Connection-based Pricing for IoT Devices: Motivation, Comparison, and Potential Problems

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***Abstract*—Most existing data plans are data volume oriented. However, due to the small data volume from Internet of Things (IoT) devices, these plans cannot bring satisfactory monetary benefits to ISPs, but the frequent data transmission introduces substantial overhead. ISPs, such as China Telecom, propose novel data plans for IoT devices that charge users based on their total number of connections per month. How does such model differ from the current volume-oriented (VO) charging models, that is, will this bring benefit to ISPs, how does this affect the users and the network ecosystem as a whole? In this paper, we answer these questions by developing a model for connection-based pricing, *i.e.*, frequency-oriented (FO) plans. We first discuss the motivation of connection-based pricing and formally develop the model. We then compare connection-based pricing with volume-oriented pricing. Based on such results, we predict that there may be potential problems in the future, and connection-based pricing calls for further study.**

I. Introduction

With the rapid growth of deep learning and cloud computing technologies, Internet of Things (IoT) has evolved from a simple remote control to a wide variety of intelligent controls [1]. One important prerequisite to these intelligent applications is the massive connections from IoT devices to the cloud, as shown in Fig. 1. To provide massive connections for the huge amount of IoT devices, cellular technology will play a major role. Existing cellular networks are overwhelmed [2], and require appropriate pricing mechanisms for different scenarios.

Like 3G/4G data plans, most existing pricing plans for IoT devices are volume-oriented (VO), *i.e.*, the monetary cost of a user purely depends on the data volume per billing cycle. In fact, VO plans are no longer ideal for IoT devices, since many IoT devices send a tiny volume of data with high frequency connection [3]. For example, as far as heart rate monitoring devices, in addition to reminding the device holder, it is more important to send data to the cloud or the collaborative party (*e.g.*, the children of the elderly at home alone). To ensure real-time performance, heart rate data should be sent at least once a minute, and the volume of data is less than 0.1 Kbytes each time. In other words, for one heart rate monitoring application, the volume of data sent will not exceed 4.32 Mbytes per month, but the frequency is as high as $43,200$ connections.

Intrinsically, the small data volume cannot bring satisfactory monetary benefits to ISPs, but the frequent data transmission

Fig. 1. Extensive deployment of IoT devices in different scenarios, which requires frequent connections to the cloud.

introduces substantial overhead, which drastically burdens ISPs' network and causes significant cost. As a consequence, ISPs are motivated to shift from *volume-oriented* plans to *frequency-oriented (FO)* plans to respond to the operational loss. For example, in the aforementioned example, the heart rate monitoring application is charged by $43,200$ connections instead 4.32 Mbytes. China Telecom proposed a novel charging plan [4], which charges by the number of connections.

In this paper, we are motivated to discuss the motivation and necessity of connection-based pricing data plans[1] for IoT devices. Our contributions are summarized follows:

- To analyze the connection-based pricing, we for the first time propose a model to describe frequency-oriented pricing and volume-oriented pricing simultaneously.
- Through the comparison between different pricing methods, we demonstrate the impacts of traffic volume per connection on different pricing methods.
- Simulation results confirm that the single-factor pricing will fail in certain scenarios, which requires further study.

II. A Utility Perspective

Following the Stackelberg-game analysis [5], a powerful game analysis to characterize pricing2response scenario, we first characterize the optimal IoT users' behavior given the price of the plans. And then, the ISP adjusts the price to optimize its own utility. We mainly focus on the FO plan, and the analysis of VO plans is similar.

A. Optimal Utility of IoT Device

For the IoT device, its overall utility is characterized by its profit gained through enjoying the network service minus the fee paid to the ISP, *i.e.*, $u(x) - p_1 x$ [5]. x is the frequency of

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[1]We use connection-based pricing data plans and frequency-oriented (FO) data plans interchangeably in this paper.

connections in a billing cycle. $u(x)$ is profit gained through x connections, and we assume that the $u(x)$ is a concave non-decreasing function, which is common sense in terms of user utility [5]. To determine the optimal usage (*i.e.*, x^*), the IoT device maximizes its own utility, which can be expressed as,

$$\max_x u(x) - p_1 x. \tag{1}$$

Due to the concave non-decreasing characteristic of $u(x)$, the marginal utility will continue to decrease. However, the price paid to the ISP is constant. Once the marginal utility is less than the boundary cost, no users will consume any traffic. Therefore, $x^* = u'^{-1}(p_1)$, where $u'^{-1}(\cdot)$ is inverse function of the first-order derivative of function $u'(\cdot)$.

