Gateway Selection Based on Game Theory in Internet of Things

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***Abstract*—In the rapid development of wireless communication network technology, the application of Internet of Things (IoT) is increasing day by day. Because the number of end devices is increasing, there is one of important issues about gateway selection for end devices. Therefore, it is important to select the most effective gateway for the application of Internet of Things. Gateway Selection strategy will be a more significant topic at the moment. In recent years, game theory in the network resource allocation or simulation of resource competition has a wide range of applications, not only can clearly understand the game model, but also that the game's equilibrium. In this paper, we focus on non-cooperative dynamic game with end devices for the game players and IoT gateways for the selection strategy. The utility function is derived from the characteristics of players and IoT gateways. Finally, we compare with the maximum received signal strength indicator to meet the overall demands of the end devices and the IoT gateway maximum load difference are superior to the traditional way.**

Keywords - game theory; gateway selection; Internet of things, load balance, wireless communication

I. INTRODUCTION

According to literature [1], Cisco estimates the number of Internet connected devices in the future, and predicts that by 2020, there will be 50 billion devices in the world that can connect data over the Internet. In the framework of Internet of Things (IoT), as shown in Fig. 1, IoT gateways located between the sensing layer and the network layer, from the literature [2][11][12] can learn not only the gateway to handle a variety wireless access protocol may also be used to help in the end device transmits data in Internet.

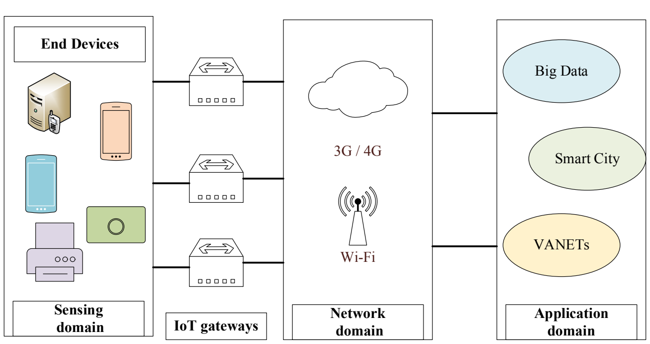

Figure 1. IoT architecture.

If the end devices are a few selected gateways connecting to help themselves, those are likely to cause excessive load gateway, a reduced efficiency, and less used gateways cause waste of resources.

Game theory [7] is widely used in many fields, such as on computer networks [3][4][8], from the allocation of resources to the simulate mode of competition between the various units can by theory game to help us understand the behavior patterns of these participants. Wu use non-cooperative game [5] to implement the environment at IoT. The end device will only consider their own criteria to select IoT gateways. The behavior of the end devices is a dynamic game, which means that each end device in the choice of gateways in order. The latter selection game will know the former's selection strategy and influence the former's utility.

This paper focuses on the non-cooperative dynamic game, defined the end devices are participants, the IoT gateways are selection strategies, and defined utility function. We will be practical examples indicating the presence of non-cooperative dynamic game equilibrium [6] - Nash equilibrium.

The rest of the paper is organized as follows. In Section II, we introduce the gateway selection related to the selection algorithm based on the correlation of game theory research. Section III is to present the definition of model and problem description. In Section IV, gateways selection algorithm based on game theory will be proposed; this section will detail the descriptions of the definition and design of this game with examples to illustrate the game to reach Nash equilibrium. In Section V, experimental results will be shown in terms of experimental simulation and analysis. Finally, Section VI concludes the paper.

II. REALTED WORK

There are many researches [2][9][10] to discuss the IoT gateway and gateway selection for IoT devices. We introduce two main research results for IoT gateway selection in below.

In the literature [9], the authors of the study is to select the link configuration issues between the mobile M2M devices and M2M gateways. The selection criteria are based on the number of gateway connected devices, the percentage of gateway residual bandwidth, and the normalized received signal strength.

The research [10] is to study the gateway selection in cyber-physical systems. This literature suggested that sensors

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want to compete with different types of devices for the bandwidth of the gateway, with the use of game theory. As can be seen, the mode of resource contention is between the different devices in the gateway.

Compared with related work, our main contribution here is to propose an IoT gateway selection strategy in terms of game theory with considering three kinds of important resources: gateway capacity, transmission demand of end devices, and load balance among gateways.

