# Towards Pricing for Sensor-Cloud

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**Abstract**—Motivated by complementing the ubiquitous wireless sensor networks (WSNs) and powerful cloud computing (CC), a lot of attention from both industry and academia has been drawn to Sensor-Cloud (SC). However, SC pricing is barely investigated. Towards pricing for SC, this paper 1) introduces five SC Pricing Models (SCPMs) first. Specifically, to charge a SC user, each SCPM considers one of the following factors respectively: i) the lease period of the SC user; ii) the required working time of SC; iii) the SC resources utilized by the SC user; iv) the volume of sensory data obtained by the SC user; v) the SC path that transmits sensory data from the WSN to the SC user. Further, this paper 2) performs analysis to discuss and exhibit the characteristics of the proposed SCPMs. With that, this paper 3) presents the case studies regarding the application of SCPMs. Eventually, this paper 4) conducts a review about the user behavior study. This paper aims to serve as a very favorable guidance for future research about pricing in SC.

**Index Terms**—Sensor-Cloud, pricing model, analysis, lease period, resource, sensory data, path, user behavior

## 1 Introduction

### 1.1 Sensor-Cloud (SC)

TRIGGERED by the incorporation of a) the ubiquitous data sensing and data gathering abilities of wireless sensor networks (WSNs) [1] as well as b) the powerful data storage and data processing capabilities of cloud computing (CC) [2], Sensor-Cloud (SC) [3] [4] [5] [6] [7] [8] [9] [10] [11] is receiving increasing interest from both industrial and academic communities. In particular, Fig. 1 presents such an example, in which the aim is on demand offering the sensory data to the SC user from the cloud. Specifically, various ubiquitous sensors (e.g., static sensors, mobile sensors, video sensors, etc.) provided by the sensor network provider form WSNs, collecting different types of sensory data (e.g., humidity, temperature, motion, image, video, etc.) regarding the surrounding environment. Then the powerful cloud consisting of data centers provided by the cloud provider, stores and processes the sensory data collected by the WSNs. SC users further have access to the processed sensory data on demand. For this new paradigm, the sources of sensory data are the WSNs, the provider of sensory data is the cloud and the requester of sensory data is the SC user.

- *This work is based in part on a poster presented at the 7th IEEE International Conference on Cloud Computing Technology and Science (IEEE CloudCom), Vancouver, Canada, Nov.-Dec. 2015. This work was partially supported by a Four Year Doctoral Fellowship from The University of British Columbia and funding from the Natural Sciences and Engineering Research Council of Canada under Grant CRDPJ 434659-12, the ICICS/TELUS People & Planet Friendly Home Initiative at The University of British Columbia, TELUS and other industry partners. The work of E. C.-H. Ngai was partly funded by the SSF ProFuN project and Vinnova GreenIoT project in Sweden. The work of L. Shu was supported by 2013 Special Fund of Guangdong Higher School Talent Recruitment, Educational Commission of Guangdong Province, China Project No. 2013KJCX0131, Guangdong High-Tech Development Fund No. 2013B010401035, 2013 top Level Talents Project in "Sailing Plan" of Guangdong Province, National Natural Science Foundation of China (Grant NO. 61401107), and 2014 Guangdong Province Outstanding Young Professor Project.*
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### 1.2 Research motivation and related work

Pricing is essential and critical for any organization which offers products or services [12], since the loyalty of users is strongly and directly impacted by the pricing mechanisms. Therefore, an appropriate or a desirable pricing model is fundamental, for the success of a product provider or a service provider (e.g., SC).

However, for the state of art, on one hand, SC pricing is barely investigated. Particularly, in [13], a priced public sensing (PPS) framework is proposed for service-based applications in smart cities. About PPS, it is assumed that the data is offered by a data cloud with multiple data sources. Then a pricing utility function is designed for data gathering and online heuristics are utilized for data delivery. Comparing PPS with two mobile data delivery protocols, evaluation results are further shown about their network sizes, lifetime, end-to-end delays, data prices and packet delivery ratios. In [14], a game based

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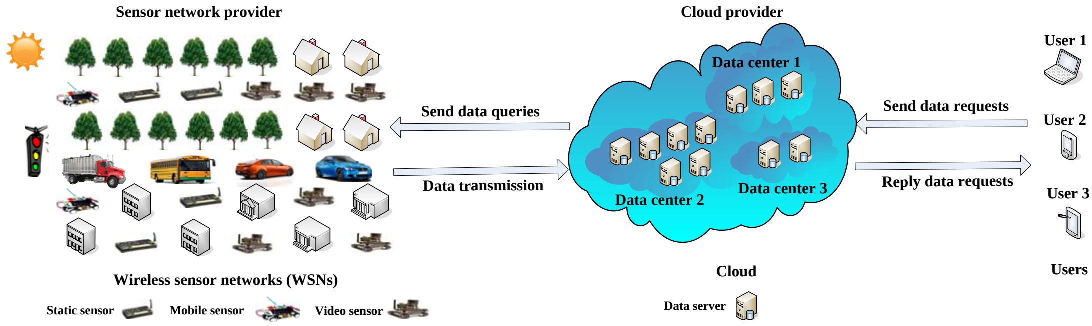


Fig. 1. An example of SC

services price decision (GSPD) model is presented for cyber-physical systems. About GSPD, it is given that entities game with other entities under the rule of "survival of the fittest" and calculate payoffs according to their own payoff-matrix, leading to a Pareto-optimal equilibrium point. Then experimental results are shown about whether GSPD can reach equilibrium points for entities with various network parameters and network structures. In [15], pricing competition is discussed for emerging mobile networks. With respect to emerging mobile networks' participants (e.g., mobile devices, services organizers, and users), how a game theory model can depict the social behavior, price competition, and the evolutionary relationship among them is explained, followed with the insights and open research issues to understand the price competition process among them. In [16], an intermediary framework which considers repurchasing and pricing is designed for big data processing with multiple clouds. For the framework, the cloud service intermediary rents the cloud services from multiple cloud providers and provides the big data processing services to the users with multiple service interfaces. Further, a pricing strategy is exhibited and simulation results are shown about the revenues with the pricing strategy, for the cloud service intermediaries. In [17], a pricing scheme consisted of pricing attributed to Hardware (pH) and pricing attributed to infrastructure (pI) is introduced for Sensors-as-a-Service utilizing the SC infrastructure. pH targets to price the physical sensor nodes and pI aims to price the SC infrastructure. Comparing pH with two hardware pricing algorithms, simulation results are presented about the physical sensor nodes regarding residual energy, proximity to base station, received signal strength, overhead, and cumulative energy consumption. Investigating pI, how SC infrastructure incurs profit considering user satisfaction is analyzed. For all the above literatures shown as examples, they are not aiming at SC pricing. Moreover, they do not focus on charging users with prices for SC.

