A Sociology-based Interaction Relationship Model in IoT

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***Abstract*—Objects having social properties is a well explored field in Sociology and the idea has been introduced into the field of Internet of Things (IoT) recently. In this paper, the authors analyze some social features of IoT and propose a Sociology-based interaction relationship model between IoT objects. The relationship model, together with the automatic relationship recognition, can enhance the dynamics and the autonomy of communications in IoT. In the latter part of the paper, the authors give an experiment based on real data as a simple example to show how the paper's idea reduces the dependency of IoT on human intervention and makes IoT objects more 'smart'.**

Keywords*—*Wisdom Web of Things; Social Internet of Things; Relationship Recognition; Reality Mining

I. Introduction

Internet of Things (IoT) is a hot research field now. Most of the recent IoT related researches focus on groundwork, such as sensors, data transmission and data integration [1], [2]. But things in IoT still lacks 'wisdom'. Communications between IoT objects are static and need external intervention. How an object communicate with another cannot be decided by objects themselves. Researches on communication patterns of IoT objects can help solve such problem and lead to the enhancement of the 'wisdom' of things.

With the development of calculation capability, the interactions between smart devices start to show social properties [3], [4]. Since objects having social properties is a well developed field in the field of philosophy of technology and has been analyzed by many socialists (e.g., [5], [6]), many researchers started to use the social side of IoT to solve problems in communication. Inspired by the great success of the social network services, L. Atzori gave a social structure to the Internet of Things (SIoT) and established social relations among things themselves but not their owners [7], [8]. But Atzori did not use the existing sociology theory to build the relations. B. Guo studied the mobility and the opportunistic feature of IoT, raised the idea of 'Opportunistic IoT' and practiced the key idea in some projects [3], [9]. But the research focused on the interaction opportunity brought by context and has not taken the influence of interaction relationships into consideration.

Besides the lack of research on interaction relationships, the relations between objects in [3], [7]–[9] are static and cannot be recognized dynamically by objects themselves. These relations need to be pre-decided via external intervention, such as human intervention. Things are not completely autonomous during the communication.

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To solve such issues, this paper introduces a Sociology-based interaction relationship model. In this model, all of the interaction relations between IoT objects are based on the combinations of four basic relations. Furthermore, this paper also shows how the model, together with a simple automatic relationship recognition solution, enhances the intelligence of objects.

The paper is organized as follows. In section 2, the paper provides a survey of related researches. In section 3, the paper first analyzes the social side of IoT and defines the basic relationship model according to the theory of A. P. Fiske [10]; then, this paper analyzes the multiple dimensions of relationship and introduces the scene factor into the model. In section 4, the paper gives an example of how the model and a relation recognition solution (which is based on the researches of MIT Media Lab [11]–[13]) work together. Finally in section 5, some concluding remarks are drawn.

II. State of Art

Recent years, the great success of social network service web sites, such as Facebook and Twitter, and the data collected though these web sites have attracted many scientists from different areas. For example, in networking and communication context, the homophily of friends choosing can help enhance the internet search [14] and the peer-to-peer network [15]. In mobile computing context, data diffusion schemes have been proposed based on the property that individuals who are social connected are more likely to meet [16], [17].

Objects with social properties have been studied by many socialists. L. Winner researched the relationship between autonomous technology and political issues in his book [5]. J. Johnson analyzed how a humble nonhuman object, a door-closer, is a social actor [6]. In that paper, it is claimed that sociability is not a property of humans but of humans accompanied by their retinue of delegated characters. It means things with delegation (which are common in IoT, like smart phones getting tweets for their owners) can also have the sociability property.

L. E. Holmquist et al. firstly introduced socialization between objects in [18]. In that paper, the focus was how to establish temporary relationships between smart wireless devices, mostly wireless sensors. Recently, some researchers begun to propose the idea that the IoT and the social network are two networks not that far apart from each other [19], [20].

