

Application-oriented Network Performance Evaluation for the Internet of Things

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Abstract—This paper addresses network performance evaluation for the Internet of Things. There are a wide variety of networks at the bottom layer of the Internet of Things, such as wireless sensor network, ad hoc network. Therefore, it is not easy for the Internet of Things to evaluate its network performance. For the heterogeneity of the Internet of Things, this paper proposes an application-oriented network performance evaluation model. This model combines the qualitative and quantitative evaluation method, giving the four levels of network performance firstly, and proposes a new network performance evaluation indicator, which is cumulative network performance evaluation value. In this model, it gives the qualitative and quantitative analysis for the performance of the Internet of Things at the application layer, and determines the level of network performance, then calculates the network performance evaluation value and the cumulative network performance evaluation value. By analyzing the network operating data collected, the experimental results show that the network performance level and the two network performance values characterize the status of the Internet of Things accurately. These evaluation results can provide basis for decision making to optimize network configuration and improve network performance.

Index Terms—the Internet of Things, heterogeneity, application-oriented, network performance evaluation, cumulative network performance evaluation value.

I. INTRODUCTION

With the rapid development of key technology of the Internet of Things (IoT), the IoT has been used widely and commonly, such as transportation and logistics domain, healthcare domain, smart environments domain, personal and social domain, futuristic applications domain [1]. The IoT are usually divided into three layers, from bottom to top, which are perception layer, transport layer, application layer [2]. However, the IoT has a strong heterogeneity at the bottom layer [3] [4], where there are wireless sensor network (WSN) [5], ad hoc network. Therefore, it is not easy for an IoT to evaluate its network performance.

Scientific evaluation of network performance helps network administrators and users understand network operating conditions timely and accurately, and provides a basis for decision making to optimize network configuration and improve network performance. However, Network performance evaluation methods varied with the different needs and applications. Reference [6], through the network measurement, puts forward a comprehensive evaluation method based on

multiple measurement indicators. By applying this method to the packet path performance evaluation and network performance evaluation, the experimental results not only reflect the packet path performance, but also reflect the performance of the network. Reference [7] defines network performance evaluation indicators, constructs a flow model, and selects the link utilization, delay and delay jitter three indicators. Lastly, it makes network performance evaluation for a multimedia network with network simulation software NS-2. Reference [8] makes normalization and quantization processing with a variety factors which affect the network performance. Reference [9] proposes a “static + dynamic” weight calculation method based on the standard deviation of the correlation variable weight. Reference [10] divides the network performance indicators into analytical indicators and experimental indicators, and proposes a protocol-oriented network performance indicator development framework model. This model makes a comprehensive network performance evaluation with relative few indicators, and reduces the number of evaluation indicators effectively. Reference [11] makes network performance evaluation with improved fuzzy AHP algorithm, which is based on triangular fuzzy number analytic hierarchy process and network simulation technology.

This article, for the heterogeneity of the IoT, proposes an application-oriented network performance evaluation model. This model gives the qualitative and quantitative analysis for the IoT performance at the application layer. The heterogeneity of the IoT is shown in Figure 1.

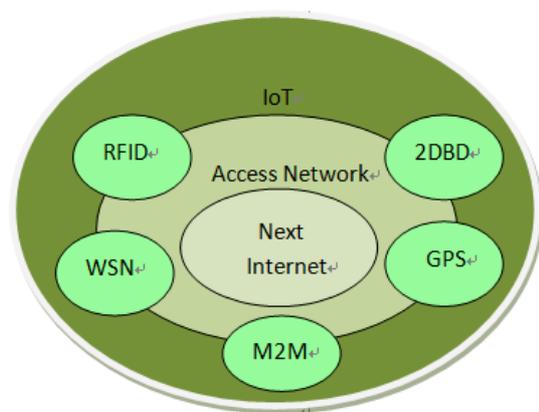


Figure 1. Heterogeneity of the Internet of Things

II. DESIGN OF APPLICATION-ORIENTED NETWORK PERFORMANCE EVALUATION MODEL FOR THE INTERNET OF THINGS

From the application point of view, regardless of the heterogeneity of the bottom layer of the IoT, this paper proposes an application-oriented network performance evaluation model.

