Differentiated Context Maintenance and Exchange oriented to Internet of Things

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Abstract

Context information can add more meaning and value to the sensor data in Internet of Things. However, due to the large amount of sources of contexts and sensor data, the exchange of contexts through the networks may cause more and more data traffic. This paper proposes a novel method for maintaining and exchanging contexts through the Internet more efficiently. Contexts are classified into different levels. Each level of contexts is maintained and exchanged using different methods. A new protocol for exchanging the contexts is designed. Through the independent transmitting of contexts and sensor data, the context-awareness in Internet of Things can be realized, and the network bandwidth usage can be greatly reduced and thus the energy of node can also be saved.

Keywords: *Contexts, Internet of Things (IoT)，DCXP.*

1. Introduction

In recent years, Internet of Things (IoT) has developed very quickly. Billions of devices collect data, communicate each other, fulfill the computation and actuation tasks. Currently, IoT has been used in a wide range of industrial, civilian and military applications, including healthcare, home automation, earthquake warning, traffic control, and industrial process monitoring etc. The researches in [1] has predicted that the present 'Internet of PCs' will move towards an 'Internet of Things' in which 26 to 50 billion devices will be connected to the Internet by 2020.

The deployment and development of IoT means that large amount of data will be collected by a vast number of devices, including sensors, and transmitted through networks. Here the collected data will not have much meaning and value until it is processed and analyzed. Especially, more value can be added to the data when the data can be used by devices in different geographical locations. Nevertheless, this means that the large amount of data needs to be transferred through the networks, which may increase heavily the network traffic.

Context is a subset of information that can be used to characterize the situation of an entity. A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user’s task [2]. Being context-aware, a device or system can become more adaptive to its environments and well satisfy users’ need. Concerning IoT, contexts can also add more value and meaning to the sensor data. Since when the collected data is associated with the contexts, the interpretation of the data can become meaningful, and the further processing and utilization of the data will become more reasonable and understandable. Moreover, more new information can be acquired from the existing data. For example, on account of the large amount of data collected by various sensors, it is impossible to process all the data. In this case, context-awareness may play an important role in deciding which data should be processed first. In addition, considering contexts makes it efficient to realize the device to device communication, since only the needed data will be transferred through the networks. Furthermore, the use of network-related context information enables also novel ways of using communication devices, services, and systems.

Due to the importance of contexts, some work has been done to transmit the context through IoT, such as work in [3][4]. However, in these work, the contexts are transmitted together with the associated data. For example, OWL [5] is used to model and share the contexts, which integrate the data with the context logic. This may result in a waste of network bandwidth and the energy of end devices. Sometimes users want to know how the data is obtained instead of the data itself. In this case, it is not necessary to transmit the data which usually occupies large network bandwidth through networks. On the contrary, sometimes some devices may be interest only on the data while not on the context. For instance, some devices may only care about the value of the temperature, while do not care about which nodes have collected the data. In this case, transmitting contexts to the devices may waste lots of energy of the devices besides the network bandwidth.

Therefore, in this paper we propose a new approach for exchanging the contexts in IoT based on analyzing the features of contexts used in IoT. In our approach, contexts are differentiated according to the stages for processing the collected data and the groups of connected devices sharing the data. Besides, the contexts are exchanged among the networked devices separately from the associated data. The proposed approach enables the context-awareness in the paradigm of IoT, which not only allow the connected devices to well understand the collected data but also reduce the usage of the network bandwidth and save the energy of the networked devices. The rest of the paper is organized as follows. In section 2, the features of contexts for IoT are analyzed, and the differentiation of contexts in the paradigm of IoT is presented. Following this in section 3, a new method for maintaining and exchanging the contexts for IoT is suggested. In section 4, a scenario of vehicular networks using the proposed approach is described, and conclusions are made in section 5.

2. Features of Contexts for Internet of Things

In the paradigm of IoT, multiple sensors collect data for certain purposes. In terms of the functions of each sensor, in general two means of co-operations among the sensors can be found. One is that each sensor can obtain a certain data, but only values from multiple sensors of the same type are valuable. For example, multiple sensors are distributed among a certain area to measure the pH value of the soil in a certain area. Normally, the data collected by one sensor cannot represent the pH value of the soil in a certain area. Similarly, multiple cameras are needed in order to monitor the traffic of a certain intersection from different perspectives and at different distances. The other is that different types of sensors can obtain different categories of data. A certain conclusive data can be summarized from all the data together. For example, a car can have a sensor to monitor if the break works well, a speed sensor to monitor the speed, a sensor to sense the condition of the road and a sensor to measure the distance with other vehicles. From the data of all the sensors a conclusion can be well made, for instance, if the car may change the lane.

