# PRIME: An Optimal Pricing Scheme for Mobile Sensors-as-a-Service

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**Abstract**—In this paper, we propose a pricing scheme, named PRIME, for provisioning *mobile Sensors-as-a-Service* (*mSe-aaS*) in the Mobile Sensor-Cloud (MSC) architecture, with an aim to optimally distribute the financial profit among different actors of MSC. Unlike traditional sensor-cloud, MSC introduces a new actor as device owner, whose mobile device hosts the physical sensor nodes. On the other hand, the device and sensor owners earn certain revenues, based on the usage of the sensor nodes and the mobile devices, for provisioning mSe-aaS to the end-users. MSC is a contemporary architecture, and therefore, no pricing scheme exists for it. In this work, we consider the presence of the device owner, sensor owner, Sensor-Cloud Service Provider (SCSP), and end-user to determine an optimal pricing strategy. In order to design such a strategy, we use the *Lagrangian multiplier* method and apply *Karush-Kuhn-Tucker* (*KKT*) conditions. On the other hand, an end-user has multiple options to select an SCSP among the available ones. Therefore, based on the reputation of all the available SCSPs, PRIME enables an end-user to select a suitable one. Extensive experimental results report that PRIME increases the profit of sensor and device owners by $25.67\%$ and $29.12\%$, respectively. We also compare PRIME with an existing pricing scheme for traditional sensor-cloud architecture. We notice that the service return using PRIME increases by $55.31\%$ as compared to the same using the traditional sensor-cloud architecture.

**Index Terms**—Mobile Sensor-Cloud (MSC), Mobile Sensors-as-a-Service (mSe-aaS), Optimal pricing, Sensor-Cloud Service Provider (SCSP), Device owner, Mobile devices.



## 1 Introduction

TRADITIONAL Wireless Sensor Networks (WSNs) are procured, deployed, and maintained by their respective owners for serving certain applications. Moreover, the owner of a WSN typically does not share the sensed data with others. Consequently, such a constraint gives rise to the single user-centric utilization of WSNs. However, the evolution of sensor-cloud architecture abolished the single user-centric perception of traditional WSNs [1]. To strengthen the sensor-cloud architecture, different authors in the existing literature addressed the problems of pricing [2], caching [3], and the formation of virtual sensors [4]. The traditional architecture of a sensor-cloud consists of three different actors – end-user, sensor-cloud service provider (SCSP), and sensor owner. In such an architecture, the static sensor nodes enable multiple end-users to receive services through *Sensor-as-a-Service* (*Se-aaS*), using the concept of sensor virtualization. The pricing mechanism in the sensor-cloud architecture is based on the *pay-per-use* model, in which an end-user pays the rent of certain services as per the usage. On the other hand, the device owners deploy the sensor nodes and earn the profit as per the usage of their respective devices. The SCSP plays a centralized role in managing the entire architecture and financial aspects using certain mechanisms [2]–[4]. However, in the process, the SCSP gains a portion of the profit and utilizes the remaining amount for the maintenance of the sensor-cloud infrastructure.

Aligned with the concept of traditional sensor-cloud architecture, the Mobile Sensor-Cloud (MSC) [5] was introduced for provisioning mobile Sensors-as-a-Service (mSe-aaS). In an MSC, the mobile devices are used to deploy the sensor nodes or the sensors are pre-equipped with these devices at the time of purchase. Based on the usage of the sensor nodes attached to the devices, the respective device owners receive the payment from the MSC platform. In an MSC architecture, a virtual sensor (VS) is formed by combining the physical sensor nodes attached to the respective devices. Unlike traditional sensor-cloud, in MSC, there is more option to include a physical sensor node in a VS. Therefore, an MSC platform is capable of providing a better and efficient service as compared to the traditional sensor-cloud. Similar to the traditional sensor-cloud architecture, in MSC, different financial transactions among different actors are involved. Also, a device owner may leave an application area at any time instant, and another device is required to be allocated for serving the existing application. Consequently, the scenarios in MSC become more dynamic as compared to the traditional sensor-cloud. Therefore, the existing pricing schemes for traditional sensor-cloud are not suitable for the MSC architecture due to the presence of an additional actor, device owner and its dynamic behavior. In this work, we propose a pricing scheme for MSC, by considering the benefit of all the actors in it.

### 1.1 Motivation

The MSC architecture features different actors such as sensor owner, device owner, end-user, and SCSP. Unlike traditional sensor-cloud architecture, in MSC, a new actor is


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introduced as device owner [5]. Based on the types and duration of the services, an end-user pays the rent to the MSC. On the other hand, the respective sensor and device owners procure and maintain the sensor nodes and devices for provisioning mSe-aaS to the end-users. The procurement of devices and sensors incur additional expenses. Therefore, the SCSP manages the payments made by the end-users and shares a fraction of the profit among different registered devices and sensor owners. Pricing in MSC is based on the pay-per-use business model, in which the cash inflow and outflow depend on the usage of the sensor and the devices. Moreover, MSC is a newer architecture, and therefore, the authors in the existing literature do not propose any specific pricing scheme for MSC. As the architecture of the MSC is significantly different from the traditional sensor-cloud, the existing pricing schemes for sensor-cloud are not applicable in it. Therefore, there persists an urgent requirement for designing an optimal pricing strategy to distribute the profit among the different actors of the MSC infrastructure. In order to make an unbiased profit distribution among different actors of MSC, we strongly motivate to design an optimal pricing scheme. Additionally, multiple SCSPs are able to serve multiple end-users with similar or distinct types of services. Consequently, for an end-user, it is difficult to select a suitable SCSP among the available ones. Therefore, the proposed pricing scheme for MSC facilitates an end-user to select a suitable SCSP based on their reputations.

### 1.2 Contribution

Sensor-cloud is a newly explored WSN architecture, where multiple actors participate for provisioning mSe-aaS to different end-users. On the other hand, the end-users receive services based on the pay-per-use model. Thus, to handle the payment transactions among multiple actors, we propose a pricing scheme, PRIME. In brief, the *contributions* of this work are as follows:

- The MSC architecture is based on certain business processes in which multiple SCSPs participate and provide similar or distinct types of services. However, for an end-user, it is inconvenient to select a suitable SCSP among the available ones. Therefore, in this work, we design a mathematical formulation for selecting a suitable SCSP based on his/her reputation. In order to select an SCSP, we introduced a few parameters such as *Efficiency, Evidentiality factor, and Service return*
- In an MSC, four primary actors – sensor-owner, device owner, SCSP, and end-user are involved. Among these actors, the device owner, sensor owner, and SCSP earn a fraction of profit from the payment of the end-users. Additionally, different expenses are associated for maintaining the devices, sensor nodes, and the MSC platform. Consequently, different monetary transactions are involved in MSC architecture. However, in the existing literature, no scheme presents the pricing mechanism for MSC. Therefore, for an unbiased distribution of the profit among different actors, we propose a pricing scheme, PRIME, specifically for MSC.
- In this work, we compute the pricing for the sensor owner, the device owner, and the SCSP. Therefore, for distributing the profit among these actors, we formulate the optimization problems and solve them using *Lagrangian multiplier* method and apply the *Karush-Kuhn-Tucker* (*KKT*) conditions [6].
- The proposed scheme, PRIME, is unique and is specifically designed for use in an MSC platform. Therefore, the performance analysis of PRIME is essential at this juncture. We analyze the performance of PRIME with extensive experiments. Moreover, we present a few results of the theoretical analysis of the various part of the proposed solution. We compared PRIME with an existing pricing scheme proposed for traditional sensor-cloud. We thoroughly analyzed the cash inflow and outflow of different sensor and device owners.

