Dynamic complex network based on status value for infectious disease

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ABSTRACT

COVID-19 plays role in every part of the world; especially, it does harm to lives of people. Thus, COVID-19 sounds the alarm that is very important to build an effective mechanism to help prevent pandemic disease. In this work, dynamic network based on status value is built, which aims to help simulate the added danger level by the addition of infected people or close contacts. First, each node of this network is labelled with different kinds of status which has special value to show its danger degree. Then, the weight of the network represents the relationship of nodes; with the value of each node, average length and average spread of danger level is calculated based on the accumulation of dynamic weight. Thus, epidemic speed and scope of the infectious disease can be simulated. Moreover, the experiments compared to other networks have verified the effectiveness of our model.

Keywords: Complex network, dynamic status, information integration

INTRODUCTION

COVID-19 is the most important global event in this year, because it changes the pattern of world including economics, social contact, medical care, and so on[1]. The situation is ill seriously. Firstly, the burden of hospitals in some countries is so huge that the patients with other diseases cannot be treated as before[2]. Second, a large number of companies have to stop their business. People lost their work; thus, the living becomes terrible. A lot of people do their best to prevent its destructive impact[3]. In order to stop from the ongoing pandemic, COVID-19 vaccines are urgently needed[4]. Besides regimens, it is an effective way to find the ill or incubatory person who should be kept in quarantine. Ideally, all the infected people can timely be given treatment and infected boundary is under control. This is to say that COVID-19 can stop its extension. However, the infected person still conducts the social work before the infected evidence is clearly. The people, who has the touch with the infected person, may be infected. This kind is called as close contacts. If we want to describe the infected boundary, all the close contacts must be found.

According to the above analysis, pandemic disease is very harmful. COVID-19 sounds the alarm that an effective mechanism is necessary to prevent the pandemic. The mechanism should include medical treatment and other assist. With the development of computer technology, it has been verified that it is useful to provide information management, data mining, and so on.

In order to get this aim, a novel network, namely Dynamic Network based on Status Value (DNSV), is built in this work. To simulate the real situation of outbreak of infectious disease, the nodes in the network are partitioned into five kinds of status which are health, first generation of close contact, second generation of close contact, isospace, and illness. This definition can help improve the effectiveness of stopping infectious process. Besides the status of the nodes, they are fully connected. The connectedness of nodes is dynamic; thus, the weight of edges is used to show the connectedness of the nodes. Moreover, the weight of the edge is convenient to control the strength change of current connectedness. The typological structure is the basis of each complex network; thus, the degree, clustering coefficient, and average path length are the necessary parts where complex network is used to research real application. DNSV has its own structure; thus, the classical definition describing the characteristic of complex network cannot provide enough information. Another important contribution of the paper is to define the novel characteristics which have ability to depict the current situation, speed, scope of the disease. Experiments also supports our model.

Section 2 gives the background. Section 3 is the main part of this paper, which shows DNSV and the new definition evaluated the network. Section 4 is the experiment. Section 5 is the conclusion.

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2. BACKGROUND

The effectiveness of complex network has been verified in lots of application[5-7]. In this part, the basic theory of complex network is introduced. A network is constituted by nodes (also can be expressed as vertices) and edges (also can be expressed as links). Nodes show the participants whose relationship is given as edges[8]. If two nodes are connected to each other by an edge; then, they are called adjacency points. In order to evaluate the topology of different networks, some definitions, which describe important characteristics, are necessary and shown as follows[9-11].

Definition 2.1 A degree of a node (DN) is the number of edges connected to this node, which is denoted as k_i. The average of degree calculated by each node is defined as the degree of the network which is shown in equation (1),

$$\langle \mathrm{k} \rangle = {}^{1}\!/\!_{n} \sum_{i=1}^{n} k_i \tag{1}$$

and n is the total number of nodes in the network.

