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Performance evaluation of recommendation algorithms on Internet of Things services

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ABSTRACT

Internet of Things (IoT) is the next wave of industry revolution that will initiate many services, such as personal health care and green energy monitoring, which people may subscribe for their convenience. Recommending IoT services to the users based on objects they own will become very crucial for the success of IoT. In this work, we introduce the concept of service recommender systems in IoT by a formal model. As a first attempt in this direction, we have proposed a hyper-graph model for IoT recommender system in which each hyper-edge connects users, objects, and services. Next, we studied the usefulness of traditional recommendation schemes and their hybrid approaches on IoT service recommendation (IoTSRS) based on existing well known metrics. The preliminary results show that existing approaches perform reasonably well but further extension is required for IoTSRS. Several challenges were discussed to point out the direction of future development in IoTSR.

1. Introduction

Technological revolution in communication and embedded computing has led to new paradigm called Internet of Things (IoT) [1]. IoT attempts to connect uniquely identified and addressed objects to Internet based on standard communication protocols. Examples of things include smartphones, power meters, heart beat monitors, temperature meters, and various sensors that can be equipped with processor and memory to become smart objects. Analysts predict that the number of interconnected objects will reach 212 billion by 2020 [2].

Nowadays, third party service providers have offered many IoT based innovative and valuable services. For instance, TELUS has launched its IoT marketplace in December 2014 featuring 75 different services and solutions hoping that the number will grow to more than 100 by the end of 2015 [3]. TELUS services include: fleet management solutions, oil and gas solutions, retail solutions, restaurant solutions, construction solutions, and public safety solutions. Another example of IoT marketplace is Libelium [4] which has listed 54 IoT applications grouped by 12 vertical markets including: urban and remote environments, agriculture and farming, water quality, security and emergencies, retail, logistics, domestic automation and e-health.

As time goes on, more smart objects along with countless services will be introduced and users will subscribe or own more of these value-added services. This causes high complexity on recommending appropriate services from increasing possible sets of service based on various smart objects owned by the users and their needs. To resolve this complex problem, Recommender Systems (RSs) is an effective solution [5,6].

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RSs are software system that analyzes information about items, users, and interactions between them in order to recommend the most suitable items to users by predicting his interest in a particular item. RSs have demonstrated its effectiveness in different domains, especially in the e-commerce domains. However, it is not examined and fully studied for the IoT. This paper addresses the problem of recommending IoT third party services to users and evaluates the usefulness of existing recommending algorithms on IoT service recommendation. To achieve the goal, we first introduce a tripartite graph-based model for IoT systems and project it into three bipartite graphs by utilizing the ternary relations hyper-edges among users, objects, and services to recommend services to the users. The graph is built by exploring users' ownership of objects, objects utilized by services, as well as user subscription to services. Second, we formalize the service recommendation problem based on graph approach and we analyze various entities and heterogeneous relationships to uncover correlations between objects, services, and users. Based on the graph model, we implement various existing recommendation algorithms and their combinations to study their behavior in IoT service recommendation. Finally, we evaluate their performance based on the some well-known metrics such as recall, precision, etc. The results illustrate that existing schemes worked decently but further extension is required to meet the challenges of IoT service recommendation. To the best of our knowledge, our work is the first attempt to designing service recommender system in the IoT.

The rest of the paper is organized as follows. Section 2 introduced related work and recommender system preliminary. Section 3 depicted the general system architecture. Section 4 presented a motivating example to illustrate the urgent need for IoTSRS. Section 5 introduced the proposed tripartite graph-based model that employs information of services and ambient objects for services recommendation. Furthermore, we give formal representation of IoT and introduced the formal model of the IoTSRS algorithm. Section 6 described in detail our datasets and the evaluation metrics used to validate IoTSRS. Preliminary results and evaluations were given in Section 7. Finally, Section 8 concludes the paper.

2. Related work

Traditional RSs use different techniques including content-based filtering (CB), collaborative filtering (CF), and hybrid techniques. As its name suggests, CB requires textual information about the items and the historical records of users [7]. CB recommends items similar to the items that active users have previously consumed or liked. It is based on description of item characteristics and a profile of the user's preference. However, it requires a mechanism to associate content to many heterogeneous networked objects. Moreover, only very similar items to previous items consumed by the users are recommended, which creates a problem of overspecialization [8].

In contrast to the CB filtering, CF does not rely on items representations and its content [9]. Instead, it relies on the opinions of other people who share similar interests. CF requires additional rating system to capture and store users' ratings. CF generates recommendations by identifying users who have similar tastes for items and recommend items that they have liked. It has been found that CF is a powerful technique that is able to produce high quality recommendations and thus it is widely used nowadays.

Fundamentally, CF can be classified into user-based and item-based approaches [10]. In the user-based CF, the K most similar users with similar rating are found, and then their ratings are used to calculate a prediction for active users. The item-based CF takes into account the similarity between items themselves [11]. There are many approaches to find similarity. The most popular similarity metrics are Pearson correlation and cosine similarity. However, constructing a collaborative user model is not a trivial task. Furthermore, CF requires an up-to-date dataset of users and their preference, which is difficult to gather specially for a large number of objects in the IoT.

To achieve higher performance and overcome the drawbacks of aforementioned techniques, hybrid technique has been proposed [12]. Hybrid RSs combine collaborative and content information by one of seven basic hybridization mechanisms by combining features of two or more recommendation techniques.

In recommender systems, the graph-based approach has been tested in the past in different domains and has shown promising results. For example, tag recommenders construct a graph with users, resources and tags, and recommend a set of tags for a given user based on previously used and assigned tags [13,14]. Many meaningful research works on tag recommendation have been proposed in recent years [15]. A well-known tag recommender approach is the Folkrank (FR) [16,17] which adapts the Google PageRank algorithm to rank the nodes within a graph based on their importance in the network. A different mechanism is based on the classic CF approach that has been adopted for tags recommendation in Refs. [18,19]. Collaborative approaches exploit the relations between users, resources, and tags of the folksonomy graph to select the set of recommended tags. Jäscke et al. [20] evaluate and compare user-based collaborative filtering, graph-based, and counting co-occurrences algorithms for tag recommendation. Other studies focus on using different approaches such as Rendle et al. [21], Wetzker et al. [22], Lops et al. [23], and Rawashdeh et al. [24]. Rawashdeh et al. applied the Katz measure to weighted undirected tripartite graph to provide tag recommendations for individual users.

Research work on recommendation for the IoT is in its infancy. To the best of our knowledge, there are very few articles that discussed recommendation in the IoT environment and current works are very primitive. For example, the work in Refs. [25,26] addressed things recommendation in IoT. They propose a framework to recommend the right thing to use at the specific time by exploring users' relations and things correlations. However, they do not consider recommending third party services. Compared with this research effort, we constructed the services–things correlation graph to capturing similarities between services.