## 2 Related Work

In this Section, we discuss the existing works related to traditional sensor-cloud architecture. The authors in the existing literature [7]–[9] discussed the virtualization of sensor networks and explored the concept of sensing-as-a-service. However, Yuriyama *et al.* [1] introduced the sensor-cloud infrastructure by envisioning the virtualization of sensor nodes. In this work, the authors presented the architecture and implementations aspects of sensor-cloud. Based on the concept of sensor-cloud, Misra *et al.* [10] designed its theoretical model. In this work, the authors reported that an end-user is provisioned Sensor-as-a-Service (Se-aaS) with the help of Virtual Sensors (VSs), which comprises of multiple physical sensor nodes. The participation of the physical sensor nodes in a VS dynamically changes with the type of applications. Therefore, Chatterjee *et al.* [11] and Roy *et al.* [4] worked on the formation of VS in sensor-cloud architecture with the consideration of overlapping and non-overlapping sensor deployment regions. On the other hand, the end-users pay a certain amount for their requested service, and consequently, they expect a satisfactory Quality-of-Service (QoS). One of the parameters for computing the QoS is delay in service delivery. Therefore, the authors in the existing literature [3], [12] proposed cache-enabled sensor-cloud architecture, while ensuring the faster delivery of end-user applications. The authors in [12] presented the two types of caching mechanism – internal and external caching – for sensor-cloud architecture. Roy *et al.* [3] presented the concept of *Special Dynamic Caching* (*SDC*) for ensuring the access of Virtual Machine (VM) contents in a sensor-cloud architecture. Wang *et al.* [13] designed a data cleaning mechanism in sensor-cloud, using edge computing, to clean the data from a huge volume of acquired data by the sensor nodes. Finally, Madria *et al.* [14] designed the Missouri S&T sensor-cloud architecture for the implementation of the virtualization of sensors. The authors designed a virtual sensor nodes deployment architecture, which is specifically designed for Missouri S&T sensor-cloud.

The cloud services are based on the pay-per-use model. The authors in the existing literature presented different pricing schemes for traditional cloud architecture. Shah-Mansouri *et al.* [15] proposed an optimal pricing scheme for mobile cloud services. The authors also claimed that the profit maximization problem, derived in their work, is non-convex. Similarly, Mashayekhy *et al.* [16] presented an auction-based pricing scheme to compute the payment of the resource allocated for a user. Additionally, in the proposed scheme [16], the authors designed an incentive-based mechanism for encouraging the users to reveal their actual requirements. In another work, Ren *et al.* [17] designed a pricing scheme, which maximizes the profit of the wireless service providers. The authors considered the currently available information while focusing on the batch services in the cloud computing environment. Dabbagh *et al.* [18] proposed a framework for cloud, which maximizes the cloud profit and minimizes the energy expenses. The authors primarily considered the elastic and inelastic task requests in a cloud infrastructure. Further, using the proposed framework, a suitable amount of resources are allocated to the elastic tasks, in order to maximize the cloud profit. The sensor-cloud architecture consists of a similar business model, in which the service provider and consumers are present. However, unlike traditional cloud architecture, in sensor-cloud, the sensor owners play an important role by lending the sensor nodes. Therefore, in order to address the pricing issues, Chatterjee *et al.* [19] proposed a dynamic pricing scheme for sensor-cloud architecture. In this work, the authors considered two types of pricing for infrastructure and hardware. Along the same line, Roy *et al.* [20] considered the presence of unintentional misbehavior – dumb behavior – of sensor nodes and proposed a pricing scheme. Finally, Chakraborty *et al.* [21] designed a pricing scheme for sensor-cloud, considering the QoS.

*Synthesis*: The analysis of the existing works reveals that the authors either focused on the problems on the traditional sensor-cloud architecture or designed different pricing schemes for the traditional cloud. However, in the MSC, in addition to the other entities of the sensor-cloud, device owners act as one of the important entities. The deployed sensor nodes on the mobile devices obtain their mobility due to continuous movement of the mobile devices with respect to time. Moreover, the mobility of sensor nodes also leads to variation in the composition of a virtual sensor. Therefore, the existing pricing schemes of traditional cloud and sensor-cloud are not suitable for such a dynamic scenario of MSC.

## 3 Problem Description

### 3.1 Problem Scenario

We consider an MSC architecture, in which the sensor nodes are attached to various mobile devices such as smartphones, vehicles, laptops, and tablets. The static sensor nodes attain their mobility with the help of the mobile devices on which they are mounted. In this architecture, the end-users request for Se-aaS services after registering through the Web portal. Following the similar concept of traditional sensor-cloud architecture, MSC is also based on the concept of virtualization of physical sensor nodes. Through the virtualization, an end-user remains completely unaware of the back-end processes of allocation or re-allocation of mobile sensor nodes in a VS. The end-users pay rent to the SCSP based on the applications selected by

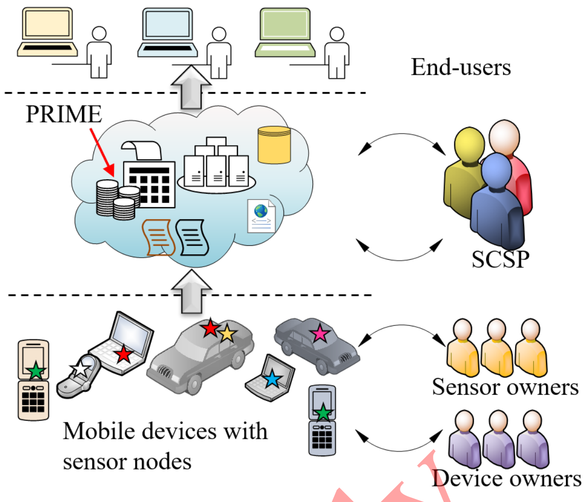



Fig. 1: System Architecture

them. Further, the SCSP provides a tariff to the sensor owner for the services imparted by their registered sensor nodes. On the other hand, the sensor owners deploy their sensor nodes on the mobile devices to earn profit from the MSC architecture. Thus, the SCSP's profit depends on the cash inflow from the end-users and the cash outflow from the device owners or the sensor owners. In order to maintain a balance between the cash inflow and outflow among the various entities of MSC, we propose the dynamic pricing scheme. We use multi-objective optimization to maximize the profit of SCSP and minimize the rent paid by end-users. In an MSC architecture, multiple SCSPs are present to serve the end-user applications. Each SCSP provides service to the end-users within a particular service region. The service regions of different SCSPs may mutually overlap. Fig. 1 depicts the system architecture, where multiple sensor owners and device owners rent out their respective devices and sensor nodes. The end-users become unaware of the back-end processes of the MSC platform and enjoy the services.

### 3.2 Mathematical Model

As discussed previously, the MSC architecture consists of four actors – end-user, sensor-cloud service provider (SCSP), sensor owner, and device owner. In this architecture, the mobile devices are equipped with pre-deployed sensor nodes at the time of procurement, or the sensor owners manually mount the sensor nodes on these devices. The set of SCSPs present in the system is represented as $\mathcal{S} = \{S_1, S_2, \cdots, S_m\}$, such that $S_m$ is the maximum number of SCSP present in the system. An SCSP, $S_i$, is able to offer $\mathbb{N}^i_{tp}$ distinct types of application. In a real scenario, there exist multiple types of end-user, such as commercial and personal end-user. Any SCSP, $S_i$, is able to serve $T_i$ different types of end-users. An end-user selects one of the SCSPs with the minimum chargeable price and maximum service return. We represent the set of end-users as $EU = \{EU_1, EU_2, \cdots, EU_n\}$, where $n$ is the total number of end-users present in the architecture. Let the total number of sensor nodes available to SCSP, $S_i$, is represented as $N_i$. Let the set of sensor owners present in the MSC infrastructure be denoted as $\mathbb{S} = \{\mathbb{S}_1, \mathbb{S}_2, \mathbb{S}_3, \cdots, \mathbb{S}_x\}$, where $\mathbb{S}_x$ is the maximum number present in the system. A set of sensors owned by sensor owner, $\mathbb{S}_i$, is represented as $\Lambda^i = \{\lambda_1^i, \lambda_2^i, \lambda_3^i, \cdots, \lambda_a^i\}$. Similarly, we define the set of device owners registered with the MSC as $\mathbb{D} = \{\mathbb{D}_1, \mathbb{D}_2, \mathbb{D}_3, \cdots, \mathbb{D}_y\}$. Any device owner, $\mathbb{D}_i$, owns maximum $b$ devices and the set of device owned by $\mathbb{D}_i$ is denoted as $\Delta = \{\delta_1^j, \delta_2^j, \delta_3^j, \cdots, \delta_b^j\}$. Therefore, the total number of sensor owners and device owners present in the MSC platform is $x$ and $y$, respectively.