A. Network Clustering of the IoT

According to the difference between the networks at the bottom layer, the IoT can be divided into the following four types of network.

Interactive network: mainly provide interactive services, such as transporting industrial control instruction, database query results, interaction information between radio transmitting and receiving ends, etc. This type of network is commonly used to support online library, remote control systems, unmanned aircraft systems, etc. Interactive network users often require quick and accurate response after sending the command, and it requires that the network delay and data packet delay are as small as possible. Therefore, the evaluation attributes of the interactive network can be response time, packet loss rate and time delay.

Multimedia network: mainly provide multimedia services, such as transporting text, sound, pictures, images and video, etc. This type of network is commonly used to support remote video conference, remote interview, remote education, remote medical treatment, video surveillance systems, etc. Multimedia network users often require large, enough network capacity, and the smaller time delay and time delay jitter. Therefore, the evaluation attributes of the multimedia network can be link utilization, packet loss rate, time delay and time delay jitter.

Data transmission network: mainly provide large-scale data transmission services, such as transporting the conditions and results of the large mathematical calculation, meteorological data, etc. This type of network is commonly used to support large mathematical calculation, weather forecast, etc. Data transmission network users often require data to be obtained is accurate and complete, and the network can deal with sudden, unexpected large amount of data transmission. They allow a certain range of data delay. Therefore, the evaluation attributes of the data transmission network can be network throughput, node throughput, link utilization and packet loss rate.

Wireless network [12] [13] [14]: mainly provide wireless data transmission services, such as wireless transmission of voice, text, instructions, environment information, etc. This type of network is commonly used to support information collection under special environment, logistics systems, supermarket goods management, parking management system, etc. Wireless network users often require the stability and reliability of the network, and the integrity and reliability of the information. Therefore, evaluation attributes of the wireless network can be packet loss rate, time delay and time delay jitter.

B. Qualitative Evaluation Model of Network Performance

From the application point of view, network performance evaluation attributes are divided into primary network performance evaluation attribute (PNPEA) and secondary network performance evaluation attribute (SNPEA) at the application layer of the IoT.

Primary network performance evaluation attribute: these evaluation attributes are related to the principal activities of the network. The primary evaluation attributes of each network are different, as their main function is different. For example, in real-time network, primary network performance evaluation attributes can be time delay, time delay jitter.

Secondary network performance evaluation attribute: the evaluation attributes can help to improve network performance, but have little relation to the principal activities of the network. Secondary network performance evaluation attributes of each network is different. For example, in an IoT, packet repetition rate can be regarded as a secondary network performance evaluation attribute.

According to primary network performance evaluation attribute and secondary network performance evaluation attribute, network performance can be divided into four levels shown in TABLE I. Color is used to indicate the level of the network performance. From the best to the worst, they are blue level, yellow level, orange level and red level.

TABLE I.
FOUR LEVELS OF NETWORK PERFORMANCE

level	PNPEA	SNPEA
Blue (the best)	all PNPEA attributes in the threshold	all SNPEA attributes in the threshold
Yellow (better)	all PNPEA attributes in the threshold	at least one SNPEA attribute out of the threshold
Orange (worse)	at least one PNPEA attribute out of the threshold	all SNPEA attributes in the threshold
Red (the worst)	at least one PNPEA attribute out of the threshold	at least one SNPEA attribute out of the threshold

C. Quantitative Evaluation Model of Network Performance

● Selection of Network Performance Evaluation Attribute

Before the analysis and evaluation for an IoT, the appropriate evaluation attributes should be selected, according to the results of the cluster analysis in section A, the characteristics of network and users' demands. After selecting evaluation attributes, evaluation attributes values should be calculated with network measurement results.

● Normalization of Network Performance Evaluation Attribute Value

Before normalization, from the application point of view, the evaluation attributes should be divided basically into two categories. One is upward attribute, and the other is down attribute.

The greater the evaluation attribute value is, the better network performance is on this property, and these attributes are called upward attributes; The smaller the

evaluation attribute value is, the better network performance is on this property, and these attributes are called down attributes.

