# Search Space Reduction in IoT using Owners Social Network Associations

Chirabrata Bhaumik
TCS Innovation Lab - Systems
Tata Consultancy Services
Ecospace, Rajarhat,Kolkata
c.bhaumik@tcs.com

Priyanka Sinha
TCS Innovation Lab - Systems
Tata Consultancy Services
Ecospace, Rajarhat,Kolkata
priyanka27.s@tcs.com

Amit Agrawal
TCS Innovation Lab - Systems
Tata Consultancy Services
Ecospace, Rajarhat,Kolkata
amitk.agrawal@tcs.com

## ABSTRACT

Today, sensors are getting placed everywhere, and through smartphones, they are reaching every corner in human civilization. A smartphone today comes with sensors like accelerometer, GPS (Global Positioning System), gyroscope, proximity, magnetometer etc. besides the ever-present microphone and camera sensors. In the world of IoT(Internet of things), as these sensors grow in numbers, data generated from them also has started increasing many folds putting a pressure on the supporting infrastructure. However if we look closely at this huge data, we will find that all data is not meaningful for all purposes i.e applications. Moreover, the utility of data generated by these sensors is limited to the common interest of the sensor owners. The data will be more meaningful for the persons or applications sharing common interest with the sensor owners than to unrelated ones. This paper discusses a novel way of reducing the search space for the generated huge sensor data by using the sensor ownership associations in the social network based on the common interest or intent of the owners. An example of ride share application is used to illustrate this concept, and the same concept will be useful while applied on use cases requiring human centric association like medical devices in Personal Healthcare vertical and smartmeters in Home Energy vertical.

## Categories and Subject Descriptors

H.3 [**Information Storage and Retrieval**]: Miscellaneous; H.1.2 [**Information Systems**]: User/Machine Systems—*Human Information Processing*; E.1 [**Data Structures**]: Graphs and Networks

## General Terms

Theory

## Keywords

Sensor data; Internet of Things; Social Network; Friend of a Friend; IoT; M2M; FOAF

## 1. INTRODUCTION

Social Networks have changed the way people interact using communication technology. These networks exhibit exact social behavior patterns and associations. There tend to be more cohesion between the persons sharing common interest and intent. Social network can be used as a tool to quickly explore and form cohesive groups based on parameters such as location, age, education, affiliations, interest, entertainment, hobbies, etc. A piece of information related to the common parameter shared by a member of a group will be more useful for other members of the same group. However, it might not be useful for other groups who do not share interest with the information owner. This property of social networks is very useful and it can be applied to any scenario where human centric associations can be formed.

Internet of Things (IoT) deals with the sensor data and provides a means to manage them. [18] shows how low cost sensor platforms are changing the traditional way of energy management by utility companies. Similarly [6, 11, 12] shows the change that can be brought in personal healthcare segment using IoT. As these sensors are changing from stand-alone mechanical devices to modern smartphones, their way of communicating with the external world has also changed. The data generated by such sensors depends upon the sensor owner's requirement and interest. With growing number of smart device users, there is a growing amount of data generated by these sensors. If IoT needs to handle and analyze such a huge amount of data, it will affect the real time performance and need more complex algorithms.

These new types of smart sensors are highly personalized and human centric. The social behavior, properties and associations formed by the sensor owners as part of their social network graph can be linked with these sensors. By linking the sensors with the owner's graph, it is now part of the social network graph sharing all the properties of owner's graph. As per the application requirement, appropriate graph parameter can be picked to find associations and create corresponding meaningful group. The sensor data will be meaningful to the members of this group. It results in significant reduction of search space for sensor data as used by IoT.

