids (CRGs) for community emergency response. Yates and Paquette (2011) and Jaegera et al. (2007) examine how OSN technologies were used and what influences they made through case studies on 2010 Haitian Earthquake and 2010 Australian Tropical Cyclone Tasha respectively. By literature review, Veil, Buehner, and Palenchar (2011) and Holmes (2012) demonstrate OSN tools can help in risk and crisis communications. Crowe (2010) and White, Plotnick, Kushma, Hiltz, and Turoff (2009) believe OSN are so important that they must be considered in all