Network Navigability in the Social Internet of Things

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***Abstract*—The Internet of Things is expected to be overpopulated by a very large number of objects, with intensive interactions, heterogeneous communications and millions of services. Consequently, scalability issues will arise from the search of the right object that can provide the desired service.**

A new paradigm known as Social Internet of Things has been introduced and proposes the integration of social networking concepts into the Internet of Things. The underneath idea is that every object can look for the desired service using its friendships, in a distributed manner.

However, in the resulting network, every object will still have to manage a large number of friends, slowing down the search of the services.

In this work, we intend to address this issue by analyzing possible strategies to drive the objects to select the appropriate links for the benefit of overall network navigability.

***Index Terms*—Internet of Things, social networks, SIoT, navigability, search engine**

I. Introduction

The Internet of Things (IoT) integrates a large number of heterogeneous and pervasive objects that continuously generate information about the physical world [1]. Most of this information is available through standard Web browsers and several platforms already offer application-programming interfaces (APIs) for accessing to sensors and actuators. Accordingly, the IoT technologies make possible to provide new services to end-users in disparate fields, from the environment monitoring to the industrial plants running, from the city management to the house management.

As explained in [2], the search of each specific service provided by the devices in the IoT represents a crucial point: the number of objects connected to the network keeps increasing, leading to an enormous searching space. According to [3], by 2015 the RFID devices alone will reach hundreds of billions. The network traffic, both in terms of the number of accesses to the devices, and of the number of queries received by the search engines, will soon become too large to be managed efficiently. Additionally, nowadays the interaction model is based on humans looking for information provided by objects (human-object interaction), but in the IoT near-future this model will quickly shift to the object-object interaction, where objects will look for others to provide complex services for the benefit of the humans, increasing the number of queries. Consequently, scalability issues will arise from the search of the right object that can provide the desired service.

In this context, several approaches for real time search have been proposed, such as those described in [4] and [5]. A common feature is that these engines are based on centralized systems and as such can not scale properly with the number of devices or/and the number of queries.

To cope with scalability issues of centralized systems, a new paradigm known as Social Internet of Things (SIoT) has been introduced [6]. SIoT proposes the integration of social networking concepts into the IoT solutions. In the SIoT, every node is an object capable of establishing social relationships with other things in an autonomous way according to rules set by the owner.

A SIoT network is based on the idea that every object can look for the desired service by using its relationships, querying its friends, the friends of its friends and so on in a distributed manner, in order to guarantee an efficient and scalable discovery of objects and services following the same principles that characterize the social networks between humans. The assumption that a SIoT network will be navigable is based on the principle of the sociologist Stanley Milgram about the small-world phenomenon. This paradigm refers to the existence of short chains of acquaintances among individual in societies [7].

According to this paradigm, each object has to store and manage the information related to the friendships, implement the search functions, and eventually employ additional tools such as the trustworthiness relationship module to evaluate the reliability of each friend. Clearly, the number of relationships affects the memory consumption, the use of computational power and battery, and the efficacy of the service search operations. It results that the selection of the friendships is key for a successful deployment of the SIoT. In this work we intend to address this issue by analyzing possible strategies for selection of appropriate links for the benefit of overall network navigability. We first propose five heuristics which are based on local network properties and that are expected to have an impact on the overall network structures. We then perform extensive experiments, which are intended to analyze the performance in terms of giant components, average degree of connections, local clustering and average path length.

The paper is organized as follows. In Section II we present the scenario of the social IoT and provide a quick survey of the solutions for the search of services in the IoT. In Section III we introduce the key aspects of network navigability, whereas Section IV presents the strategies for link selection and the experimental evaluation. Section V draws the final remarks.

II. Background

A. Social IoT

The idea of using social networking elements in the IoT to allow objects to autonomously establish social relationships is gaining popularity in the last years. The driving motivation is that a social-oriented approach is expected to boost the discovery, selection and composition of services and information provided by distributed objects and networks that have access to the physical world [8], [9], [10] and [11].