In [7], [8], L. Atzori et al. introduced a social architecture into the IoT. The authors also identified policies for the establishment and the management of social relationships between smart IoT objects.

In [3], [9], B. Guo et al. analyzed the opportunistic feature of IoT and proposed the idea of Opportunistic IoT. B. Guo attempted to enhance the intelligence of IoT under the vision of Wisdom Web of Things (W2T). The authors also discussed the characteristics, the research issues and major applications of their idea.

All the studies described above are trying to build the Internet of Things like people build their social network. It is believed that the social side of IoT can bring more effective, efficient and smart ways of communication and networking services.

III. A SOCIOLOGY-BASED RELATIONSHIP MODEL

In the human society, people organize their social life in terms of their relationships with other people. The interactions between people are largely based on these relations. However, the cited literature above still lacks in such aspect. Although Atzori mentioned social relations between IoT objects in his architecture [7], [8], he only defined the relations in a simple way.

A. P. Fiske studied human behavior patterns in different domains and proposed that most social relations are the combinations of 4 psychological models [10]. Fiske also tested the relations model theory in [21].

Based on Fiske's theory, this paper introduces an interaction relationship model of IoT in this section. The model not only defines the relations of objects in IoT, but also defines how objects interact with each other under these relations. Once both sides of the interaction know their relationship(s), via pre-assignation or automatic relationship recognition, the objects can communicate with each other without human intervention.

A. Definition

A. P. Fiske concluded that the motivation, planning, production, comprehension, coordination and evaluation of human social life may be based on combination of 4 psychological models: Communal Sharing, Equality Matching, Authority Ranking and Market Pricing [10].

Considering the characteristic of IoT, this paper re-defined the four elementary relationships in Fiske's theory and raised an interaction relationship model. The following are some detailed definitions:

1. The Communal Sharing (CS) relationship is the relationship of resource sharing. In such relationship, the responder of the interaction must serve the requester what it can with no premise. The requester does not need to give something in order to get something in return. The requester only requests for what it needs. CS relationships mainly exist between imitate devices in a system. For example, different devices of the same owner can share the user profiles.

2. The Equality Matching (EM) relationship is a balanced interaction relationship. Elements in EM relationship are concerned about the relationship balance and focus on how far the relationship is out of balance. Elements keep track of the following values:

- Contribution c. It stands for how much an element contributes to the other in an one-to-one interaction dyad, or to the whole system in a group relation. It can be influenced by how many times it served others, how much data it provided, etc.
- Interaction Balance Δc. It means how far the interaction relationship is out of balance. In a dyad EM relation, it is the difference between the responder's and the requester's contribution.

$$\Delta c = c_{response} - c_{request} \tag{1}$$

  In a group EM relation, it is the difference between the average contribution of the group and the requester's contribution.

$$\Delta c = c_{avg} - c_{request} \tag{2}$$

- Response Probability p_{serve}. It indicates the probability of the responder's serving the requester. The probability is given by Δc and a nonzero constant k.

$$p_{serve} = \begin{cases} 1 & \Delta c \leq 0 \\ k^{-\Delta c} & \Delta c > 0 \end{cases} \tag{3}$$

EM relationships mainly exist when multiple devices cooperate with each other in a single task. For example, the allocation of calculation to every nodes in a computer cluster trends to a balance status.

3. The Authority Ranking (AR) relationship is a liner ordering relationship as it was defined in [10]. It is a dyad relationship. Objects higher in rank have full control of elements lower in rank. Relations between the controller and the controlled are usually AR relationships. High rank objects also have authority over low rank objects. When there is a consensus problem within two objects, the data value from high rank objects is selected to be the final consensus value.

4. The Market Pricing (MP) relationship is a relationship under which elements attend to ratios. The responders in MP relationships organize their interaction with reference to ratios of a single value. Every resource under such relation have their values, and the requester must provide other things with the same value to get these resources from the provider in return. MP relationships can be found in mobile payments field.