# 4 Solution Approach: PRIME

## 4.1 Selection of SCSP

In this work, we consider the presence of multiple SCSPs. Our aim is to select a suitable SCSP among the available ones. In order to select the SCSP, we minimize the *fixed chargeable price* and maximize the *service return*. We define a term, *efficiency*, which serves in computing fixed chargeable price. The efficiency of an SCSP depends on the *time factor*, defined as follows:

***Definition* 1.** *Time factor ($\tau_i$) of the $i^{th}$ SCSP is the ratio of average duration ($t$) of activation of all available sensor nodes, $N_i$, belonging to the SCSP ($S_i$) to the maximum allowable delay ($t_{max}$) by $S_i$, to provide the service.*

$$\tau_i = \frac{\sum_{j=1}^{N_i} t_j}{t_{max}} \tag{1}$$

The increasing time of activation a sensor node, available with an SCSP, helps an end-user to receive better service quality. Therefore, we consider the time factor as an important parameter to compute the efficiency of the SCSP.

***Definition* 2.** *Efficiency ($Eff_{S_i}$) measures the ability of any SCSP, $S_i$, considering the number of templates available ($\mathbb{N}_{tp}^i$) with $S_i$, to serve the number of types of end-users ($T_i$) by $S_i$ and the time factor ($\tau_i$) of $S_i$.*

$$Eff_{S_i} = \mathbb{N}_{tp}^i T_i \tau_i \tag{2}$$

An MSC infrastructure is based on the *pay-per-use* model. Therefore, the end-users need to pay the charges to the SCSP as per the usage of the services. A SCSP charges two types of price to an end-user – *Fixed chargeable price* and *Variable price*.

***Definition* 3.** *Fixed chargeable price is the one-time cost charged to an end-user ($EU^j$), which constitutes of per-unit charges ($C_E$) to maintain the efficiency of the SCSP and the maintenance cost ($C_M$) of the infrastructure.*

We compute the total fixed chargeable price ($CP_i^{EU_j}$) as:

$$\mathcal{CP}_i^{EU_j} = (Eff_{S_i} \times C_E) + C_M \tag{3}$$

In an MSC, the sensor nodes attain mobility by virtue of the mobility of the host device to which it is attached. Therefore, a sensor node may exit its application area at any time instant, and consequently, the quality of service disrupts. Thus, we include a mechanism for the end-users to provide feedback to the SCSP. An end-user, $EU_j$, provides feedback in response to the service availed from the $i^{th}$ SCSP. Further, the event of belief and disbelief of any end-user, $EU_j$, on the $i^{th}$ SCSP is defined by $\mathcal{BD}_{S_i}^{EU_j}$ as follows:

$$\mathcal{BD}_{S_i}^{EU_j} \begin{cases} [1,0], & EU_j \text{ has belief on } S_i \\ [0,1], & EU_j \text{ has disbelief on } S_i \end{cases} \tag{4}$$

The belief, $Bel(\mathcal{BD}_{S_i}^{EU_j})$, and the disbelief, $Dis(\mathcal{BD}_{S_i}^{EU_j})$, provides a binary value in the form of $[Bel(\mathcal{BD}_{S_{c_i}}^{EU}), Dis(\mathcal{BD}_{S_{c_i}}^{EU})]$.

We do not consider the case, $\mathcal{BD}_{S_i}^{EU_j}$=$[1,1]$, which represents the end-user's belief and disbelief on the SCSP simultaneously. In the practical scenario, if an end-user has a belief on the $i^{th}$ SCSP for the service, he/she cannot have disbelief the same SCSP at the same time. We also ignore the case $\mathcal{BD}_{S_i}^{EU_j}$=$[0,0]$, which represents the no response from the end-user.

We denote the number of beliefs and disbeliefs returned by the end users, for the $i^{th}$ SCSP, for a particular time duration, $t$, as $\mathcal{N}_b$ and $\mathcal{N}_d$, respectively. Further, for combining the beliefs and the disbeliefs, we apply *Josang beta reputation* model [22] to compute the *Entropy*, $E_{S_i}^{EU_j}$, for the $i^{th}$ SCSP as:

$$E_{S_i}^{EU} = \begin{cases} \frac{\mathcal{N}_b}{\mathcal{N}_b+\mathcal{N}_d+2}, & \text{if users belief upon SCSP} \\ \frac{\mathcal{N}_d}{\mathcal{N}_b+\mathcal{N}_d+2}, & \text{if users disbelief upon SCSP} \\ \frac{2}{\mathcal{N}_b+\mathcal{N}_d+2}, & \text{otherwise} \end{cases} \tag{5}$$

In order to determine whether we should depend on an SCSP or not, we defined a new parameter as *Evidential Dependability Factor*.

***Definition* 4.** *The Evidential Dependability Factor ($EDF_{S_i}$) is the product of the number of nodes ($N_i$) present with $S_i$ and the total number of beliefs, $\mathcal{N}_b$, of that SCSP.*

$$EDF_{S_i} = N_i \times \mathcal{N}_b \tag{6}$$

As an end-user pays a significant amount of money for the availed services, it is pertinent for an end-user to estimate the expected quality of service offered by the SCSP. Therefore, we define the new metric as *service return*, which is defined as follows:

***Definition* 5.** *The service return ($\mathcal{SR}_i^{EU_j}$) represents the expected service from the $i^{th}$ SCSP, considering the entropy ($E_{S_i}^{EU}$), Evidential Dependability Factor ($EDF_{S_i}$), and the average time for providing service by $S_i$.*

$$\mathcal{SR}_i^{EU_j} = \left( \frac{E_{S_i}^{EU} + EDF_{S_i}}{\frac{t_{info}}{t_{max}}} \right) \times \mathcal{SP} \tag{7}$$

where $t_{info}$ and $\mathcal{SP}$ denote the average time for providing the service and per unit service price of $S_i$, respectively.

Our aim is to maximize the service return and minimize the fixed chargeable price. Therefore,

$$\text{Maximize } (\mathcal{SR}_i^{EU_j} - \mathcal{CP}_i^{EU_j}) \tag{8}$$

subject to

$$t_{info} < t_{max}, \mathbb{N}_{tp} \geq 1, \text{ and } (C_E, C_M, N_i, \tau, \mathcal{N}_b) > 0 \tag{9}$$

***Proposition* 1.** *At a particular time instant, a registered end-user with the MSC is required to provide a fixed chargeable price,* *independent of the service return received from the SCSP*

*Proof.* Consider the maximization function defined in Equation (8) as:

$$F = \mathcal{SR}_i^{EU_j} - \mathcal{CP}_i^{EU_j} \tag{10a}$$

$$= \left[\left(\frac{E^{EU}_{S_i} + EDF_{S_i}}{\frac{t_{info}}{t_{max}}}\right) \times \mathcal{SP}\right] - [(Eff_i \times C_E) + C_M] \tag{10b}$$

Let

$$F = \frac{k_1}{t_{info}} - k_2 \tag{11}$$

At a particular time instant, $k_1$ and $k_2$ are constants. We apply double differentiation w.r.t. $t_{info}$ and obtain the minimum value of $F$ as:

$$\frac{\partial F}{\partial(t_{info})} = -\frac{k_1}{(t_{info})^2} \tag{12}$$

when $k_1 = 0$, function, $F$ reach to its minimum value as:

$$F = -k_2 \tag{13}$$

From Equation (13), we conclude that a registered end-user in an MSC needs to pay a fixed charged price independent of the service return from the SCSP. □

### 4.2 Optimal Pricing

Both the sensor owners and the device owners have certain expenditures and income for providing the services in an MSC platform. Therefore, we propose the financial model for the expenditure and the income of the sensor owners and the device owners, who are associated with the MSC infrastructure. The sensor nodes are possible to be deployed externally on the devices by the sensor owners, and in such a situation, the sensor owner and device owner are two different entities. On the other hand, a device may be pre-equipped with different sensors, in which case, both the device and sensor owners are both the same entity. Therefore, we derive the pricing scheme for the following two cases:

**Case 1: Sensor and device owner are different**: In this case, we consider that the sensor owners deployed the sensor nodes on the devices, and thus, the sensor and device owners are distinct from one another. In this case, we determine the cash inflow and outflow of sensor owners and device owners individually.