Without losing the generality, in this paper we refer to the Social IoT model proposed in [6] (we use the acronym SIoT to refer to it). According to this model, a set of forms of socialization among objects are foreseen. The *parental object relationship* (POR) is defined among similar objects, built in the same period by the same manufacturer (the role of family is played by the production batch). Moreover, objects can establish *co-location object relationship* (CLOR) and *co-work object relationship* (CWOR), like humans do when they share personal (e.g., cohabitation) or public (e.g., work) experiences. A further type of relationship is defined for objects owned by the same user (mobile phones, game consoles, etc.) that is named *ownership object relationship* (OOR). The last relationship is established when objects come into contact, sporadically or continuously, for reasons purely related to relations among their owners (e.g., devices/sensors belonging to friends); it is named *social object relationship* (SOR). These relationships are created and updated on the basis of the objects' features (such as: type, computational power, mobility capabilities, brand, etc) and activities (frequency in meeting the other objects, mainly).

B. Service search in IoT

In this section, we provide some examples of the existing solutions for service search in IoT context, in order to highlight existing problems. [12] and [5] cope with the large number of real-world entities by using a hierarchy of mediators: the ones in the lower level are responsible for groups of sensors in geographical areas, while the single mediator on the top level maintains an aggregated view of the entire network. These approaches are not scalable in case of frequent data and network changes whereas work well in case of pseudo-static metadata.

In [4], the authors propose a centralized system where objects are contacted based on a prediction model that calculates the probability of matching the query. In this way, the search engine does not need to contact all the sensors leading to good scalability with the number of objects; nevertheless, it is not scalable with the network traffic, since the number of possible results is significantly larger than the number of actual results, so a lot of sensors are contacted for no reason.

III. Reference scenario

A. Distributed search in the IoT

In the same way the search of contents of different kind, such as videos and web pages, is one of the most popular services on the Internet, the search of data from sensors and real-world entities is expected to be a major service in the IoT in the near future. However, the huge number of objects and the frequent changes in their data put a great stress on the service search.

In the SIoT, the objects inherit some capabilities of the humans and mimic their behavior when looking for new friends or services [10]. Indeed, the relationships devised for the SIoT follow the ones studied in sociological and anthropology fields, such as [13] and [14], since the owner sets the rules for their creation. The object then creates and manages several kinds of relationships and uses them to navigate the network, looking for services. The object asks its friends if they can provide a particular service or if they "know", i.e. if they have any connections to, nodes that can provide it.

Figure 1 provides a simple example of a SIoT network, where links represent friendship ties while the bold line is the best route for node 1 to reach the requested service. In this network, when node 1 needs a particular service, it does not send a request to a centralized search engine, but it uses its own friendships to look for, in a decentralized manner, a node with the desired service, by contacting its friends and the friends of its friends. In this scenario, we aim to evaluate the impact of several strategies for link selection in order to select an optimal set of friendships to limit the use of computational resources needed for the search operations.

B. Key aspects of Network Navigability

In the past years, the problem of network navigability has been widely studied. As defined by Kleinberg [15], a network is navigable if it "contains short paths among all (or most) pairs of nodes". Several independent works, such as [16] and [17], formally describe the condition for navigability: all, or the most of, the nodes must be connected, i.e. a giant component must exist in the network, and the effective diameter must be low. In other words, the greatest distance between any pairs of nodes should not exceed $log_2(N)$, where N is the number of nodes in the network.

When each node has full knowledge of the global network connectivity, finding short communication paths is merely a matter of distributed computation. However, this solution is not practical since there should be a centralized entity, which would have to handle the requests from all the objects, or the nodes themselves have to communicate and exchange information among each other; either way a huge amount of traffic would be generated.