Definition 2.2 If any edge in a network is directed, each node has in-degree and out-degree. In-degree is the number of edges by which this node can get information from other connected nodes; out-degree is the number of edges through which this node can send information to other nodes. In order to calculate in-degree and out-degree, adjacent matrix is given as equation (2).

$$\begin{bmatrix} a_{11}\, a_{12} \cdots a_{1n} \\ a_{21}\, a_{22} \cdots a_{2n} \\ \ddots \\ a_{n1}\, a_{n2} \cdots a_{nn} \end{bmatrix} \tag{2}$$

where $a_{ij} = \begin{cases} 1 & node_{\,i}\ get\, a\, link\ from\, node_{\,j}; \\ 0 & otherwise. \end{cases}$ Thus, in-degree of node$_i$ is the sum of the ith row of equation (2). The calculation of out-degree is similar as the process of in-degree. Thus, the work does not give unnecessary details.

Definition 2.3 For any node in a network, S is the set of adjacency points linked to this node. $|S|$ is the number of elements in S. Then, the number of the edges, which just connect the nodes in S, is denoted as λ. The clustering coefficient of this node is $\frac{2\lambda}{|s|*(|s|-1)}$.

Definition 2.4 Average path length is $\frac{2}{n*(n-1)}\sum_{i\geq j} d_{ij}$ where d_{ij} is the path length of node$_i$ and node$_j$.

3. INTEGRATION AND DYNAMIC NETWORK

Besides medical treatment, computer technology can be used in a system to prevent the pandemic. Because computer technology can cut the burden of time, cost of human, and so on.

3.1 Integration system

It is clear that finding infected person is very useful to stop viral transmission. Incubation period makes finding infected person or close contacts more difficult. Health code help search close contacts; then, effective strategy, such as isolation, can be employed to prevent the spreading. However, the whole process is not full-automatic, which includes medical testing, finding infected person or close contacts and informing staff. Every part in prevent the transmission of the disease has own information management. If we can integrate all necessary parts and advance a reliable algorithm to accomplish information conveyance function based on the network expressed the health status of each person, it is very helpful to enhance the efficiency of finding infected persons and making decisions to stop transmission. Figure 1 shows the components of the system which can provide automatic warning based on dynamic complex network and intelligent computer technology. The core of this system is the information integration and decision center. Since information security and sensitive data must be protected; direct data exchange among each element needs complex procedure which adds time cost. It is easy to know that the system needs automatic and effective data processing. Thus, an integration center gets different kind information from the related organization at first. Then, it filters information as the defined rule and sends the necessary data to next step. Besides core center, Medical treatment, Isolation and Data mining are the main parts in the system.

Hospital accomplishes testing and medical treatment. At the same time, the result of testing and the necessary data of hospital is provided to the centre. With the help of computer- aided analysis, an optimal scheduling of medical resource can cut time and human cost. Isolation can stop the possible spreading of disease, which needs data analysis and testing result to keep the period. The last part is the main part discussed in this work. It is a useful method to find the infected cases and close contacts. Under medical treatment, the possibility of severe case is reduced. At the same time, isolation of close contact can cut the infectious link. Health code tracked record of people. However, special case makes health code unuseful, such as private family gathering. Thus, this part conducts a dynamic complex network based social relationship and action record. Then, Community discovery is given to finish data analysis.