In these cases, the context is very important for making the decisions, in other words, for processing data. In the above examples, only when certain contexts, such as the width of each street and how many lanes in each street is known, a conclusion about if the intersection is congested can be concluded. Similarly, only when the geographical situation of a certain area is known and the geographical distribution of the sensors is fixed, can proper pH values of the soil be useful to the agricultural research and administration. Hence, context plays a critical role during analyzing, processing, interpreting, understanding and utilizing the collected data in IoT.

As illustrated in Fig. 1, the raw data collected through multiple sensors needs to be processed, analyzed and interpreted before they become understandable information and valuable to be used. The processing of the data can be done at anywhere in networks independent of the deployment of the sensors. In order to make the collected data meaningful to every user potentially at anywhere, contexts for processing the data should be annotated and associated with the data, and potentially transferred to the user who will use the information. Similarly, reasoning techniques can be used to deduce new knowledge from the acquired information. In this stage, contexts are also necessary for understanding and using the deduced knowledge by users possibly at anywhere of the networks.

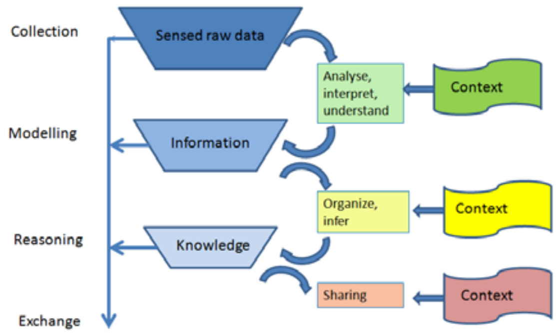

Fig. 1 Contexts and data processing in IoT

It should be noted that all types of data, including the collected raw data, information and deduced knowledge can be transmitted through the networks depending on users' need and wish. But normally it is much more efficient to transmit knowledge through the networks than to transfer raw data considering the amount of information a user can obtain by transmitting per unit data through the networks. Of course, in any case the contexts associated with the data needs to be transmitted through the networks too. Nevertheless, it is not necessary to transmit the contexts always together with the associated data. In addition, different contexts may require different ways to represent themselves and different ways and frequencies for sharing them among the users throughout the networks. For instance, it might be easier to describe the contexts associated with reasoning knowledge using ontologies, whereas using markup schemes to describe the contexts for processing the raw data. Also, the contexts for reasoning knowledge might seldom change and do not need to be transmitted to other users each time when the knowledge is transmitted.

In general, contexts lie in different levels concerning IoT, for example,

- Contexts associated with data collection;
- Contexts for modeling information;
- Contexts for reasoning knowledge.

At each level, the contexts may have their own features, therefore they can be modeled using different methods. The existing methods, such as key-value [6], markup schemes [7], graphical [8], object based [9], logic based [10], and ontology based modeling [11] etc. can be used simultaneously to model the contexts at different levels in the same application scenarios in IoT. Moreover, due to the features of the contexts, the contexts at different levels should also be exchanged by using different mechanisms.

In addition, at each level, the user/device groups concerning the contexts may be greatly different in terms of the geographically distribution of the users/devices, and the processing capability (including the CPU processing, networking and storing capability etc.) and the application scenarios. Thus, the mechanisms for sharing the contexts among the users should also be different.

3. Differentiated Context Maintenance and Exchange

Based on the features of the contexts in the paradigm of IoT, an approach for differentiated context maintaining and exchange for IoT should be used.

3.1 Context differentiation and maintenance

Fig.2 illustrates a typical networking scenario of IoT. Devices, including sensors and actuators, which are responsible for collecting and consuming data, are normally connected to a powerful gateway with high processing, networking and storing capabilities. Through the gateways, the collected data are fused, processed, organized and transmitted. In addition, some devices may form a local network according to the geographical location or the functions of the devices. To be convenient, we call each local network a domain, such as D11, D12, D21, D31 etc. in Fig.2.