On the other hand, although a lot of existing pricing models have been proposed for various service oriented architectures (SOAs) (e.g., Infrastructure-as-a-service (IaaS)/Platform-as-a-Service (PaaS)/Software-as-a-Service (SaaS)), these pricing models were generally designed for homogeneous types of services (e.g., infrastructure/platform/software) [17]. For SC that follows a heterogeneous SOA incorporating various services (e.g., network, data, hardware, software, platform, infrastructure), existing pricing models are generally not fit for it.

Therefore, to be a guidance for pricing in SC, 1) new pricing models need to be proposed first. Further, concerning the performance of the proposed pricing models, 2) the features of the proposed pricing models need to be analyzed. Besides, concerning the application scenarios of the proposed pricing models, 3) the case studies of the proposed pricing models need to be discussed. Finally, concerning the extensions of the proposed pricing models for various users, 4) a review about the user behavior study needs to be performed.

### 1.3 Research novelty and contribution

Towards pricing for SC, this paper 1) proposes five SC Pricing Models (SCPMs) first. In particular, charging a SC user, each SCPM takes account of one of the following elements respectively: i) the lease period of the SC user; ii) the required working time of SC; iii) the SC resources utilized by the SC user; iv) the volume of sensory data obtained by the SC user; v) the SC path that transmits sensory data from the WSN to the SC user. Further, this paper 2) conducts analysis to discuss and exhibit the features of the proposed SCPMs. With that, this paper 3) shows the case studies about the application of SCPMs. Eventually, this paper 4) performs a review regarding the user behavior study. This paper targets to serve as a very favorable guidance, for future research about pricing in SC.

The following points show the main novelty and contributions of this paper.

- Different from previous research, this paper is a pioneering work investigating SC pricing. This clearly demonstrates the novelty of this paper.
- Towards pricing for SC, this paper puts forward five SCPMs, in which various pricing factors are taken into consideration. This paper further

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presents the analysis and case studies with respect to the characteristics and application of SCPMs. In addition, this paper conducts a review concerning the study of user behavior.

### 1.4 Organization

The remainder of this paper is organized as follows. The system model is presented in Section 2 and the pricing preliminaries are shown in Section 3. Section 4 introduces the proposed SCPMs and Section 5 analyzes the features of SCPMs. The case studies about the application of SCPMs and the review about the user behaviors, are performed in Section 6 and Section 7 respectively. This paper is concluded in Section 8.

## 2 System model

The system model is presented as follows.

- There are multiple clouds. For each cloud (private cloud, public cloud or hybrid cloud [18]), it is consisted of at least one data center. Particularly, a public cloud delivers services to a general public and a private cloud offers services to only a single organization. A hybrid cloud is the combination of a private cloud and a public cloud.
- There are multiple WSNs. In each WSN, the sensory data are transmitted from the normal sensor nodes (e.g., static sensors, mobile sensors, video sensors, etc.) to the sink node.
- There are multiple users. Each user issues requests to the cloud(s) for obtaining the sensory data gathered by the WSN(s).

## 3 Preliminaries about pricing

Based on [19] [20], current cloud pricing schemes have the following attributes.

1) The most critical factors which influence pricing are: initial costs (IC), lease period (LP), Quality of Service (QoS), age of resources (AR), cost of maintenance (CM). In addition, as generally users will compare the prices of all providers which offer their required services, pricing fairness should be considered.
2) The pricing process is fixed, dynamic or market-dependent. The charged price is constant regardless of the time, in fixed pricing. The charged price is dynamically changing, in dynamic pricing. The charged price is established based on the real-time market conditions, in market-dependent pricing.
3) Users will select prospective providers in consideration of pricing approach, QoS and utilization period. The "pay as you go" model and the "pay for resources" model are two common pricing models. In the former case, the user pays a fixed price for each unit of use. In the latter case, the user pays for the amount of resources (e.g., storage) used.

## 4 Overview of SCPMs

In a SC, since the achievements of i) lease period ii) working time iii) resource utilization iv) sensory data and v) SC path are with an effort or at a cost intuitively, they are considered by SCPMs to charge a SC user. Specifically, there are five SCPMs (i.e., SCPM1, SCPM2, SCPM3, SCPM4 and SCPM5) and their overall mechanisms are shown as follows.

### 4.1 SCPM1

For charging the SC user, i) the lease period of the SC user is considered by SCPM1. In particular, given that the SC is leased by a SC user for a period $LT$. Based on the IC, LP, QoS, AR and CM mentioned in Section 3, a constant value (i.e., $C_{LT}$) will be determined by the SC as the price (i.e., $P_1$) which the SC user will be charged, for leasing the SC for $LT$ time.

$$P_1 = C_{LT} \tag{1}$$

### 4.2 SCPM2

Charging the SC user, SCPM2 takes into account ii) the required working time of SC. Specifically, during the lease period $LT$, assume that the required total working time of WSN is $T_N$ ($T_N \leq LT$) and the required total working time of cloud is $T_C$ ($T_C \leq LT$). In addition, considering IC, LP, QoS, AR and CM mentioned in Section 3, the unit price for the WSN to work is $PT_N$ and the unit price for the cloud to work is $PT_C$. Then, the price that the SC user will be charged with SCPM2 is

$$P_2 = T_N \times PT_N + T_C \times PT_C \tag{2}$$

### 4.3 SCPM3

Based on iii) the SC resources utilized by the SC user, the pricing mechanism of SCPM3 is performed. Particularly, suppose that the WSN resources utilized by the SC user is $R_N$ and the cloud resources utilized by the SC user is $R_C$, during the lease period $LT$. Further, evaluating the prices of $R_N$ and $R_C$ with IC, LP, QoS, AR and CM, the SC user will be charged with a price

$$P_3 = FN(R_N) + FC(R_C) \tag{3}$$

$FN$ and $FC$ are the functions which compute the prices of $R_N$ and $R_C$, determined by the sensor network provider and cloud provider, respectively.