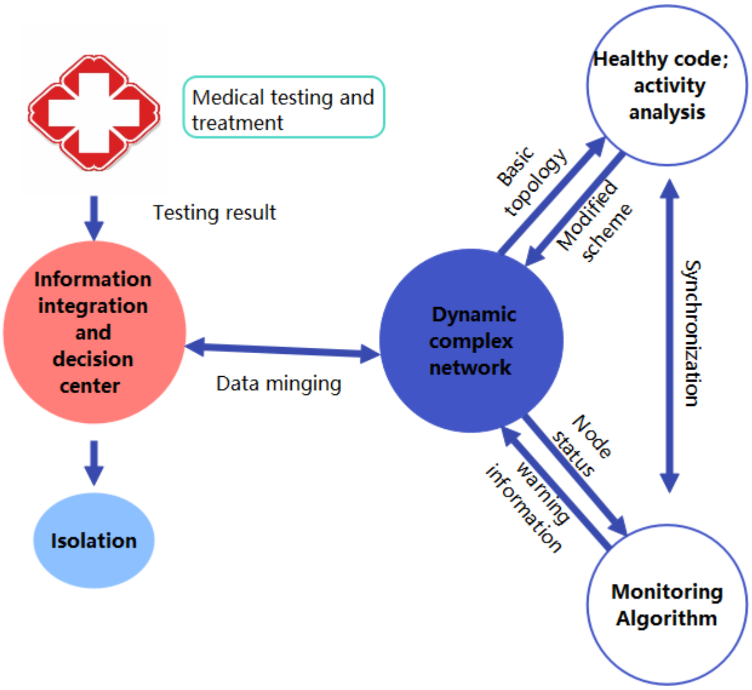

Figure 1. Information integration and decision.

3.2 Dynamic complex network

According to the analysis in the last paragraph, finding the conformed cases and close contacts is a very important in convincing pandemic. Complex network can show the relationship and the process of information transmission among the nodes. Thus, it is a very useful tool to research infectious disease. In this work, a network is firstly constructed to describe the status of people and their social relationship, which is called Dynamic Network based on Status Value (DNSV). Every node of this network is one of five kind statuses namely health, first generation of close contact (CC), second generation of close contact, isospace, and illness. And the status of each node can be changed. These are illustrated in Figure 2. The initial status of each node in the network is health. If the node has information transmission with a node with the status of illness, then its status is changed to first generation of CC. If a node has information transmission with a node with the status of first generation of CC, the status of the node is second generation of CC. Isospace means that a node arrives at the same building as a node of illness at the similar time. It can be seen that the arrows in Figure 2 tell the direction of status change.

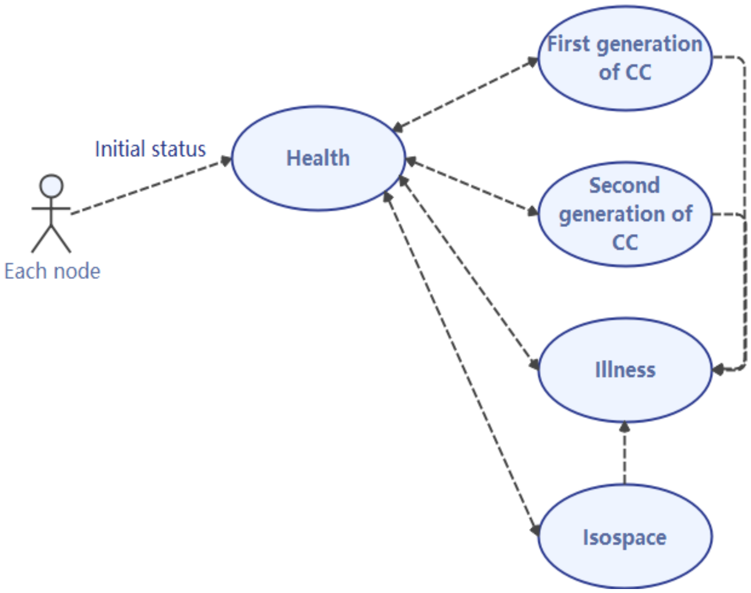

Figure 2. Status change of a node.

