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Efficient and timely misinformation blocking under varying cost constraints

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ABSTRACT

Online Social Networks (OSNs) constitute one of the most important communication channels and are widely utilized as news sources. Information spreads widely and rapidly in OSNs through the word-of-mouth effect. However, it is not uncommon for misinformation to propagate in the network. Misinformation dissemination may lead to undesirable effects, especially in cases where the non-credible information concerns emergency events. Therefore, it is essential to timely limit the propagation of misinformation. Towards this goal, we suggest a novel propagation model, namely the Dynamic Linear Threshold (DLT) model, that effectively captures the way contradictory information, i.e., misinformation and credible information, propagates in the network. The DLT model considers the probability of a user alternating between competing beliefs, assisting in either the propagation of misinformation or credible news. Based on the DLT model, we formulate an optimization problem that under cost constraints aims in identifying the most appropriate subset of users to limit the spread of misinformation by initiating the propagation of credible information. We prove that our suggested approach achieves an approximation ratio of $1 - 1/e$ and demonstrate by experimental evaluation that it outperforms its competitors.

1. Introduction

The massive use of Online Social Networks (OSNs), that enumerate millions of daily active users [1,2], have led to drastic changes on the communication and information sharing among users. Many people have integrated popular online social networks in their everyday lives and rely on them as one of their major news sources, with over 28% of people claiming to get their news from social media and even local news media exploit OSNs to report news.[1] For instance, during the Marathon Bombing in Boston on April 15, 2013, the news broke initially on Twitter and local news media actively exploited the platform to report news regarding the event.[2] However, there are differences in terms of the triggers, actions and news values that are prevalent in news media and in general in public shares in social media [3].

An intriguing behavior of the users of an OSNs is information sharing. Aside from being informed through the network, users further propagate information of interest to their friends. An interesting study reveals that more than 45.1% of the messages published by a user are further propagated by his/her followers and over 37.1% are propagated by followers of up to 4 hops away from the original publisher [4]. However, it is not uncommon for false news to propagate through social networks, causing significant repercussion outside the network, e.g., a tweet stating that there was an explosion in the White House caused stocks to temporarily plung.[3] It becomes therefore clear that it is vital to detect and timely block the propagation of deceptive information, since dissemination of false news in OSNs can have undesirable effects with a disastrous impact outside the network. Especially in cases where the news concern emergency related events, limiting the spread of misinformation becomes imperative.

Misinformation is defined as any malicious, deceptive or irrelevant information regarding an event, that is spread either deliberately or unintentionally [5,6]. Manifold factors contribute to the complexity of the task of misinformation blocking. Sources of misinformation are multiple and varying, as is the users' susceptibility

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[1] http://www.mushroomnetworks.com/infographics/social-media-news-outlets-vs.-traditional-news-infographic.

[2] https://media.twitter.com/success/bostonglobe-uses-twitter-to-source-news-and-keep-the-public-informed-during-the-boston.

[3] http://www.cnbc.com/id/100646197.

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to the news they are exposed. Furthermore, the longer the deceptive information propagates in the network without contradiction from a reputable source, the greater is the effect the misleading information can have, and it is thus crucial to timely notify users about the credible information. To effectively accomplish the limitation of misinformation, understanding the way news propagate and how contradictory information affect users' decision to accept and share content is required. Moreover, it is desirable to avoid unnecessary broadcasting of messages, since this causes excess load to the infrastructures that might be already over-utilized during emergencies [7].

For the effective and efficient solution of the problem, a set of interesting research questions should be addressed: (i) how can a user's susceptibility be estimated, so as to efficiently approximate the degree to which the user is willing to adopt or renounce an idea, (ii) how can we identify the sources of misinformation, (iii) how can we estimate the the influence of the users across the network, and finally (iv) given cost constraint, expressed as the number of sources to contradict misinformation, which is the most appropriate subset of users to initiate the cascade in order to timely limit the dissemination of misinformation?

