DIVISOR: Dynamic Virtual Sensor Formation for Overlapping Region in IoT-based Sensor-Cloud

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***Abstract*—In this work, we propose a scheme for the formation of *DynamIc VIrtual Sensor for Overlapping Region* (*DIVISOR*) in a IoT-based sensor-cloud platform. Practically, the interest of deployment area of similar sensor nodes by respective sensor owners may be the same, and consequently, the areas of coverage of the deployed sensor nodes of the different owners overlap with one another. Thus, in such a scenario, each of the sensor owners must get equal opportunity to earn profit from the deployment of their sensor nodes. Therefore, in order to provide an equal privilege to all sensor owners, we propose the scheme, DIVISOR, in order to form virtual sensors. This is one of the first attempts for the dynamic formation of virtual sensors, where the overlapping area of deployed sensor nodes by different sensor owners is considered. The experimental results demonstrate that the proposed scheme is energy-efficient and the average number of participating nodes increases with the increase in the total number of nodes in the network. Moreover, each sensor owner gets almost equal opportunity to rent their nodes.**

***Keywords*—Virtual Sensor, Virtual Sensor Group, Sensor-Cloud, Overlapping Region, Coalition Formation.**

I. INTRODUCTION

Due to the recent advancement of Micro-Electro-Mechanical Systems (MEMS), Wireless Sensor Networks (WSNs) are popularly being used in different application domains such as target tracking [1], healthcare [2], and agriculture [3]. In order to use WSN for a particular application, a user needs to procure sensor nodes, and thereafter, deploy them over the area of interest. Consequently, the same WSN may not be usable for some other applications in the future. Thus, the use of traditional WSNs become costly, when the application demands of a user changes. However, the development of sensor-cloud replaced the traditional WSNs, in which the concept of sensor *virtualization* is explored [4]–[6]. In the age of Internet of Things (IoT), sensor-cloud is based on the concept of *pay-per-use* by the end-users, without worrying about the additional burden of procurement, deployment, and maintenance of sensor nodes.

Sensor-cloud typically consists of four actors – sensor owners, sensor-cloud service provider (SCSP), end-users, and cloud. End-users demand for payment-based services. On the other hand, sensor owners deploy physical sensor nodes over different geographical locations, and thereafter, based on the usage of their respective sensor nodes, receive rent from the users. SCSP plays an intermediate role between the sensor owners and end-users by providing the facility of *Sensor-as-a-Service* (*Se-aaS*) to the end users. Depending upon the requirement of the end-users' services, virtual sensor (VS) are required to be formed with multiple homogeneous physical sensor nodes. Further, the end-users receive services from the virtual sensor group (VSG), which is a combination of heterogeneous virtual sensors. The areas of coverage of the deployed sensor nodes by respective owners overlap with one another. Thus, focusing on the overlapping region of different sensor owners, we propose the scheme, DIVISOR, using coalition game theory in order to form VSs dynamically, in the sensor-cloud platform. Thereafter, we extended the scheme in order to form VSG, considering the different region of deployed sensor nodes. Fig. 1 depicts the overlapping sensor deployed regions of different sensor owners. Thus, in such a situation, each of the sensor owners should get equal priority for renting out his/her sensor nodes.

A. Motivation

Virtual sensors (VSs) could be mapped to homogeneous physical sensor nodes to serve the requests of end-users. The physical sensor nodes in a VS belong to different sensor owners. As monetary benefits are involved in the sensor-cloud infrastructure, every sensor owner wishes to deploy the sensor nodes over such a region from where s/he can earn maximum profit by providing the services. Consequently, the areas of sensor node deployment by sensor owners overlap. If in a particular region, multiple similar sensor nodes exist, which belongs to different sensor owners, then the nodes of same sensor owner may be rented out repeatedly, which, in turn, is a biasness towards a particular sensor owner. This forms the strong motivation for this work, in order to provide an equal opportunity to every sensor owner to provide their sensor nodes for the formation of VS.