III. Definition of Model and Problem Description

Non-cooperative dynamic game is proposed. All of gateways known the values of signal-to-noise ratio (SNR ratio) between the gateway and the end devices in the communication ranges. Assumptions are made in below:

1. Each gateway has the same bandwidth.
2. New players cannot join the game before the end of game.
3. Each participant only pursue the maximum utility strategy.

Channel capacity between the end device and the gateways plays a very important decision factor in this paper. The size of the maximum channel capacity will affect the transmission amount of end devices. Below is channel capacity by Shannon Theorem used.

$$C_{e_i}^{g_j} = W \log_2(1 + SNR) \tag{1}$$

The channel capacity $C_{e_i}^{g_j}$ is between the end device e_i and the gateway g_j. W is the bandwidth of the channel. SNR (signal-to-noise ratio) can be obtained. Based on the known gateways received signal strength by the power equation, such as Equation 2, we can estimate the received signal power of the end devices. P_0 is the maximum signal intensity is estimated 1 meter from the gateway; pl is the path loss value usually set at a value of 2 to 7; $dist_{e_i}^{g_j}$ is the distance between the end device and the gateway, a receiver signal power, as shown in Equation 3; P_g is a given gateway power. Receiving noise power, as shown in Equation 4, two important factors are to compute the noise power, the distance and power between the devices. After them, the SNR can be estimated in Equation 5.

$$Rssi_{e_i}^{g_j} = P_0 - 10 \times pl \times \log_{10}\left(dist_{e_i}^{g_j}\right) \tag{2}$$

$$P_{e_i} = \frac{P_g}{10^{\frac{\left|Rssi_{e_i}^{g_j}\right|}{10}}} \tag{3}$$

$$P_{noise} = \sum_k \left(\frac{P_{e_i}}{dist_{e_i}^{e_k}}\right) \tag{4}$$

$$SNR = \frac{P_{e_i}}{P_{noise}} \tag{5}$$

IV. Gateway Selection Strategy Based on Game Theory Algorithm

In this section, we will address the game theory gateway selection (GTGWS for short) strategy.

A. Game Model

Players: End device e_i having two or more choices for gateway selection, where N is the number of players, $1 \leq i \leq N$.

Strategies: For the players, $S = \left\{s_i^j | j = 1,2, \ldots j. j \geq 2\right\}$ is the strategy set. There are at least two strategies that can be selected. s_i' is the current selected strategy.

Utility function: Participants and other participants in the current strategy and the selected utility function can be derived to compute the utility value of the strategy. The utility function is proposed in Equation 6, where B is gateway bandwidth; m is the number of end device connected to the gateway; D_i is the demand of end device and channel capacity $C_i^{s_i'}$ between the end device and gateway; α is a threshold value for the difference between demand and channel capacity.

$$U_i(s_i', s_{-i}') = \frac{B}{m} - K_i,$$

$$where\ K_i = \begin{cases} 0, \ if\ D_i - C_i^{s_i'} \leq 0 \\ \frac{D_i}{C_i^{s_i'}}, \ if\ 0 < D_i - C_i^{s_i'} \leq \alpha, \ \alpha > 0 \\ D_i - C_i^{s_i'}, \ others \end{cases} \tag{6}$$

The strategy for game to IoT gateway selection is to maximize the utility function derived in Equation 7.

Nash Equilibrium: If no participant may change their strategy, in other words, none of the currently selected participants utility strategy value is even lower than before. This strategy combination is called Nash equilibrium point. The current state is said Nash Equilibrium, as shown in Equation 8.

$$\max_{1 \leq i \leq n}(U_i(s_i', s_{-i}')) \tag{7}$$

$$U_i(s_i^*, s_{-i}^*) \geq U_i(s_i', s_{-i}^*) \tag{8}$$

B. Game Example

In this subsection, an example as shown in Fig. 2 is to illustrate the gaming for IoT gateway selection. In Fig. 2, there are six end devices e_i, $1 \leq i \leq 6$, and three gateways g_j, $1 \leq j \leq 6$. Assuming that the distance between the device and the gateway is known, the received signal strength can be obtained by Equation 2. By Equation 3, the power of the device can be obtained. α =1. As depicted in Table I, the known distances, we can first select the strategy that each device is initialized; the symbol ⊚ represents strategy is currently selected; the symbol ○ indicates the candidate strategy; blank indicates no connection is among end devices and gateways.

