An Internet of Things QoS Estimate Approach based on Multi-Dimension QoS

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***Abstract*—Internet of things(IoT) has highly got recognition for its important application prospects from the day of emerging. Academia and industry have carried out extensive research aiming at the key theories and technologies of IoT. How to estimate the QoS of applications of IoT is an important problem in IoT research. To address this problem, this paper presents an IoT QoS estimate approach based on multi-dimension QoS which introduces multi-dimension QoS to estimate the QoS of applications of IoT. At last, an application example of IoT is used to explain how this approach to estimate the QoS of applications of IoT.**

***Index Terms*—Internet of things(IoT), multi-dimension qos, qos management.**

I. INTRODUCTION

IoT is referred to as the third wave of global information industry after computer and internet[1]. In recent years, academia and industry have carried out extensive research aiming at the key theories, technologies and industry applications in IoT. The research covers the whole process of information acquisition, transmission, storage, processing and application. It includes RFID technology which is used to tag things, sensor technology which is used to perceive things, smart technology which is used to think about things and nanotechnology which is used to miniature things. Correlative research about IoT is very active.

In applications of IoT, the requirement of users is divided into two groups, one is the functional requirement, the other is the non-functional requirement. Functional requirement describes the function which applications of IoT should provide. Non-functional requirement describes the service which applications of IoT provide or the restriction of function. With more and more research of IoT, many researchers propose that the nonfunctional properties, also known as quality of service(QoS), should be taken into consideration as one of the key factors for applications of IoT success[2]. Based on this fact, this paper presents an IoT QoS estimate approach based on multi-dimension QoS which introduces multi-dimension QoS to estimate the QoS of applications of IoT. This approach can guarantee the non-functional requirement of applications of IoT under the precondition of satisfying the functional requirement of applications of IoT.

Firstly, this paper introduces some concepts of IoT and QoS, analyses the architecture and key technologies of IoT. Then, aiming at the problem that how to estimate the QoS of applications of IoT, this paper presents an IoT QoS estimate approach based on multi-dimension QoS which introduces multi-dimension QoS to estimate the QoS of applications of IoT. At last, an application example of IoT is used to explain how this approach to estimate the QoS of applications of IoT.

II. IOT AND QOS

A. IoT

The concept of IoT originates initially from the networked RFID system which is presented by Auto-ID Labs of MIT in 1999. This system couples all things with internet to realize intelligent identification and management according to information sensing devices such as RFID[3]. In 2005, international telecommunication union(ITU) issues a report named *ITU Internet reports 2005-the Internet of things* and officially presents the concept of IoT[4]. This report explains

978-1-4799-2951-1/14/$31.00 ©2014 IEEE

the concept of IoT from function and technology. From the angle of function, ITU thinks that all things in the world can exchange information by internet and from anytime, anyplace connectivity for anyone, we will now have connectivity for anything. From the angle of technology, ITU thinks that IoT includes RFID technology, sensor technology, smart technology and nanotechnology.

IoT is a ubiquitous network based on internet and brings about the connection of all things by the converge of various wired network, wireless network and internet[5]. The architecture of IoT can be divided into three layers, sensing layer, network layer and application layer, which is showed in Fig. 1. Sensing layer realizes intelligent identification and information acquisition for the physical world. Network layer realizes the transmission, routing and control of information. Application layer includes application infrastructure and various applications of IoT.

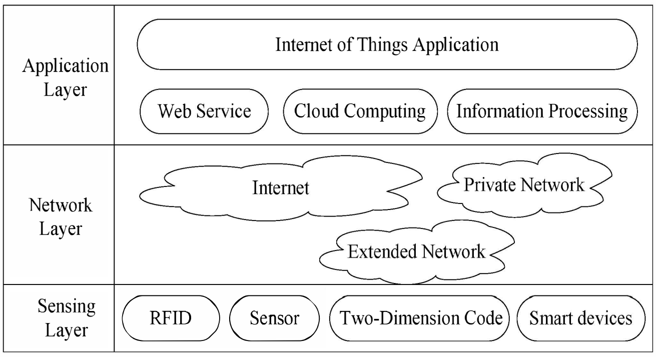

Figure 1. Architecture of IoT

B. QoS

Definition of QoS is given initially by international telephone and telegraph consultative committee(CCITT): QoS is a integrated indicator to measure satisfaction with a service and describes some performance characteristics of a service. Academia generally agreed that QoS has narrow and broad sense. Narrow QoS refers to some technical indicators of the network transmission. Generalized QoS refers to end-to-end QoS, involving network layer, system layer, middleware layer and application layer, including resource allocation, utilization, and consultations between the layers. Applications of IoT refer to sensing layer, network layer and application layer. QoS of every layer will influence QoS of the whole application.