Nevertheless, starting from the Milgram experiment [7], Kleinberg concluded that there are structural clues that can help people to find a short path efficiently even without a global knowledge of a network [18] [19]. This means that there are properties in social networks that make decentralized search possible. Let us suppose to have a network as represented in Figure 1, where node 1 wants to get access to the information owned by node 10 (1 doesn't know where the information is located); obviously the optimum path leads through nodes 5 and 7. However, node 1 has three possible

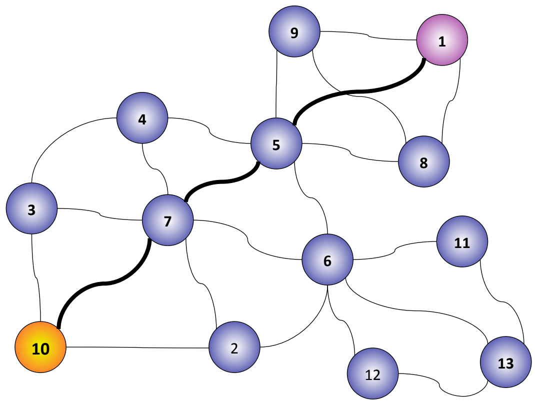

Fig. 1. Decentralized search

paths to choose from and only knows few information about its neighbors: the property that will guide node 1 to select node 5 as a next hop is that node 5 has a high degree of centrality, i.e. it has many connections. As such, node 5 represents then a network hub, i.e. a node that is connected to many other nodes. The ability for a node to quickly reach a network hub is assured by the existence of network clusters where nodes are highly interlinked: this characteristic is assured with high value of the local clustering coefficient, described by Watts and Strogatz [20], and is calculated for each node in a network. It measures how close the neighbors of a node are to being a clique, i.e. a complete graph, and it is calculated as follows:

$$C_{local}(n) = \frac{2 * e_n}{k_n * (k_n - 1)} \tag{1}$$

where k_n represents the number of neighbors of the node n and e_n is the number of edges among the neighbors.

Still, node 5 needs some additional hints in order to choose node 7 over node 6, since both of them have the same degree. This characteristic is the node similarity, an external property to the network, derived from some additional information about the nodes. In the SIoT, node similarity will depend on the particular service requested and on the types of relationships involved.

The problem of global network navigability is then shifted to the problem of local network navigability, where neighboring nodes engage in negotiation to create, keep or discard their relations in order to create network hubs and clusters.

IV. Experimental evaluation

A. Selection of network links

As described in Section II-A, objects can create, through the mimic of their owner's behavior, several types of relationships. Other types of friendships could be added in the future, leaving to the node the hard work to cope with a huge number of connections. To make the service search process more efficient and scalable, we propose five heuristics to help the nodes in the process of selection of the best set of friends.

At first, a node accepts all the friendship requests until it reaches the maximum number of connections allowed - N_{max}. This parameter is intended to limit the computational capabilities a node needs to resolve a service search request. Then, a node applies one of the following strategies, to manage any further request:

1) A node refuses any new request of friendships so that the connections are static.
2) A node accepts new friendships and discards the old ones in order to maximize the number of nodes it can reach through its friends, i.e. to maximize the average degree of its friends; the node sorts its friends by their degree and the node with the lowest value is discarded.
3) A node accepts new friendships and discards the old ones in order to minimize the number of nodes it can reach through its friends, i.e. to minimize the average degree of its friends; the node sorts its friends by their degree and the node with the highest value is discarded.
4) A node accepts new friendships and discards the old ones in order to maximize its own local cluster coefficient; the node sorts its friends by the number of their common friends and the node with the lowest value is discarded.
5) A node accepts new friendships and discards the old ones in order to minimize its own local cluster coefficient; the node sorts its friends by the number of their common friends and the node with the highest value is discarded.

Let us consider a network example, as shown in Figure 2, where the maximum number of connections is set to $N_{max} = 5$ and let us suppose that node 2 sends a friendship request to node 1 (dashed line). Since node 1 has already reached N_{max} connections, the decision on this request will depend on the implemented strategy. If node 1 implements strategy 1, it will simply refuse the request; with strategy 2, node 1 checks the degree of all its friends and of node 2 and then it terminates the relationship with node 4, which has only one more friend, in order to accept the request from node 2 (3 friends). In the same way, using strategy 3, node 1 terminates the relation with node 6, which has N_{max} connections, and accepts the request. With strategy 4, node 1 compares the common friends among its friends and with the requester node and discards the node 3 with which it has no common friends. In a similar way, with strategy 5, node 1 discards the relation with node 5 to which it has the highest number of common friends.