In DNSV, the link is used to simulate the contact among people. The frequency analysis and different scene play role in the infectious possibility, which is denoted as weight of the link in this work. Thus, the status of nodes and the weight of links are coordinated to model the spreading of the disease, which is given in Figure 3. Since, the weight of each edge is dynamic; DNSV is set as fully connected network. It means that the connected two nodes have no relationship when the weight of the link is 0. Different shape of nodes means different status. A good understanding of the network is very useful to build correct decision to stop the illness. It has been approved that complex network is an important tool to analyze diseases. However, the basic characteristic definition of complex network in Section 2 is not suitable for the special network. In order to solve this problem, the novel definition is given.

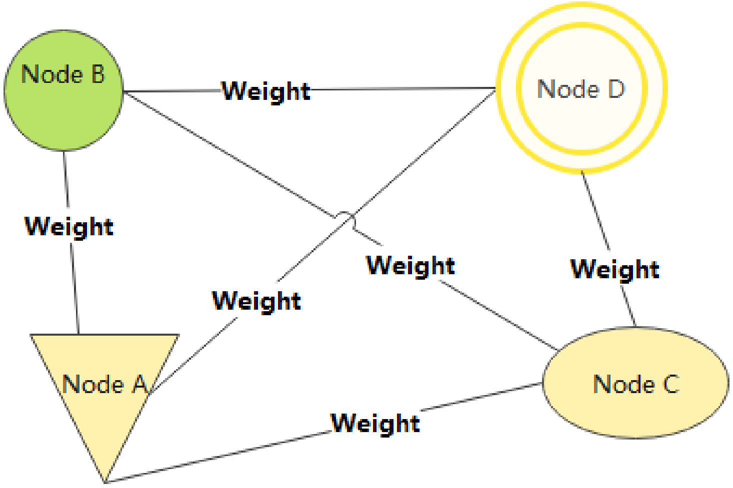

Figure 3. Prototype of the network.

Since DNSV in this work is special, the basic definition cannot give enough information. The status of each node decides whether the information transmitted to the linked nodes are danger. Thus, the status should be considered in the definition. There are five kinds named health, first generation of CC, second generation of CC, illness, isospace. According to the danger degree, we give the value of each status as

$$\left|node_i\right| = \begin{cases} \chi, \ \text{status is Health or Isospace} \\ \chi + \delta_{i1}\Delta, \ \text{status is Second generation of CC} \\ \chi + \delta_{i2}\Delta, \ \text{status is first generation of CC} \\ \chi + \delta_{i3}\Delta, \ \text{status is Illness} \end{cases} \tag{3}$$

where $\left|node_i\right|$ means the value of node$_i$, and $\chi, \delta_{ij}, \Delta \geq 0$. χ is the initial value; δ_{ij} is the step; $, \Delta$ is the increased value.

Defintion 3.1 Dynamic weight danger degree-based node value is defined as below:

$$\langle \mathrm{k} \rangle = \frac{1}{n*3} * \sum_{i=1}^{n} \sum_{j=1}^{n} \left(w_{ij} + m \sim t(\Delta w_{ij}) \right) * \left|node_j\right| \tag{4}$$

where $w_{ij} = 0$ if node$_j$ is not linked to the current node$_i$; otherwise, w_{ij} is the weight of the edge between node$_j$ and node$_i$. And $m \sim t(\Delta w_{ij}) = ave(\Delta t * \Delta w_{ij})$; Δt is the variation of time step.

Definition 3.2 Ave-length of dynamic danger is $\frac{1}{3*n*(n-1)} \sum \left(\left|S_{ij}\right| * \sum_{j=1}^{n} \left(w_{ij} + m \sim t(\Delta w_{ij}) \right) * \left|node_j\right| \right) \quad \forall d \in S_{ij}, w_d > \alpha$,where S_{ij} is the edge set of path, and $\left|\bullet\right|$ is the amount of the set.

It is clear that the beginning of S is node$_i$ and its end is node$_j$. The Ave-length of dynamic danger is defined to focus the nodes of high danger level in the process of the derivation of the connectedness. Then, the spreading length of the current infectious disease is calculated. Besides this, the scope of the disease is also needed to be considered. Ave-spread of danger level is given in Definition 3.3.