B. Contribution

The main aim of this work is dynamic formation of the virtual sensor and virtual sensor group, considering the profit of every sensor owner. The specific *contributions* of this work are as follows:

- We propose a novel approach, in order to form virtual sensors dynamically from a collection of homogeneous physical sensor nodes deployed in a region.

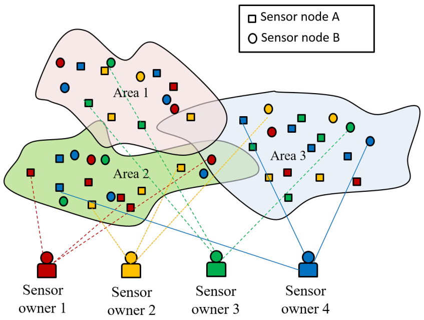

Fig. 1: Overlapping area of deployed sensor nodes

- We apply a cooperative coalition game theoretic approach to form virtual sensor groups by combining virtual sensors in the presence of overlapping region of physical sensor nodes, deployed by respective sensor owners.

II. RELATED WORK

In this Section, we discuss the relevant literature which are related to our work. Currently, sensor-cloud is a promising technology, on which many research issues are being addressed. Yuriyama *et al.* [4] propose the concept of sensor virtualization in the sensor-cloud architecture. They explain the architecture of sensor-cloud in detail. Theoretical modeling of sensor-cloud is done by Misra *et al.* [6]. Pricing is an important issue, which is essential for managing the business perspective of sensor-cloud infrastructure. From this perspective, Chatterjee *et al.* [5] proposed a scheme for dynamic optimal pricing in the sensor-cloud. In the proposed scheme, the authors discuss two types of prices - hardware and infrastructure. An application of sensor-cloud in the medical field is explored by Guezguez *et al.* [7]. The architecture of sensor-cloud proposed by the author is designed for healthcare, in order to serve the purpose of different medical staffs. The formation of virtual sensors and VSG in a sensor-cloud infrastructure is essential. Thus, Chatterjee *et al.* [8] provided a solution for the formation of virtual sensors and VSG. Chatterjee *et al.* considered a non-overlapping area of the deployed sensor nodes of different sensor owners.

Different research works explored different aspects of the sensor-cloud platform in the IoT scenario. In order to strengthen the different parts of the architecture of sensor-cloud, authors discuss several approaches in the existing literature. Only one work [8], proposed a solution for the formation of VSs for the non-overlapping sensor node deployed regions. However, in a realistic scenario, the region on which the sensor nodes are deployed by different owners are overlapping. Consequently, in such a scenario the proposed approach of formation of VSs is not applicable.

III. PROBLEM DESCRIPTION

A. Problem Scenario

We consider a Iot-based sensor-cloud infrastructure, which consists of four actors – a Sensor Cloud Service Provider (SCSP), several sensor owners, end-users, and cloud. Each sensor owner deploys heterogeneous types of sensor nodes over different geographical locations. Based on the utilization of the sensor nodes, the respective sensor owner gets rent. On the other hand, the end-users request for services from the sensor-cloud based on payment. The virtual sensor comprises of homogeneous physical sensor nodes, which belong to different or the same sensor owner. Multiple virtual sensors form VSGs from physical sensor nodes, which exist in distinct or overlapping geographical regions. The formation of virtual sensors from physical sensor nodes is mapped as a *many-to-many* relationship [9]. The energy level of a sensor node reduces due to the sensing and transmitting operations. Consequently, when the energy level goes below a threshold value, the sensor node is unable to perform its normal operation. In such a scenario, the sensor nodes which are incapable to perform their normal operation, are required to be replaced dynamically by other homogeneous sensor nodes.