B. Optimal Utility of ISP

For the ISP, its source of revenue is by charging IoT device. Meanwhile, the ISP needs to pay a certain amount of operational costs while delivering services, including the cost of transporting user's traffic and initiating user's connection. The overall utility of the ISP is characterized as the service charge of the IoT device minus operational costs, and the goal of the ISP is to maximize its own utility with an optimal price,

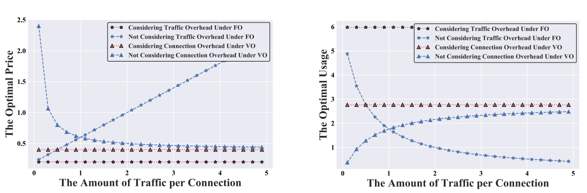
$$\max_{p_1} p_1 x^* - c_1 x^* - c_2 y, \tag{2}$$

where $c_1 x^*$ and $c_2 y$ refer to the connection initiation cost and data transmission cost, respectively. c_1 and c_2 are the cost per connection initiation and the cost of per unit data transmission. y is the data volume transmitted by the IoT device in the billing cycle. For IoT applications, during each connection, it is adequate to send required data once using a predetermined data format and length. Therefore, the overall data volume can be rewritten as $y = \alpha x^*$, where α is the length (*i.e.*, the volume of traffic) per connection.

As formerly notified, the analysis of VO plans is similar. When IoT device is charged in term of the data volume, its utility gained through enjoying the network service will be based on data volume, denoted by $u(y)$. More specifically, $u(y)$ is also a concave non-decreasing function. Similar to the FO plan, $y^* = u'^{-1}(p_2)$ is the optimal usage for IoT devices, where p_2 is the price of per unit volume. Furthermore, the revenue obtained from IoT device is $p_2 y^*$, and the operating expenses of the ISP is $(c_1/\alpha + c_2)y^*$.

III. Comparison of Charging Plans

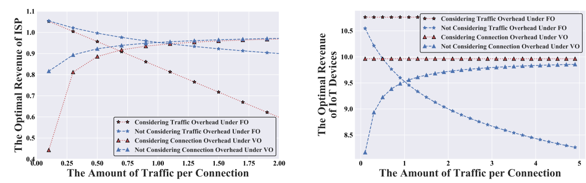
Based on the newly proposed model and simulation experiments, we compare the FO plan and VO plan in terms of optimal strategies and optimal revenue.



(a) Optimal price for ISP. (b) Optimal usage for IoT device.

Fig. 2. The optimal strategies for the ISP and IoT device.

For the two pricing method, they can be connected through the traffic volume per connection. However, both of them are priced based on single factor, *i.e.*, ignoring the overhead of other factors. In our simulation experiments, we analyze multiple situations simultaneously. Fig. 2 shows the optimal strategies for the ISP and IoT device. More specifically, when not considering the traffic (connection) overhead under FO (VO) plan, the difference of optimal price decreases (increases) with the traffic volume per connection. And the difference of optimal usage for IoT device under FO (VO) plan, has a similar trend. These results demonstrate that it is reasonable to ignore another factor (*i.e.*, the cost of transporting traffic per connection for FO plan, and the cost of initiating connection for VO plan) under FO (VO) plan, when the amount of traffic per connection (*i.e.*, α) is relatively small (large).



(a) Revenue of ISP. (b) Revenue of IoT device.

Fig. 3. The optimal revenue for the ISP and IoT device.

In term of the optimal revenue for the ISP and IoT device in Fig. 3, we can find the similar phenomena to Fig. 2. In other words, it is unreasonable to ignore another factor under FO (VO) plan, when α is relatively large (small). In addition, when the amount of traffic per connection is small, the ISP prefer FO plans to obtain higher revenue.

IV. Congestion

Through analysis and simulation experiments, we have for the first time demonstrated the motivation of connection-based pricing. And we have found that FO plans and VO plans are suitable for different scenarios according to the traffic volume per connection. In the future, how to price with multiple factors instead of one single factor deserves more attention.

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