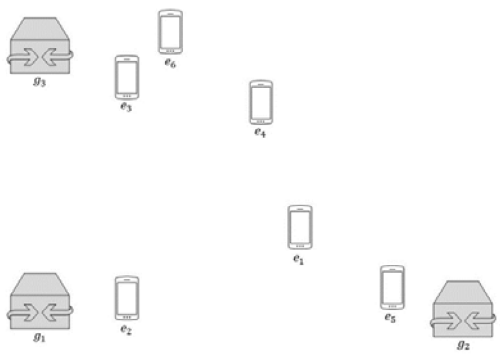

Figure 2. Environmental distribution

Demand for e_1 is assumed 2.668372 Mbps here. In addition to e_1, e_5 can communicate to g_2 (denoted as $m = 2$). Assume that each gateway bandwidth is 50 Mbps. According to the utility function Equation 6, the utility value is set to 50/2-(2.668372/2.249727)=23.8139. Its channel capacity 2.249727 can be obtained by Equations 2, 5 and 6. We find that the difference between the demand of e_1 and channel capacity is not greater than the value of α. The maximum value of utility value can be obtained till now based on Equation 7.

TABLE I. INITIAL SELECTION STRATEGY TABLE

strategy set	g_1	g_2	g_3
e_1	○	◎	○
e_2	◎	○	○
e_3	○		◎
e_4	○	○	◎
e_5	○	◎	
e_6	○		◎

During the game restart, e_1 selected g_1 as gateway, there is another end device e_2 can communicate to g_1, so the utility value is set to 50/2- (2.668372-1.2171)=23.54876, and no greater than the original g_2 utility value. Then, in the same way, we found that when e_3 selected g_1, the utility value is set to 50/2-(2.923288-0.289234)=22.365946, we found that the utility value is greater than the original g_3 of the utility value of 16.39628, so e_3 will change the strategy selection for g_1 gateway link. Because e_3 changed its original strategy, it didn't reach equilibrium, we will play the next game again. Finally, in a new round of the game, we will find that all the participants will not be changed again, which reached the Nash equilibrium.

V. RESULTS AND EVALUATIONS

TABLE II. SIMULATION PARAMETERS

Parameters	Values
Simulation area	450m× 450m
Gateways power	10mW
Channel frequency	2MHz
Communication range	200m
Gateway bandwidth	50Mbps
Number of end devices	30,60,90,120,150,180
Number of gateways	9 (3x3 grid, 100 meters away)
Path loss	2
End device demand	≤15Mbps

A simulator is designed in using Java programming language for simulation performance. Simulation parameters are depicted in Table II. Our proposed strategy is compared to the maximum received signal strength (named MaximumRssi) referred to in [4][9]. In addition, a game theoretic approach designed to consider the bandwidth allocation of gateways (GTBA) is designed to compare with our method (GTGWS). Each experiment was performed 1000 times; and the experimental data were averaged. The end devices are distributed in the environment with unequal distribution and random number distribution. Two performance metrics are simulated.

- Total demand of end devices:

In the presence of limited gateway bandwidth, the total demand of the end devices can be seen that the more the demand is satisfied, the higher the overall transmission efficiency is.

- Maximum load difference of gateways:

We will observe the load on gateways with the maximum difference between gateways. If the difference is small, the gateway load is balanced on the network environment.

First of all, the different alpha (α) values are discussed as in Fig. 3. We have the average of 1000 experiments. The number of end devices is set to 100. The alpha value of 1 has the best total demand. The reason is that when the ratio of alpha values can be very good to limit demand and the channel capacity is 1. The demand for each end device more close to the channel capacity is better.

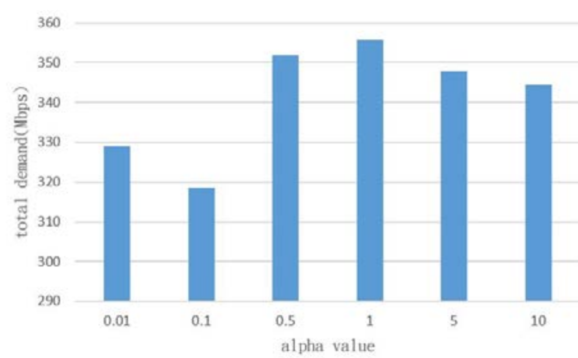

Figure 3. The total demand for different α values.