B. Multi-Dimensions of Relationships and the Scene Factor

In real life, there may be multiple relationships between two people. For example, a teacher does have authority over his students in class (AR), while he shares the resources in the classroom with students (CS). This kind of situation also exists in IoT, and the paper calls it the multi-dimensions of relationship (MDR). In a single interaction context, the relationship between two things may base on the combination of the four elementary relationships defined in section III-A.

Simultaneously, MDR may also be caused by the communication context changes. For example, the manager may have full control of what the worker should do at work (AR), but the manager and the worker can be friends in a bar after

TABLE I. FOUR ELEMENTARY FORMS OF SOCIALITY IN A. P. FISKE'S THEORY AND THEIR CHARACTERISTICS.

Relational Models	Scales of Measurement	Features
Communal Sharing	nominal	All of the elements are equivalent. People take what they need and contribute what they can.
Equality Matching	interval	People are concerned about the relationship balance. People who are not intimate often interact on this basis.
Authority Ranking	ordinal	A perfect liner ordering relationship. People higher in rank have prestige and prerogatives.
Market Pricing	ratio	Relationship based on ratio. Organized with reference to ratios of a utility metric.

work (CS). The model needs to describe such MDR brought by context changes.

To solve such issues, the paper introduces the 'Interaction Scene' factor. Interaction Scene means the context environment of the interaction (e.g., when and where the interaction happens). Interactions relationship between things are related to interaction scenes. Suppose that R_a is the set of elementary relationships between two things in scene A and R_b is the relations set between the same two things in scene B, R_a and R_b are independent and uncorrelated. Relationships in a scene can only influence the interactions aim at resources belong to the same scene.

For example, the manager and the worker are friends (CS) in the scene 'After-Work' and can share information about their hobbies. But the manager cannot share his office key with the worker because the key belongs to the scene 'At-Work' but not the scene 'After-Work'.

IV. A SAMPLE SCENARIO: DORMITORY INFORMATION SHARING

A. Description

Yuji has just bought a wireless router and created an access point secured with WPA2-PSK in the dormitory room. At the beginning, only Yuji and his devices know the SSID and the password of the access point. If Yuji wants to share the access point to his roommates, he needs to tell his roommates the SSID and the password of it. Also, his roommates need to scan for the access point and manually enter the password before their devices can connect to it.

By exploiting the social relations between objects, the devices of Yuji's roommates can connect to the access point in a more 'smart' way. Once Yuji's device (which already knows the information of the new access point) identifies its 'roommates' (e.g., devices of Yuji's roommates or other devices placed in the dormitory), it can share the information of the access point to these 'roommates' directly without human becoming the information transmission agency. Under this scenario, there are CS relations between the roommate objects in the dormitory scene. Not only the wireless access point, these objects can also share information about other dormitory resources, for example printers and faxes.

B. One Problem before Goes On

Besides the relationship model definition, how to use the model is another important issue. Put it another way, the problem is how the objects can know the relations between themselves and other objects that they need to communicate with. As the paper has shortly mentioned before, there are two ways to reach the goal. One is pre-assignation which means people need to assign the relationships of every couple of objects tediously before the whole system starts to work. The boring assignation process will become even more exhausting while more and more objects join the system. The other way is to recognize the relations between objects automatically via some pre-defined rules or a recognition algorithm.

Many efforts have already been taken in the field of relationship recognition. Relation detection and recognition is a part of the Automatic Content Extraction (EAC) program [22] which aims to extract information from natural language. N. Eagle of MIT Media Lab used factor analysis to research the relations between the friendship and the temporal and spatial patterns in proximity [11]. The factor score is used to estimate whether two people are friends.