### 4.4 SCPM4

Considering iv) the volume of sensory data obtained by the SC user, SCPM4 conducts pricing. Specifically, in the lease period $LT$, provided that the volume of sensory data obtained by the SC user is $V$ and the unit price of the obtained sensory data is $PV_{SC}$, the

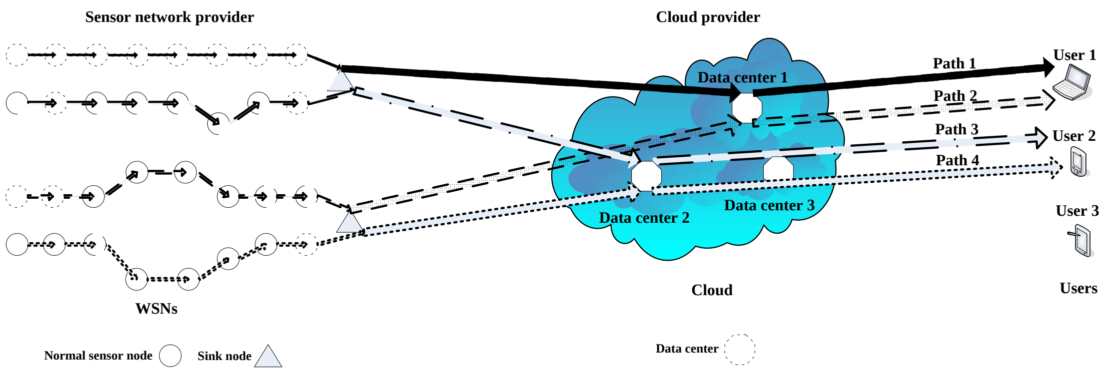


Fig. 2. An example of SC path

price that the SC user will be charged according to SCPM4 is

$$P_4 = V \times PV_{SC} \tag{4}$$

$PV_{SC}$ is also determined based on the IC, LP, QoS, AR and CM.

### 4.5 SCPM5

About SCPM5, the design is based on v) the SC path that transmits sensory data from the WSN to the SC user. The SC path is introduced first, followed with the description of SCPM5.

#### 4.5.1 SC path

As presented in Fig. 2, there is a path in SC, from the normal sensor node to the SC user. Specifically, the SC path includes: normal sensor node, intermediate normal sensor nodes, sink sensor node (or WSN gateway), cloud gateway, cloud data center, SC user. Moreover, involving the IC, LP, QoS, AR and CM, the SC path is formed and used.

#### 4.5.2 SCPM5

Inspired by the observation that the establishment and utilization of the SC path incorporate the IC, LP, QoS, AR and CM, it is assumed that each SC path $i$ is worth a price $PP_i$, with a path price computation function (i.e., $PPF$). Namely, $PP_i = PPF(i)$. Further, charging the SC user with SCPM5, the price is

$$P_5 = \sum_{i=1}^{i=M} PP_i = \sum_{i=1}^{i=M} PPF(i) \tag{5}$$

$M$ denotes the total number of SC paths.

## 5 Analysis of SCPMs

In this section, a general comparison about the proposed SCPMs is conducted first. With that, the price changes in SCPMs are discussed and the detailed analysis regarding SCPMs is shown.

### 5.1 General comparison

Based on the preliminaries about pricing in Section 3, a general comparison about the features of SCPMs is performed as follows and summarized in Table 1.

1) The IC, LP, QoS, AR and CM factors are incorporated into all SCPMs during their pricing designs. In terms of the pricing fairness of SCPMs, they are not available, due to that the market prices of SC are not available.
2) Regarding SCPM1, the pricing process is fixed for a specific time period, because the price charged is a constant for a specific time period. About SCPM2, SCPM3, SCPM4 and SCPM5, the pricing processes of them are dynamic, since the prices are dynamically changing with time.
3) SC users will select the SC provider, which has the highest level of QoS and lowest price within the utilization period. Thus, one potential approach for the SC provider to attract more SC users, is utilizing various technologies and techniques to lower their costs and prices. In addition, about SC, the popular pricing model is currently unknown yet.

### 5.2 Price changes in SCPMs

Referring to the designs about SCPMs in Section 4, the changes of the prices in SCPMs are discussed. Specifically, indicating the trend that the price changes with time, the examples about the changes of the prices in SCPMs are shown in Fig. 3.

1) SCPM1: Presented by Fig. 3(a) and Fig. 3(b), for a specific time period, the price is stable regardless of the SC user behavior.
2) SCPM2: Shown by Fig. 3(c) and Fig. 3(d), if the required working time of WSN or the required working time of cloud is increased, the price is increased.
3) SCPM3: Demonstrated by Fig. 3(e) and Fig. 3(f), increased resource utilization will result in increased price.

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TABLE 1
A comparison of proposed SCPMs

| Pricing model | Pricing approach | Pricing process | Factors considered | Fairness |
|---|---|---|---|---|
| SCPM1 | Lease period of SC user | Fixed for a specific time period | IC, LP, QoS, AR, CM | Not available |
| SCPM2 | Required working time of SC | Dynamic | IC, LP, QoS, AR, CM | Not available |
| SCPM3 | Resources utilized by SC user | Dynamic | IC, LP, QoS, AR, CM | Not available |
| SCPM4 | Sensory data volume obtained by SC user | Dynamic | IC, LP, QoS, AR, CM | Not available |
| SCPM5 | SC path | Dynamic | IC, LP, QoS, AR, CM | Not available |