This paper emphasizes horizontal and generic aspect of search space reduction in IoT space using graph properties. We focus on illustrating the idea of sensor data and its link with the owner's social network graph using ride share application. Sensor data search space reduction is clearly pointed out using Friend of a Friend (FOAF) relationship in Facebook graph. Here FOAF relationship aptly maps to trust and significantly reduces search space for a ride sharing application. Around medical data, several applications such as detecting similar health conditions within a closed knit group, identifying hereditary traits within a family or workspace imposed health conditions among a group of co-workers could benefit from FOAF based search space reduction. In addition to FOAF, there may be additional graph properties and relationships, which can further reduce the search space depending on the use case. In personal healthcare domain, similar health conditions could be a good additional filtering criteria whereas in home energy domain, timeline could serve as an additional criteria to reduce the search space. For home energy segment a load balancing application build around energy consumption data in IoT repository can analyze the graph of smartmeter and all the smart electrical appliances associated with a home which were used simultaneously. Here timeline along with FOAF is a better criteria to reduce the search space in IoT repository. A similar application could be devised for grid level load balancing by considering the timeline and FOAF graph of all the appliances lying within a grid zone.

Next section "Related Work" explores similar works and their closeness with our work. In "System Overview" section, details of the IoT platform used and mapping of ride share application on this platform is mentioned with an explanatory diagram. "Application Details" section describes application design using a flowchart followed by a detailed discussion on algorithms. This section also contains a final subsection on experimental setup and graph images. The "Conclusions" section discusses the benefits and shortcomings of our work and scope for future work.

## 2. RELATED WORK

Representing the social network data in FOAF vocabulary is very much prevalent in the semantic web as seen from [14]. However this has been used more for formation of basic trust relationship rather than search space reduction purpose. [19] explores formation of social network of devices, but this has not taken the owners in consideration, and so it has not been able to leverage the existing social network relationships between the owners of devices or sensors. [25, 21] explains how two-tier and three-tier architectures are getting proposed in IoT world to tackle this huge sensor data generated. Our work is trying to solve this problem in IoT, wherever there is an existing human centric relationship between the sensors. We have taken the use case of a ride-sharing to illustrate this novel concept.

Ride-sharing is a nice and smart way to reduce cost, fuel emissions and traffic congestion. It is an active research area with lot of relevant prior work, out of which [9, 10, 15, 22, 17, 13] are close to our work. [9] is an important survey paper which discusses the goals and needs for a ride-sharing system and suggests that users are willing to participate if three core issues are addressed viz. trust, convenience and incentives. [10] defines a dynamic ride sharing community service architecture which combines Information Technology System (ITS) with social networking and uses dynamic resources in traffic information grid system to provide immediate and dynamic ride sharing service. [15] presents a case study on developing an agile ride-sharing system in a context-aware system and its evaluation from the human perspective. [22] introduces an easy-to-use dynamic ride-sharing management system running on modern Smartphones termed as vHike. [17] formally defines dynamic ride-sharing and outlines the optimization challenges. [13] addresses real-time requirement of ride-share problem and looks for suitable matches between passengers requesting ride-share services with proper drivers available for carpooling credits and lane privileges.

Trust is one of the basic requirements for a ride-share system. We have used trust as a basic filter to illustrate the concept of search space reduction, and it is defined as FOAF association in social networks. Few relevant papers were found which suggest trust based on social network associations out of which [9, 26, 16, 20, 24, 22, 14] were close to our work. [9] explains association of trust factor with social network and its variation with depth of social network hierarchy. Based on the sampling survey, it suggests that 82% would give a ride to the friend of a friend, where as 69% would accept ride from the friend of a friend. [26] proposes social network based trust establishment (SN-TE) for User Assisted Communication (UAC) implementation. [16] proposes six trust based filters that use three social-based estimators of trust including common interests, common friends, and the distance in the social graph. [20] identifies cyber social status based on various activities in cyber social space and suggest its use as a token of trust in open collaboration. [24] proposes a model for trust establishment, which is based on social computing and tries to avoid interactions with non-desirable participants. [22] suggests the use of well-known techniques from Web 2.0 and social networks to mitigate the threats and social discomfort emanated by ride-sharing. [14] suggests growing importance of trust in social networks and FOAF as a basis for trust in social network. [5] explores trust in both offline and online mode for extraction of components and principles of trust definition in true sense. [8] proposes an approach for supporting and expanding mobile social ride-sharing networks in particular localities using an iterative designing methodology.