*Cash outflow of device owner*: The device owners play a vital role in an MSC architecture. Therefore, we consider the device owners as one of the actors, who receive profit depending on the usage of their respective devices. In MSC, typically, the sensor nodes, which are deployed over the mobile devices, are battery-powered. Consequently, there is a requirement of charging the batteries of these sensor nodes. The total power consumed and dissipated of the device, $\delta_q$, for charging a sensor node, $\lambda_p$, is denoted by $PC_p^q$ and $PD_p^q$, respectively. Further, in Equation (14), we compute the effective power factor, $EPF_p$, of the $p^{th}$ sensor node.

$$EPF_p^q = (PC_p^q - PD_p^q)\eta_p^q \tag{14}$$

where $\eta_p^q$ is the power efficiency of the $p^{th}$ sensor node placed on the $q^{th}$ device. A device owner may own multiple devices and multiple sensor nodes may be placed on these devices. We express the total expenses, $\mathcal{E}d^j$, of a device owner, $\mathbb{D}_j$, as:

$$\mathcal{E}d^j = EPF_p^q \times EPC_p^q \tag{15}$$

where $EPC_p^q$ represents the per unit $EPF_p^q$ cost.

*Cash inflow of device owners*: A device owner receives rent from the SCSP for the usage of their devices. On the other hand, a sensor owner, $\mathbb{S}_i$, pays an one-time cost ($\mathcal{O}_p^i$) to the device owner for permitting him/her to place the sensor nodes, $\lambda_p$, on the device. A device owner may own one or multiple devices and these devices contain multiples sensor nodes. The SCSP pays a rental charge to the device owner, $\mathbb{D}_j$, based on the usage of the sensor nodes attached to his/her device. Let $\lambda_p$ be placed on the device of $\mathbb{D}_j$ and let the activation duration of $\lambda_p$ be $\mathcal{AT}_p^j$. We compute in Equation (16) the income of $\mathbb{D}_j$ from SCSP and the sensor owner for the $p^{th}$ sensor node.

$$\mathcal{I}d^j = (\mathcal{AT}_p^j \times SVC_q^j) + \mathcal{O}_p^i \tag{16}$$

where $SVC_q^j$ denotes the service charge paid by the SCSP to the $j^{th}$ device owner for the service of the $p^{th}$ sensor node attached to the $q^{th}$ device. The profit of the device owner is expressed as:

$$\mathcal{P}d_q^j = (\mathcal{I}d^j - \mathcal{E}d^j) \tag{17}$$

We consider the presence of multiple device owners in an MSC architecture. Therefore, a SCSP and sensor owner have multiple options to chose a device owner. Consequently, the device owner must claim the service charge, $SVC_q^j$, and the one time charge, $\mathcal{O}_p^i$, in such a way that a SCSP and sensor owner can afford it. Therefore, the device owner must charge an optimal $SVC_q^j$ and $\mathcal{O}_p^i$. In order to optimize $SVC_q^j$ and $\mathcal{O}_p^i$, we define a utility function of device owner, $\mathcal{U}_q^j$ for the $q^{th}$ device in Equation (18), where $\alpha_1$, $\beta_1$, and $\gamma_1$ are the proportionality constants. In Equations (18), we denote the *service charge effect* and *one time charge effect* by $(SVC_q^j)^{m_1}$ and $(\mathcal{O}_p^i)^{n_1}$, respectively, such that $\mathcal{U}_q^j$ is directly proportional to $(SVC_q^j)^{m_1}$ and inversely proportional to $(\mathcal{O}_p^i)^{n_1}$. The increasing values of $m_1$ and $n_1$ result in the decrease in the $\mathcal{U}_q^j$. Consequently, the device owner, $\mathbb{D}_j$, earns less profit, with the decrease in the value of $\mathcal{U}_q^j$.

$$\mathcal{U}_q^j = \alpha_1 \mathcal{P}d_q^j - \left(\beta_1 (SVC_q^j)^{m_1} + \gamma_1 (\mathcal{O}_p^i)^{n_1}\right) \tag{18a}$$

$$\mathcal{U}_q^j = \alpha_1 (\mathcal{I}d_q^j - \mathcal{E}d_q^j) - \left(\beta_1 (SVC_q^j)^{m_1} + \gamma_1 (\mathcal{O}_p^i)^{n_1}\right) \tag{18b}$$

$$\mathcal{U}_q^j = \alpha_1 \left(\left(\mathcal{AT}_p^j \times SVC_q^j\right) + \mathcal{O}_p^i\right) - \left(EPF_p^q \times EPC_p^q\right) - \left(\beta_1 (SVC_q^j)^{m_1} + \gamma_1 (\mathcal{O}_p^i)^{n_1}\right) \tag{18c}$$

Therefore, the objective of the device owner is to maximize $\mathcal{U}_q^j$ by charging an optimal $SVC_q^j$ and $\mathcal{O}_p^i$.

$$\text{Maximize} \quad \mathcal{U}_q^j \tag{19}$$

subject to

$$\mathcal{A}T_p^j \leq LT_p, SVC_q^j > 1, \mathcal{O}_p^i > 1, \text{ and } EPC_p^q > 1 \tag{20}$$

**Theorem 1.** *The increasing values of $m_1$ and $n_1$ result in the decrease in $\mathcal{U}_q^j$.*

*Proof.* From Equation (18) we obtain the value of $\mathcal{U}_q^j$. On replacing $m_1$ and $n_1$ with $(m_1+1)$ and $(n_1+1)$ in Equation (18), we obtain Equation (21), where $((m_1+1) > m_1)$ and $((n_1+1) > n_1)$.

$$\mathcal{U}_q'^j = \alpha_1 \mathcal{P}d_q^j - \left(\beta_1 (SVC_q^j)^{(m_1+1)} + \gamma_1 (\mathcal{O}_p^i)^{(n_1+1)}\right) \tag{21}$$

On subtracting Equation (18) from Equation (21), we obtain:

$$\begin{aligned}\left(\mathcal{U}_q'^j - \mathcal{U}_q^j\right) = \beta_1 \left(SVC_q^j\right)^{m_1} \left(1 - SVC_q^j\right) \\ + \gamma_1 \left(\mathcal{O}_p^i\right)^{n_1} \left(1 - \left(\mathcal{O}_p^i\right)\right)\end{aligned} \tag{22}$$

According to Equation (19), $SVC_q^j > 1$ and $\mathcal{O}_p^i > 1$. Therefore, Equation (22) is represented as:

$$\mathcal{U}_q'^j - \mathcal{U}_q^j > 0 \tag{23a}$$

$$\mathcal{U}_q'^j > \mathcal{U}_q^j \tag{23b}$$

Therefore, from Equation (23a), we infer that the increasing values of $m_1$ and $n_1$ result in the decrease in $\mathcal{U}_q^j$. □

For solving the maximization function, $\mathcal{U}_q^j$, we use the *Lagrangian multiplier* and apply the *Karush-Kuhn-Tucker* (*KKT*) conditions [6]. Therefore, we express the Lagrangian form, $\mathcal{L}_d$, of Equation (18) as:

$$\begin{aligned}\mathcal{L}_d = \mathcal{U}_q^j - \mu_1(\mathcal{A}T_p^j - LT_p) + \mu_2(SVC_q^j - 1) \\ + \mu_3(\mathcal{O}_p^i - 1) + \mu_4(EPC_p^q - 1)\end{aligned} \tag{24}$$

