SSSSS: Search for Social Similar Smart Objects in SIoT

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***Abstract*—As Internet of Things (IoT) is overpopulated with multitude of objects, services and interactions, efficiently locating the most relevant object is emerging as a major obstacle. Over the last few years, the Social Internet of Things (SIoT) paradigm, where objects independently establish social relationships among them, has become more popular as it provides a number of exciting characteristics to boost network navigability and carryout reliable discovery approaches. Given a large scale deployment of socially connected objects, finding the shortest path to reach the service provider remains as a fundamental challenge. In most of the existing search techniques, the physical significance of the objects is not very well explained and the geographical location of mobile objects is not considered. In this paper, to improve the search performance over the SIoT, we propose a novel object search mechanism based on physical location proximity and social context of users in social communities. The results show an enhancement over the existing search technique in terms of average path length.**

***Index Terms*—Absolute Location, Object Discovery, Physical and Social Proximity, Relative Location, Social Internet of Things.**

I. Introduction

Internet of Things (IoT) has been populated by a multitude of objects, that are capable of interacting with heterogeneous objects, have intensive communication capabilities and provides numerous services with which a number of applications can be built to provide support across different domains like Smart Cities, Smart Homes, Healthcare, Transportation, Logistics, Aviation, *etc*. These applications seek objects in the IoT network that offers particular service requested by either human user or objects in the network. Searching for the objects that offer desired service in the IoT represents a critical issue due to heterogeneous object types, dynamic topology of the IoT network, varieties of data generated by objects in large volume and at different velocities, *etc*. [1]. In this context, [2] and [3] recommends a number of techniques for real-time search. Typically, these search engines are centralized and therefore cannot scale effectively with the multitude of objects and the search request. To handle scalability issues, social aspects have been applied into the IoT. Integrating social networking principles into IoT has given birth to a novel paradigm called Social Internet of Things (SIoT), where objects establish a new relationship based on social network of their properties and present state of operations, improving the network navigability and thus aid in object discovery [4]. In SIoT, objects autonomously creates a relationship with the other objects based on the criterion set by the owner of the object. Relationship can be of varied types such as friendship, community of interest, social contact, ownership *etc*. Depending on the type of the object involved in relationship, Atzori *et al.* [5] defined five different types of relationship such as : *POR* - Parental Object Relationship defines relationships between identical objects unaffected by time (for instance ovens built by the same manufacturer, in same time-period, *etc.*) *CWOR* - Co-Work Object Relationship are identified between objects that jointly work to offer service for a common IoT application (sensing units, alarm systems in a residence and *apps* on mobile phones offering a burglar alarm system that can be tracked on-line) *CLOR* - Co-Location Object Relationship is formed when objects are located at the same spot (sensing units on devices that exist in the same location to provide service for instance automation in a office or home) *OOR* - Ownership Object Relationship is established among objects that belong to the same user (iPad, mobile phones, tablet etc. belonging to a user) *SOR* - Social Object Relationship where objects get in touch with each other considering the social relationships (relationship between devices and sensing units belonging to friends in the social network). In the Social Internet of Vehicle (SIoV) scenario Alam *et al.* [6] define the *GOR* - Guardian Object Relationship where vehicles On-Board Units (OBU) turn into a child in association to the super objects of Road Side Units (RSU), thus giving a special signification to a novel hierarchical relationship. In addition Ali *et al.* [7] have identified few other relationships such as: *SIBOR* - Sibling Object Relationship is established among objects that belong to a family member or a group of friends. *GSTOR* - Guest Object Relationship is formed among objects owned by the users in the guest role, for instance, when a person spends time socially at friends place and takes the liberty as a guest. *STGOR* - Stranger Object Relationship exists among objects that encounter the existence of each

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other in the public surroundings or on the go. *SVOR* - Service Object Relationship is formed between objects that fulfill the service request by coordinating the same service composition. Every object in the network autonomously establishes various types of relationships and uses the resulting links for network navigation.

Motivation: In SIoT, objects with the similar characteristics or features exchange solutions among themselves to resolve issues that they experience and thus social-driven concept improves the service search, selection, and composition, in addition to data capturing and fusion techniques provided by the dispersed objects and networks that have accessibility to the real world. The most significant thought behind the SIoT paradigm is to build connections between objects without human intervention and navigate them in a logical manner to build easier solutions to discovery problems of objects, and provide scalability in the same way as seen in the social networks of humans. In the recent past, several research studies have interpreted the feasible strategies that initiate the objects to choose the relevant link to navigate in the overall network. [8], [9], however, the literature still lack a routing algorithm that considers the objects physical and social context similarity for the search operation.