Pickup Pal [3] and Zimride [4] are rideshare applications similar to ours where social identities are used for trust, however they do not talk about search space reduction using social associations. [19] provides a similar concept in IoT where devices themselves can form an intelligent social network of their own and thereby reducing search space. [7] first introduces this novel concept of search space reduction using social network association. We have developed our work based on the concept proposed in [7].

## 3. SYSTEM OVERVIEW

The platform on which the "Share a Ride" application has been developed and deployed is an elastic cloud for sensor networks which allows application deployment across components and sub-systems. The platform consists of three broad sub-systems, the application sub-system, the edge sub-system and the backend sub-system. The architecture block diagram is shown in Figure 1. Figure 1 gives a high level view of the interactions between different sub-systems. The layered approach is depicted in Figure 2 by showing

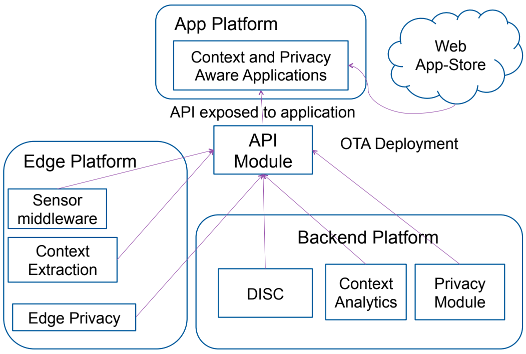


**Figure 1: Overall Platform Architecture**

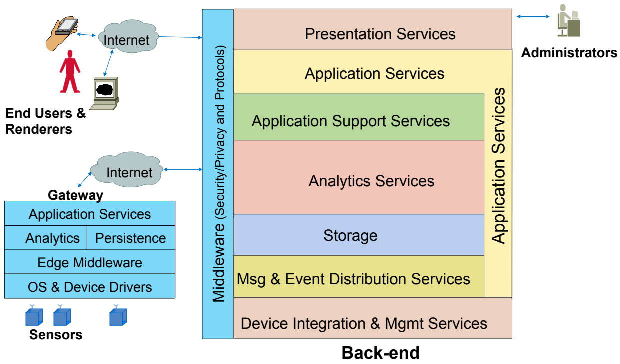


**Figure 2: Layers in Platform Architecture**

layers in each sub-system.

## 3.1 Backend Platform

The backend platform is the sensor sink where all raw or processed sensor data terminates and are stored. Aggregated analytics are run on the sensor data in this sub-system. It has been built using 52 North[1] based implementation of OGC(Open Geospatial Consortium) standards, an apache tomcat based web container and Play based lightweight web applications. Along with this Neo4J is being used as a graph database for caching social network data.

## 3.2 Edge Platform

The edge platform can be a Smartphone or other consumer device (like tablet, notebook) or dedicated embedded sensor gateway devices, based on the application use case. In context of the current application, the edge platform is the user's mobile phone which is carrying the "Share a ride" application.

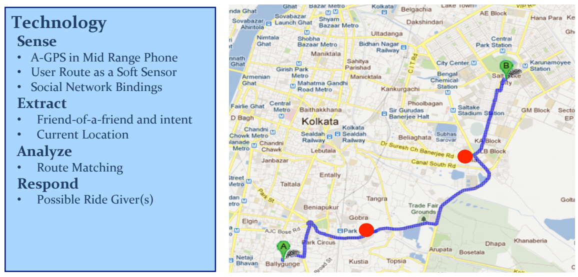


**Figure 3: Share A Ride Application Mapped on Platform**

## 3.3 Application Platform

The application platform is a logical platform which resides partially on the edge and partially on the backend subsystem. A part of the application that gathers data from individual sensors and runs some "context extraction" algorithm to extract meaningful feature vectors from raw sensor generated data, runs on the edge sub-system. However, the portion of the application that does aggregation or runs analytical algorithms like fusion, statistical modeling on the sensor or the extracted context information, typically runs on the backend sub-system. Since the platform is built for IoT and M2M(machine-to-machine) communications, applications that run on the platform typically follow the workflow state of sense-extract-analyze-respond. Figure 3 shows how the "Share a Ride Application" has been mapped to the platform workflow.

