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A growing social networks model of physical objects in IoT[①]

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Abstract

In Internet of Things (IoT), physical objects can build their own social networks. How do social networks of physical objects generate, and what characteristics do the social networks have. In order to solve these problems, according to the interaction of physical objects in IoT, this paper presents a growing social network model of physical objects and researches the attachment mechanism of the model that includes three modes, physical distance, social distance and preference. Through the simulation realizations of the model, the characteristics (e.g. degree distribution, community structure) of social network are analyzed. The model can forecast the growth of social networks of physical object in IoT and simulate social networks of physical objects in the large scale IoT.

Key words: Internet of Things(IoT), social networks, physical objects

0 Introduction

IoT (Internet of Things) senses physical world through all types of sensors and has a supercomputing ability[1]. IoT has been applied in medical, transportation and other fields[2-4].

In IoT, physical things include physical objects, behaviours, tendencies and physical events, in which physical objects (e.g., people, vehicles, tables, and birds) refer to concrete things with tangible bodies. With the development of short distance wireless communication technology (e.g. bluetooth, WI-FI), the physical objects can establish temporary, self-organizing Ad hoc network. These physical objects can be smart phones, wearable devices, smart cars, etc. and can also be called smart objects. The physical objects communicate with each other and supply services to humans. Here, smart objects except human will be discussed[5].

Each object usually has natural attributes and social attributes. Natural attributes refer to the characters of the physical object itself. Social attributes refer to some attributes associated with human society or various relations among physical objects. For example, a desk has colour, length, width and height, which are nature attributes, but if a desk is owned by Emily, the desk and Emily has ownership relation, which is social attributes. In IoT era, social attributes of object have the following benefits: Helping nation, government or individuals to efficiently deal with some social questions: such as crime, food safety, medical, traffic, etc; Through social network among physical objects (thing's society), solving some questions in IoT to improve quality of service (QoS) of IoT[6].

The perception, the interconnecting and the interworking among the physical objects show up the complex social attributes. The physical objects can interact with each other and form own social networks. For example, in smart homes, some smart devices are connected to serve the old people. The old people can be assisted in the event of an emergency. Some wearable devices can collect some physical signs information in real time, e.g. blood pressure, heart rate, blood sugar. This information can be transmitted to other devices through social networks. Only the friends of the device can obtain this information. The device needs to save this friend list and use it in the future service search. How are social networks generated in IoT, and what are the characteristics of social networks in IoT. For these questions, the model of social networks of physical objects is studied.

The authors of the work put forward a growing social network model of physical objects in IoT, research the attachment of the model, and analyse the characters of the model through simulation realization.

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The remainder of this paper is organized as follows. In Section 1, related work is reviewed with social attributes research related to IoT and social networks model. In Section 2, a growing social networks model of physical objects in IoT is put forward. And the section provides the social network generating algorithms, and analyzes the characteristics of the model through simulation realizations. In Section 3, a conclusion is given.

1 Related work

The knowledge of social networks models of human is important for creating the social networks model of physical objects. The Internet, the social networks, the information networks and the biological networks are complex networks. Social networks of human have general complex network model and also have their own special network model. In this section, some models related with the complex network and social network of human are reviewed.

1.1 Social attributes in IoT

Many researchers have paid attention to the social attributes of IoT. Liu[7] introduced a perceived social theory idea and emphasized the social attributes of IoT such as network socialization, coordinated socialization and service socialization. Ning[8] proposed U2IoT architecture of IoT consisting of unit IoT like mankind neural system and ubiquitous IoT like social organization framework. Furthermore, the author studied the physical objects' identification, state, behaviour, relationship and other social attributes, and proposed social attributes (dimension) concept for the IoT[9].

Atzori introduces a novel paradigm of 'social networks of intelligent objects', namely social IoT (SIoT), which integrates social networks concepts into the IoT solutions[10]. It has several advantages: guaranteeing the network navigability, establishing trustworthiness, addressing IoT related issues. Every object can look for the desired service using its friendships relationship. The author analysed possible strategies for selection of appropriate links for the benefit of overall network navigability. But this research doesn't involve social networks model of physical objects.