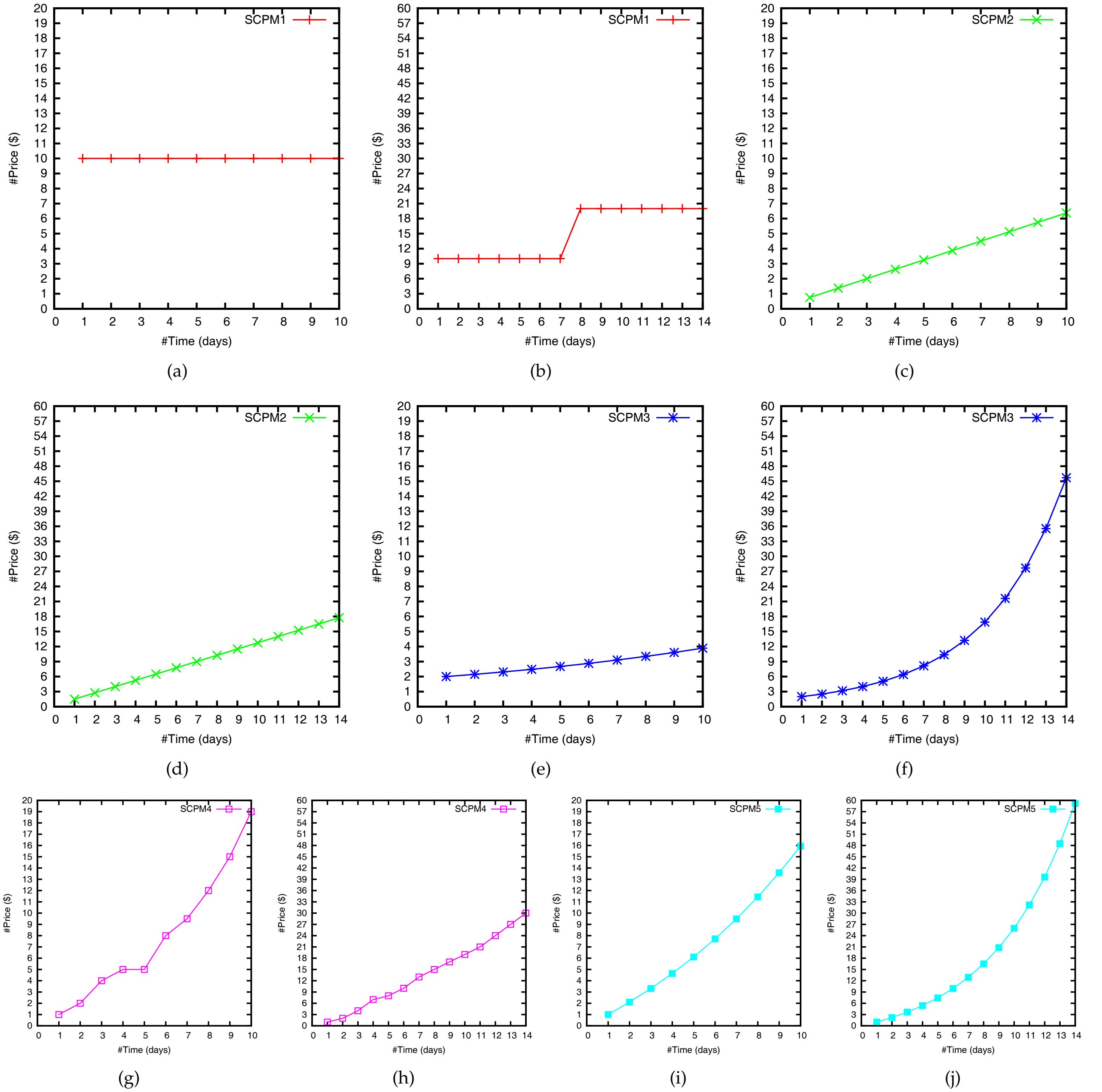


Fig. 3. Examples of price changes in SCPMs: (a) (b) SCPM1, (c) (d) SCPM2, (e) (f) SCPM3, (g) (h) SCPM4, (i) (j) SCPM5

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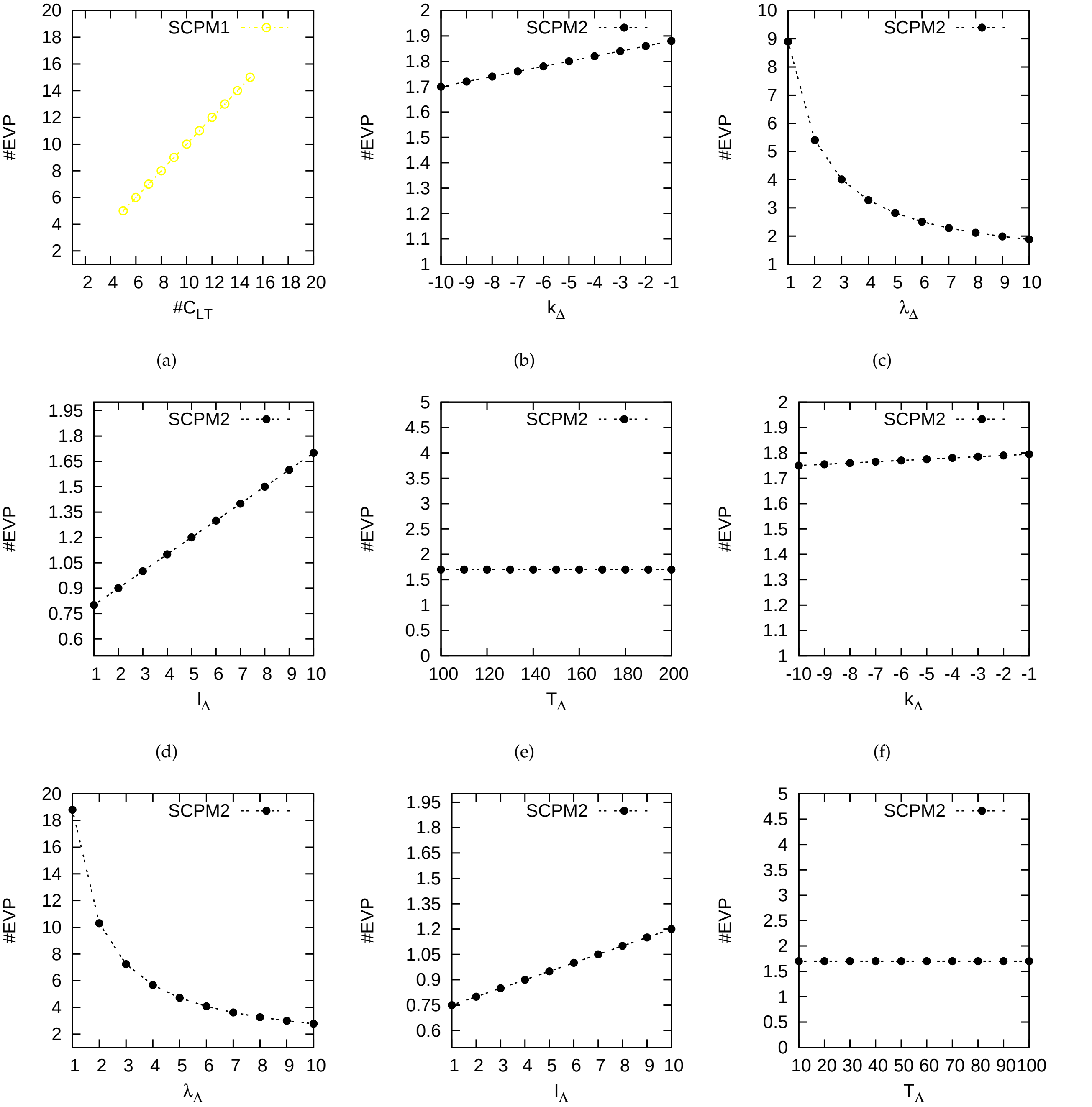


(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

Fig. 4. Examples of EVP's changes with different parameters in SCPM1 and SCPM2: (a) SCPM1, (b)-(i) SCPM2

4) SCPM4: Depicted by Fig. 3(g) and Fig. 3(h), with more sensory data volumes, the prices are increased.
5) SCPM5: Exhibited by Fig. 3(i) and Fig. 3(j), increased number of SC paths will generate increased price.

### 5.3 Detailed analysis

Regarding the detailed analysis, since various SC users have their own preferences, it is hard to determine which SCPM is the best. In addition, the practical pricing mechanism could be determined by the SC provider, based on the detailed application scenario. Therefore, as instances, the following analysis concerning the expected values of the prices (EVP) with various SCPMs is shown. The corresponding examples regarding the changes of EVP with different parameters in SCPMs are presented in Fig. 4, Fig. 5 and Fig. 6.