B. Formal Definition of the Problem

Let, $\mathcal{S} = \{\mathbb{S}_1, \mathbb{S}_2, \cdots, \mathbb{S}_m\}$ denote a set of sensor owners, where $\mathbb{S}_i \in \mathcal{S}$ represents any sensor owner and $1 \leq i \leq m$. Each sensor owner deploys heterogeneous types of sensor nodes, s_j, where $j \in \{1, 2, \cdots, k\}$, and thus, maximum k types of sensor nodes are available in our system. The available types and number of physical sensor nodes of any sensor owner, $\mathbb{S}_p$, varies from other sensor owner, $\mathbb{S}_q$, where $p, q \in \{1, 2, \cdots m\}$. Therefore, the total number of sensor nodes, $\mathcal{N}$, available in the system is represented by Equation (1), where $\mathcal{X}_{ij}$ represents the number of s_j^{th} type of sensor nodes belonging to sensor owner $\mathbb{S}_i$.

$$\mathcal{N} = \sum_{i=1}^{m} \sum_{j=1}^{k} \mathcal{X}_{ij} \tag{1}$$

On the other hand, any end-user, E_x, requests the service from sensor-cloud, where $1 \leq x \leq y$. Among the available sensor nodes in the system, the similar types of sensor nodes form virtual sensors. The available set of virtual sensors is denoted by $\mathcal{V}_i \in \mathbb{V}$, where each $\mathcal{V}_i$ is any virtual sensor and $i \in \{1, 2, \cdots, z\}$. Multiple virtual sensors form virtual sensor group VSG_j, where $j \in \{1, 2, \cdots, \eta\}$. Every $\mathbb{S}_i$ deploys physical sensor nodes over a finite geographical location, represented as a set, $\mathbb{R}$, such that, any $\mathcal{R}_i \in \mathbb{R}$, and $i \in \{1, 2, \cdots, m\}$. The overlapping region among the deployed sensor nodes of respective sensor owners, is represented as $\bar{\mathcal{R}}_c$.

$$\bar{\mathcal{R}}_c = \mathcal{R}_1 \cap \mathcal{R}_2 \cap \cdots \cap \mathcal{R}_m \tag{2}$$

In this work, we provide a solution to form virtual sensor, $\mathcal{V}$, dynamically from different physical sensor nodes. Thereafter, based on the end-user request, the VSG is formed from the virtual sensors.

IV. SOLUTION APPROACH

The proposed scheme, DIVISOR, selects a set of physical sensors in order to form a virtual sensor. Thus, a set of physical sensors is chosen based upon the following parameters:
Normalized residual energy ($\mathcal{E}^{norm}_{\mathbb{S}^j_i}$): The ratio of the difference between the initial energy and utilized energy of any sensor node, to the initial energy of the sensor node is the

normalized residual energy. Mathematically,

$$\mathcal{E}^{norm}_{\mathbb{S}_i^j} = \frac{\left(\mathcal{E}^{init}_{\mathbb{S}_i^j} - \mathcal{E}^{util}_{\mathbb{S}_i^j}\right)}{\mathcal{E}^{init}_{\mathbb{S}_i^j}} \tag{3}$$

where $\mathcal{E}^{init}_{\mathbb{S}_i^j}$ and $\mathcal{E}^{util}_{\mathbb{S}_i^j}$ represent the initial and utilized energy of the j^{th} sensor node of the i^{th} sensor owner.

The sensor nodes are deployed over various geographical locations by different sensor owners. We consider that each physical sensor node, s_j, is deployed over a particular geographical position, ϕ_j. Mathematically,

$$\phi_j = \langle long_j, lat_j \rangle \tag{4}$$

where $long_j$ and lat_j are the longitude and latitude of the sensor node, s_j, respectively. As we know, Earth's surface is a sphere, so to calculate the distance between any two points on a spherical surface haversine distance is applied.