The normalization methods of upward attributes and down attributes are different. The normalization method of upward attributes values is shown in (1).

$$v_i = \frac{AV_i - T_i}{T_i} \quad (1)$$

In (1), AV_i represents attribute value of upward attribute i ; T_i represents threshold of upward attribute i ; represents value of i after normalization.

The normalization method of down attributes values is shown in (2).

$$v_i = \frac{T_i - AV_i}{T_i} \quad (2)$$

In (2), AV_i represents attribute value of down attribute i ; T_i represents threshold of down attribute i ; represents value of i after normalization.

For some evaluation attributes whose values exceed their threshold range, the evaluation attribute has lost their original significance. After normalization, their values are set to zero.

● **Calculation of Network Performance Evaluation Value**

A certain period of time is separated as follows: $[t_1, t_2, t_3, \dots, t_i, \dots, t_j, t_k, \dots, t_n]$. This time can be divided into equal time segments, and it also can be divided into unequal time segments.

The network performance evaluation value (NPEV) in time segment $[t_i, t_j]$ can be calculated as follows.

$$V(t_i, t_j) = w_1 * v_1 + w_2 * v_2 + \dots + w_k * v_k + \dots + w_n * v_n \quad (3)$$

The variable $V(t_i, t_j)$ represents the network performance evaluation value in time segment $[t_i, t_j]$; w_k represents the weight of evaluation attribute k ; v_k represents the value of evaluation attribute k after normalization.

Using time t_i as the starting time, the cumulative network performance evaluation value (CNPEV) at time t_k can be calculated as follows.

$$LV(t_i, t_k) = w_{ij} * LV(t_i, t_j) + w_{jk} * V(t_j, t_k) \quad (4)$$

The variable $LV(t_i, t_k)$ represents the cumulative network performance evaluation value at the time t_k .

$w_{ij} = \frac{t_j - t_i}{t_k - t_i}$, $w_{jk} = \frac{t_k - t_j}{t_k - t_i}$. The variable w_{ij} represents the ratio of the time segment $[t_i, t_j]$ and the time segment $[t_i, t_k]$. And w_{jk} is same as w_{ij} .

From (4), it can be seen that CNPEV has a memory function. It can record previous network status. NPEV may reflect the operational status of the network in an hour of one day, but CNPEV can reflect the operational status of the network all day.

● **Flow Diagram of Application-oriented Network Performance Evaluation Model for the Internet of Things**

The flow diagram of application-oriented network performance evaluation model for the Internet of Things is shown in Figure 2.