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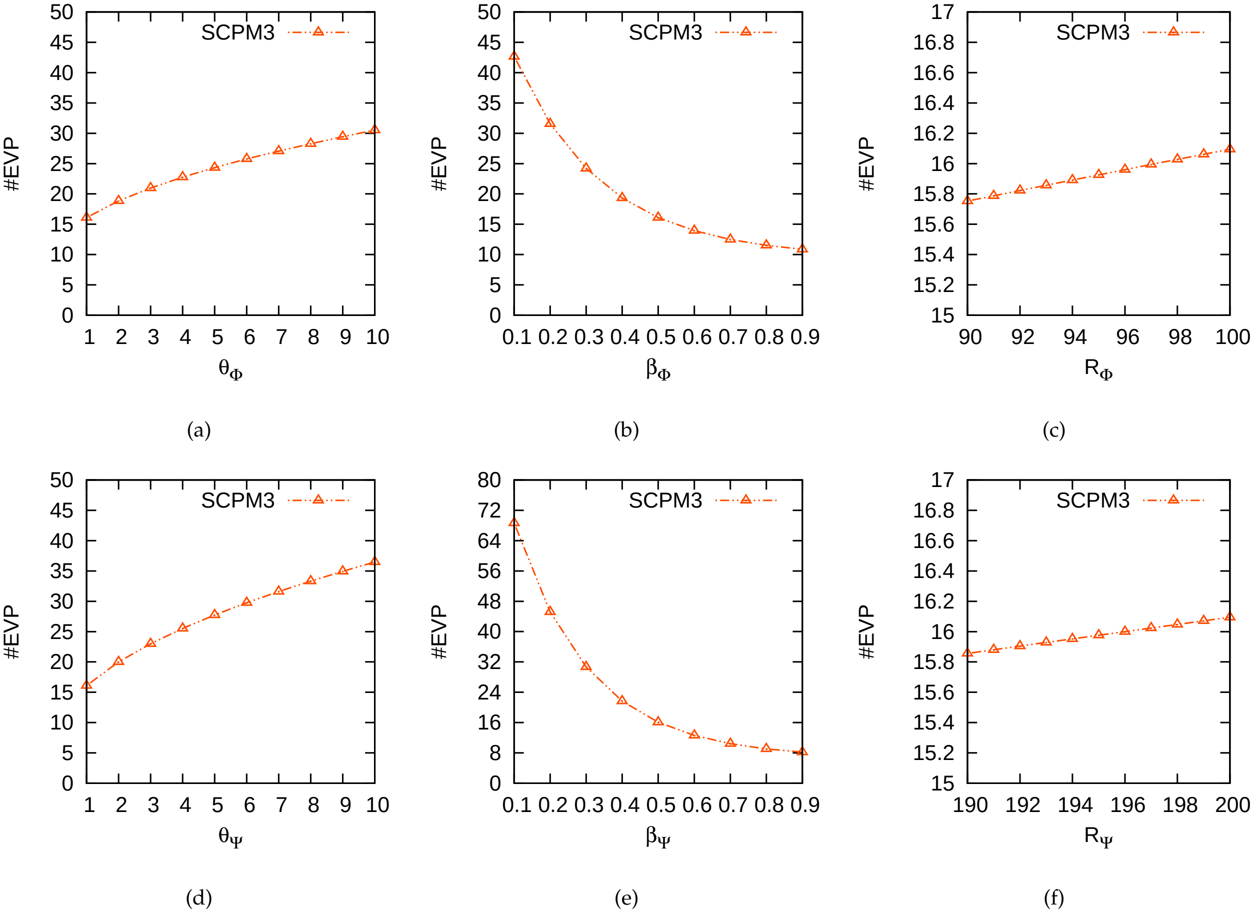


Fig. 5. Examples of EVP's changes with different parameters in SCPM3

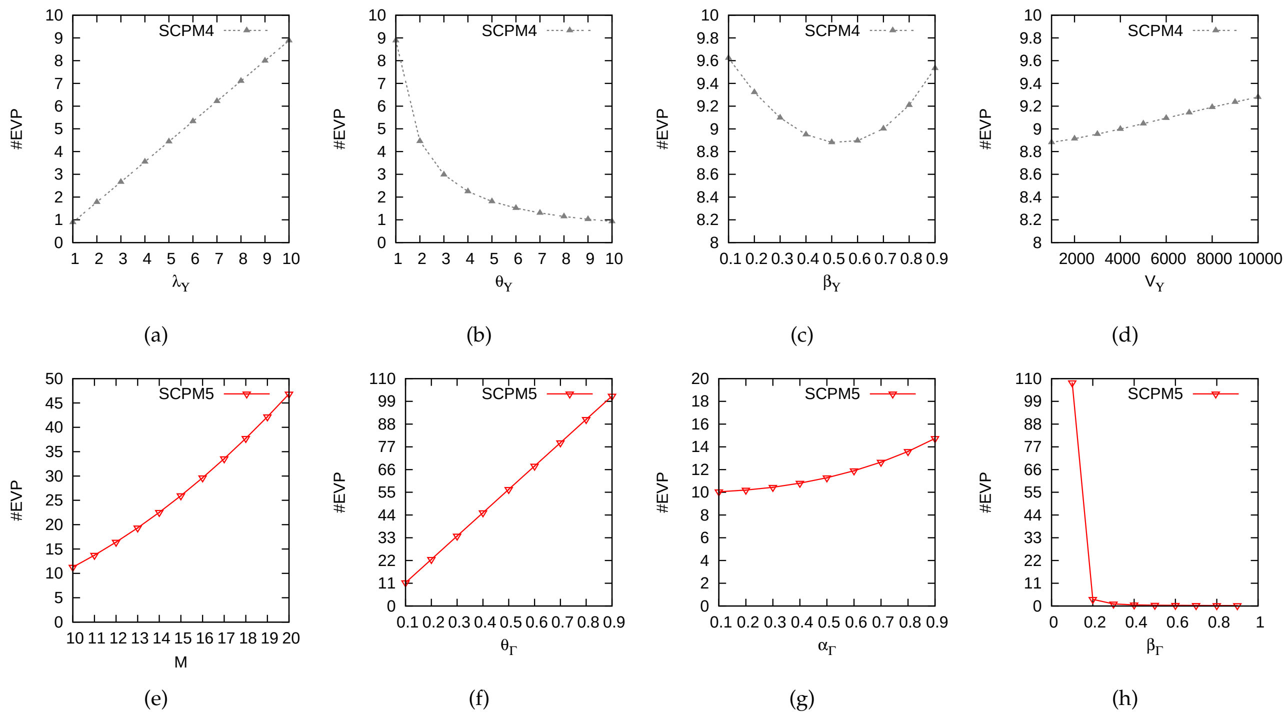


Fig. 6. Examples of EVP's changes with different parameters in SCPM4 and SCPM5: (a)-(d) SCPM4, (e)-(h) SCPM5