Normalized effective distance ($\mathcal{D}_{ab}$): The normalized effective distance is the *Haversine* distance [10] between any physical sensor node, a, and the base station, b.

$$\mathcal{D}_{ab} = \mathcal{H}_i(\phi_a, \phi_b)\frac{\pi}{180^\circ}, \forall a, b \in \{1, 2, \cdots, k\} \tag{5}$$

where $\mathcal{H}_i(\phi_a, \phi_b)$ is the Haversine distance between the sensor node, a and the base station, b. The Haversine distance, $\mathcal{H}_i(\phi_a, \phi_b)$ is computed as:

$$\mathcal{H}_i(\phi_a, \phi_b) = 2\mathbb{E}_r \sin^{-1}\sqrt{hav\left(\frac{\mathcal{H}_i(\phi_a, \phi_b)}{2\mathbb{E}_r}\right)} \tag{6}$$

In Equation (6), $\mathbb{E}_r$ represents the radius of the Earth. Further, $hav(\mathcal{H}_i(\phi_a, \phi_b))$ is represented in Equation (7).

$$hav(\mathcal{H}_i(\phi_a, \phi_b)) = \sin^2\left(\frac{\Delta lat_{ab}}{2}\right) + \cos(lat_a lat_b)\sin^2\left(\frac{\Delta long_{ab}}{2}\right) \tag{7}$$

where $\Delta(lat_{ab}) = |lat_a$ - $lat_b|$, $\forall a, b \in \{1, 2, \cdots, k\}$ and $\Delta(long_{ab}) = |long_a - long_b|$, $\forall a, b \in \{1, 2, \cdots, k\}$.

Reputation rating ($\Re$): Reputation rating signifies the expected reputation of any physical sensor node. $\Re$ is calculated using the *Beta Reputation model* [11]. Mathematically:

$$\Re_j = E(f(p|x, x')) = \frac{x+1}{x+x'+2} \tag{8}$$

In Equation (8), the event of successful and unsuccessful data transmission from the sensor nodes to the base station are denoted by y and y'. The degree of satisfaction and dissatisfaction of the base station over the received sensor data from any sensor node is denoted by x and x', respectively. The expected value of the reputation function is denoted by $E(f(p|x, x'))$, where p is the probability of the event of successful data transmission, y, by the sensor node to the base station.

In a practical scenario, every sensor owner deploys sensor nodes over a defined geographical location. Subsequently, across some portion of the same geographical location, a sensor owner deploys similar sensor nodes as other sensor owners. Thus, in order to provide an equal opportunity to every sensor owner for renting their sensor node, we consider the number of times usage of the respective sensor node after a certain time duration τ, ψ_j^τ.

Lemma 1. *There exists 15 effects for the formation of virtual sensor with 4 factors,* $\mathcal{E}^{norm}_{\mathbb{S}_i^j}, \mathcal{D}_{ab}, \Re_j$, *and* ψ_j^τ .

Proof: Consider the formation of virtual sensors as an experiment. The effects of the factors $\mathcal{E}^{norm}_{\mathbb{S}_i^j}, \mathcal{D}_{ab}, \Re_j$ and ψ_j^τ for the formation of the virtual sensor, $\mathcal{V}_i$, are the *main effects* and the adjacent effects among the factors are the *interaction effects* [12]. Therefore, according to 2^k factorial design, for k factors, there exists $(2^k - 1)$ effects. Thus,

$$\text{main effects} = \binom{4}{1} : \mathcal{E}^{norm}_{\mathbb{S}_i^j}, \mathcal{D}_{ab}, \Re_j, \psi_j^\tau \tag{9}$$

2-factor interaction effects

$$= \binom{4}{2} : \mathcal{E}^{norm}_{\mathbb{S}_i^j}\mathcal{D}_{ab}, \mathcal{D}_{ab}\Re_j, \mathcal{E}^{norm}_{\mathbb{S}_i^j}\Re_j, \mathcal{E}^{norm}_{\mathbb{S}_i^j}\psi_j^\tau, \mathcal{D}_{ab}\psi_j^\tau, \Re_j\psi_j^\tau \tag{10}$$