Contribution: In this paper, we propose the network link selection procedure that uses the object similarity characteristic to choose the right neighbouring object to benefit the overall network navigability in SIoT System. Object similarity is an external property with respect to the network characteristics which defines the similarity between objects and the search request, based on the following factors:

i) *Co-presence Durations of Objects:* The duration during which the objects are near or overlapped to each other.
ii) *Contacts between Objects:* Number of times the social objects have encountered each another.

Using the object similarity property described above, the search request can quickly reach the desired target object contacting only a limited number of intermediate objects.

Organization: The paper is organized as follows. Section II presents the related works and existing techniques. In Section III, we explain the background work. Section IV contains problem definition and the system model and performance evaluation of the proposed search mechanism in Section V. Finally, conclusions are presented in Section VI.

II. Related Work

In this section, we present the state-of-the-art review to search objects for the SIoT. Different research activities are carried out for an object to efficiently choose an appropriate friend to improve the overall network navigability.

Nitti *et al.,* [10] have determined the navigability characteristics of the SIoT network where the objects are connected as friends and every object in the network has information about the neighbouring nodes and uses that to pick friends and navigate the network globally. Nitti *et al.,* [8] proposed feasible heuristics based on the local network properties which should be implemented by every node in the network when adding new friends. Further, Nitti and Atzori [11] figured out the possible solutions to minimize the distance between service requester and service provider in the SIoT instance by recommending two approaches, namely a caching system and friendship selection mechanism. It uses the conventional graph structures to search the objects and therefore they cannot capture the dynamic nature of IoT objects.

Jung *et al.,* [12] proposed a smart object discovery mechanism choosing hypergraph based overlay network model. Militano *et al.,* [9] proposed a distributed friendship selection approach based on a game theoretic model using the Shapely-value based algorithm. It aims to define a strategy to select friends that is efficient, distributed and dynamic. Further in [13] a new utility feature for the objects is suggested, which improves the performance by reducing the computational complexity and ensures convergence.

Han *et al.,* [14] studied the features that correlates the users interest to improve the social based services such as friend prediction and recommendation using three kinds of users details: demographic information, social relations and users interest. Yang *et al.,* [15] designed a joint friendship interest propagation model that combines the friendship and interest structures, enabling users to predict both the objects of potential interest and various other users with the same interests. The model chooses information from user-object communication and user-user relationship and builds the recommender systems by integrating users social network details in each trust network and friend network .

Shen *et al.,* [16] proposed the peer assisted video clip posting system, named *SocialTube*. It describes the interest collection communities named as swarm, and posted the video chunks in every swarm that possesses a higher possibility of having the targeted video clip. As a result, it minimizes the rising expenses of web server storing space and larger size of query flooding. They even identified that the majority of users based on their interests possess identical viewing patterns. Thus, the SocialTube permits the user to search the intended resources easily within the swarm ensuring the navigability and cost efficiency. Similarly, when every object of Social IoT possesses identical pattern for the desired resources, it can be categorized to repeatedly yield target resource.

Chen *et al.,* [17] described a peer-to-peer social network based content file sharing method for disconnected MANETs. The system utilizes interest extraction criteria to obtain nodes interests offered by its own files for content driven file browsing. It combines nodes with similar interest that often meet one another as neighbours for effective file search. Thus interest based similarity can successfully search the required resources.

Nitti *et al.,* [18] proposed a SIoT based decentralized object search algorithm to provide specific application services. The Social IoT establishes a friendship links between objects and creates a social structure of objects. Every time, an object receives a new query, it finds out if anyone of its friends has the ability to execute them, or else it chooses within them the one that possesses the greater chance to fix the query. Mardini *et al.,* [19] proposed a link selection approach utilizing genetic algorithm [20] to locate the near optimal link in the SIoT network. Kang *et al.,* [21] proposed the Social Correlation Group (SCG) to locate the target resource in SIoT environment. The