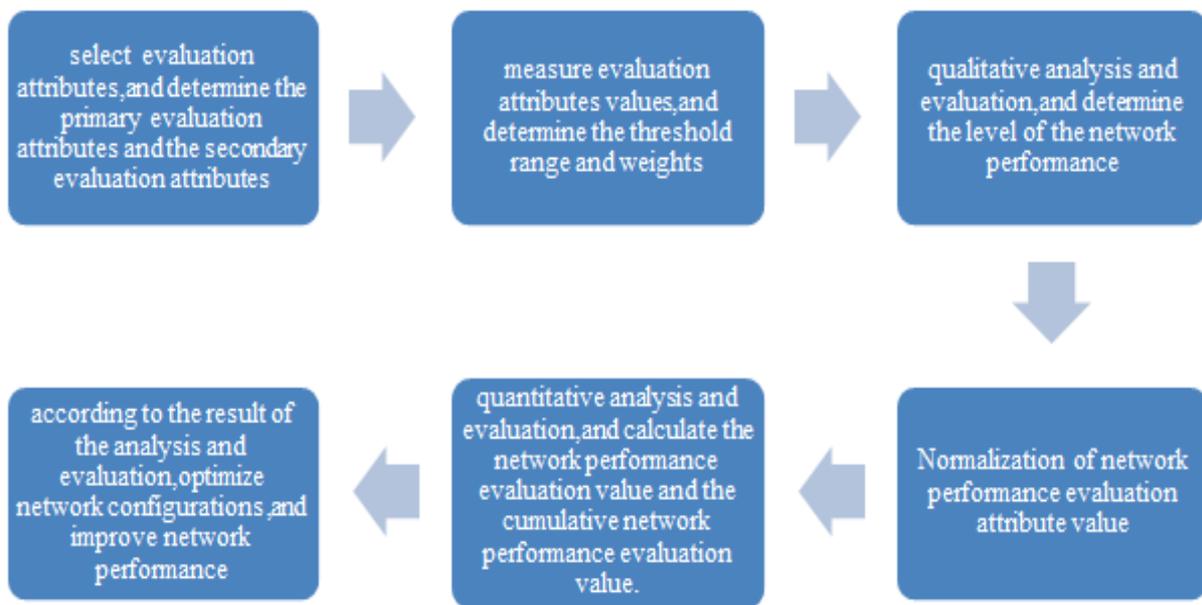


Figure 2. Flow diagram of application-oriented network performance evaluation model for the Internet of Things

III. EXPERIMENT

A. Experiment Environment

Deploy an IoT platform for environmental monitoring. The bottom layer of this IoT is a wireless sensor network [15], consisting of 22 sensor nodes (one of them is gateway node). The server in the application layer collects data through gateway node and the Internet, then saving the data in the server-side database.

B. Selection of Network Performance Evaluation Attribute

This IoT platform is mainly used for long-term environmental monitoring, getting reliable and accurate information in the target environment. However, sensor nodes usually carry limited energy. Therefore, it is very necessary to make node load balancing, and make packet repetition low, which can extend the network lifetime effectively. Environmental information to be collected should be accurate and reliable, which requires low packet loss rate. Small R delay contributes to access to information timely in some special cases. According to the IoT clustering analysis and special application requirements of this IoT, packet loss rate (PLR), packet repetition rate (PRR), node load balancing degree (NLBD), and R delay (RD) are selected as the evaluation attributes of the IoT platform.

From the application point of view, packet loss rate, node load balancing degree, and R delay belong to primary network performance evaluation attributes; Packet repetition rate belong to secondary network

performance evaluation attributes. Packet loss rate, packet repetition rate, and R delay belong to down attributes; node load balancing degree belongs to upward attributes.

Node load balancing degree: the ratio of the number of the nodes whose load are in the reasonable range and the total number of nodes in this IoT. In this experiment, the reasonable load range is %: [1, 6], and the threshold range of NLBD is %: [50, 100].

R delay: the average arriving time of the valid packets received by the terminal at the application layer of the IoT. In this experiment, the threshold range of RD is s: [0, 30].

In addition, the threshold range of PLR is %: [0, 50]; the threshold range of PRR is %: [0, 10].

C. Experimental Data

100,000 data collected from this IoT platform for environmental monitoring was used as experimental data. The data collection time is from 18:00 to 12:00 the next day. Each data consists of node id, parent id, seq, data arrival time, etc. After removing the invalid data and redundant data, the remaining data are divided into three groups in order, and each group has data of 6 hours: [t1, t2), [t2, t3), [t3, t4), and t1=18:00, t2=0:00, t3=6:00, t4=12:00.

D. Measurement of Evaluation Attribute Value

Analyze experimental data with data statistical analysis software, IBM SPSS Statistics 20. The results obtained are shown in TABLE II.

TABLE II.
MEASUREMENT RESULTS OF EVALUATION ATTRIBUTE VALUE

	PLR	RR	NLBD	RD
[t1,t2)	27.0110%	17.0932%	52.3810%	13.4465s
[t2,t3)	86.2678%	2.5503%	61.9048%	76.4929s
[t3,t4)	64%	6.2128%	66.6667%	25.3014s
threshold	%:[0,50]	%:[0,10]	%:[50,100]	s:[0,30]
weight	0.3	0.1	0.3	0.3

The threshold range and weights come from experience and application requirements of the IoT platform for environmental monitoring [16].

According to the measurement results and qualitative evaluation model of network performance, a preliminary qualitative evaluation result can be given: Network performance of this IoT platform is at the yellow level in segment [t1, t2); It is at the orange level in segments [t2, t3) and [t3, t4). The result shows that network performance of this IoT platform decline overall over time. The node load (number of data packets that nodes transmit) from t1 to t4 can be shown in Figure 3, Figure 4 and Figure 5.