# 4. APPLICATION DETAILS

This section focuses on "Share a Ride" application design, algorithms and experiments. The design subsection describes the information flow of the application with a flowchart. The algorithm subsection discusses various approaches for Ride-Sharing application and their comparative advantages and shortcomings. In experiment subsection, details of experiments along with result screenshots are provided.

## 4.1 Application Design

To comply with the basic requirements for a ride share application as mentioned in [9], we have designed a Facebook application that allows ride givers to register their intent. While matching a ride share buddy, the application takes ride taker preferences and first identifies friend of friend for ride taker. This list is used to establish trust and it results in huge reduction of search space as well. Ride giver vehicle keeps on posting its location and timing details at regular intervals to sensor data repository as depicted in flowchart (Figure 4) labeled as B1 and B2. This repository provides route and timing details for the ride giver.

The starting point of the application is a web page which asks the ride giver to login using Facebook credentials la-

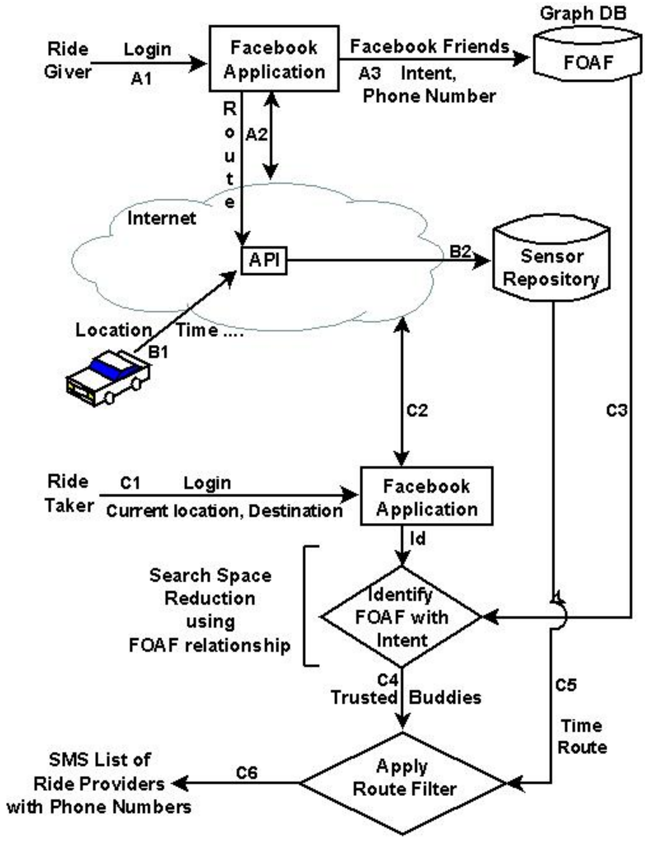


**Figure 4: Application Flowchart**

beled as A1. The application caches ride giver preferences along with friend details from Facebook in a local graph database labeled as A2 and A3. Facebook id is used to index the data. As new ride givers login to register their intent, the database grows and ride giver automatically connects with the friends having an entry in the existing database.

To find a ride provider, Ride taker also needs to login to a Facebook application and provide preference for time and route. The application uses ride takerâĂŹs Facebook id and local graph database to identify their friend of friend list, which is their trusted potential buddy list. On this list, time filter and route filters are applied to get a final list of ride share buddies. These sequences of steps are labeled in flowchart (Figure 4) as C1 to C6.