Definition 3.3 For any node, the set of adjacency points is NN . Ave-spread of danger level is $\frac{2}{3n} \sum_{i} \left(\frac{|S|}{|NN| * \left(|NN| - 1\right)} * \sum_{j=1}^{n} \left(w_{ij} + m \sim t(\Delta w_{ij}) \right) * \left|node_j\right| \right), \forall d \in S, w_d > \alpha$,where $\left|S\right|$ is the mount of edges connected the nodes NN .

4. SIMULATION

In order to evaluate our method, the classical models of complex network are used in this work. Table 1 gives the related results. First, we need to explain the setting of each work. SW_net (N, P, RW) means this is a WS Small Word Network; N is the amount of nodes in the network; P is the edge possibility; RW represents the rewriting possibility. BA (N, IND) mean BA scale-free network; IDN is the number of initial nodes. P of RW (N, P) is the edge possibility. Table 1 shows the results of these networks.

Table 1. Result of classical networks.

Type of network	Setting	Average degree	Average path Length	Clustering coefficient
Small world	SW_net (100, 0.2, 0.01)	20	2.3162	0.6779
	SW_net (100, 0.2, 0.05)	20	2.2042	0.6442
	SW_net (100, 0.2, 0.1)	20	2.0430	0.5593
	SW_net (200, 0.5, 0.01)	100	1.4975	0.7282
	SW_net (200, 0.5, 0.05)	100	1.4975	0.6809
	SW_net (200, 0.5, 0.1)	100	1.4975	0.6267
BA scale free	BA (100, 10)	16.62	1.8879	0.2796
	BA (100, 20)	18.18	1.8671	0.3714
	BA (100, 30)	21.42	1.8364	0.5202
	BA (200, 10)	17.99	2.0877	0.1791
	BA (200, 20)	18.74	2.0750	0.2179
	BA (200, 30)	20.2	2.0510	0.2948
Radom network	RW_net (100, 0.05)	4.96	INF	0.0498
	RW_net (100, 0.1)	9.9	2.2382	0.1211
	RW_net (100, 0.15)	14.86	1.9614	0.1746
	RW_net (200, 0.05)	9.95	2.5581	0.0568
	RW_net (200, 0.1)	19.9	2.0459	0.1204
	RW_net (200, 0.15)	29.85	1.8733	0.1725

Table 2 shows the results of our model. The possibility of nodes in first class is is 70%; the possibility of nodes in second class is 20%; the possibility of nodes in other class is 5%. Derivation Possibility (DP) is the possibility to increase the value of each node. With the addition of DP, the danger level increases. In order to provide a clear comparison to the three kinds of complex network, the threshold value of weight is set as 0. That is to $\alpha = 0$. The addition value in Table 2 shows that the whole status of the network become more danger than before. This cannot be described by others.

Table 2. Results of DNSV.

Network	Derivation Possibility	Dynamic weight danger degree-based node value	Ave-length of dynamic danger	Ave-spread of danger level
WN100	0	1.2781	2.286	0.2755
NW100_0.05	0.05	1.4227	2.5438	0.3071
NW100_0.1	0.1	1.5767	2.8211	0.3402
WN200	0	2.6436	4.7046	0.607
NW200_0.05	0.05	2.9163	5.1894	0.6699
NW200_0.1	0.1	3.2439	5.7724	0.7446

5. CONCLUSION

In this work, an integration system is discussed to finish the information transmission in an automatic way. This system includes the data center to control whole process of the information transmission. Besides this, a complex network is built to help assess the situation of infectious disease. The status of nodes in the work is an important content to simulate the spreading process. With the changes of status of the nodes, the danger level of the whole network must be updated. New definitions are used to evaluate the epidemic length and scope of the disease. The mathematic and experiments compared to other networks verify the effectiveness of the work.

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