### 5.3.1 EVP with SCPM1

About SCPM1, because a constant value (i.e., $C_{LT}$) is determined by the SC as the price (i.e., $P_1$), the EVP of SCPM1 is

$$\mathbb{E}\{P_1\} = C_{LT} \tag{6}$$

### 5.3.2 EVP with SCPM2

In terms of SCPM2, let $T_\Delta$ and $T_\Lambda$ be the maximum working time of WSN and cloud, respectively. Let $P_\Delta = T_N \times PT_N$ and $P_\Lambda = T_C \times PT_C$. In addition, assume that a) $P_\Delta$ and $P_\Lambda$ increase when the required working time (i.e., $T_N$ and $T_C$) increase; b) the unit prices (i.e., $PT_N$ for the WSN to work and $PT_C$ for the cloud to work) decrease linearly when $T_N$ and $T_C$ increase, respectively; c) the required working time (i.e., $T_N$ and $T_C$) follow the normalized exponential distributions. In other words,

$$\begin{cases} 2k_\Delta \cdot T_\Delta + l_\Delta \le 0 \\ 2k_\Lambda \cdot T_\Lambda + l_\Lambda \le 0 \\ PT_N = k_\Delta \cdot T_N + l_\Delta, \quad 0 \le LT_N \le T_\Delta \\ PT_C = k_\Lambda \cdot T_C + l_\Lambda, \quad 0 \le LT_C \le T_\Lambda \end{cases}$$

where $k_\Delta$ and $k_\Lambda$ are negative constants while $l_\Delta$ and $l_\Lambda$ are positive constants. Further,

$$\begin{cases} P_\Delta = T_N \times PT_N = k_\Delta \cdot T_N^2 + l_\Delta \cdot T_N \\ P_\Lambda = T_C \times PT_C = k_\Lambda \cdot T_C^2 + l_\Lambda \cdot T_C \\ P_2 = P_\Delta + P_\Lambda \end{cases}$$

Moreover, denote $f_\Delta(T_N)$, $f_\Lambda(T_C)$ as the probability density functions (PDFs) of $T_N$ and $T_C$, respectively. $f_\Delta(T_N) = \frac{\lambda_\Delta}{1-\mathrm{e}^{-\lambda_\Delta \cdot T_\Delta}} \mathrm{e}^{-\lambda_\Delta \cdot T_N}$, $T_N \in [0, T_\Delta]$, and $f_\Lambda(T_C) = \frac{\lambda_\Lambda}{1-\mathrm{e}^{-\lambda_\Lambda \cdot T_\Lambda}} \mathrm{e}^{-\lambda_\Lambda \cdot T_C}$, $T_C \in [0, T_\Lambda]$. Here, $\lambda_\Delta$ and $\lambda_\Lambda$ are positive constant parameters.

Thus, it can be achieved that $\mathbb{E}\{T_N\} = \int_0^{T_\Delta} f_\Delta(T_N) \cdot T_N \, \mathrm{d}T_N = \frac{1}{\lambda_\Delta} + T_\Delta \cdot (1 - \frac{1}{1-\mathrm{e}^{-\lambda_\Delta \cdot T_\Delta}})$. $\mathbb{E}\{T_N^2\} = \int_0^{T_\Delta} f_\Delta(T_N) \cdot T_N^2 \, \mathrm{d}T_N = \frac{2}{\lambda_\Delta^2} + (\frac{2T_\Delta}{\lambda_\Delta} + T_\Delta^2)(1 - \frac{1}{1-\mathrm{e}^{-\lambda_\Delta \cdot T_\Delta}})$. Similarly, it can be obtained that $\mathbb{E}\{T_C\} = \frac{1}{\lambda_\Lambda} + T_\Lambda \cdot (1 - \frac{1}{1-\mathrm{e}^{-\lambda_\Lambda \cdot T_\Lambda}})$. $\mathbb{E}\{T_C^2\} = \frac{2}{\lambda_\Lambda^2} + (\frac{2T_\Lambda}{\lambda_\Lambda} + T_\Lambda^2)(1 - \frac{1}{1-\mathrm{e}^{-\lambda_\Lambda \cdot T_\Lambda}})$.

Eventually, the EVP of SCPM2 is

$$\mathbb{E}\{P_2\} = \mathbb{E}\{P_\Delta\} + \mathbb{E}\{P_\Lambda\} \tag{7}$$

in which $\mathbb{E}\{P_\Delta\} = k_\Delta \cdot \mathbb{E}\{T_N^2\} + l_\Delta \cdot \mathbb{E}\{T_N\} = \frac{2\,k_\Delta}{\lambda_\Delta^2} + \frac{l_\Delta}{\lambda_\Delta} + \left[k_\Delta \cdot (\frac{2T_\Delta}{\lambda_\Delta} + T_\Delta^2) + l_\Delta \cdot T_\Delta\right] \cdot (1 - \frac{1}{1-\mathrm{e}^{-\lambda_\Delta \cdot T_\Delta}})$, and $\mathbb{E}\{P_\Lambda\} = k_\Lambda \cdot \mathbb{E}\{T_C^2\} + l_\Lambda \cdot \mathbb{E}\{T_C\} = \frac{2\,k_\Lambda}{\lambda_\Lambda^2} + \frac{l_\Lambda}{\lambda_\Lambda} + \left[k_\Lambda \cdot (\frac{2T_\Lambda}{\lambda_\Lambda} + T_\Lambda^2) + l_\Lambda \cdot T_\Lambda\right] \cdot (1 - \frac{1}{1-\mathrm{e}^{-\lambda_\Lambda \cdot T_\Lambda}})$.

### 5.3.3 EVP with SCPM3

Regarding SCPM3, let $P_\Phi = FN(R_N)$ and $P_\Psi = FC(R_C)$. In addition, denote $PR_N$ and $PR_C$ as the unit prices for the resources of WSN and cloud respectively. $R_\Phi$ and $R_\Psi$ are the maximum resources of WSN and cloud, respectively. Then,

$$\begin{cases} P_\Phi = FN(R_N) = PR_N \times R_N, \quad 0 \le R_N \le R_\Phi \\ P_\Psi = FC(R_C) = PR_C \times R_C, \quad 0 \le R_C \le R_\Psi \\ P_3 = P_\Phi + P_\Psi \end{cases}$$

Further, it is assumed that a) an isoelastic demand function [21] [22] is utilized to model how the level of resource demand changes when the unit price (i.e., $PR_N$ or $PR_C$) changes; b) the utilized resource (i.e., $R_N$ or $R_C$) follows uniform distribution. Namely,

$$\begin{cases} R_N = \theta_\Phi \cdot (\frac{1}{PR_N})^{\frac{1}{\beta_\Phi}}, \quad \beta_\Phi \in (0,1) \\ R_C = \theta_\Psi \cdot (\frac{1}{PR_C})^{\frac{1}{\beta_\Psi}}, \quad \beta_\Psi \in (0,1) \end{cases}$$

where $\theta_\Phi$ and $\theta_\Psi$ are constant parameters, $\beta_\Phi$ and $\beta_\Psi$ are elasticity coefficients. It can be deduced that

$$\begin{cases} PR_N = (\frac{\theta_\Phi}{R_N})^{\beta_\Phi} \\ PR_C = (\frac{\theta_\Psi}{R_C})^{\beta_\Psi} \end{cases}$$