SCG includes extremely related neighbouring nodes, obtained on computing the social correlation between an individual and each neighbour. The correlation value shows the way the nodes are related and extremely correlative neighbours are used to search the required resources. Li *et al.,* [22] have developed a resource discovery algorithm for disconnected and delay-tolerant Social IoT. The recommended algorithm is based on the similarity of the nodes preference and movement pattern and includes the 3-D geographical locality interest to increase the effectiveness of search to limit the system overlays for SIoT settings. Misra *et al.,* [23] proposed a community detection algorithm for the combined network of IoT and social network. To handle the problems in the complex structure of IoT and social network, it employs a graph mining concept in which the nodes in complex networks are separated as basic nodes and IoT nodes. It specifies that two nodes are claimed to a part of community, only if the nodes are in the range of one hop and have a minimal of two common friends. A node may be a part of various communities, and it functions effectively for weighted graphs. The approach is not generalized to all networks; it is based on social networks such as Facebook and it cannot give results for directed networks, and it does not address the problems of the self loops in graphs. Li and Wu *et al.* [24] proposed a Mobile community-based Publish/Subscribe scheme (MOPS) that facilitates the content based service in Disruption Tolerant Networks (DTNs) using the neighbouring connections among the nodes. It construct communities in a distributed manner by extracting the nodes encounter frequencies. Jian *et al.,* [25] have developed a cognition algorithm to check out the behaviour of the movable nodes by analysing the social characteristics. The algorithm determines the social relationship of the nodes and extracts the parameters like distance and interaction factor by quantifying the social relationship. The typical theory of social networks has been applied to study the behaviour of the movable nodes.

You *et al.* [26] proposed a mobility pattern based optimal routing for social delay tolerant networks utilizing a local and tabu-search scheme. The tabu-search based routing guides the relay node sets in evolving the optical node sets. The mobile-aware nodes in target region are selected by analysing their social relations and by mining activity rules and community property of the nodes. It efficiently discovers the nodes and improves the success ratio of service discovery.

Girolami *et al.,* [27] proposed a proactive service discovery procedure for MANETs that utilize both social behaviour and human mobility. The protocol is based on the idea that the efficiency of service discovery is highly impacted by the users behaviour with time and by their mobility. In fact, people with similar interests generally have interactions with each other, therefore they may be interested on the same services. The protocol obtains an enhanced performance while finding the services.

III. Background Work

Nitti *et al.,* [8] proposed friendship selection strategies (FSS) that helps the objects to search its friends exploiting the local information, such as their degree of connections. Militano *et al.,* [13] proposed a distributed Friendship Selection Algorithm based on Shapely-Value (FSASV) that helps the objects to choose the right friend to improve the overall network navigability.

A. Friendship Selection Strategies (FSS)

Nitti *et al.,* [10] proposed object searching method using the key aspects of navigability characteristics of the SIoT network. It considers the degree centrality of an object to enable decentralized search using network hubs. The objects are connected as friends and every object in the network has information about the neighbouring objects and uses that to find friends and navigate the network globally. Five heuristics are described to select an appropriate link in the network and the network performance is analyzed in terms of local cluster coefficient, average degree, average path length and giant component.

B. Friendship Selection Algorithm based on Shapely Value (FSASV)

Militano *et al.,* [13] proposed a distributed friendship selection approach based on a game theoretic model using the Shapely-value based algorithm. It defines a strategy to select friends that is efficient, distributed and dynamic. Further, a new utility feature for the objects is suggested, which improves the performance by reducing the computational complexity and ensure tractability in real problems.

However, it has been proven that friends often like to visit the same location [28] and jointly take part in some activities in real life and share similar interests bringing a homophily phenomenon [29]. Therefore, it is highly probable to choose the objects with the similar interest as a next hop and reduce the average path length between all the pairs of objects in the network. In the existing search techniques, objects reach their destination using intrinsic characteristic of the network such as object's degree, social relationship diversity, local clustering coefficient and between centrality. Nevertheless, so far object similarity property has not been considered for the search operation. In our approach, we use the spatiotemporal dimensions to measure the behaviour similarity of IoT objects.

IV. Problem Definition and System Model

A. Problem Definition

Given a large scale of SIoT, our objective is:

1) To choose an optimal set of friends to scale down the intermediate objects required for the search operation using objects physical and social context.
2) To minimize the average path length, which measures the average number of connections between all the pairs of objects in the network.

B. Assumptions

1) It is assumed that every user possess a set of smart objects connected to Social IoT network, such as Smartphone, iPad etc.,

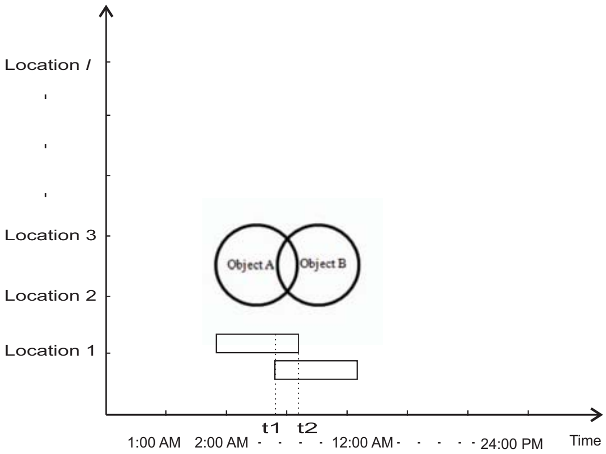

Fig. 1. Sojourn Time of *Object A* and *Object B*

2) Upon users contact with their friends their smart objects also come in contact with each other and then have the chance to establish relationships such as *SOR*, *CWOR* and *CLOR*.
3) The objects are uniformly distributed throughout the space of interest.