B. Simulation setup

With this simulation analysis, we want to study the impact of each of the proposed strategies on the objects' network navigability.

To analyze the navigability of a SIoT network, we would need information about the requests of establishing new relationships the objects would receive on the basis of their profile, settings and movements. And we would need this information for huge numbers of real objects. Even if some platforms already exist that implement the SIoT paradigm, such as [21],

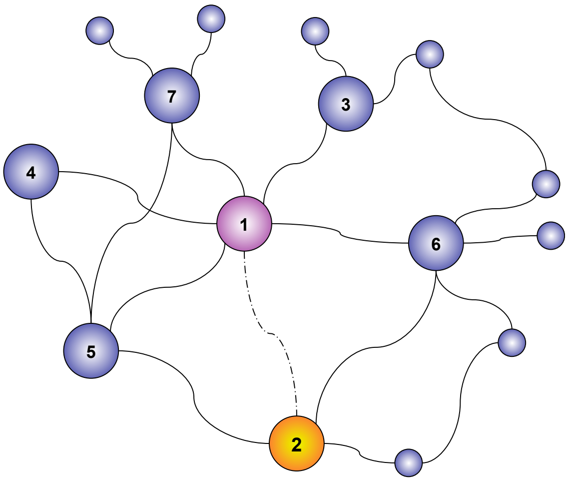

Fig. 2. Selection of network links

this data is not available to date as real applications have not been deployed yet. For this reason we had to adopt an alternative solution to test our heuristics as follows:

1) first we analyze a social network of humans;
2) from this, we extract the information needed to build the social network of objects;
3) in the next stage, we extract the characteristics of this network and use these to run a model that generates synthetic networks with similar properties;
4) and finally we apply the strategies described previously and analyze the results.

For the first step we relied on the real dataset of the location-based online social network Brightkite obtained from the Stanford Large Network Dataset Collection [22]. This dataset consists of more than 58k nodes and more than 200k edges, so in order to better analyze its properties and compare them to synthetic data, we consider only the nodes enclosed between Atlanta and Boston for a total of approximately 12k nodes and 40k nodes. However, the output of the Brightkite dataset is a trace of the position of humans and of their relationships; since we are interested in the relationships of the objects we have extended it as follows (step 2): starting from the scaled network, we suppose that every person carries at least one smart object, for example a smartphone, so when they get in touch with their friends their objects also come into contact and have then the possibility to create a SOR. In a similar way, we also simulate the creation of CWOR and CLOR. The resulting SIoT network has around 14.5k nodes and 67k edges. The parameters of the two networks, obtained from Gephi [23], are showed in Table I, while the node distribution is shown in Figures 3 and 4 for Brightkite and SIoT network respectively.

Both networks comply with the condition for network navigability: at global level, there is a giant component and the average path length is low; at local level, we can observe how the nodes are highly interlinked, thanks to the high values of the clustering coefficients, and the networks have a scale-free degree distribution thus indicating the existence of hubs.

Moreover, it is important to point out that the tail of the degree distribution deviates from the power law due to the scaling, where nodes near the borders do not have a complete set of friendships. Furthermore, even if the SIoT is expected

TABLE I
PARAMETERS OF BRIGHTKITE, SIOT NETWORK AND BARABSI-ALBERT MODEL

	Brightkite	SIoT network	BA model
Nodes	12275	14557	15000
Number of Edges	39515	67363	75000
Average Path Length	4.570	4.534	3.905
Average Clustering Coefficient	0.247	0.375	0.255
Diameter	14	14	6
Average Degree	6.631	9.808	10
Giant Component	84.32%	93.45%	100%