We represent the KKT conditions in Equations (25), in which Equations (25a) and (25b) represent the *dual feasibility* and Equation (25c) represents the *complementary slackness*.

$$\nabla_{SVC_q^j} \mathcal{L}_d = \nabla \mathcal{U}_q^{j*} + \mu_2 = 0 \tag{25a}$$

$$\nabla_{\mathcal{O}_p^i} \mathcal{L}_d = \nabla \mathcal{U}_q^{j*} + \mu_3 = 0 \tag{25b}$$

$$\mu_i g_i(x) = 0, \text{ and } \mu_i \geq 0 \quad \forall i = \{1, 2, 3, 4\} \tag{25c}$$

Let $g_1(x) = (\mathcal{A}T_p^j - LT_p)$, $g_2(x) = SVC_q^j$, $g_3(x) = \mathcal{O}_p^i$, and $g_3(x) = EPC_p^q$. We obtain an optimal service charge, $SVC_q^{j*}$, and one time charge, $\mathcal{O}_p^{i*}$, in Equations (26) and (27), from the utility function, $\mathcal{U}_q^j$, of the device owner.

$$SVC_q^{j*} = \left(\frac{\alpha_1 \mathcal{A}T_p^j + \mu_2}{m_1 \beta_1}\right)^{\frac{1}{(m_1-1)}} \tag{26}$$

$$\mathcal{O}_p^{i*} = \left(\frac{\alpha_1 + \mu_3}{n_1 \gamma_1}\right)^{\frac{1}{(n_1-1)}} \tag{27}$$

*Cash outflow of sensor owner*: A sensor owner has to procure the sensor nodes to places them on the mobile devices. Therefore, for computing the total *Deployment Cost*, $DC^i$, for the sensor nodes by the sensor owner, $\mathbb{S}_i$, we consider the procurement cost, $PRC^i$, and the node placement cost, $PLC^i$. The procurement cost of the sensor nodes varies, depending on their types and features. Similarly, depending on the types of vehicles, the node placement cost also varies between nodes. Moreover, for deploying the $p^{th}$ sensor node on the $q^{th}$ device, a sensor owner pays $\mathcal{O}_p^i$ to the device owner. We express the total deployment cost, $DC^i$, for deploying the $p^{th}$ sensor node on the $q^{th}$ device as:

$$DC_p^i = PRC_p^i + PLC_p^i + \mathcal{O}_p^i \tag{28}$$

We consider the quality of the sensor nodes, in order to provide an efficient service to the end-users. Therefore, we derive the quality of the $p^{th}$ sensor node owned by the $i^{th}$ sensor owner as follows:

$$\mathcal{Q}_p^i = \frac{SC_p^i \times LT_p^i}{SC_{max} \times ST_p^i} \tag{29}$$

where $SC_j^i$, $LT_j^i$, and $ST_j^i$ represent the storage capacity, life-time, and average service time of the $p^{th}$ sensor node, owned by the $i^{th}$ sensor owner. $SC_{max}$ represents the maximum storage capacity of the sensor node in an application area.

In order to maintain the quality of sensor nodes, $\lambda_p$, a sensor owner, $\mathbb{S}_i$, pays $QLC_p^i$ amount. Therefore, overall maintenance cost paid by sensor owner, $\mathbb{S}_i$, is represented as:

$$MC_j^i = QLC_p^i \times \mathcal{Q}_p^i \tag{30}$$

We compute the total expenditure, $\mathcal{E}s_p^i$, of $\mathbb{S}_i$ for sensor node, $\lambda_p$ as:

$$\mathcal{E}s_p^i = DC_p^i + MC_p^i \tag{31a}$$

$$\mathcal{E}s_p^i = (PRC_p^i + PLC_p^i + \mathcal{O}_p^i) + (QLC_p^i \times \mathcal{Q}_p^i) \tag{31b}$$

*Cash inflow of sensor owner*: In order to calculate the cash inflow of a sensor owner, we define the term *Serviceability*.

***Definition 6.*** *Serviceability ($\rho^i$) of a sensor owner, $\mathbb{S}_i$, measures the ability of a sensor owner to provide the services to the end-users, considering the type of the sensor nodes available, $\mathcal{T}^i$, to $\mathbb{S}_i$ and the average quality of the sensor nodes, ($\mathcal{Q}_p^i$).*

$$\rho^i = \mathcal{T}^i \times \frac{1}{k} \sum_{p=1}^{k} \mathcal{Q}_p^i \tag{32}$$

As the MSC infrastructure follows the pay-per-use model, a sensor owner receives rent based on the duration of usage of his/her sensor nodes. Thus, the total income, $\mathcal{I}s^i$, of the sensor owner, $\mathbb{S}_i$, for the $p^{th}$ sensor node is expressed as:

$$\mathcal{I}s^i = \rho^i \times \left(SVC_p^i \times \mathcal{A}T_p^i\right) \tag{33a}$$

$$\mathcal{I}s^i = \left(\mathcal{T}^i \times \frac{\mathcal{Q}_p^i}{a}\right) \times \left(SVC_p^i \times \mathcal{A}T_p^i\right) \tag{33b}$$

where $SVC_p^i$ and $\mathcal{A}T_p^i$ represent the service charges and activation time of the $p^{th}$ sensor node, owned by $\mathbb{S}_i$.

*Profit of sensor owner*: The profit of a sensor owner ($\mathcal{P}^i$) depends on the total income and expenditure of the $i^{th}$

sensor owner. Therefore, from Equations (31) and (33), we calculate the profit of sensor owner, $\mathbb{S}_i$, for the $p^{th}$ sensor node as:

$$\mathcal{P}s_p^i = (\mathcal{I}s_p^i - \mathcal{E}s_p^i) \tag{34}$$

In an MSC architecture, a sensor owner earns a profit by claiming the service charge ($SVC_p^i$) from an SCSP. On the other hand, the SCSP has a sufficient number of options to select a sensor owner. Consequently, a sensor owner, $\mathbb{S}_i$, optimally levies the service charge, $SVC_p^i$, for a sensor node, $\lambda_p$. Therefore, we design a utility function, $\mathcal{U}_p^i$, of sensor owner for choosing the optimal $SVC_p^i$ by senor owner, $\mathbb{S}_i$, for the $p^{th}$ sensor node. The value of $\mathcal{U}_p^i$ is directly proportional to the profit, $\mathcal{P}s^i$, and inversely proportional to the *service charge effect*, $(SVC_p^i)^{m_2}$. We define the utility function of sensor owner in Equation (35), where $\alpha_2$ and $\beta_2$ are the proportionality constants. The utility, $\mathcal{U}_p^i$, of the sensor owner, is inversely proportional to the value of $m_2$.

The objective of the sensor owner is to maximize his/her profit by optimizing the service charge, $SVC_p^i$, for the sensor node, $\lambda_p$. Therefore,

$$\text{Maximize} \quad \mathcal{U}_p^i \tag{36}$$

subject to

$$\mathcal{A}T_p^i \leq LT_p, QLC_p^i > 1, \mathcal{O}_p^i > 1, \text{ and } SVC_p^i > 1 \tag{37}$$

**Corollary 1.** *With the increasing value of $m_2$, the utility, $\mathcal{U}_p^i$, decreases.*

*Justification*: We substitute $m_2$ with $m_2 + 1$ in Equation (35) and apply the methodology similar to the one used in Theorem 1. We also define in Equation (36) $SVC_p^i > 1$. Therefore, we obtain:

$$\mathcal{U}_p'^i < \mathcal{U}_p^i \tag{38}$$

Equation (38) justifies the statement.