C. Basic Definitions

1) *Encounter:* We define two objects as Encounter if these two objects check-in the same location at the same time slice.
2) *Candidate Friends:* Friends for the *object A* are defined as the nearby objects Encounter in the proximity.
3) *Encounter Frequency:* Number of times both *object A* and its candidate friend that encounter one another in the past.
4) *Encounter Duration:* Time during which the *object A* and its candidate friend overlap.
5) *Absolute Location:* Absolute location expresses the coordinates such as latitude and longitude indicating a specific fixed point on the earths surface.
6) *Relative Location:* Relative location refers to locations based on its proximity to the location of the *object A*.

D. System Model

In SIoT, objects develop friendship with one another based on their common interests. Stating from Bisgin experiment, similar individuals associate with each other more often than others, bringing the homophily phenomenon [29] and therefore social features can be exploited to find the neighbouring object in the network. The proposed system model is presented in Figure 1, which illustrates that Objects with similar interest meet more often at the same location at the same time slice. The *object A* and *object B* both check-in at the same location and their sojourn time is same from time *t1* to time *t2*.

Figure 2 illustrates an overlay of SIoT network, where friendship ties are represented as links while the best route for *object A* to reach the service provider is denoted as bold line. In this network, when the *object A* requires a particular service it contacts it friends in a distributed manner to look for an object that provides the required service instead of sending a request to a centralized search engine. The property that guides *object A* to select the next hop is the object similarity. Initially, for the *object A*, we generate the nearby candidate friends who have similar preferences based on their physical context such as location and social interaction like encounters or meetings in the real world. Then calculate the behaviour friendship similarity between *object A* and these candidate friends according to their encounter frequency and duration of stay.

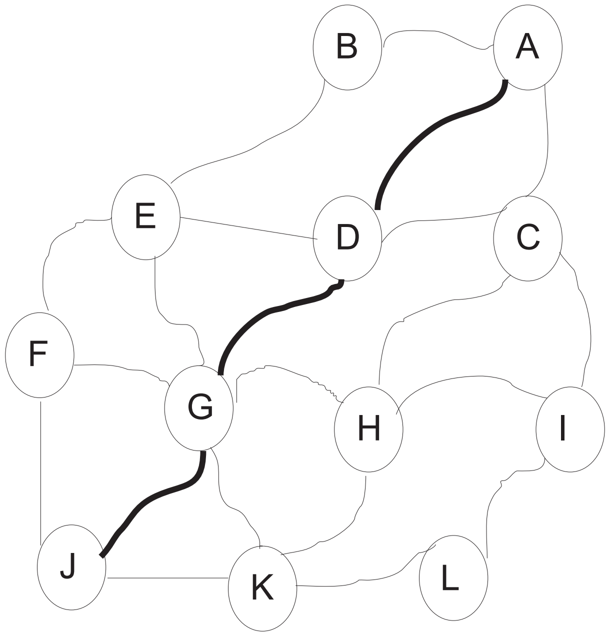

Fig. 2. Distributed Object Search in SIoT

1) Generation of Nearby Candidate Friends: To generate the nearby Candidate friends for object *A*, the prerequisite is to first locate Object *A* in the real-time. The current check-in location of object *A* is obtained *via* GPS (Global Position System) coordinates at a specific timestamp.
i.e., K=(location id, latitude, longitude).
From the current check-in location *K* we find the set of nearest locations *L* in the vicinity within the range of *r* km radius, *i.e.,*

$$L = \{l_i \mid\mid D(l_i - l_k)| <= r \; and \; \forall_i, 1 \leqslant i \leqslant m\} \quad (1)$$

Where, D is the distance between two locations and *m* is the total number of locations in the range of *r* km radius for the object *A*. The Cosine-Haversine formula [30] is used to measure the distance between two locations utilizing their latitude and longitude values. The presence of the objects that all have checked in the locations *L* are identified during $[t - \delta t, t]$ time interval, *i.e.,* $O = \{o_1, o_2, ..., o_n\}$ to form a set of nearby candidate friends *CFs* for object *A*, *i.e.,*

$$CFs = \{o_i \mid o_i \; is \; an \; Object \in O \;, \forall_i, 1 \leqslant i \leqslant n \; and \; [t{-}\delta t, t]\} \quad (2)$$

Where, n is the number of objects in Location *L* of l_i.