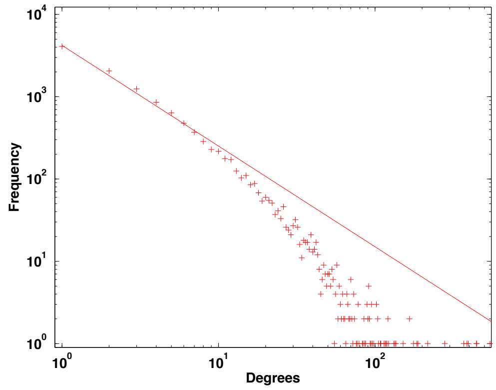

Fig. 3. Degree distribution for Birghtkite

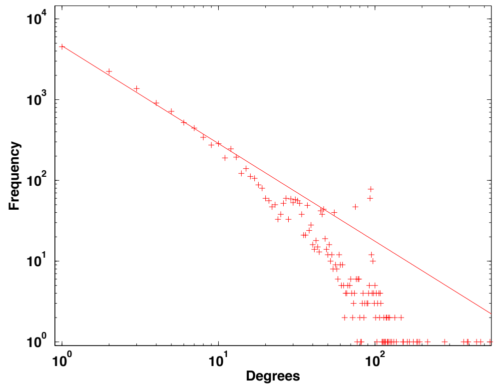

Fig. 4. Degree distribution for SIoT

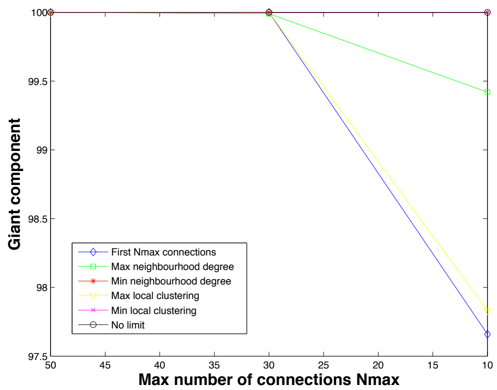

Fig. 5. Giant component for all the strategies

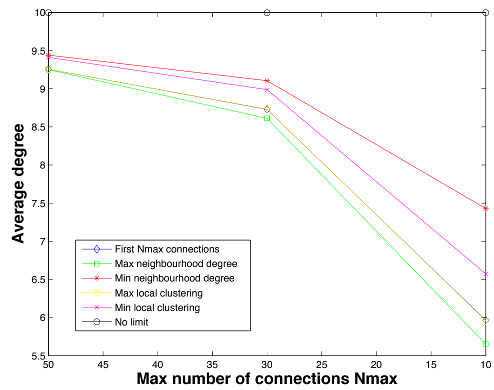

Fig. 6. Average degree for all the strategies

to have a shorter average path length with respect to classical social networks, in this case this does not happen since the new relationships are due to CLORs and CWORs that are indeed short range; however, for the same reason, it is possible to observe a 50% increment of the average local clustering.

To generate and analyze similar networks, we rely on the Barabási-Albert model [3], which is able to generate scale-free networks based on preferential attachment. Starting with a small number of nodes, at each step, it adds a new node with m edges (m is a parameter for the model) linked to nodes which are already part of the system. The probability p_i that a new node will be connected to an existing node i depends on its degree k_i, so that $p_i = k_i/(\sum_j k_j)$ leading to the name preferential attachment. However, since this model generates networks with a low average cluster coefficient, we use the modified version from Holme and Kim [24], that adds a triad formation step to the model: after a node j connects to node i, it also connects to one of its neighbor, thus resulting in a triad formation. The results of this model, using 15k nodes, connecting each node to $m = 5$ other nodes and averaged over 5 runs, are shown in Table I, and it can be observed that it represents a good approximation for the real scenario.