For solving the maximization function, $\mathcal{U}_p^i$, we follow a method similar to the one used for solving the maximization problem defined in Equation (19). Further, we express the *Lagrangian multiplier* form, $\mathcal{L}_s$, of the Equation (36) as:

$$\begin{aligned}\mathcal{L}_s = \mathcal{U}_p^i - \mu_1(\mathcal{A}T_p^i - LT_p) + \mu_2(QLC_p^i - 1)\\ +\mu_3(\mathcal{O}_p^i - 1) + \mu_4(SVC_p^i - 1)\end{aligned} \tag{39}$$

After applying the KKT conditions, we get:

$$\nabla_{SVC_p^i}\mathcal{L}_s = \nabla\mathcal{U}_p^{i*} + \mu_4 = 0 \tag{40a}$$

$$\mu_i g_i(x) = 0, \text{ and } \mu_i \geq 0 \quad \forall i = \{1,2,3,4\} \tag{40b}$$

Let $g_1(x) = (\mathcal{A}T_p^i - LT_p)$, $g_2(x) = QLC_p^i$, $g_3(x) = \mathcal{O}_p^i$, and $g_4(x) = SVC_p^i$.

Thus, we obtain the optimal service charge, $SVC_p^{i*}$:

$$SVC_p^{i*} = \left(\frac{\alpha_2\rho_i\mathcal{A}T_p^i + \mu_4}{m_2\beta_2}\right)^{\frac{1}{(m_2-1)}} \tag{41}$$

**Case 2: Sensor owner and device are same**: In this case, we consider the devices are already equipped with sensor nodes. Therefore, the sensor owner does not need to deploy the sensor nodes on the devices. Consequently, we do not compute the deployment cost of the sensor nodes in this case. Additionally, in this case, we do not consider the one-time cost, which is required to be paid by sensor owner to the device owner.

*Cash outflow of device owner*: A device owner pays the procurement cost for the devices. These devices are equipped with different sensors. However, the device owner has some expenditure towards the maintenance of the devices. Let a device owner, $\mathbb{D}_j$, pay an amount of $\mathcal{M}^j$ for maintaining a device. Therefore, the expenditure, $\mathcal{E}sd^j$ of the device owner, $\mathbb{D}_j$ is $\mathcal{M}^j$.

*Cash inflow of device owner*: We consider that a device owner, $\mathbb{D}_j$, receives one time charge, $\mathcal{O}sd^j$, from the SCSP, as fixed cost for the sensor node, $\lambda_p$, on the devices, $\delta_q$. Additionally, the SCSP pays rental charges to $\mathbb{D}_j$ for the service of the devices owned by him/her. Therefore, the total income of the device owner for sensor node $\lambda_p$ is:

$$\mathcal{I}sd^j = \mathcal{O}sd^j + (\mathcal{A}T_q^j \times SVC_q^j) \tag{42}$$

We derive the total profit of the device owner as:

$$\mathcal{P}sd^j = \mathcal{O}^j + (\mathcal{A}T_q^j \times SVC_q^j) - \mathcal{M}^j \tag{43}$$

Similar to Case 1, in this case, we optimize the service charge ($SVC_q^j$) and the one-time charge ($\mathcal{O}sd^j$) of the device owner. We define the utility function, $\mathcal{U}_{sd}$ in Equation (44) for the device owner in this case, which is maximized as: .

$$\text{Maximize} \quad \mathcal{U}_{sd} \tag{45}$$

subject to

$$\mathcal{A}T_p^i \leq LT_p, SVC_q^j > 1, \mathcal{O}sd_p^i > 1, \text{ and } \mathcal{M}^j > 1 \tag{46}$$

**Corollary 2.** *With the increasing value of $m_3$, the utility, $\mathcal{U}_{sd}$, decreases.*

$$\mathcal{U}_p^i = \alpha_2\mathcal{P}s_p^i - \beta_2(SVC_p^i)^{m_2} \tag{35a}$$

$$\mathcal{U}_p^i = \alpha_2(\mathcal{I}s_p^i - \mathcal{E}s_p^i) - \beta_2(SVC_p^i)^{m_2} \tag{35b}$$

$$\mathcal{U}_p^i = \alpha_2\left(\rho^i \times \left(SVC_p^i \times \mathcal{A}T_p^i\right)\right) - \left(\left(PRC_p^i + PLC_p^i + \mathcal{O}_p^i\right) + \left(QLC_p^i \times \mathcal{Q}_p^i\right)\right) - \beta_2\left(SVC_p^i\right)^{m_2} \tag{35c}$$

$$\mathcal{U}_{sd} = \alpha_3\mathcal{P}d_{sd}^j - \left(\beta_3(SVC_q^j)^{m_3} + \gamma_2(\mathcal{O}_{sd}^j)^{n_2}\right) \tag{44a}$$

$$\mathcal{U}_{sd} = \alpha_3\left(\left(\mathcal{A}T_p^j \times SVC_q^j\right) + \mathcal{O}sd^j - \mathcal{M}^j\right) - \left(\beta_3(SVC_q^j)^{m_3} + \gamma_2(\mathcal{O}sd)^{n_2}\right) \tag{44b}$$

*Justification*: To justify the statement, we use the proof of Theorem 1. We re-define Equation (45), by substituting $m_3$ and $n_2$ with $m_3+1$ and $n_2+1$, respectively. As $SVC_q^j > 1$, $\mathcal{O}sd_p^i > 1$, $\mathcal{M}^j > 1$, we obtain:

$$\mathcal{U}'sd < \mathcal{U}_{sd} \tag{47}$$

Equation (47) justifies the statement.

We use the Lagrangian function and apply KKT condition in order to optimize the $SVC_q^j$ and $\mathcal{O}sd_p^i$. The Lagrangian form, $\mathcal{L}_{sd}$, of Equation (45) is expressed as:

$$\mathcal{L}_{sd} = \mathcal{U}_{sd} - \mu_1(\mathcal{A}T_p^i - LT_p) + \mu_2 SVC_q^j + \mu_3 \mathcal{O}sd_p^i + \mu_4 \mathcal{M}^j \tag{48}$$

Therefore, we represents the KKT conditions in Equations (49a)-(49c), in which Equations (49a) and (49b) represents *dual feasibility* and Equation (49c) represents the *complementary slackness*.

**Algorithm 1** Optimal Selection of SCSP

**INPUTS:**
$\mathcal{S} = \{S_1, S_2, S_3, \cdots, S_m\}$ ▷ set of SCSPs
$EU = EU_1, EU_2, \cdots, EU_n$ ▷ Set of end-users
**OUTPUTS:**
Selection of SCSP based on maximum service return and minimum fixed chargeable price
**PROCEDURE:**
**for** 1 to m **do**
  $\forall i$ Compute $\mathcal{CP}_i^{EU_j}$ using Equation (3)
  $\forall i$ Compute $\mathcal{SR}_i^{EU_j}$ using Equation (7)
**end for**
Compute the maximum service return by the SCSP and the minimum charged price from the end-user using Equation (8)

$$\nabla_{SVC_q^j} \mathcal{L}_{sd} = \nabla \mathcal{U}_{sd}{}^* + \mu_2 = 0 \tag{49a}$$
$$\nabla_{\mathcal{O}sd^j} \mathcal{L}_{sd} = \nabla \mathcal{U}_{sd}{}^* + \mu_3 = 0 \tag{49b}$$
$$\mu_i g_i(x) = 0, \text{ and } \mu_i \geq 0 \quad \forall i = \{1,2,3,4\} \tag{49c}$$

Let $g_1(x) = (\mathcal{A}T_p^i - LT_p)$, $g_2(x) = SVC_q^j$, $g_3(x) = \mathcal{O}sd^j$, and $g_4(x) = \mathcal{M}^j$. The optimal service charge, $SVC_q^{j\,*}$, and one time charge, $\mathcal{O}sd^{j\,*}$ is derived as:

$$SVC_q^{j\,*} = \left(\frac{\alpha_3 \mathcal{A}T_p^j + \mu_2}{m_3 \beta_3}\right)^{\frac{1}{(m_3-1)}} \tag{50}$$

$$\mathcal{O}sd^{j\,*} = \left(\frac{\alpha_3 + \mu_3}{n_2 \gamma_2}\right)^{\frac{1}{(n_2-1)}} \tag{51}$$

# 5 Performance Evaluation

In this Section, we analyze the performance of the proposed scheme, PRIME. First, we explain the details of the simulation design, and then, we discuss the results with their analysis. Algorithm 1 represents the selection procedure of a suitable SCSP, whereas Algorithm 2 highlights the procedure of computing the optimal service and one-time charges of sensor and device owners, respectively.