Opportunistic IoT[11] is that IoT has opportunistic networks connection ability. Mobile phones, smart vehicles, wearable devices and other smart objects can form opportunistic IoT by using short-range radio techniques. The IoT realizes a perfect convergence of cyber-physical-social-thinking hyperspace. The social space considers both human and things societies. The things society means that a physical object establishes inherent and acquires connections (acquaintances) with other physical objects or cyber entities in both real and digital worlds[12]. The researches mentioned above only focus on the social attributes of the IoT, but not pay attention to the social network model of physical objects in IoT.

1.2 Social network models in human society

A complex network is a graph with non-trivial topological features. These features do not occur in simple networks such as random graphs, but often occur in graphs modelling of real systems[13]. In complex network, some parameters, e. g. degree distribution, clustering coefficient, show the characteristics of the complex network. The distribution function $P(k)$ can be used to describe the degree distribution. $P(k)$ denotes the probability that the degree of a node is k. If node i has k_i edges, then it has k_i neighbour nodes. There are at most $k_i(k_i - 1)/2$ possible edges among those k_i neighbours. Therefore, the clustering coefficient is defined: $C_i = 2E_i/(k_i(k_i - 1))$. E_i is the actual number of edges of node i. The modularity Q is a method that can describe the intensity of the community. When Q is close to 1, the network community intensity is stronger. Modularity social community partition algorithm is frequently-used[14].

In human society, the social networks are a group of people who are connected together in a certain relationship. Modelling social networks can discover real social network characteristics and can help the human in understanding these characteristics. The social networks are dynamic, which means that the network topology changes and the social behaviour changes. The change of network topology is mainly reflected in node increasing or reducing, and the generation, maintenance and removal of the connection between nodes. The social behaviour evolution is mainly reflected in the information dissemination, virus spreading, viewpoint information, and so on.

Research has discovered that social networks have several typical characteristics: positively skewed degree distribution, high average clustering coefficient, positive degree correlations, small average shortest path length, and existence of community structure[15].

In the research of complex networks, some network structure models are studied that can simulate the connection mode of real network and help to understand the meaning of these connecting modes. For example, random graph is a typical network structure model. In recent years, the research in complex network has discovered that the degree distribution function of complex networks is power law distribution. This type of network is scale-free network. In order to explain the mechanism of power-law distribution, Barabasi and Albet proposed a scale-free network model called BA model. In BA model, the real network has two importance characters: (a) Growth: The scale of the network is growing. For example, every month there will be a large number of new scientific research articles published; (b) Preferential attachment: there is a Matthew effect or rich getting richer, which means that new nodes are more inclined to connect with nodes that have greater degrees[16].

Researchers have also proposed some models for social networks. One social network model is based on the social distance attachment. The social distance is defined on the metric social space. Individuals establish social connections (acquaintances) according to their social distance. Link probability r between nodes i and j is shown in

$$r = \frac{1}{1 + [b^{-1} \times d(i, j)]^{\alpha}} \quad (1)$$

where b is the characteristic length scale that eventually will control the average degree, $d(i, j)$ is the social distance, $\alpha > 1$ is a measure of homophily, that is the tendency of physical objects to connect to similar physical objects[17]. Riitta Toivonen, et al[18]. presented a model for an undirected growing network. The model consisted of two growthing processes: random attachment and implicit preferential attachment resulting from following edges from the randomly chosen initial contacts. Lynne Hamill, et al[19]. proposed a simple structure for agent-based social network model. The model is based on the concept of social circles. The circle limits the size of the personal network, which has the characteristic of low density, high clustering coefficient and assortativity of degree of connectivity. Arturo, et al[20]. presented a new model for growing social networks. The attachment mechanism of the model is based on the existence of network communities of friends. Thus, the model is called friend attachment model. Alberto, et al[15]. proposed an energy-based model for spatial social networks and established dimensional spatial networks based on energy as the realistic constraint to create the links.

The physical objects dynamically enter into the IoT and create social relation with other physical objects. The social network changes with time variation. The social networks in IoT also have growing and preferential attachment mechanism. Then, the growing social network model of physical objects will be discussed.

2 Social networks model and experiment

In IoT, each physical object has a communication scope in short distance communication. The scope defines a physical reach. The physical objects can communicate within mutual physical reach. Homophily is a typical characteristic of social networks. Two people who have social similarity can make friends. For example, people who have similarities in identity, age and economy are easier to make friends[21]. Thus, the physical objects in the IoT can establish social networks according to their social distances. The social attribute sets of the physical objects include the following attributes:

Object type. This denotes the category of physical object, e. g. smart car, smart phone.