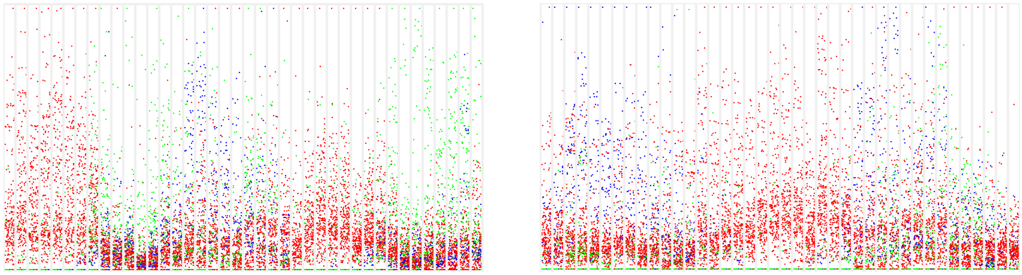
The relation recognition solution in this section is based on Eagle's method. Firstly, it does a factor analysis on the history communication data, attaches factors to interaction scenes and calculates the factors' scores. The meaning of the factor score here is different from [11] and is more than the measurement of friendship. It can describe how intimate two things are in certain interaction scene. Since CS relationship generally exists between intimate elements, the factor score can be used to detect whether two things have a CS relationship. Then, it classifies relation dyads based on factor scores. In this paper, the solution simply calculates the posterior probabilities of relations given factor score via Bayes' theorem and uses Bayesian Decision Theory to do the relationship recognition.

C. Experiments Details

The experiments in this section are based on the Social Evolution dataset collected by MIT Media Lab [12] which includes WIFI access points records, hourly proximity record, phone record (tracked with mobile phones) and self-reported relationships of a whole undergraduate dormitory in MIT. Although this dataset is used by socialists to study the relationships between real people, this paper uses this dataset to study the relations between smart phones which are the proxy objects of people in IoT.

Unfortunately, there is no location record in the dataset because of privacy protection. Since it will be hard to analyze the action pattern without location records, the first experiment tries to use the vitality of WIFI access points at different time to estimate the places where these WIFI access points locate.

In figure 1, it is clear that the red spots have high access rate at night and in the early morning; green spots are more active at work time; blue spots are active after work and at weekends. According to the clustering result, it can be estimated that red WIFI access points locate at dormitories, green access points locate at work spaces and blue access points lie at social locations.



(a) The time interval ranges from 23:00 Monday to 14:00 Wednesday.

(b) The time interval ranges from 7:00 Saturday to 23:00 Sunday.

Fig. 1. Two parts of simple k-means clustering result of WIFI access points. Each horizontal section means a single hour in a week (7*24 hours), and the vertical axis displays the vitality of WIFI access points.

TABLE II. FACTOR LOADING MATRIX.

Variable Name	Factor 1	Factor2	Factor 3
SMS	0.1160	0.0066	0.9907
Calls	0.0594	-0.0037	0.9284
Loc 1 Prox (N)	0.9936	-0.0009	0.0443
Loc 1 Prox (D)	0.8688	0.0243	0.0030
Loc 2 Prox (N)	0.6828	-0.0031	-0.0105
Loc 2 Prox (D)	0.6815	0.0248	0.1548
Loc 3 Prox (N)	0.0009	0.9939	0.0011
Loc 3 Prox (D)	0.0117	0.9974	0.0017
Loc 4 Prox (N)	0.5673	-0.0056	0.1090
Loc 4 Prox (D)	0.5782	-0.0090	0.0122

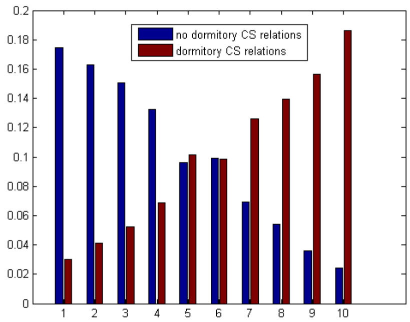


Fig. 2. The histogram shows the conditional probabilities of dormitory factor scores given dom-relationships. The horizontal axis displays the ten average intervals of factor score.