**Algorithm 2** Optimal One-time Charges

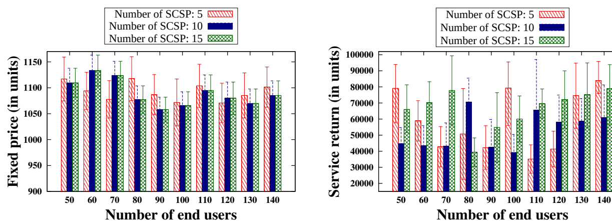
**INPUTS:**
$\mathbb{S} = \{\mathbb{S}_1, \mathbb{S}_2, \mathbb{S}_3, \cdots, \mathbb{S}_x\}$ ▷ set of sensor owners
$\mathbb{D} = \{\mathbb{D}_1, \mathbb{D}_2, \mathbb{D}_3, \cdots, \mathbb{D}_y\}$ ▷ Set of device owners
**OUTPUTS:**
Optimal $SVC_q^{j\,*}$, $SVC_p^{i\,*}$, and $\mathcal{O}_p^{i\,*}$
**PROCEDURE:**
**if** the sensor owner and device owner are different, **then**
  **for** i=1 to x **do**
    **for** j=1 to y **do**
      for all sensor owners compute $\mathcal{I}d^j$, $\mathcal{E}d^j$, $\mathcal{P}d_q^j$ using Equations (15), (16), and (17)
      Compute $\mathcal{U}_q^j$ using Equation (18) and obtain optimal $SVC_q^{j\,*}$ and $\mathcal{O}_p^{i\,*}$
      for all device owner compute $\mathcal{I}s_p^i$, $\mathcal{E}s_p^i$, and $\mathcal{P}s_p^i$ using Equations (31), (33), and (34)
      Compute $\mathcal{U}_p^i$ using Equation (35) and obtain optimal $SVC_p^{i\,*}$
    **end for**
  **end for**
**else**
  **for** j=1 to y **do**
    $\forall$ device owner, compute $\mathcal{P}sd^j$ using Equation (43)
    Compute $\mathcal{U}_{sd}$ and obtain optimal $SVC_q^{j\,*}$ and $\mathcal{O}sd^{j\,*}$
  **end for**
**end if**

## 5.1 Simulation Design

We consider the presence of 100-1,000 physical sensor nodes deployed over $45-75$ mobile devices. Initially, these devices are placed at different locations over a simulation area of $10km \times 10km$. The mobile devices move in a certain direction with initial speed within the simulation area. The speed and direction change after a pre-defined time interval. Motivated by the concept of [23], we use the *Gauss-Markov mobility* model for calculating the speed of the mobile devices. The speed of the mobile devices is mathematically represented as:

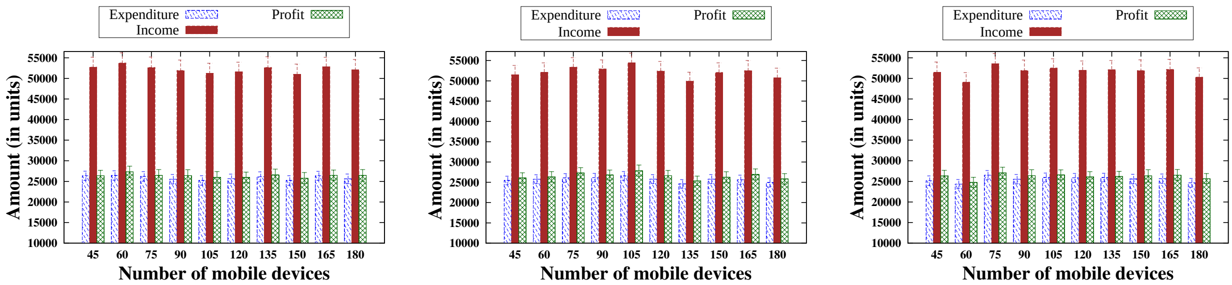
$$s_n = \alpha s_{n-1} + (1-\alpha)\bar{s} + \sqrt{(1-\alpha \times \alpha)} \times s_{x_{n-1}} \tag{52}$$

where $\alpha$ is the tuning parameter, and $\bar{s}$ denotes the mean speed. The random variable from the Gaussian distribution is represented by $s_{x_{n-1}}$, which assigns randomness to the speed of the mobile devices. Different parameters considered for the simulation are listed in Table 1.



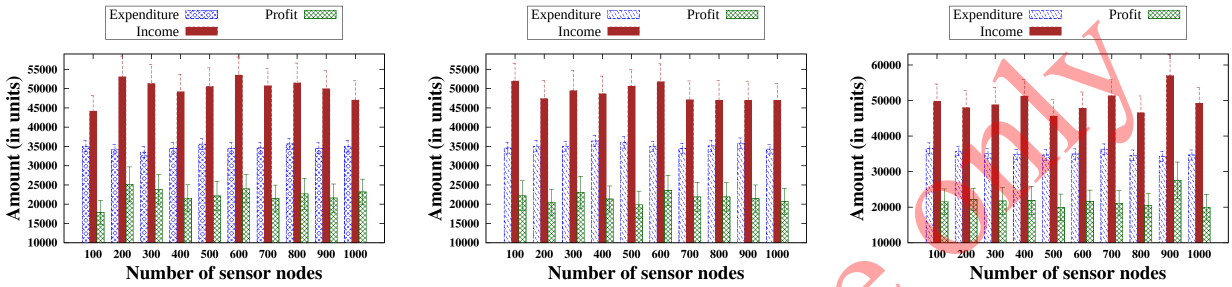

(a) Fixed chargeable price (b) Service return

Fig. 2: Variation in fixed chargeable price and service return




(a) Number of sensor nodes=100 (b) Number of sensor nodes=500 (c) Number of sensor nodes=1,000

Fig. 3: Cash flow of sensor owners when sensor owners and device owners are different

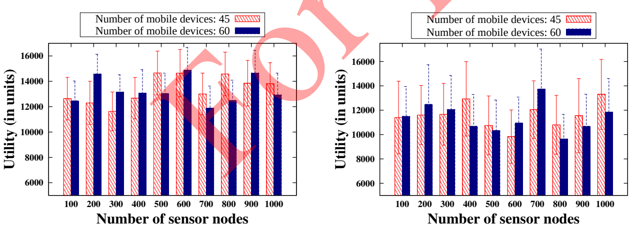



(a) Number of devices = 45 (b) Number of devices = 60 (c) Number of devices = 75

Fig. 4: Cash flow of device owners when sensor owners and device owners are different

TABLE 1: Simulation Parameters

| **Parameter** | **Value** |
|---|---|
| Simulation area | $10Km \times 10Km$ |
| Type of sensor nodes | $5$ |
| Number of sensor nodes | $100 - 1,000$ |
| Number of end-users | $100 - 1,000$ |
| Number of SCSP | $5 - 15$ |
| Per unit service price by SCSP | $70 - 100$ unit |
| Procurement cost of a sensor node | $150 - 200$ units |
| Cost for energy loss | $30 - 50$ unit |
| Speed of the vehicle [23] | $25 - 105$ Kmph |




(a) Utility of device owner (b) Utility of sensor owner

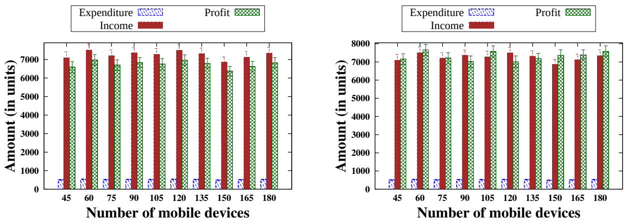
Fig. 5: Change in utility

***Benchmark***: The concept of MSC is new. Therefore, none of the existing literature discusses the issue of pricing in MSC. However, we compare our proposed scheme, PRIME, with an existing pricing scheme, proposed by Chatterjee *et al*. [19], for the traditional sensor-cloud. In [19], the authors proposed a dynamic pricing scheme for the sensor cloud platform, where the sensor nodes are considered as static. For simplicity, we abbreviate the work of Chatterjee *et al.* [19] as *DOPH*.