With that, it can be achieved that

$$\begin{cases} P_\Phi = PR_N \times R_N = \theta_\Phi^{\beta_\Phi} \cdot R_N^{(1-\beta_\Phi)} \\ P_\Psi = PR_C \times R_C = \theta_\Psi^{\beta_\Psi} \cdot R_C^{(1-\beta_\Psi)} \end{cases}$$

Moreover, given that $f_\Phi(R_N)$ and $f_\Psi(R_C)$ denote the PDFs of the utilized resource $R_N$ and $R_C$, respectively. Then, $f_\Phi(R_N) = \frac{1}{R_\Phi}$ and $f_\Psi(R_C) = \frac{1}{R_\Psi}$. Further, $\mathbb{E}\{P_\Phi\} = \int_0^{R_\Phi} f_\Phi(R_N) \cdot P_\Phi \, \mathrm{d}R_N = \frac{1}{2-\beta_\Phi} \cdot \theta_\Phi^{\beta_\Phi} \cdot R_\Phi^{(1-\beta_\Phi)}$ and $\mathbb{E}\{P_\Psi\} = \int_0^{R_\Psi} f_\Psi(R_C) \cdot P_\Psi \, \mathrm{d}R_C = \frac{1}{2-\beta_\Psi} \cdot \theta_\Psi^{\beta_\Psi} \cdot R_\Psi^{(1-\beta_\Psi)}$. Thus, the EVP of SCPM3 is

$$\begin{aligned} \mathbb{E}\{P_3\} &= \mathbb{E}\{P_\Phi\} + \mathbb{E}\{P_\Psi\} \\ &= \frac{\theta_\Phi^{\beta_\Phi}}{2-\beta_\Phi} \cdot R_\Phi^{(1-\beta_\Phi)} + \frac{\theta_\Psi^{\beta_\Psi}}{2-\beta_\Psi} \cdot R_\Psi^{(1-\beta_\Psi)} \end{aligned} \tag{8}$$

### 5.3.4 EVP with SCPM4

With respect to SCPM4, define $V_\Upsilon$ as the maximum volume of sensory data obtained by the SC user. Similarly, it is assumed that a) an isoelastic demand function [21] [22] is utilized to model how the level of data demand changes when the unit price (i.e., $PV_{SC}$) changes; b) the obtained data (i.e., $V$) follows normalized exponential distribution. Thus,

$$\begin{cases} V \in [0, V_\Upsilon] \\ V = \theta_\Upsilon \cdot (\frac{1}{PV_{SC}})^{\frac{1}{\beta_\Upsilon}}, & \beta_\Upsilon \in (0,1) \\ PV_{SC} = (\frac{\theta_\Upsilon}{V})^{\beta_\Upsilon}, & \beta_\Upsilon \in (0,1) \\ P_4 = V \times PV_{SC} = \theta_\Upsilon^{\beta_\Upsilon} \cdot V^{1-\beta_\Upsilon}, & \beta_\Upsilon \in (0,1) \end{cases}$$

where $\theta_\Upsilon$ is a constant parameter and $\beta_\Upsilon$ is an elasticity coefficient.

Moreover, denote $f_\Upsilon(V)$ as the PDF of the volume $V$ of the obtained sensory data. $f_\Upsilon(V) = \frac{\lambda_\Upsilon}{1-\mathrm{e}^{-\lambda_\Upsilon \cdot V_\Upsilon}} \cdot$

$\mathrm{e}^{-\lambda_\Upsilon \cdot V}$, where $\lambda_\Upsilon$ is a constant parameter. With that, the EVP of SCPM4 is

$$\begin{aligned}\mathbb{E}\{P_4\} &= \int_0^{V_\Upsilon} f_\Upsilon(V) \cdot P_4 \,\mathrm{d}V \\ &= \frac{\lambda_\Upsilon \cdot \theta_\Upsilon^{\beta_\Upsilon}}{1-\mathrm{e}^{-\lambda_\Upsilon \cdot V_\Upsilon}} \int_0^{V_\Upsilon} V^{1-\beta_\Upsilon} \cdot \mathrm{e}^{-\lambda_\Upsilon \cdot V} \,\mathrm{d}V \quad (9)\end{aligned}$$

which can be computed by numerical methods.

#### 5.3.5 EVP with SCPM5

Concerning SCPM5, assume that $p_i$ is the probability that the SC user uses the $i$-th SC path ($1 \leq i \leq M$). In addition, about the path price computation function $PPF$ which relates the SC path $i$ to its path price $PP_i$ with $PP_i = PPF(i)$, it is assumed that $PP_i$ increases as $p_i$ decreases. Without loss of generality, it is given that $p_i$ is sorted in a decreasing order, i.e., $p_1 \geq p_2 \geq \ldots \geq p_M$. In other words, the $PP_i$ of the $i$-th SC path is defined as

$$PP_i = PPF(i) = \theta_\Gamma \cdot (\frac{1}{p_i})^{\frac{1}{\beta_\Gamma}}, \forall i$$

where $\theta_\Gamma$ is a positive constant parameter, $\beta_\Gamma \in (0,1)$ is also a constant parameter. Thus,

$$\mathbb{E}\{P_5\} = \sum_{i=1}^{M} p_i \cdot PP_i = \sum_{i=1}^{M} \theta_\Gamma \cdot p_i^{(1-\frac{1}{\beta_\Gamma})} \quad (10)$$

For instance, assume that the probability of the utilization of the paths (i.e., $p_i$) follows Zipf distribution. Then,

$$p_i = \frac{i^{-\alpha_\Gamma}}{\sum_{m=1}^{M} m^{-\alpha_\Gamma}}, \forall i$$

where $\alpha_\Gamma \in (0,1)$ is a constant parameter which denotes the sketch of the probability distribution. Thus, in this case, the $PP_i$ and the EVP of SCPM5 become

$$PP_i = \theta_\Gamma \cdot \left(\frac{i^{-\alpha_\Gamma}}{\sum_{m=1}^{M} m^{-\alpha_\Gamma}}\right)^{-\frac{1}{\beta_\Gamma}}, \forall i$$

$$\mathbb{E}\{P_5\} = \sum_{i=1}^{M} \theta_\Gamma \cdot \left(\frac{i^{-\alpha_\Gamma}}{\sum_{m=1}^{M} m^{-\alpha_\Gamma}}\right)^{(1-\frac{1}{\beta_\Gamma})}$$

## 6 Case studies of SCPMs

In this section, the potential real application scenarios of SC are envisioned first, followed with the use cases of SCPMs in these application scenarios.