Owner relationship (OR). This denotes the owner of the objects.

Social object relationship (SOR). If the owners of two objects are friends, the two objects have SOR. The social network based on SOR is shown in Fig. 1.

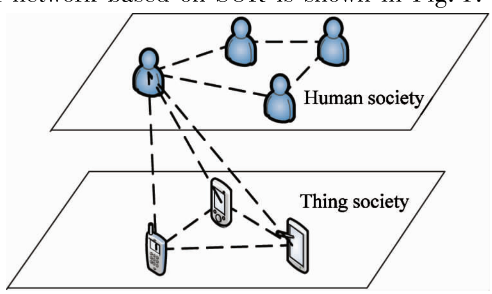

Fig. 1 Social networks based on SOR

In IoT, the newly entered objects are more likely to communicate with some of the centre objects that have strong communication ability. Thus, the form of social networks in the IoT has three attachment mechanisms.

Physical distance attachment: the physical reach is defined as R. If the distance between any two nodes is less than R, a connection is added on the two nodes. The distance is given by the standard Euclidean metric. Of course, other distance method can be used, e. g. Manhattan distance.

Social distance attachment: a physical object can use three-tuples to represent itself, object = (Id, T, O). Id is the identification of physical objects. T is the object type of physical objects. O is the owner of physical objects. If any two physical objects are the same type (T1 = T2), they have a priority of building relationship. If the owners of any two physical objects are same (O1 = O2), they can build relationship. If the owners of any two physical objects are friends and they can build SOR relationship. If the physical object hasn't found an object with social similarity, it will randomly select an object to connect with itself. This mechanism makes it recognize more different objects and make friends in global scope.

Preferential attachment: the new node connects with existing node i according to the preferential attachment probability shown in Eq. (2). k_i is the degree of the node i. $\sum_j k_j$ is the sum of all node degree.

$$p(k_i) = k_i / \sum_j k_j \tag{2}$$

IoT supplies service for people, so there are all sorts of applications, for example, smart home, smart transportation, smart city, etc. The physical objects may build social networks based on specific service. When the node enters the network, it may select an object based on the physical distance, the social distance or the preference. Therefore in the realization, the probability is used to express the selection mechanism. The social networks of physical objects that can supply service to people are shown in Fig. 2.

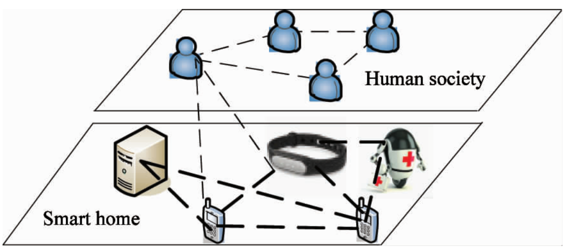

Fig. 2 Social networks based on social service

The generation process of social networks based on service is shown in Fig. 3.

Initial network: the initialization network has m_0 nodes that supply specific service. m_0 nodes can select full connection, isolate nodes or random connection.

Network growing: a new node enters into the network, and builds connections with m nodes, $m \leqslant m_0$.

Attachment selection: the attachment mechanism is selected with probability p_1 physical distance attachment, probability p_2 social distance attachment and with probability p_3 preference attachment.

The experiment is carried out in Matlab. The running host is equipped with Intel Xeon CPU 2.80GHz, 8-core, 8GB memory, and running Windows Server 2008 OS. In the experiment, different p is set to analyze the characteristics of the social network of physical objects. N is the total nodes of the generated social network. When $p_1 = p_2 = 0$, the network is a BA network based on preference. When $p_1 = p_3 = 0$, the network is a social network based on social distance. When $p_2 =$