### 5.2 Results

Fig. 2 depicts the variation in the fixed chargeable price and service return with the varying number of end-users. We consider the presence of $5$, $10$, and $15$ SCSP, respectively. For each case, we observe that the fixed chargeable price attains a maximum value of $1,150$ units, whereas the service return attains a maximum $8,200$ units. The service return and the fixed chargeable price depends on the reputation and capability of the SCSP. Therefore, we also observe that the fixed chargeable price and service return vary randomly and are independent of the total number of end-users present in the system.

The primary aim of this work is to design a pricing scheme for MSC architecture. Therefore, we analyze the detailed expenditure, income, and profit of the sensor owners and the device owners. Fig. 3 depicts the cash flow of sensor owners. This figure includes the analysis of expenditure, income, and profit of the sensor owners with the change in the number of mobile devices from $45$ to $180$. Figs. 3(a)-3(c) depict the results in the presence of $100$, $500$, and $1,000$ sensor nodes in the system. We observe in each case that the income of the sensor owners is at least twice its expenditure. Therefore, the sensor owners gain the profit of the same amount as the expenditure. A sensor owner owns multiple types and number of sensor nodes, which are deployed over different mobile devices. Practically, a mobile device leaves the application region at any time instant. However, the sensor nodes, which are attached to different mobile devices, serve the application area. Consequently, the sensor owner gains continuous profit from the MSC architecture. From these plots, we infer that the MSC architecture generates a significant amount of profit for the sensor owners. Similarly, we examine the expenditure, income, and profit




(a) Number of sensor nodes = 100 (b) Number of sensor nodes = 200

Fig. 6: Cash flow of device owners when sensor owners and device owners are same

of the device owner with the variations in the total number of sensor nodes in the system. Fig. 4 depicts the cash flow of the device owners, considering the total number of mobile devices as 45, 60, and 75, respectively. The profit of the device owners depends on the duration of service provided by his/her respective owned devices. Moreover, when a mobile device exits the application area, it is unable to serve the application, and consequently, the owner of the device does not gain any profit. However, in Figs. 4(a)-4(c), we observe that the sensor owners gain a significant profit out of the services provided to the MSC. We observe that both the sensor and device owners gain profit from the MSC architecture when those are different entities.

Fig. 5 represents the results of variation in utility with varying number of sensor nodes in the network in the presence of 45 and 60 mobile devices. We observe random variations in the utility in both the cases of the device owner and sensor owner. The possible reason for the random trend in the plot is that the utility of a sensor owner depends on the duration of activation of his/her respective sensor node. Similarly, the mobile device of an owner may not always serve the application regions. Moreover, the procurement and deployment cost of the sensor nodes depends on its type.

We also evaluate the profit of device owners when the sensor owner and device owner are the same entity. Fig. 6 represents the cash flow of the device owner when the sensor nodes are pre-deployed in the mobile devices. We notice in Figs. 6(a) and 6(b) that the profit of the device owner is much higher as compared to the expenditure. The possible reason for such a trend is that – when the sensor owners and device owners are the same, there are no costs associated for procuring and deploying the sensor nodes. Therefore, the device owners incur more profit as compared to the scenario when sensor and device owners are different.

Finally, we compare our proposed scheme, PRIME, with an existing pricing scheme for traditional sensor-cloud architecture, DOPH [19]. We analyze the variations in fixed chargeable price, service return, and participation of sensor owners for PRIME and DOPH. Fig. 7(a) depicts the plot of variations in fixed chargeable price with varying number of end-users from 100-$1,000$. In DOPH, the chargeable price depends on the demand of the end-users, whereas in PRIME multiple device owners are present to serve the end-user application, irrespective of demand. On the other hand, more sensors are present, which are capable of serving end-user applications. Consequently, the fixed chargeable price in PRIME is significantly less as compared to the DOPH. The service return is an important factor in PRIME. Therefore, in Fig. 7(b), we depict the comparative analysis of service return in DOPH and PRIME, respectively. The service return of the SCSPs depends on different factors as derived in Equation (7). We notice that the service return in the case of PRIME is higher as compared to that using DOPH. The possible reason for this trend in the plot is that the mobility of the sensor nodes by their host device. Due to the presence of a mobile device, the option for serving an end-user application increases. Moreover, the SCSP can serve a wide variety of application areas. Consequently, the competency of an SCSP increase, which, in turn, improves the service return using PRIME as compared to that using DOPH. Fig. 7(c) depicts the participation of sensor owners in an MSC and traditional Sensor-Cloud architecture. This plot conveys the benefit and distribution of participation of sensor owners in MSC. In this analysis, we consider the presence of 5 types of sensor nodes – $A, B, C, D$, and $E$, respectively, along the x-axis. These nodes are mounted on different mobile devices and attain mobility. In MSC, the sensor owners have a fair opportunity to participate and earn as compared to the traditional sensor-cloud architecture. Therefore, for each type of sensor node, we observe that the percentage of participation of the sensor owner is higher in PRIME as compared to that using DOPH.

## 6 Conclusion

In this work, we study the problem of optimal pricing in MSC, which is a newly proposed architecture for provisioning mobile sensors-as-a-service. In this architecture, different actors such as sensor owner, device owners, SCSP, and end-users are involved with monetary transactions. As MSC is a new and unique concept, the existing pricing mechanisms for the traditional sensor-cloud architecture are not suitable for managing the monetary transactions in MSC. Therefore, we proposed a pricing model, PRIME, which helps in regulating the pricing issues in MSC. We analyzed the proposed scheme with theoretical and experimental analysis. The proposed pricing scheme, PRIME, helps in determining pricing for two cases – (a) sensor and device owners being different entities, and (b) they being the same entity.

The MSC architecture consists of multiple different types of actors–security is an essential issue to be addressed. Therefore, we plan to address the issues of secure data and monetary transactions in MSC. We also plan to propose in the future a virtual currency mechanism for MSC architecture, where the users will be able to participate in it without real cash transactions.

## 7 Acknowledgment

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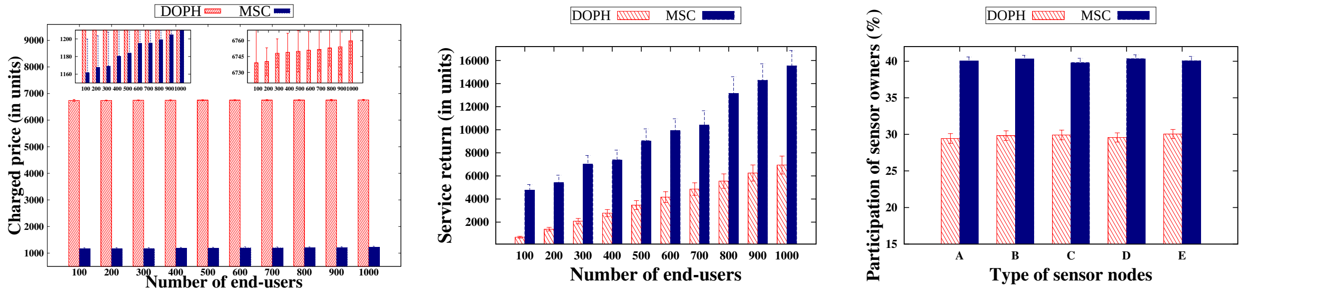


(a) Fixed chargeable price (b) Service return (c) Percentage of Sensor owner

Fig. 7: Comparison with DOPH

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