The problem of limiting misinformation or rumors in OSNs, commonly referred as misinformation or rumor blocking, is the subject of study in [8] where the authors discover the minimal subset of users that minimize the propagation achieved by rumor originators. Authors in [5] also study the problem of identifying the smallest set of users to act as protectors against the dissemination of misinformation. Their goal is to find the smallest set of highly influential users whose decontamination with good information assists in limiting the spread of misinformation to a desired ratio within a given number of steps. In [9] authors consider the evolving propagation of competitive campaigns and aim at selecting the appropriate subset of nodes so that the eventual influence of the misinformation campaign is minimized. Albeit the aforementioned works address the problem of misinformation blocking, there are significant limitations: First, none of the above schemes considers propagation times and therefore, fail to capture any time constraints during the dissemination of the information in their models. Furthermore, the susceptibility of a user related to the propagation of content is ignored. Finally, they assume that whenever a user is convinced about certain information, the user will remain loyal to this belief as the propagation unfolds, regardless of the state of its neighbors. However, this assumption is not always correct. There are multiple examples of users that have unintentionally contributed to the spread of false news and they later apologize for their mistakes.[4]

The objective of this work is to minimize the misinformation spread while overcoming the above limitations. Our approach is two-fold: First, we propose a novel propagation model, namely the Dynamic Linear Threshold (DLT) model, where each user is associated with a *renouncement* threshold that expresses her susceptibility to adopt an idea. Instead of considering that the threshold remains static throughout the propagation process, we define it to be dynamically adjusted after a user adopts an idea. The adjustment of the threshold denotes that a user has the ability to renounce a previously adopted belief. However, adopting a different opinion regarding the validity of the information is less likely after the user is convinced on a specific piece of information. Furthermore, the proposed model considers the impact of competing ideas to the users' choice of adopting an idea. Finally, contrary to existing models such as the LT model, we consider that the influence of a user over any other user in the network varies over time and there is a certain time frame that a user is more likely to be influenced by a specific neighbor.

To limit the spread of misinformation, in the second part of our approach, we propose an algorithm that, given a budget, aims at selecting an appropriate subset of users to initiate the propagation of credible information. Our goal is to identify a subset of users to act as seeds for the dissemination of credible news, so that the number of users *infected* during the spread of a non-credible information is minimized. We define as infected the users that contribute to the propagation of the misinformation. We formulate the problem as an optimization task and propose a greedy approach for selecting the subset of users to contradict the misinformation. We require that the size of the subset does not exceed the budget, satisfying therefore the cost constraints. The suggested technique exploits simulated annealing to determine the credible seed set, i.e., the users that initiate the propagation of credible information and we formally prove that our approach achieves an approximation ratio of $1 - 1/e$.

1.1. Contributions

The contribution of this work is summarized as follows:

- We introduce a novel propagation model where users' susceptibility to news dynamically adapts over time. The model captures the hesitance of users to renounce their beliefs, making it appropriate to realistically describe the spread of information in OSNs. Furthermore, while previous works ignore time constraints during the propagation process, we capture time as an actual unit. We argue that propagation time differs among any two users and exploit the Poisson Distribution to capture the probability of timely delivery of messages.
- We suggest a greedy approach that efficiently solves the problem of misinformation limitation by selecting an appropriate subset of users to decontaminate the network. Our proposed model for seed selection is efficient and independent of the structure of the underlying network. We prove that it approximates the best solution with an approximation ratio of $1 - 1/e$ and it is suitable for real-time misinformation containment, as it requires less than 23 min to identify up to 1000 seeds in dense networks.
- We illustrate through extensive experimental evaluation that our approach achieves notably better results than its competitors with respect to misinformation limitation with a remarkable reduction in resource costs. The suggested approach requires in all cases a significantly lower amount of messages exchange in the network, while achieving better results in misinformation blocking under different cost constraints, making it thus efficient and cost-effective.

2. Model and problem definition

In this section we describe the network model and formally define the problem of misinformation blocking. We further prove that identifying the appropriate subset of users to limit the spread of misinformation is NP-complete.

2.1. Network model

A social network is commonly represented as a directed weighted graph $G(V, E)$. Users of the network constitute the nodes and a directed edge from user u to v denotes the flow of information. For example, in the Twitter network, the edge $u \rightarrow v$ denotes that user v has replied to or retweeted messages published by u. We associate each edge $u \rightarrow v$ with a weight w_{uv}, which expresses

[4] http://twitchy.com/2015/05/04/we-screwed-up-shep-smith-apologizes-for-false-report-on-baltimore-shooting-video/.