## 4.2 Algorithms

In this subsection, we discuss three different approaches to find a ride share buddy along with their merits and shortcomings. We start with a basic and simple approach which uses a spatial database to find the ride provider, and explore the issues related to this approach. Then we refine our first approach and provide intent based algorithm, which fix few issues reported in the first approach but still way behind. Then finally we discuss intent and trust based approach which fixes the major issues reported for other two approaches.

The Simple Approach is described in Algorithm 1.This approach matches route and time to suggest potential rideshare buddies, but it does not take care of the basic needs for a ride-share application viz. trust, intent and convenience as mentioned in [9]. Following are the major shortcomings of this approach:

- The growing number of application users will result in a huge search space.
- As, the intent to share the ride is not available, the list of potential ride-share buddies will be indicative. It does not ensure that the persons in the suggested list are willing to share the ride
- In this approach, trust is missing, which is considered to be one of the basic requirements for a rideshare application [9]. It is more likely that people want to share the ride with their acquaintance rather than strangers.

**Algorithm 1** Simple Approach

**INPUT:**
PR: Potential Ride Providers List
Rt(PR): Travelling Route
Tr(PR): Travelling Time Range
RS: Ridetaker Source
RD: Ridetaker Destination
RTr: Ridetaker's Timerange
**OUTPUT:**
PB:Potential Buddy List
**PSEUDOCODE:**

▷ For each ride provider
$\forall i \in PR$
  **loop**
    ▷ Apply time range & route match filters
    **if** $RTr$ ⊂Tr(i) && $RS$ ∈Rt(i) && $RD$ ∈Rt(i) **then**
      ▷ Append ride provider to buddy list
      PUSH $[Rt(i), Tr(i)]$ *to* PB
    **end if**
  **end loop**
  ▷ Return potential buddy list
  **return** PB

The Intent based approach is described in Algorithm 2. This improves over the previous one by adding intent component to Algorithm 1. The ride givers declare their intent to share the ride by installing the application. Addition of intent provides the following improvements and shortcomings:

- Explicit intent can be used as a first level filter to reduce the search space. However, this reduction in search space is limited by the number of users who have declared their intent.
- Even though, the intent is known (i.e. ride giver is willing to share the ride), but in absence of trust, ride giver may not agree to share the ride. The trust component is missing in this approach. It needs manual intervention to establish trust.

**Algorithm 2** Intent Based Approach

**INPUT:**
PR: Potential Ride Providers List
Rt(PR): Travelling Route
Tr(PR): Travelling Time Range
In(PR): Provider's Explicit Intent (Boolean)
RS: Ride Taker Source
RD: Ride Taker Destination
RTr: Ride Taker's Time Range
**OUTPUT:**
PBint: Potential Buddy List with Intent
**PSEUDOCODE:**

```
                              ▷ First level filter for explicit intent
∀i ∈ PR&&In(i) ≡ true
  loop
                         ▷ Apply time range & route match filters
    if RTr ⊂Tr(i) && RS ∈Rt(i) && RD ∈Rt(i) then
                              ▷ Append ride provider to buddy list
      PUSH [In(i), Rt(i), Tr(i)] to PBint
    end if
  end loop
                        ▷ Return potential buddy list with intent
  return PBint
```

Algorithm 3 adds trust component to Algorithm 2 to address the shortcomings in previous approach. It uses social network based friend of a friend (FOAF) relationship to establish trust. Following are the major improvements:

- FOAF is applied as a first filter to ensure that only trusted buddies are picked.
- Application of FOAF relationship as a first filter results in huge reduction of search space. [23] conducted Facebook social graph study on Nov. 2011, and provided following statistics related to Facebook friends.
  - An average Facebook user has around 190 reciprocal friends (excluding subscriptions).
  - A user with 100 friends has 27, 500 unique friends-of-friends.
  - The number of unique friends-of-friends grows almost linear. As per [23], a linear fit here will produce a slope of 355 unique friends-of-friends per additional friend.
- Using this data, we can project average number of unique friends-of-friends for an average Facebook user.
  - Friend count for average user = 190
  - FOAF count for a user with 100 friends = 27,500
  - Increase in FOAF count for an increment of 90 friends = 90 * 355 = 31950
  - FOAF count for an average Facebook user with 190 friends = 27,500 + 31,950 = 59,450
- We have also gathered popular Facebook application usage statistics. As per [2], Facebook applications are ranked based on monthly active user (MAU) count. MAU count for rank 1 application exceeds 41 million, whereas it exceeds 17 million for an application ranked 25. The above statistics suggest that Application user count will be much larger than the friends-of-friends count for a popular Facebook application.
- In this approach, intent is explicitly declared and trust is also established. It successfully addresses the issues in the first two approaches.

**Algorithm 3** Intent augmented with Trust (FOAF)

**INPUT:**
PR: Potential Ride Providers List
Rt(PR): Travelling Route
Tr(PR): Travelling Time Range
In(PR): Provider's Explicit Intent (Boolean)
RS: Ride Taker Source
RD: Ride Taker Destination
RTr: Ride Taker's Time Range
RFl: Ride Taker's FOAF List (Trust Component)
**OUTPUT:**
PBit: Potential Buddy List with Intent and Trust
**PSEUDOCODE:**

```
 ▷ First level filter using FOAF for Search Space Reduction
∀i ∈ RFl
  loop
                                          ▷ Apply Intent Filter
    if In(i) ≡true then

                          ▷ Apply time range & route match filters
      if RTr ⊂Tr(i) && RS ∈Rt(i) && RD ∈Rt(i) then
                                  ▷ Append ride provider to list
        PUSH [RFl(i), In(i), Rt(i), Tr(i)] to PBit
      end if
    end if
  end loop
        ▷ Return potential buddy list with intent and trust
  return PBit
```

## 4.3 Experiment

In this subsection we discuss how we have carried out the experiment and the results obtained.

### 4.3.1 Setup

The application is implemented using java servlet, Facebook SDK(Software Development Kit), Google Map API(Application Programming Interfaces), Neo4j graph database, IoT platform services and Bulk SMS(Short Message Service) API. The implementation spans across three different modules viz. Ride Giver module, Ride Taker module and Vehicle Sensor Data module. **Ride Giver Module** provides a web interface, where the users, wiling to share the ride, register their intent by explicitly logging to this module using their Facebook credentials. The module accesses ride provider's basic information and friends list using Facebook javascript SDK and cache this information. The ride provider is presented with another page (using google javascript API) to mark their preferred route on google map. It also accepts ride provider inputs regarding their time range for probable ride and phone number. The Facebook information gathered about the ride provider along with the friend list