### 6.1 Application scenarios of SC

1) SC1: There is a public cloud with 10 data centers. There is a WSN with 100 normal sensor nodes and one sink node. The sensor nodes are deployed to monitor the traffic status of a town. Multiple SC users request the traffic information about their interested regions from the SC [3] [23].
2) SC2: There is a private cloud with 1 data center. 50 normal sensor nodes and one sink node are in the WSN. The status (e.g., images, videos) of the sightseeing place is monitored by the deployed sensor nodes. Multiple SC users access the SC, for guiding them to walk directly to the specific sightseeing spots [3] [24].
3) SC3: There are a number of public clouds and each of them is with 10 to 100 data centers. There are a number of WSNs. The number of normal sensor nodes in the WSNs ranges from 100 to 1000 and there is a sink node in each WSN. The sensor nodes are deployed to monitor the status (e.g., temperature, humidity) of a city. Multiple SC users issue requests to the SC, for the weather information regarding various areas in the city [23] [25].
4) SC4: A private cloud is with 1 data center. A WSN is with 20 normal sensor nodes and one sink node. Deploying the sensor nodes, is to monitor the status (e.g., plant growth, security) in a farm. One SC user (i.e., the farm owner) issues requests frequently to the SC, to obtain the plant growth and security information about the farm [23] [26].
5) SC5: A private cloud and a WSN are included in the SC. There is 1 data center in the cloud. 50 normal sensor nodes and one sink node are in the WSN, for performing industry process monitoring in a factory. One SC user (i.e., the factory manager) obtains the monitored industry process information, by issuing requests to the SC [27] [28].

### 6.2 Use cases of SCPMs

The use cases of SCPMs in the above application scenarios are shown as below, assuming that each SC user is with different behavior.

1) SCPM1: SC1 offers service to 100 SC users. Referring to equation 1, the lease periods of different SC users will lead to different prices.
2) SCPM2: 10 SC users utilize SC2. Different SC users require different working time of SC, and they lead to different prices charged referring to equation 2.
3) SCPM3: SC3 is used by 1000 SC users. The SC resource utilizations of different SC users result in different charged prices, based on equation 3.

4) SCPM4: One SC user utilizes SC4. The sensory data with volume is requested by the SC user. Finally, the SC user pays the price according to equation 4.
5) SCPM5: One SC user uses SC5. Various SC paths are needed to transmit the sensory data from the WSN to the SC user. The price is calculated based on equation 5.

# 7 Review of user behavior study

For designing a customized pricing mechanism, the study about user behavior is very instructive, since various users generally own different behaviors. However, currently there is no study specially directed against SC user behavior. Being a guidance, the existing study about user behavior is reviewed in this section. Particularly, attention is devoted to the following two aspects: 1) the sources of use behavior 2) the analysis of user behavior.

## 7.1 Sources of user behavior

The evidences of user behavior could come from a) the user, b) the interaction between the user and the cloud, c) the data in the mobile application. Specifically, regarding a), motivated by protecting cloud from malicious insiders, [29] shows that *user' keystroke dynamics* can obtain information about user behaviors. About keystroke dynamics, it is an approach which studies the keystrokes distinguishing each user based on the manner and the rhythm (e.g., typing speed, latency between keystrokes, pressure applied on keys, etc.). Analyzing a dataset of Google cloud users, the dynamic behaviors of users are modeled with *user's session view* in [30]. As a user based modeling hypothesis, session view addresses the patterns of activities displayed by specific users during their utilization periods. Investigating a large-scale data set gathered from a major cellular network in Northeastern China, it is introduced in [31] that *user's mobility* acquired with the cell towers can be utilized to analyze the online video user behaviors. Regarding mobility, it is closely related to where and when a user utilizes the service. Discussing IPTV user behaviors with MapReduce, [32] presents that *user's log data* gathered from the set-top box (STB) and network devices can be used to understand the IPTV user behaviors. This is a very straightforward method to achieve user behaviors. In terms of b), [33] mentions that the *characteristics of the communications and computations within the cloud* (e.g., the requests sent from cloud users and processed in the cloud) can be utilized to observe the user behavior, with fractal modeling technique. With respect to c), conducting a single-case and pretest-posttest as well as quasi experiment which includes a smartphone device and a suite of Google mobile applications, [34] proofs that the *residual data in cloud-based synchronized apps* can be used to broadly identify user behavior patterns.

## 7.2 Analysis of user behavior

The analysis of user behavior is highly related to the contexts, due to that there are different user behaviors in different scenarios. In particular, concerning *online social networks*, [35] discovers key features of the social network workloads, including a) the frequencies and time people connect to social networks b) the types and sequences of activities that users perform on social networks. In this study, gathered over a 12-day period, the analysis is based on the click-stream data containing HTTP sessions of 37,024 users who accessed four social networks (i.e., Orkut, MySpace, Hi5, and LinkedIn). About *website identification registration*, [36] focuses on the following three views: a) the complexity of each identification component; b) correlation between identification components; and c) user preference in selecting password and email provider. This study is based on the database offered by the Chinese Software Develop Net (CSDN), in which more than 90 percent of excellent Chinese programmers registered. Regarding *P2P streaming systems*, [37] obtains the following commonly used metrics through user behavior measurements: a) channel/video popularity; b) session duration; c) online duration; d) user arrival/departure; e) downloaded/uploaded traffic. In this study, the achieved results are on account of summarizing existing studies performed for various P2P streaming systems. With respect to *mobile applications*, [38] discovers the following points about whether users tend to access the application more often when they are waiting at airports: a) the application open rates of air travelers measured during their airport-dwelling time is 8 times higher than their application open rates at other locations; b) for the same group of travelers who own application open behaviors at both airports and other locations, their application open rates at airports is 45 times higher than that at other locations and time periods. In this study, a particular iPhone application data within 2 weeks from a major retailer in United States is utilized. Focusing on *infrastructure as a service (IaaS)*, [39] conducts a survey about the end-user market of cloud computing in Korea and observes that a) the service fee and b) the stability of QoS are the most two critical adoption factors for the users in the survey. This study is with a quantitative analysis, by analyzing the gathered data in the survey using bayesian mixed logit model and multivariate probit model.

# 8 Conclusion

As a pioneering work towards pricing for SC, 1) five SCPMs have been proposed first. In particular, to charge a SC user, each SCPM takes account of one of the following five factors respectively: i) the lease period of the SC user; ii) the required working time of SC; iii) the SC resources utilized by the SC user; iv) the volume of sensory data obtained by the

SC user; v) the SC path that transmits sensory data from the WSN to the SC user. Moreover, 2) detailed analysis has been conducted about the discussion and demonstration of the characteristics of the proposed SCPMs. In addition, 3) case studies have been presented concerning the application of SCPMs. Finally, 4) a review is performed, about the study of user behavior. The aim of this work is to be a very valuable guidance for future research regarding SC pricing.

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