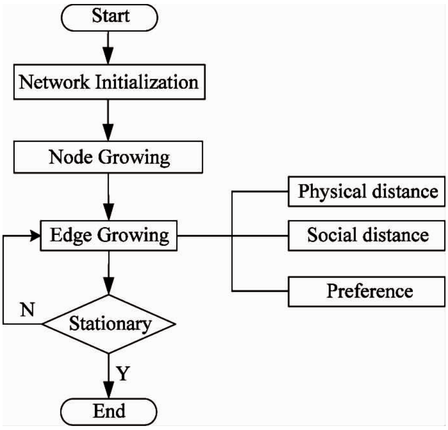

Fig. 3 The growing process of social networks

$p_3 = 0$, the network is a social network based on physical distance. Different parameters are used to construct the network and describe its characteristics. In the simulation, three attachments are set as three branches. The rules for the generation of p_1, p_2 and p_3 and the selection of branch are as follows: a number is randomly generated in the interval [0, 1], and is assigned as p_1. If $p_1 > 0.5$, the first branch will be selected; else a number is randomly generated in the interval [0, 1], and is assigned as p_2. If $p_2 > p_1$ and $p_2 + p_1 < 1$, the second branch will be selected, otherwise $p_3 = 1 - p_1 - p_2$, the third branch will be selected. The experiment uses degree probability and clustering coefficient indexes to show the characteristics of the network. According to the computing method of these indexes, the result is acquired from the realization algorithm, and the figure is drawn through plot function of Matlab. Next, different p_1, p_2 and p_3 will be set to show the characteristics of different network.

2.1 $p_1 = p_2 = 0$

When $p_1 = p_2 = 0$, the attachment is only preference attachment. Thus, the network is BA network. When $m = m_0 = 3$, $N = 2000$, the network generates 2944 edges. The average degree is 2.994. The degree probability distribution that follows power-law distribution is shown in Fig. 4. The average path length is 3.543. Therefore, the network has small world characteristic. The clustering coefficient is 0.027, which means that the clustering characteristic isn't obvious.

2.2 $p_1 = p_3 = 0$

The attachment mechanism is social distance attachment. In social distance attachment network model[13], the degree distribution follows Poisson distribution. The network has large clustering coefficient and community structure. According to the experimental

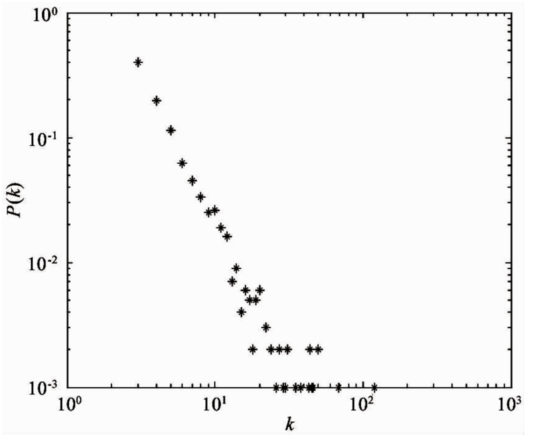

Fig. 4 Degree probability distribution in $p_1 = p_2 = 0$

result, the clustering coefficient is close to 1. When $N = 1000$, $m = 50$ and $m_0 = 100$, the network is divided into 51 communities and the modularity is 0.976. The degree distribution is shown in Fig. 5. Multiple experiments validate that the network always has an obvious community structure. The degree distribution is close to Poisson distribution.

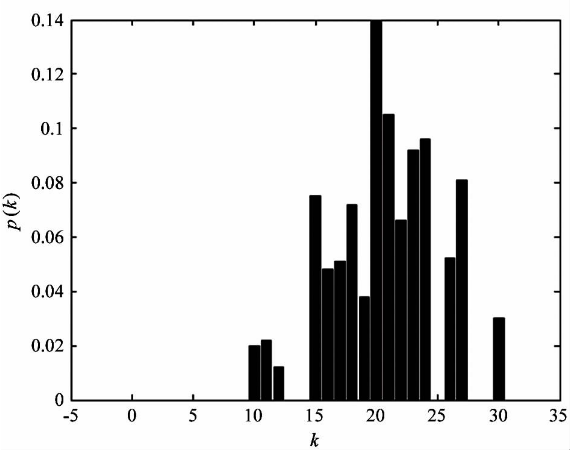

Fig. 5 Degree probability distribution in $p_1 = p_3 = 0$

2.3 $p_2 = p_3 = 0$

The attachment mechanism is physical distance attachment. According to the simulation result, when R remains invariant, the average degree becomes large with the growth of the number of nodes, that is because of more connected nodes. When the number of nodes remains invariant, the average degree becomes large with the growth of R. This is because the distance of more pairs of nodes is less than R. In real network, R has a maximum value due to the limitation of the communication distance. In the result, the clustering coefficient always remains near 0.6 with the changes of N and R. In Random Geometric Graph, the clustering coefficient has been demonstrated to be $1 - \frac{3\sqrt{3}}{4\pi} \approx 0.5865$. The average degree equals $\pi N R^2$, so the degree distribution follows a Poisson distribution[22]. When $N = 2000$ and $R = 0.068$, Q is 0.77 and the number of communities is 15. The network has an obvious community structure. The degree distribution is shown in Fig. 6. The degree distribution is close to Poisson distribution.