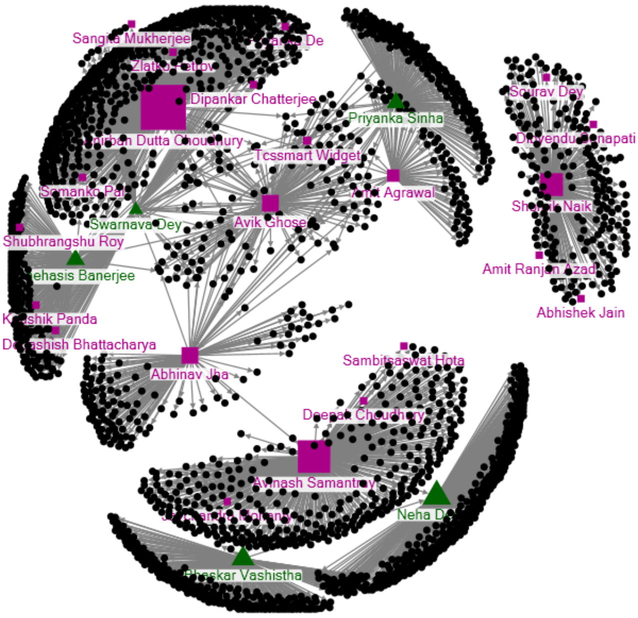


**Figure 5: Snapshot of Full Social Network adapted from [7]**

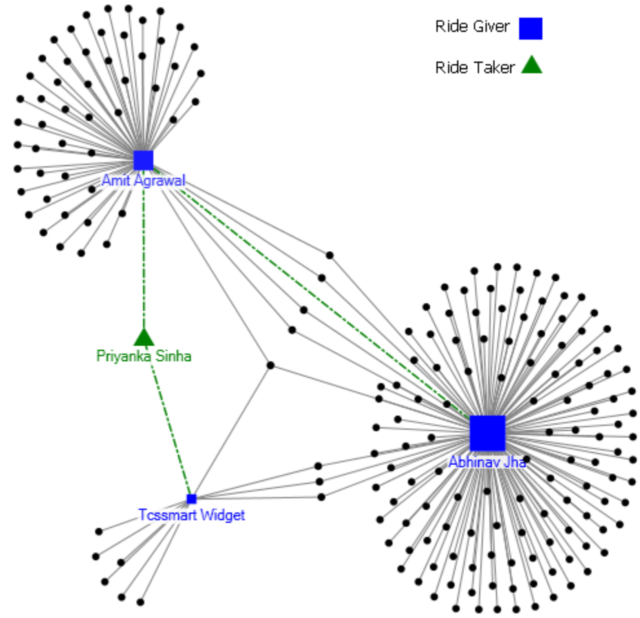


**Figure 6: Snapshot of Reduced Search Space adapted from [7]**

is forwarded to servlet which in turn stores it in a Neo4j graph database. The ride provider's phone number and intent are stored as attributes of the ride provider in Neo4j graph database. The route and time range information is forwarded to sensor repository using IoT platform services.

**Ride Taker Module** provides a web interface, where a user willing to take a ride needs to login using Facebook credentials and provide inputs like time range to avail the ride and source or destination geographical locations. The module fetches the user's information and friend list from Facebook account and forwards it along with user inputs (time range and source or destination points) to the servlet. Servlet stores Facebook information in Neo4j database and search for ride taker's FOAF with intent attribute as true. Application of this first level of filter leaves us with a list of potential trusted buddies with explicit intent. Now for each and every potential ride provider, time range filtering and route matching is applied using IoT platform services which results in a potential ride providers list with intent, trust, route and time range matching. This list augmented with phone number attribute is provided to ride taker as output. It may be sent to the ride taker as an SMS using Bulk SMS API services from telecom provider.

**Vehicle Sensor Data Module** is implemented as an application housed within OBD(On-board Diagnostic) sensor, installed in the vehicle. Whenever a vehicle is on the move, this module tracks time, GPS location, speed and various other vehicle parameters at regular intervals and post them to the sensor repository using IoT platform services. Alternatively a smartphone in the car could also have been used as a senor for the same purpose. This data is used for analysis purpose and dynamic route matching.

### *4.3.2 Results*

Figure 5 shows the network complexity when all the nodes are involved without any filtering mechanism in place. This depicts out an open space where any kind of combination is possible for matching the query result. Figure 6 shows the reduction in data points and eventual lessening of complexity when a FOAF based filtering approach is applied.

## 5. CONCLUSIONS

In this paper we have presented how using FOAF associations and intent (common interest) filters, we can reduce search space for sensor data analytics. The present paper provides a way for effective accumulation and analytics of sensor data by utilizing existing social networking structure of the sensor owners for creating a reduced set of related sensor data. In the future, we plan to bring the same concept in the ubiquitous network of sensors themselves and prove that reduction in search space possible whenever sensors have some kind of relationships between themselves other than existing social network relationship of their owners. We also plan to use social graph analysis in these networks to come out with other interesting results.

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