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A ranking method for sensor services based on estimation of service access cost

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ABSTRACT

The concept of sensing-as-a-service is proposed to enable a unified way of accessing and controlling sensing devices for many Internet of Things based applications. Existing techniques for Web service computing are not sufficient for this class of services that are exposed by resource-constrained devices. The vast number of distributed and redundantly deployed sensors necessitate specialised techniques for their discovery and ranking. Current research in this line mostly focuses on discovery, e.g., designing efficient searching methods by exploiting the geographical properties of sensing devices. The problem of ranking, which aims to prioritise semantically equivalent sensor services returned by the discovery process, has not been adequately studied. Existing methods mostly leverage the information directly associated with sensor services, such as detailed service descriptions or quality of service information. However, assuming the availability of such information for sensor services is often unrealistic. We propose a ranking strategy by estimating the cost of accessing sensor services. The computation is based on properties of the sensor nodes as well as the relevant contextual information extracted from the service access process. The evaluation results demonstrate not only the superior performance of the proposed method in terms of ranking quality measure, but also the potential for preserving the energy of the sensor nodes.

1. Introduction

Development of the Internet of Things (IoT) has the potential to add billions of devices to the future Internet (the Cisco IBSG predicts that there will be around 25 billion devices connected to the Internet by 2015 and 50 billion by 2020 [19]). As the most fundamental constituent of the IoT, wireless sensor networks (WSNs) have attracted considerable research interests from both academia and industries [46,16]. One of the research directions is to create an interoperable and scalable platform for sensor discovery and access, which is termed as the "sensor Web" [11]. To address the interoperability problem, researchers propose the use of semantic technologies for representing, storing, interconnecting, searching and organising information generated by heterogeneous things [6,37]. To address the challenge of scalability, they believe that the platform should be developed using the service-oriented paradigm, for example, to create a service-oriented IoT [8] and/or service-oriented sensor Web [20].

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Following the service-oriented paradigm, if all sensors expose their functionalities in terms of services, then there will be numerous sensor services generating tremendous amount of streaming data continuously. This highlights the significance of efficient sensor service discovery, which aims to locate relevant sensor services at large scale [18]. In the past few years, different techniques have been proposed for sensor service discovery. While these efforts represent an important step towards scalable and efficient access of distributed sensor services, we believe that this is not the end of the story. The outcome of such service discovery process is usually a limited number of semantically equivalent services which all match the searching criteria. The discovery engine is not able to differentiate between the retrieved services and to rank them in an appropriate order.

The problem of ranking sensor services is difficult as they usually have scarce features. This is very different from ranking Web services and semantic Web services, which contain abundant features for effective algorithm design (e.g., textual descriptions and quality of service information) [27,12,43]. Characteristics of the sensor services are also different as the exposing sensors are mostly capability constrained, location dependent, heterogeneous and operating in highly dynamic physical environments. The challenge is to design useful ranking methods for sensor services by taking the above mentioned factors into consideration. Such methods are essential for many upper layer applications that need data aggregation, service recommendation, automated service composition and runtime adaptation [45]. For example, the system can recommend a number of highly ranked services in real-time for disaster monitoring and warning applications. The system can also suggest the best ranked services for data aggregation to high level applications which can subsequently subscribe to those services. In case of service failure, the system can initiate the ranking again and find new services for compensation.

The starting point for this research is the observation of the fact that accessing a sensor service involves data communication with other sensor nodes in the network and the process generates cost (e.g., the energy consumed by itself and others which act as the relay nodes). This is significantly different from accessing a Web service and is essential from the sensor network's point of view. The fundamental idea is to estimate the cost incurred during the service access cycle, which involves not only the sensor node exposing the required service, but also other nodes participating in the data communication (e.g., those act as routing nodes). For the nodes, information about their energy level, importance (a concept introduced to measure the significance of a sensor node to the whole WSN. See Section 4.3 for more details.), and the link quality among them all has various degree of influence in the cost estimation. The information represents key features for sensor services, which can be either collected from the sensor nodes themselves (e.g., energy level), or the underlying WSN (e.g., link quality), or inferred using certain algorithms (e.g., importance and WSN topology). We refer to all the relevant information together as the contextual information for the sensor service in consideration.

The contribution of this work is the design of such a ranking method, which presents the following novelties: (1) a function which estimates the cost of accessing sensor services with respect to the queries and properties of the relevant sensor nodes (e.g., importance, energy and link quality); (2) a probabilistic method for deriving importance of sensor nodes based on the overlay topology of WSN; (3) seamless integration with the quality of service (QoS) framework (e.g., accuracy and response time) used in many existing ranking methods; (4) independence of the complexity and heterogeneity of low-level WSNs implementations (e.g., routing, broadcasting and power-saving algorithms for sensor network optimisation). To our best knowledge, the work is the first attempt to design such a ranking by performing analysis on the sensor service access process using relevant contextual information collected from the WSN.

The rest of the paper is organised as follows. In Section 2, we review the recent research progress on sensor service discovery and ranking. In Section 3, we briefly outline our previous work on sensor service discovery and elicit the challenges and requirements for the ranking. Section 4 presents the rationale of the ranking algorithm. Concepts such as the overlay topology of WSNs, importance value and the most probable path are explained in details. The experiment and evaluation results are reported in Section 5 and compared to those generated with the benchmark methods in terms of ranking quality and potential for energy preservation. Finally, Section 6 concludes the paper and outlines the future work.

2. Related work

Recent research on sensor service computing (or more generally, IoT service) mainly focuses on representation and discovery. The work on representation is to develop formal knowledge representation frameworks for devices, entities and services on the IoT, for example, the Semantic Sensor Network (SSN) ontology [16], and the ontology for service and resource modelling [17]. Many different techniques for sensor service discovery have been proposed; some of the notable work in this line include the IrisNet, a wide-area architecture for pervasive sensing services in distributed and heterogeneous environments [20]; discovery and on-demand provisioning of services for IoT based business applications [21]; IoT based service discovery using distributed hash table [29] and geographical indexing [45]. However, the problem of ranking sensor services has not received much attention and has not been well investigated.

There has been considerable amount of research on the ranking of Web services (and semantic Web services). It mostly employs content-oriented ranking paradigms, e.g., by analysing the relevance of Web service descriptions with regard to queries [27]. To improve the discovery performance, machine learning based methods can be applied to perform deep semantic analysis on the service descriptions, for example, the work in [12] first applies Latent Dirichlet Allocation [39] to derive a latent factor model from service descriptions, and then computes service matchmaking using the latent model. The experiments show that the discovery results are more promising than the existing methods. The major limitation of