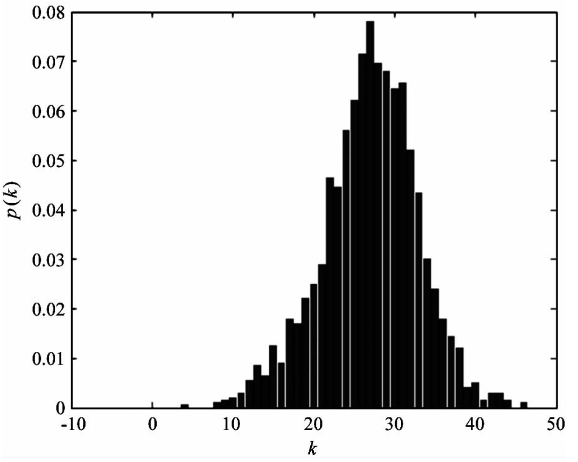

Fig. 6 Degree probability distribution in $p_2 = p_3 = 0$

2.4 p_1, p_2 and p_3 are not 0

When $m_0 = 3$, $m = 3$ and N takes different value, the parameters of the network are shown in Table 1. According to the value of average clustering coefficient, the network does not have obvious clustering characteristics when the network size is large. When $m_0 = 3$, $m = 3$ and $N = 1000$, a network is generated with 2709 edges. The degree distribution is shown in Fig. 7. The degree distribution (log-log) of social network model follows the power-law distribution.

When people get in touch with each other, their devices (e. g. smart phones) also begin to contact with each other. In the SIoT, the author has used the data source that comes from online social network Brightkite[23], and certified that the network has a small average shortest path length, high clustering coefficient and community structure. From the above three social network models, social connections are different in different situations. Thus, the social network models are different and have respective characteristics.

Table 1 The characteristics of networks for different nodes

N	Average clustering coefficient	Average degree
100	0.13705	3.72
300	0.06158	2.26
500	0.08144	4.796
700	0.08721	5.091
900	0.09398	5.382
1000	0.07448	5.417

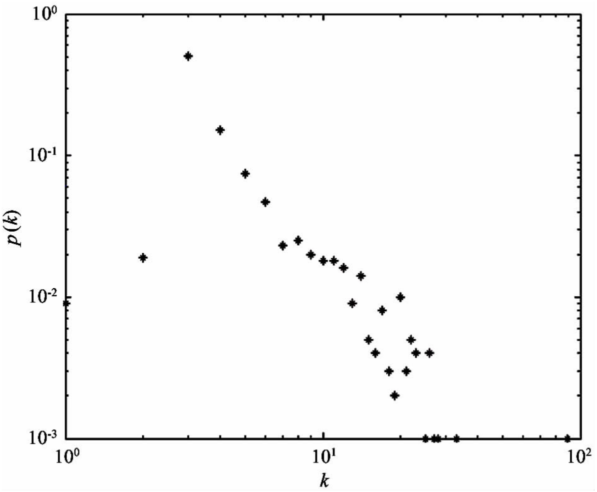

Fig. 7 Degree probability distribution in p_1, p_2 and $p_3 \neq 0$

3 Conclusion

In this work, a growing social network model of physical object in IoT has been proposed which has growing attachment mechanisms. The attachment mechanisms have three situations, which are physical distance attachment, social distance attachment and preference attachment. The social network can be generated according to different attachment mechanisms and growing mechanisms. The degree distributions of networks are generated according to physical distance attachment and social distance attachment following the Poisson distribution, and clustering coefficients is respectively close to 0.6 and 1. However, if the network is generated according to preference attachment, its degree distribution follows a power-law distribution and its clustering coefficient is close to 0. The proposed model is generated by considering the real situation. Therefore, the proposed model can be used to forecast the social interaction growing of physical objects and simulate the social networks of physical objects in large scale in IoT.

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