III. MULTI-DIMENSION QOS ATTRIBUTES OF IOT

A. Multi-dimension QoS

With the further research on QoS, the kind of QoS parameters becomes more abundant and the range of QoS parameters is much wider. For exploring QoS more deep researches of Carnegie Mellon present multi-dimension QoS.

The concept of dimension is from geometry. In geometry, dimension is the coordinates of points in space and is the basic element to make up of space. According to the concept of n dimensions, QoS of an application can be considered as a space of n dimensions. Every kind of QoS parameters is one dimension which makes up the space. So the relation among QoS parameters of different dimensions can be expressed by the restrictive condition among different dimensions, which is helpful to research the intrinsic relation among QoS parameters.

B. Multi-Dimension QoS Parameters of IoT

As a ubiquitous network, IoT is the converge of various sensing devices, wired network, wireless network and upper applications. It includes lots of heterogeneous systems. From the view of architecture, applications of IoT are divided into three layers, sensing layer, network layer and application layer. The main function between the layers is different. QoS attributes of applications of IoT can be interpreted as a group of parameter set that can be quantified used to measure the satisfaction of the service provided by service provider. In applications of IoT, simplex QoS parameter is difficult to describe QoS attributes systemically because QoS requirement between the layers is usually different. In order to describe QoS attributes of applications of IoT more exactly, the concept of multi-dimension QoS is introduced to this paper.

QoS attributes of applications of IoT refer to sensing layer, network layer and application layer. So their QoS parameters are more complicated. For describing QoS attributes of applications of IoT accurately, we think QoS of applications IoT as a space of three dimensions which includes sensing dimension, transmission dimension and application dimension. It is showed as table Ⅰ.

TABLE I. MULTI-DIMENSION QOS PARAMETERS OF IOT

Dimension	**QoS Parameters**		
sensing dimension	Accuracy	Availability	Stability
transmission dimension	Transmission time	Storage capacity	Reliablity
application dimension	Functionality	Normative	Robustness

QoS of sensing dimension describes QoS parameters of sensing layer. It includes accuracy, availability and stability. Accuracy stands for the accurate degree of data which are collected by sensing devices in sensing layer. Availability stands for the number of sensing devices which are available. Stability stands for the normal working hours of sensing devices.

QoS of transmission dimension describes QoS parameters of network layer. It includes transmission time, storage capacity and reliability. Transmission time stands for the transmission time of data which is collected by sensing devices. Storage capacity stands for the space of data transmission. Reliability stands for the number that data transmit successfully.

QoS of application dimension describes QoS parameters of application layer. It includes functionality, normative and robustness. Functionality stands for the number of functions which the application achieves. Normative stands for the number of documents which are provided by the application. Robustness stands for the ability of the application to resist change without adapting its initial stable configuration.

IV. AN IOT QOS ESTIMATE APPROACH BASED ON MULTI-DIMENSION QOS

A. Normalization of QoS Attributes

In multi-dimension QoS, QoS described by every dimension QoS attributes is different while there are differences among meaning and values range expressed by every QoS parameter of every dimension. For comparing QoS on a uniform platform, it is necessary to normalize QoS parameters to map these different QoS parameters into the same interval. Or else, the QoS which is contributed by numerical value in different domains should not compare.

The QoS attributes of IoT can be divided into positive attributes and negative attributes. For positive attributes, the bigger are QoS attributes, the better is QoS, such as accuracy and availability. For negative attributes, the smaller are QoS attributes, the better is QoS, such as transmission time and storage capacity. Based on above considerations, we use two different formulae to normalize the two types of QoS attributes. They can map QoS attributes of every dimension into the interval between 0 and 1 and make them in the same growth direction.

