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Applying Strategies for Fast Containment of Diseases

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ABSTRACT

Infectious disease presents great hazards to public health, due to their high infectivities and potential lethalities. One of the effective methods to hinder the spread of infectious disease is vaccination. However, due to the limitation of resource and the medical budget, vaccinating all people is not feasible in practice. Besides, the vaccinating effects are difficult to be timely observed through traditional ways, such as outpatient services. To tackle above problem, we propose an e-healthcare mobile social internet of things (MSIoTs) based targeted vaccination scheme to fast contain the spread of the infectious disease. Specifically, we first develop an e-healthcare MSIoT architecture by integrating the e-healthcare system and MSIoTs, whereby the spread status of the infectious disease is timely collected. Furthermore, a graph coloring and spreading centrality-based optional candidate searching algorithm is devised to hunt for the candidates that are powerfully capable of preventing infectious disease. Especially, in order to reduce the vaccination cost, we design an optimal vaccinated target selection algorithm to choose a minimum number of targets whose locations are differentially distributed. Extensive simulations demonstrate that the proposed scheme can effectively prevent infectious disease as compared to conventional schemes.

1. INTRODUCTION

Infectious disease exhibits a serious threat to our lives since the beginning of human civilization. The outbreak of an infectious disease makes a great loss of life and property, and even leads to social instability and riot [1]. Historical records show that the Black Death spreaded across the Europe in the 14th century, killing more than 25% of the European population [2]. The Spanish flu during 1918-1919, induced about 20-50 million deaths worldwide within one year, which is more than the casualties of World War I [3]. In recent years, according to the report of the World Health Organization (WHO), the outbreak of Ebola in 2014 caused high mortalitie in many countries, with a fatality rate of 70% [4]. Containing infectious disease is certainly a major concern to save lives and ensure the stable social condition. To minimize the number of casualties and costs for fighting disease, the effective and efficient measure is to timely detect the outbreak of the infectious disease and conduct vaccination in the critical, early stage of di ease spreading. For example, smallpox has been worldwide eradicated by the real-time monitoring and vaccination campaign [5].

However, the traditional infection containment approaches have some defects in controlling the spread of infectious disease. On one hand, the discovery of an infectious disease is mainly through patients visiting doctors with hospital diagnoses and treatments, where it is intractable to predict the outbreak of the infection. On the other hand, the isolation of susceptible persons needs a large amount of the government's health expenses and labor resources, and also incurs the susceptible persons' economic losses. Recently, a promising e-health system based on wearable Internet of Things (IOTs) [6] is proposed to address above public health crisis, by continuously sensing users' real-time health information, e.g., temperature, heart rate, blood pressure, and electrocardiogram, etc. In the e-healthcare system, a sever is deployed to collect the health data and detect the abnormal phenomena for providing supporting information of diagnoses [7] [8]. With the analysis on the health data, the medical centre can observe the users' health conditions. When the health conditions indicate that some users are infected by an infectious disease, the medical centre would execute immune strategies to control the spread of this infectious disease.

Targeted vaccination has been extensively studied [14]–[22]. For example, the artificial intelligence and simulation methods are jointly utilized to search for mobile users with the highest influence for tracking disease spread [21]. The wireless sensor system is employed to contain the infectious disease in [22], where the connectivity centrality is considered to find the most important mobile users. However, most of the existing works are still intractable to fast prevent infectious disease with e-healthcare MSIOTs. First, the location distribution of infection sources is not sufficient considered in the most of the existing works. Indeed, the infection sources are usually located in different areas, thereby the vaccinated targets with differential locations would induce different effects on prevent the infectious disease. Second, most of the existing works [19], [23] have an implicit assumption that all mobile users are uninfected during the searching of the vaccinated targets, where the infection sources may be selected as vaccinated targets. Third, the overlapping preventing effects of vaccinate targets are not taken into account in some of the related works, i.e., some vaccinated targets have the same effects on controlling the spread of the infectious disease. Therefore, a novel efficient targeted vaccination scheme needs to be devised for preventing infectious disease.