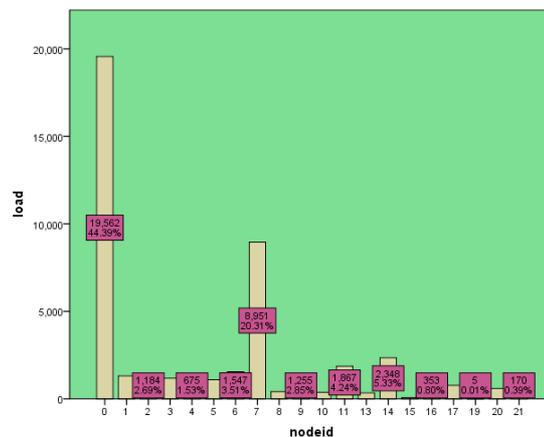


Figure 3. Node load from t1 to t2

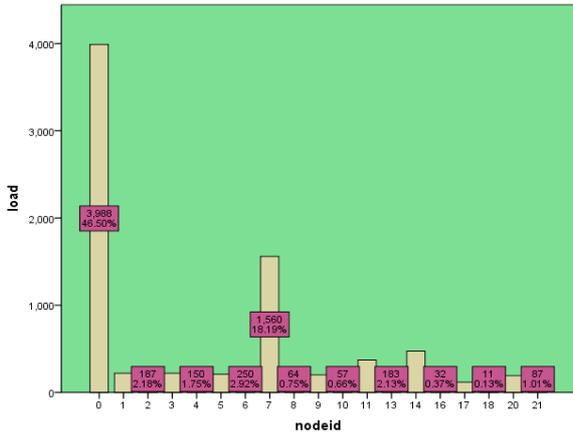


Figure 4. Node load from t2 to t3

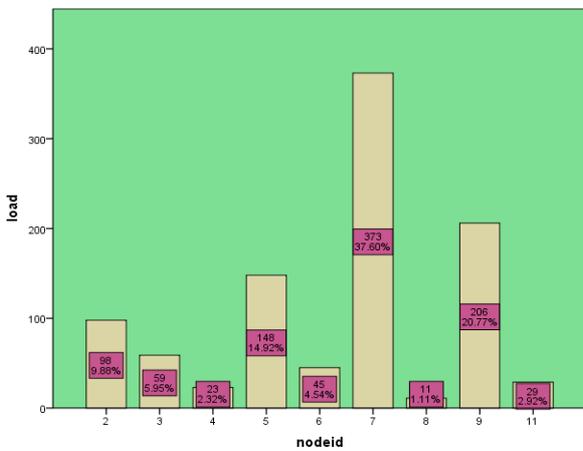


Figure 5. Node load from t3 to t4

E. Experimental Results and Evaluation

According to quantitative evaluation model of network performance, the results obtained are shown in TABLE III.

TABLE III. RESULTS OF NEWTORK PERFORMANCE EVALUATION

	NPEV	CNPEV
[t1,t2)	0.3177	0.3177
[t2,t3)	0.1459	0.2319
[t3,t4)	0.1849	0.2162

From table 3, the network performance evaluation value (NPEV) is down then up, but it declines overall from the results. The cumulative network performance evaluation value (CNPEV) is not high and declines all the time. This result is consistent with the level of network performance given above.

After analysis, it can be found that the packet loss rate (PLR) in segments [t2, t3) and [t3, t4) is so high that the performance of the IoT platform becomes poor. According to the evaluation result, network administrators could optimize network configuration of the IoT platform, reduce PLR, and improve network performance.

IV. CONCLUSIONS

For the heterogeneity of the IoT, this article proposes application-oriented network performance evaluation model. This model gives the qualitative and quantitative analysis for the performance of the IoT at the application layer, and determines the level of network performance, then calculates the network performance evaluation value and the cumulative network performance evaluation value. From the Experiments Results, it can be known that the network performance level and the two network performance values characterize the status of the Internet of Things accurately. And these evaluation results can provide basis for decision making to optimize network configuration and improve network performance.

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