In general, the contexts for modeling information and for reasoning knowledge are associated with the networked nodes with high processing capability, such as gateways or intelligent mobile phones. Since they are responsible for processing and disseminating the collected data, and thus possess the contexts. On the other hand, as the devices are responsible for collecting data, they possess the contexts associated with data collection. Hence, four facts need to be noted regarding the data collection and context sharing in IoT:

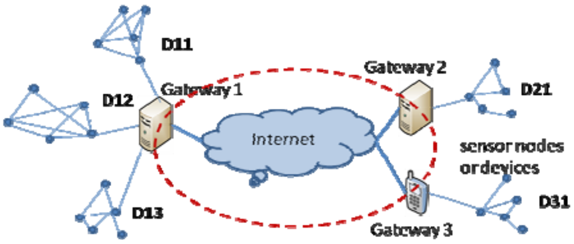

Fig. 2 A typical scenario of IoT

First, the devices in the same domain (e.g., in D11 or in D12) normally do not need the data collected by other devices, since they more often cooperate or are complementary to each other in finishing certain tasks. Therefore, the contexts associated with each device's data collection do not need to be shared among the devices in the same domain. However, the gateway of each domain needs to know the "cooperation" of the devices within the domain, and may need the contexts associated with data collection of each device in the domain.

Second, devices in different domains are normally interested in the data from each other after the data have been processed. In other words, they concern more often the information and knowledge in order to fulfill their own tasks, for the information and knowledge are more concise and informative. Hence, only the contexts for modeling information and reasoning knowledge need to be shared among the devices in different domains.

Third, since the gateways are responsible for processing, analyzing and interpreting the collected data, knowing the contexts will help them to finish their tasks easily and efficiently. Hence, they should know all the contexts.

Fourth, a context will not be interested by all the devices. In other words, a context should be shared among a certain group of nodes; no matter they are in the same or different domain.

Based on above considerations, different levels of contexts should be maintained using different mechanisms, and be exchanged differently among certain group of users.

- Contexts associated with data collection are maintained by the devices that collected the associated data and the corresponding gateways responsible for the domain;
- Contexts for modeling information and reasoning knowledge are maintained among the gateways in a distributed way, i.e., using a distributed algorithm. This can increase the scalability of the networks sharing the contexts and avoid the problem like single point failure and attack etc. on the one hand, and satisfy the needs of context sharing among the devices in different domains efficiently on the other hand.
- A group sharing the same context can be established dynamically. The identity of a device (IP addresses or names) and some attributes of the contexts, such as the identities and the validity period of the contexts should be maintained associated with the group identity.

In summary, the differentiation lies in the following aspects.

First, the maintenance of contexts at different levels is different. The CS (client-server) mode is used to exchange context between a smart node and the corresponding gateway. DHT (Distributed Hash Table) based distributed algorithm is used for exchanging contexts among the gateways, and a mixed mode of CS and DHT is used to exchange contexts among devices belonging to different domains. Especially, a context ID is applied to distinguish the contexts associated with the data collection within a domain. This may simplify the identification and exchanges of the contexts for the devices. Currently, we use the UCI (Universal Context Identity) [12] in our system since it is similar to URI (Uniform Resource Identifiers) and easy to be accepted and used by the users. However, we still use IP addresses to identify the gateways in order to be able to implement the system easily.

Second, we use different methods to model and transmit the contexts at different levels. Currently, we use the TLV (Type/Length/Value) format to describe the contexts associated with the data collection and ontologies to model the contexts at the other two levels. Depending on the application scenarios, object and graphical based method can also be used.

Third, different groups are established for sharing different contexts. According to the features of the contexts, the contexts can be pushed to each member in the group at different intervals.

3.2 Differentiated context exchange protocol (DCXP)

Generally two ways can be used to exchange the contexts among the Internet. One is associated exchange, which means the devices obtain the contexts together with the associated data. For example, a device can get the value of the temperature together with from where (or which sensor) the temperature is monitored. The other is separated exchange, which means the devices obtain the contexts independent with the associated data. This is because sometimes the context varies much more infrequently than its associated data. It would be much efficient to transfer the contexts only when changes occur to the contexts. Of course in this case, certain binding information between the contexts and the associated data should be maintained. Due to the efficiency of the usage of network bandwidth, we use the second way to exchange contexts among the devices in IoT.