For QoS of sensing dimension, we mark the data which are collected by sensing devices with sdata, the actual data of the environment with sadata, the total working hours of sensing devices with sstime, the normal working hours of sensing devices with stime, the number that sensing devices can work normally with snum, the sum of sensing devices with ssnum. s1, s2 and s3 denote the value of weight of QoS parameters in QoS of sensing dimension and the sum of s1, s2 and s3 is 1. Thereout after normalizing the accuracy acc, the availability ava, the stability sta, and the QoS of sensing dimension S can be denoted as follows:

$$acc=1-|sdata-sadata|/sadata \quad (1)$$

$$ava=snum/ssnum \quad (2)$$

$$sta=stime/sstime \quad (3)$$

$$S=s1*acc+s2*ava+s3*sta \quad (4)$$

For QoS of transmission dimension, we mark the maximum of transmission time among applications of IoT with maxtime, the minimum of transmission time among applications of IoT with mintime, the maximum of storage capacity among applications of IoT with maxsto, the minimum of storage capacity with minsto, the transmission time of current application of IoT with ctime, the storage capacity of current application of IoT with csto, the sum of transmission in the current application of IoT with tsumnum, the num of succeccful transmission in the current application of IoT with tsucnum. t1, t2 and t3 denote the value of weight of QoS parameters in QoS of transmission dimension and the sum of t1, t2 and t3 is 1. Thereout after normalizing the transmission time tra, the storage capacity sto, the reliability rel and the QoS of transmission dimension T can be denoted as follows:

$$tra=(maxtime-ctime)/(maxtime-mintime) \quad (5)$$

$$sto=(maxsto-csto)/(maxsto-minsto) \quad (6)$$

$$rel=tsucnum/tsumnum \quad (7)$$

$$T=t1*tra+t2*sto+t3*rel \quad (8)$$

For QoS of application dimension, we mark the sum of functions that the application layer needs to accomplish with fsumnum, the num of functions that the application layer has actually accomplished with factnum, the sum of documents that the application layer needs to provide with nsumnum, the num of documents that the application layer has actually provided with nactnum, the sum of inputs which are without adapting their initial stable configuration with rsumnum, the num of successfully disposing inputs which are without adapting their initial stable configuration with rsucnum,. a1, a2 and a3 denote the value of weight of QoS parameters in QoS of application dimension and the sum of a1, a2 and a3 is 1. Thereout after normalizing the functionality fun, the normative nor, the robustness rob and the QoS of application dimension A can be denoted as follows:

$$fun=factnum/fsumnum \quad (9)$$

$$nor=nactnum/nsumnum \quad (10)$$

$$rob=rsucnum/rsumnum \quad (11)$$

$$A=a1*fun+a2*nor+a3*rob \quad (12)$$

B. An IoT QoS Estimate Approach based on Multi-Dimension QoS

With the rapid development of technology, applications of IoT are more and more widely used. In order to compare their QoS quantitatively, this paper presents an IoT QoS estimate approach based on multi-dimension QoS. This approach introduces multi-dimension QoS to describe QoS attributes of applications of IoT carefully and takes the QoS of applications of IoT as points in a space of multi-dimension QoS. It estimates QoS of applications of IoT according to comparing points that applications of IoT stand for.

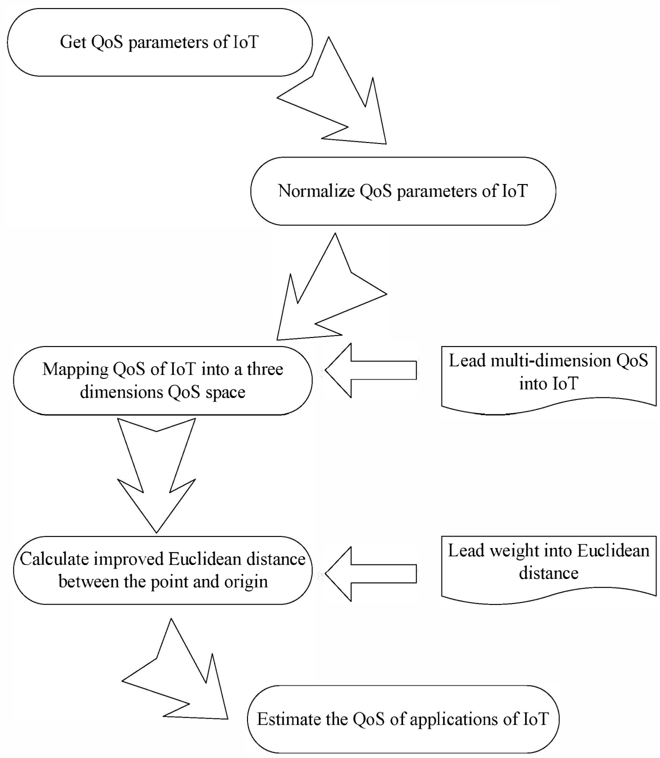

Figure 2. IoT QoS estimate approach based on multi-dimension QoS

The concrete procedure of this approach is showed in Fig2. Firstly, introduce multi-dimension QoS to describe the QoS attributes of applications of IoT and normalize these QoS parameters in order to map them into the same interval. Secondly, take QoS of applications of IoT as points in a space of three dimensions QoS and calculate Euclidean distance between points corresponding to QoS of applications of IoT and origin. Euclidean distance only calculates distance between points in a space of multi-dimensions, and considers no about different weight among different dimensions. So we improve the formula of Euclidean distance and introduce weight factor[6]. Supposed that T(t1, t2, t3) is a point in a space of three dimensions QoS. k1, k2 and k3 denote the value of weight of each dimension in a space of three dimensions QoS and the sum of k1, k2 and k3 is 1. So the improved Euclidean distance L of the point in a space of three dimensions QoS can be denoted as expression (13).