C. Simulation results

Figure 5 shows the percentage of the giant component for all strategies. It is important to note that if we try to minimize the neighborhood degree or the local clustering, we can always achieve a giant component which includes all nodes. This happens due to the fact that, when a node with N_{max} connections receives a friendship request from a low connected node, it will always accept it to the detriment of a node with higher connectivity which has high probability to remain connected to the network. Moreover, we can observe that when using the strategy 1, 2 or 4, the dimension of the giant component naturally decreases with the reduction of the N_{max} value, thus making the network not fully navigable. In the case of using the strategy 2, a node connected to other nodes with N_{max} friends will not accept any other relation

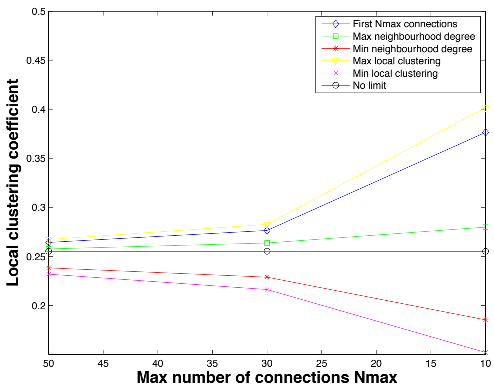

Fig. 7. Local cluster coefficient for all the strategies

request, similarly to a node in a near-clique in strategy 4. Furthermore, we also want to point out, that with strategy 2 and 4 a node can not refuse or discard relationships if this action is going to isolate a node; in this way, we can achieve larger giant component and we do not have isolated nodes but at least isolated couples of nodes.

From Figure 6 we can observe how the average degree changes with different strategies. Strategy 3 tries to equalize the number of friendships between the nodes, resulting in a higher number of relationships in the network and consequently a higher average degree. Similarly, strategy 5 discards the nodes with higher local cluster coefficient, to connect with nodes with low values. Yet, since the local cluster coefficient is not directly connected to the number of friends, the average degree is lower than in strategy 3. Strategy 2 achieves the lowest average degree due to the fact that the resulting network has a core of high degree nodes, with N_{max} friendships, and highly interconnected between themselves. These nodes hardly accept any new friendship, leaving many nodes with a low degree.

Figure 7 shows the local cluster coefficient. Strategy 4

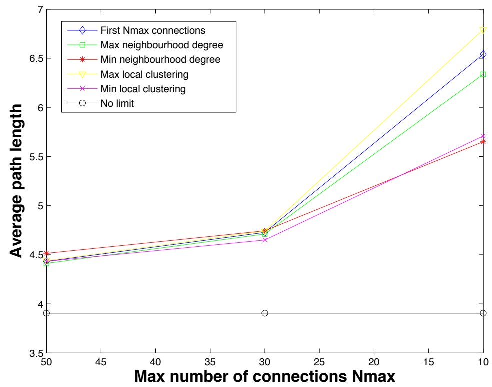

Fig. 8. Average path length for all the strategies

and 5 exhibit the highest and lowest value respectively, since they are designed to achieve these results. Strategy 1 has a high value due to the triad formation step in the model and to the fact that there is not further rearrangement of relationships after these has been created; this effect is even stronger when the number of maximum connections is decreasing. Strategy 2 achieves a higher value than the model since the core nodes in the network are highly interconnected. It is important to point out the behavior of the local clustering coefficient for Strategy 3: it has a lower value than the model and decreases with N_{max}. This is a result of the equalization of the number of friendships, leading to a high average degree and easily destroying the triad formation step in the model.

Figure 8 shows the average path length. It indicates that strategy 3 and 5 provide shorter paths than other strategies. This is due to the fact that these strategies manage to create many long distance relationships. On the other hand, strategy 4 has the worst performance for the exact opposite reason: nodes are too close to be a clique and have difficulties reaching other nodes; similar reasons hold also for strategy 1 and 2.

V. Conclusion

In this paper we have focused on the link selection in the social IoT. The driving idea is to select a narrow set of links in order for a node to manage more efficiently its friendships. We first demonstrate how a SIoT network has the characteristics of navigability and then we apply several heuristics for link selection and analyze the behavior of the network in terms of giant component, average degree, local cluster coefficient and average path length.

As future work, we plan to focus on the service discovery in the same scenario and analyze the performance differences in finding the right object and service.

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