According to the discussions in section 3.1, the exchange of contexts may happen between:

- a node (i.e., a device) in a given domain with the corresponding gateway, for example, between a sensor node in D11 and the Gateway 1 in Fig.2. This can be the case that a gateway notifies a device that the context for processing the data has changed or a node tells the gateway that the context for collecting the data has changed.
- gateways connecting different domains. This can be the case that a gateway announces that the context for fusing or processing or reasoning etc. a certain type of data has changed. It can be also the case that a gateway wants to ask the current contexts for processing a certain type of data from another gateway.
- nodes in different domains, for instance, a sensor node in D11 and a node in D31. This deals with the context request or notification between devices in different domain.

Hence, we design a differentiated context exchange protocol (DCXP) which mainly consists of the following procedures in order to exchange the contexts between two nodes in IoT:

- Context Request: a node asks a certain context from a context holder.
- Context Response: the result is sent back to the node that requests the contexts.
- Context Notification: if the context of a node changes, the node may notify other related nodes actively about the change.
- Group Initiation: a gateway can initiate a context

sharing group depending on certain characteristics of contexts.

- Group Registration: devices may join a context sharing group through registration procedure.
- Context Push: if the contexts associated with a group change, the contexts will be pushed to the registered members.

It should be noted that a DHT PUT, GET operations may happen during the above procedures. Fig.3 illustrates the message sequence when a context request between nodes in different domains happens (e.g., the node n1 in domain D11 request a context for modeling the information provided by the data collected by the node n2 in D21). Here the node n2 notifies his context to the gateways in advance.

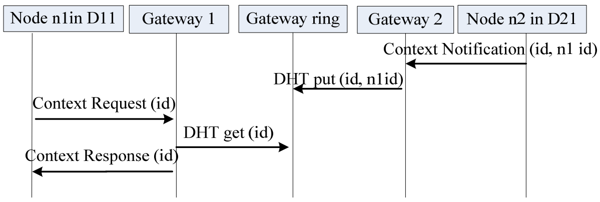

Fig. 3 Context request between nodes in different domains

4. DCXP for Vehicular Networks

To validate our proposed approach, we will apply the approach in the context exchange in vehicular networks. Fig.4 shows the architecture of our vehicular network.

Here vehicles near each other construct an ad hoc network, such as Domain A, B, C illustrated in Fig.4. Each vehicle monitors the road condition (construction site) and the distance with other vehicles. The context for the monitored data is the location of the data (GPS coordinate) and time. The Road Side Units (RSUs) within the radio coverage of each vehicle act as the gateways for the vehicles. The monitored data are collected by RSUs and processed, and the decision of where there is traffic jam will be obtained at the RSUs.

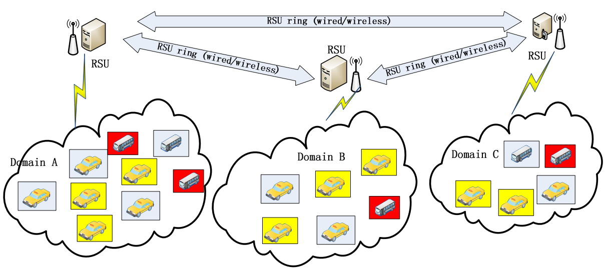

Fig. 4 Context exchange for vehicular networks

The contexts are maintained at the RSUs and the corresponding vehicles. The RSUs communicate each other through wired or wireless networks, and construct a DHT ring. According to the data obtained from the vehicles, the RSUs can deduce how long the traffic queue at a certain area. If a driver wants to know the detail about the traffic in a certain area, he can send a message (Context Request) to the current RSU. The current RSU will look for the time information associated with the location and traffic status. Then the time and the location of the traffic queue will be sent back.

5. Conclusions

Context information can add more meaning and value to the sensor data in IoT, and needs to be exchanged. In order to reduce the network usages and therefore save energy of the devices by exchanging the context information, we suggest an approach to maintain and exchange contexts in different ways in the paradigm of IoT.

In our approach, contexts are classified into three different levels. Contexts associated with data collection are maintained by the devices locally, while contexts for modeling information and reasoning knowledge are maintained globally using a distributed algorithm. Moreover, contexts are only shared among the users that need them. Correspondingly, a Differentiate Context Exchange Protocol (DCXP) protocol is designed to exchange the contexts among the devices in IoT. Through the independent transmitting of sensor data and context information, the context-awareness in IoT can be realized and the network bandwidth usage can be greatly reduced.

Currently the performance of the suggested approach is being evaluated and implemented in our vehicular network system.

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