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An effective rumor-containing strategy

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HIGHLIGHTS

- The issue of suppressing a false rumor by use of the truth is addressed.
- A rumor-truth mixed spreading model is proposed.
- The original problem is modeled as an optimization problem.
- Some optimal rumor-containing strategies are derived.
- The influence of different factors on the highest cost effectiveness is uncovered.

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ABSTRACT

False rumors can lead to huge economic losses or/and social instability. Hence, mitigating the impact of bogus rumors is of primary importance. This paper focuses on the problem of how to suppress a false rumor by use of the truth. Based on a set of rational hypotheses and a novel rumor-truth mixed spreading model, the effectiveness and cost of a rumor-containing strategy are quantified, respectively. On this basis, the original problem is modeled as a constrained optimization problem (the RC model), in which the independent variable and the objective function represent a rumor-containing strategy and the effectiveness of a rumor-containing strategy, respectively. The goal of the optimization problem is to find the most effective rumor-containing strategy subject to a limited rumor-containing budget. Some optimal rumor-containing strategies are given by solving their respective RC models. The influence of different factors on the highest cost effectiveness of a RC model is illuminated through computer experiments. The results obtained are instructive to develop effective rumor-containing strategies.

1. Introduction

Rumors are a common form of social interactions. A rumor is dispersed for achieving specific purpose, especially when a major public event occur and people do not have exact information and knowledge about the event [1–3]. The rapidly popularized online social networks (OSNs) greatly enhance the speed and enlarge the extent of rumor spreading [4,5]. However, most false rumors can inflict economic losses or disrupt social order [6]. To exemplify, Syrian hackers once broke into the twitter account of Associated Press (AP) and dispersed the rumor that explosions at White House had injured Obama,

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leading to a loss of 10 billion US dollars before the rumor was clarified [7]. Therefore, mitigating the impact of bogus rumors is of primary importance [8].

To effectively inhibit rumors, we have to gain insight into the laws governing rumor spreading. For this purpose, we need to establish and study appropriate rumor spreading models. The seminal work by Daley and Kendal [9] introduced the first rumor spreading model, in which a homogeneously mixed population is divided into three groups: ignorants who are unaware of the rumor, spreaders who are aware of the rumor and spread it, and stiflers who are aware of the rumor but do not spread it. See Ref. [10] for a popular introduction of the model. Since then, a multitude of rumor spreading models based on homogeneous networks have been proposed [11–19].

Empirical studies that started about two decades ago fully indicate that most realistic OSNs are heterogeneous rather than homogeneous [20,21]. In the past decade, therefore, much efforts were focused on rumor spreading models based on complex networks [22–37]. However, it is uncertain whether these models accurately characterize actual rumor spreading processes, because the models are derived through a series of approximations and do not perfectly accommodate the spreading network [38–40].

In 2009, Van Mieghem et al. [41] proposed an elegant individual-level susceptible–infected–susceptible (SIS) epidemic model, in which the time evolution of the state of each individual is characterized by a separate differential equation. Due to the exact modeling and the perfect accommodation of the network topology, this model characterizes the SIS epidemics more accurately as compared with all previous SIS models. Moreover, this model is analytically tractable, resulting in profound conclusions. In recent years, this individual-based modeling approach has been widely applied to areas such as epidemic spreading [42–44], malware propagation [45–52], cyber security [53–57], and message transmission [58]. To our knowledge, to date the rumor-containing problem has not yet been studied under individual-level rumor spreading models.

Clarifying rumors by releasing truths is a common way to inhibit rumors [59,60]. In this context, every individual may choose to believe the rumor or believe the truth or be uncertain. This paper focuses on the problem of how to inhibit a false rumor by use of the truth. Based on a novel individual-level rumor-truth mixed spreading model, the effectiveness and cost of a rumor-containing strategy are quantified. Thereby, the original problem is modeled as a constrained optimization problem (the *rumor-containing (RC) model*), in which the independent variable and the objective function represent a rumor-containing strategy and the effectiveness of a rumor-containing strategy, respectively. The goal of the optimization problem is to find the most effective rumor-containing strategy subject to a limited rumor-containing budget. Some optimal rumor-containing strategies are given by solving their respective RC models. The influence of different factors on the highest cost effectiveness of a RC model is uncovered through computer simulations. These results are conducive to the design of practical rumor-containing strategies. To our knowledge, this is the first time the rumor-containing problem is treated in this way.

The subsequent materials of this work are organized in this fashion: Section 2 establishes the rumor-truth mixed spreading model; Sections 3 and 4 formulate and study the RC model, respectively; Section 5 examines the influence of different factors on the highest cost effectiveness; this work is closed by Section 6.

2. The modeling of the rumor-truth mixed spreading process

This paper focuses on the following problem:

The rumor-containing (RC) problem: Find an effective strategy of containing a false rumor, provided the truth is released.

The key to solving the problem is to properly quantify the effectiveness of a rumor-containing strategy. For this purpose, we have to model and study the rumor-truth mixed spreading process. This section is dedicated to establishing the model.

2.1. The state of a population

Consider a closed population of N individuals labeled $1, \ldots, N$. Let $V = \{1, \ldots, N\}$. Suppose in the time horizon $[0, T]$ a false rumor is dispersed in the population through a rumor-spreading network $G_R = (V, E_R)$, where each node stands for an individual, and $(i, j) \in E_R$ if and only if person i can deliver the rumor to person j. Let $\mathbf{A} = \left[a_{ij}\right]_{N\times N}$ denote the adjacency matrix of G_R, i.e., $a_{ij} = 1$ or 0 according as $(i, j) \in E_R$ or not. Suppose in the time horizon $[0, T]$ the truth against the rumor is circulated in the population through a truth-spreading network $G_T = (V, E_T)$, where $(i, j) \in E_T$ if and only if person i can deliver the truth to person j. Let $\mathbf{B} = \left[b_{ij}\right]_{N\times N}$ denote the adjacency matrix of G_T.

At any time in the time horizon $[0, T]$, every individual in the population is in one of three possible states: *rumor-believing*, *truth-believing*, and *uncertain*. Let $X_i(t) = 0$, 1, and 2 denote the event that person i is uncertain, rumor-believing, and truth-believing at time t, respectively. Then, the vector

$$\mathbf{X}(t) = [X_1(t), X_2(t), \ldots, X_N(t)] . \tag{1}$$

represents the *state* of the population at time t.

Let $U_i(t)$, $R_i(t)$, and $T_i(t)$ denote the probability of the event that person i is uncertain, rumor-believing, and truth-believing at time t, respectively, i.e.,

$$U_i(t) = \Pr\{X_i(t) = 0\}, \quad R_i(t) = \Pr\{X_i(t) = 1\}, \quad T_i(t) = \Pr\{X_i(t) = 2\}. \tag{2}$$