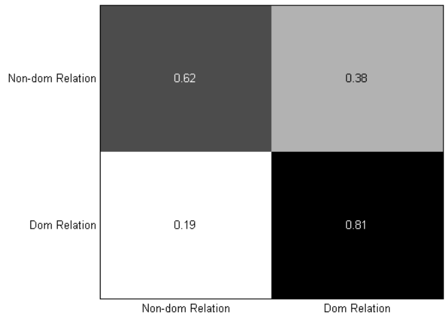


Fig. 3. The confusion matrix of result of classification.

Based on the clustering result, the second experiment does a factor analysis on the interaction history data between every relationship dyads and tries to measure the intimacy.

Table II shows the result of the factor analysis based on hierarchy clustering of WIFI access points. The contributions of the first three factors are 41.82%, 24.80% and 23.51%.

Factor 1 loads most heavily on proximity at location 1 and location 2 (dormitories). This factor is related to dormitory scene and labeled 'dormitory factor'. Figure 2 shows the conditional probabilities of dormitory factor scores given dom-relationships. An object dyad with dormitory CS relationship means they are close in the dormitory building. In figure 2, it is clear that relation dyads with CS relationship are more likely to get a higher score, while, conversely, relation dyads with non-CS relationship tend to get a lower factor score.

The third experiment uses Bayes' theorem to convert conditional probabilities to posterior probabilities and tries to predict whether a relation dyad has CS relationship in dormitory scene. Figure 3 shows the confusion matrix of the classification result on the left. There are 81% dyads with CS relationship and 62% of dyads without CS relationship in dormitory scene recognized successfully.

So far, the CS relations between objects (smart phones) in the 'dormitory scene' has been recognized automatically by objects themselves, and objects with CS relations can communicate and share information (e.g., the SSID and the password of the access point in this scenario) with each other now. Since unnecessary human intervention has been removed from the communication process, it can be considered that the IoT's dependency on human has been reduced and the objects in IoT have become more 'smart'.

V. CONCLUSION

To reduce the IoT's dependency on human intervention and make objects in IoT more 'smart', this paper analyzed the social side of IoT, and raised a Sociology-based interaction relationship model. In this model, all interaction relations are based on the combinations of four basic relationships. Each relation has its own features and communication patterns. This paper also studied the multi-dimensions of interaction relationships. In the latter part, the paper gave a sample scenario of the model. The sample showed how the relationship model, together with a simple Bayesian Decision Theory based relationship recognition solution, can be used in IoT. Different relation detection methods were also discussed in that part. But there are still some issues left that have not been solved completely and need to be followed up.

Firstly, it is the model evaluation. As it is shown in table I, the four basic relations in the model correspond closely to four basic measurement scales. Although some other measurement scales (e.g., the discrete scale) are used in scientific measurement, there is nearly no social relationship found having these kinds of structures in human society. Since the communication patterns in IoT is much simpler than communication patterns in human society now, it does make sense to think that the combinations of the four basic interaction relationships can cover all the possible relations between objects in IoT. But it is not a rigorous proof. Another direct way to do the evaluation is fitting the model to all possible relations between IoT objects. But there is no doubt that the mission is impossible. There are too many kinds of relations in real world to enumerate. Further studies are needed to see whether there is a better way to evaluate the model more rigorously.

Secondly, it is the recognition algorithm. The solution in this paper is very simple and can recognize 81% dyads with CS relations and 62% dyads without CS relations. It means 38% non-CS dyads are mis-recognized and these objects can access the information they should not get. The hit rate of the recognition will not be 100% even a more powerful algorithm is used. It seems harmless when the information to transmit is not that important. But it does harm when the IoT system demands great security. In that case, additional efforts (e.g., tokens or authorization) are needed.

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