In this paper, we extend our previous conference version on the construction of e-healthcare MSIOTs [19] and propose a novel targeted vaccination scheme to contain the spread of the infectious disease. The proposed scheme can timely detect the outbreak of infectious disease and fast find the optimal vaccinated targets by fusing and analyzing the health data and social data. As such, both the infectious ratio and casualty ratio are sharply decreased, where the stable social condition and people's property can be jointly guaranteed. Specifically, we first integrate the e-healthcare system and MSIOTs to develop the architecture of e-healthcare MSIOTs for fast-tracking the spread of the infectious disease. Then, we exploit the graph coloring-based optional candidate searching algorithm to find the most widely distributed vaccinated candidates. Especially, taking both mobile users' infecting abilities and infected

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possibilities into account, a new metric named spreading centrality is presented for proper candidate selection. Finally, based on the infectious disease spreading analysis model, we design an optimal vaccinated target selection algorithm to avoid the overlapping containment effects. The main contributions of this paper are three-fold.

_ First, we propose a graph coloring and spreading centrality-based optional candidate searching algorithm. The graph coloring theory is exploited to find the most widely distributed mobile users for enlarging the range of immunity. Furthermore, we present a novel concept named spreading centrality by considering both the mobile user's infecting ability and infected possibility, whereby the proper candidates could be hunted for.

_ Second, we develop a dynamic equation-based analysis model to observe the spread of the infectious disease with the consideration of both mobile users' social data and health data. With the analysis model, we can fast observe the number of infected patients over time. Then, we can identify the effect of each mobile user on containing the infectious disease when he/she is vaccinated.

_ Third extensive simulations are carried out to evaluate the performance of the proposed scheme. We first evaluate the evolution of the infection ratio over time with different parameters including the number of vaccinated mobile users, disease spreading rate, and recovery rate. Afterwards, we compare the proposed scheme with conventional schemes to show the outperformed performances

2. BACKGROUND WORK

Since Kermack and McKendrick (1) established the theory of the SIR models and other corresponding compartmental models in the 1920s and 1930s, ordinary-differential-equation based compartmental models are among the most popular methods. Researchers continue to expand and employ them in modeling numerous infectious diseases (2-4). Besides compartmental models, other methods to predict the outbreak trend include network models (6), stochastic simulation (7), Markov chain Monte Carlo methods (8,9), and the Global Epidemic and Mobility model which captures the influence of potential traveling patients (5,10,11,12).

Medical resource supplement and allocation to contain a pandemic outbreak are also considered. Lewnard et al. developed a transmission model for Ebola and estimated the number of beds at the local Ebola virus disease treatment centers needed to effectively control the disease (13). Lee et al., working with Centers for Disease Control and Prevention, established simulation-optimization computational tools for mass dispensing of medical countermeasure operations that optimize resource allocation for maximum population protection while tracking and mitigating disease spread through sensible clinical design (14-20). Their system can be used in any treatment / shelter facilities. Wallinga et al. studied the optimal allocation of medical resources with limited data by targeting intervention measures at the group with the highest risk of infection per individual (22). Medlock and Meyers optimized the allocation of vaccines when there is a delay in vaccine supply (23).

Over the last two decades, our team has worked with thousands of public health leaders and frontline emergency responders, providing them with decision support tools and analytic-informatics expertise as they respond to numerous domestic and global public health crises, and establish state and federal guidelines. Specifically, we have developed specialized mathematical theory and computational systems for numerous infectious diseases including smallpox, hepatitis A, H1N1, Ebola, Zika, MERS, avian flu, and COVID-19 (17,19,20,21,24-28) and have the honor to assist on-the-ground operations with great success (16,18). Our experiences and lessons learnt reveal the challenge and urgency to derive a unified mathematical theory that is applicable to any type of infectious disease (29) and develop a holistic biological-behavior-intervention computational framework that allows for in-depth validation and adaption.