In Fig. 4, our approach shows good performance regardless of the number of end devices with random distribution in network environment, especially in comparison with MaximumRssi. In Fig. 5, in our approach, the maximum load difference is relatively small, which represents in different quantity, load the whole network gateway is balance, which can meet the demand of more end devices. Finally, the number of end devices is increasing, the more each gateway by using the load difference will be reduced.

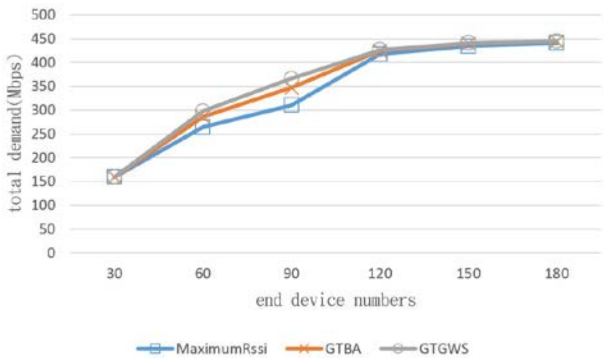

Figure 4. The total demand of end devices in a random distribution.

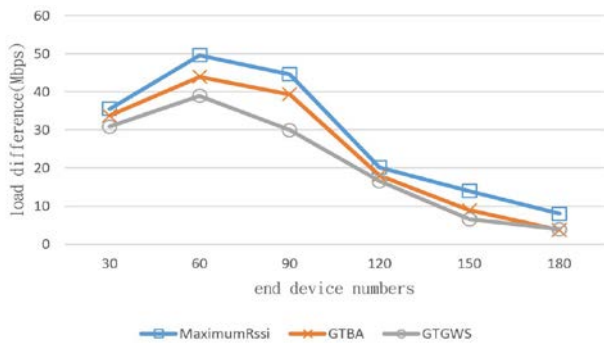

Figure 5. The maximum load difference in a random distribution of end devices.

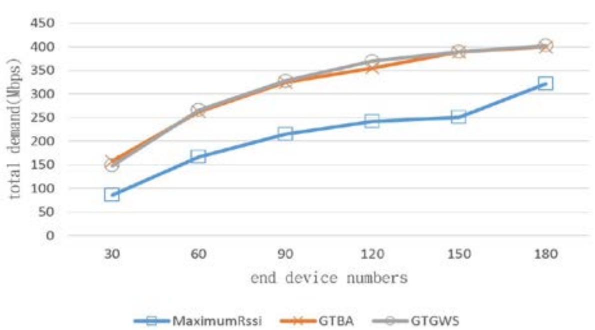

Figure 6. The total demand of end devices in a nonuniform distribution.

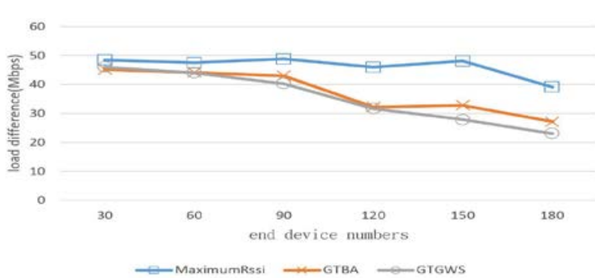

Figure 7. The maximum load difference in a nonuniform distribution of end devices.

In Fig. 6 and Fig. 7, in the nonuniform distribution, some of gateways have to handle more end devices. This cause the gateway load is much higher. Our approach GTGWS can meet the demand in this environment and obtain more load balance among IoT gateways compared to GTBA and MaximumRssi.

VI. Conclusions

In this paper, a game-based gateway selection strategy was proposed for Internet of things. With a limitation of IoT gateways, end devices are to select the more suitable IoT gateways to transmit data by using a non-cooperative dynamic game. In simulations, the total demand for end devices and the load balance among gateways are efficient than previous work.

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