Once a set of candidate friends are extracted, the behaviour friendship similarity between object A and all its candidate friends $o_i \in CFs$ is measured. This process can be applied to instantly generate nearby candidate friends for the other checkin locations of object A at different time intervals.

2) Friendship Similarity Computation: For a given Object A, many candidate friends are generated and the most relevant among these candidates must be ranked in the first position to select as the next hop in the network. This ranking can be achieved by finding the friendship similarity between object A and its candidate friends. To measure this association, a spatio-temporal encounter frequency and encounter duration vector for object A and its candidate friends *CFs* with reference to absolute location and relative location is constructed.

Algorithm 1 outlines the object similarity technique to select an appropriate neighbouring object to improve the overall network navigation in the SIoT system.

Algorithm 1: SSSSS: Search for Social Similar Smart Objects in SIoT

Input: object *A*
Output: Friendship Similarity list for *A*, in the order of relevance
Step 1 : Candidate Friends *CFs* Extraction.
for *object A* **do**
  Extract the list of nearby objects in the physical location proximity.
end
Step 2 : Friendship Similarity Computation between *object A* and *CFs*.
foreach $object \in CFs$ **do**
  1) Extract Encounter Frequency with similar interest.
  2) Extract Encounter Duration with similar behaviour and movement patterns for absolute and relative locations.
  Friendship Similarity(*A*, *object*)
end
Step 4 : Return the Friendship Similarity list.

V. Performance Evaluation

To study the impact of applying object similarity technique to navigate in the SIoT network, we need information about the objects settings, profile and mobility patterns for the large number of real objects. Though there are some existing SIoT platforms [31] to implement SIoT paradigm this information is not feasible since no SIoT applications has been deployed in the real world till date. Therefore, we have relied on time and location information of check-ins made by users from Stanford Large Network Dataset Collection, Brightkite [32] confined to Atlanta and Boston Region with 953 nodes, 3939 edges and 953 user check-ins. The SIoT network is visualized and analyzed using a Gephi [33], Open Graph *Viz* Platform. However, as discussed in Section IV-D, we are interested in

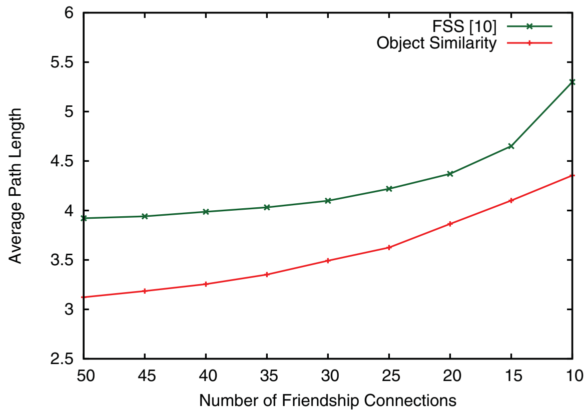

Fig. 3. Average Path Length for the Intrinsic Characteristic and Object Similarity Technique of the SIoT Network

using external property with respect to network characteristics for navigability. First nearby candidate friends are generated for an object based on encounter frequency and duration and then measure the association to choose the most relevant candidate friend. For instance, *object A* wants to communicate with object J. The first step is to find all the nearby friends for an object and then choose the object D that has highest friendship similarity to discover a path to J. D then repeats the process until it arrives at B. Figure 3. show the results with reference to average path length, an important indicator that measures the avegare shortest path between any two objects in the network. We have observed the results for upto 50 set of friends, the object similarity technique that exploits the similarity characteristic of SIoT network, reduced the average path length compared to third stratergy in FSS [10] technique. For the lower number of friendship connections, the network has too many clusters resulting with lesser average path length. As the number frienship connections are more the performance of the network is increased, since the number of local clustering is reduced. The object similarity ouperforms with 80 percent improvement over the existing FSS [10] technique, since the objects with similarity characteristic in the SIoT network is highly associated.

VI. Conclusions

In this paper we have discussed the object similarity characteristic to experiment the navigability of SIoT network. We first generate the nearby candidate friends for an objects who have similar preferences based on their physical context such as locations and social interaction like encounters or meetings in the real world. The behaviour friendship similarity between objects according to their encounter frequency and duration of stay with reference to absolute and relative location are evaluated. Our proposed object similarity technique outperforms FSS [10] in terms of average path length. As a future enhancement to the object discovery technique, the relay objects trustworthiness can also be considered in the routing process and design a social similarity based secured routing.

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