3. PROPOSED SYSTEM

In the proposed system, the system extends our previous conference version on the construction of e-healthcare MSIoTs [19] and propose a novel targeted vaccination scheme to contain the spread of the infectious disease. The proposed scheme can timely detect the outbreak of infectious disease and fast find the optimal vaccinated targets by fusing and analyzing the health data and social data. As such, both the infectious ratio and casualty ratio are sharply decreased, where the stable social condition and people's property can be jointly guaranteed.

Specifically, we first integrate the e-healthcare system and MSIoTs to develop the architecture of e-healthcare MSIoTs for fast-tracking the spread of the infectious disease. Then, we exploit the graph coloring-based optional candidate searching algorithm to find the most widely distributed vaccinated candidates. Especially, taking both mobile users' infecting abilities and infected possibilities into account, a new metric named spreading centrality is presented for proper candidate selection. Finally, based on the infectious disease spreading analysis model, we design an optimal vaccinated target selection algorithm to avoid the overlapping containment effects. Themain contributions of this paper are three-fold.

First, we propose a graph coloring and spreading centrality-based optional candidate searching algorithm. The graph coloring theory is exploited to find the most widely distributed mobile users for enlarging the range of immunity. Furthermore, we present a novel concept named spreading centrality by considering both the mobile user's infecting ability and infected possibility, whereby the proper candidates could be hunted for.

Second, we develop a dynamic equation-based analysis model to observe the spread of the infectious disease with the consideration of both mobile users' social data and health data. With the analysis model, we can fast observe the number of infected patients over time. Then, we can identify the effect of each mobile user on containing the infectious disease when he/she is vaccinated.

Third, extensive simulations are carried out to evaluate the performance of the proposed scheme. We first evaluate the evolution of the infection ratio over time with different parameters including the number of vaccinated mobile users, disease spreading rate, and recovery rate. Afterwards, we compare the proposed scheme with conventional schemes to show the outperformed performances.

Advantages

1) According to the type of infectious disease diagnosed by the e-healthcare server and the medical centre, the medical centre evaluates the infectious disease spreading parameters in effective and fast way (e.g., disease spreading rate and recovery rate, etc.) and the spreading features of the infectious disease.

2) The system is more effective due to presence of MSIoTs to develop the architecture of e-healthcare MSIoTs for fast-tracking thespread of the infectious disease..

4. IMPLEMENTATION

Healthcare Server

In this module, the Admin has to login by using valid user name and password. After login successful he can do some operations such as Login, View All Users and Authorize, View All Infection Diagnosis and Social Data Analysis, View Fast Containment Zones, Infectious Disease Spreading Analysis, View Vaccinated Users Status, View All Disease Results.

Bob

In this module, there are n numbers of users are present. User should register with group option before doing some operations. After registration successful he has to wait for admin to authorize him and after admin authorized him. He can login by using authorized user name and password. Login successful he will do some operations like Register and Login, My Profile, Add Infectious Diseases, View My Disease.

Social Server

In this module, there are n numbers of users are present. Transport Company user should register with group option before doing some operations. After registration successful he has to wait for admin to authorize him and after admin authorized him. He can login by using authorized user name and password. Login successful he will do some operations like Register and Login, View All Diseases, Search Patients.

5. CONCLUSION

We have proposed a novel e-healthcare MSIOTs based targeted vaccination scheme to control the spread of the infectious disease. The architecture of e-healthcare MSIOTs is developed by integrating the e-healthcare system and MSIOTs, whereby the health data and social data are jointly collected. With the health data and the social data, the infectious disease spreading analysis model has been devised to observe the spreading process of the infectious disease. Furthermore, we have designed a graph coloring and spreading centrality based vaccinated candidate searching algorithm to find the most widely distributed and influential candidates. To reduce the vaccination cost, we have devised a vaccinated target selection algorithm to choose the optimal ones for preventing infectious disease. The simulation results show that the proposed scheme is superior to other conventional schemes. On the future work, we will study the privacy preservation mechanism during the exchange of both health data and the construction one healthcare fog of social IOTs.

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