$$L= sqrt(k1*(t1)^2+k2*(t2)^2+k3*(t3)^2) \qquad (13)$$

V. EXPERIMENTS

A. Example used in experiments

In order to show further the IoT QoS estimate approach based on multi-dimension QoS that this paper presents, we use java to realize this approach and use the smart campus which is a common application of IoT to elaborate how this approach to estimate the QoS of applications of IoT.

Smart campus is a typical application of IoT. It has changed the way of college life and achieved intelligent life in college according to technologies of IoT. Smart campus covers every aspect of college life. For example, dorm module is mainly used to manage and control dorms. It includes environmental monitoring, fire alarm, access control system and so on.

B. Explanation

We use two smart campus systems as an example to elaborate how this approach to estimate QoS of applications of IoT. Firstly, use mutil-dimension QoS to describe QoS attributes of smart campus system A and smart campus system B. QoS parameters of smart campus system A and B are showed as table Ⅱ.

TABLE II. QOS PARAMETERS OF SMART CAMPUS SYSTEM A AND B

		Smart Campus A	**Smart Campus B**
sensing dimension	Accuracy	26/28	29/28
	Availability	16	18
	Stability	28	26
transmission dimension	Transmission time(s)	3	4
	Storage capacity(M)	11	13
	Reliablity	47	45
application dimension	Functionality	95	92
	Normative	19	17
	Robustness	22	20

Then, normalize the above QoS parameters with the expressions to map them into the same interval and calculate the overall QoS parameters of each dimension according to the expressions. Supposed that the weight ratio of QoS parameters in every dimension is 1:1:1. QoS parameters of smart campus system A and B after normalizing are showed as table Ⅲ.

TABLE III. ORTHONORMAL QOS PARAMETERS OF SMART CAMPUS SYSTEM A AND B

		Smart Campus A	**Smart Campus B**
sensing dimension	Accuracy	0.93	0.96
	Availability	0.8	0.9
	Stability	0.93	0.87
transmission dimension	Transmission time(s)	0.88	0.75
	Storage capacity(M)	0.9	0.7
	Reliablity	0.94	0.9
application dimension	Functionality	0.95	0.92
	Normative	0.95	0.85
	Robustness	0.73	0.67

Finally, calculate the overall QoS parameters of each dimension according to the expressions and use the improved Euclidean distance(expression 13) to calculate the QoS of smart campus system A and B according to the weight of each dimension in multi-dimension QoS. We consider the weight of each dimension as follows: k1 is 0.4, k2 is 0.2 and k3 is 0.4. The result is showed as table Ⅳ. So the QoS of smart campus system A is better than the QoS of smart campus system B.

TABLE IV. QOS OF SMART CAMPUS SYSTEM A AND B

	Smart Campus A	**Smart Campus A**
sensing dimension	0.89	0.91
transmission dimension	0.91	0.78
application dimension	0.88	0.81
QoS	0.89	0.85

VI. CONCLUSION

This paper firstly introduces some concepts of IoT and QoS. Aiming at the problem that How to estimate the QoS of applications of IoT, this paper presents an IoT QoS estimate approach based on multi-dimension QoS. This approach normalizes QoS parameters on the basis of the same growth direction to map these different QoS parameters into the same interval. Then this approach introduces multi-dimension QoS to describe QoS attributes of applications of IoT and takes the QoS of applications of IoT as points in a space of three dimensions QoS. It calculates Euclidean distance between points corresponding to QoS of applications of IoT and origin by the improved Euclidean distance and uses it to estimate the QoS of applications of IoT. Finally, an application example of IoT is used to elaborate how this approach to estimate the QoS of applications of IoT.

ACKNOWLEDGMENT

This work is partially supported by the Natural Science Foundation of Jiangsu Province of China(BK2011281); Natural Science Foundation of the Jiangsu Higher Education In stitutions of China(10KJB520019).

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