3-factor interaction effects

$$= \binom{4}{3} : \mathcal{E}^{norm}_{\mathbb{S}_i^j}\mathcal{D}_{ab}\Re_j, \mathcal{E}^{norm}_{\mathbb{S}_i^j}\mathcal{D}_{ab}\psi_j^\tau, \mathcal{D}_{ab}\Re_j\psi_j^\tau, \mathcal{E}^{norm}_{\mathbb{S}_i^j}\Re_j\psi_j^\tau \tag{11}$$

$$\text{4-factor interaction effects} = \binom{4}{4} : \mathcal{E}^{norm}_{\mathbb{S}_i^j}\mathcal{D}_{ab}\Re_j\psi_j^\tau \tag{12}$$

As for the formation of the virtual sensors, we have considered 4 factors. Hence, there exists 15 effects, as shown in Equations (9) - (12). ■

A. Game formulation

We use cooperative coalition game theory for the formation of virtual sensors from multiple physical sensors of similar types. In our problem, we consider the active physical sensor nodes, $\mathcal{N}$, as players. Therefore, the possible number of coalitions with $\mathcal{N}$ sensor nodes is $2^{\mathcal{N}}$ [13]. In the strategic form, the game can be mathematically defined as:

$$\Gamma = \{(s_j)_(s_j \in \mathcal{N}), s_j^{type}, (\mathcal{U}_{\mathcal{T}_i})_{i\in\omega}\} \tag{13}$$

The various constituents of the game are:

- s_j is the physical sensor node, which acts as player.
- s_j^{type} is a particular type of the physical sensor node.
- $\mathcal{U}_{\mathcal{T}_i}$ is the utility function of the physical sensor nodes, which have joined together to form any coalition $\mathcal{T}_i$ $(i \in \omega)$.

Let there are $\mathbb{Y}$ partitions, with ω number of coalitions. Mathematically,

$$\mathbb{Y} = \{\mathcal{T}_1, \mathcal{T}_2, \cdots\cdots \mathcal{T}_\omega\} \tag{14}$$

where the coalitions are disjoint if $\mathcal{T}_i \cap \mathcal{T}_j = \phi$, $i \neq j$. The utility of any coalition is represented as $\mathcal{U}((\mathcal{E}^{norm}_{\mathbb{S}_i^j})_{j\in n}, \Re_j, \mathcal{D}_{ab}, \psi_j^\tau)_{\mathcal{T}_i}$, where s_j is deployed over the region $\mathcal{R}$. The coalition is formed using normalized residual energy ($\mathcal{E}^{norm}_{\mathbb{S}_i^j}$), reputation rating of the physical sensor node ($\Re_j$), distance of the physical sensor nodes with the base station ($\mathcal{D}_{ab}$), and the number of times the sensor node is rented (ψ_j^τ).

If similar types of physical sensor nodes of different owners are deployed over an overlapping region, $\bar{\mathcal{R}}_c$, then in such a situation we provide the priority to those sensor nodes which are rented less number of times. Consequently, we consider a counter, which counts the number of times a physical sensor

node is rented. However, we also consider other parameters, such as $\mathcal{E}^{norm}_{\mathbb{S}_i^j}$, $\Re_j$, and $\mathcal{D}_{ab}$ in order to include a physical sensor node into a virtual sensor. The players (sensor nodes) form coalition based on the utility obtained by considering $\mathcal{E}^{norm}_{\mathbb{S}_i^j}$, $\Re_j$, $\mathcal{D}_{ab}$, and ψ_j^τ.
The utility function can be increasing or non-increasing, depending on the different factors, as mentioned in Equations (15) - (18).

- The utility function is considered to be non-decreasing with the increase in residual energy of the physical sensor node, assuming other factors to be constant.

$$\frac{\partial\big(\mathcal{U}((\mathcal{E}^{norm}_{\mathbb{S}_i^j})_{j\in n}, \Re_j, \mathcal{D}_{ab}, \psi_j^\tau)\big)}{\partial \mathcal{E}^{norm}_{\mathbb{S}_i^j}} \geq 0 \tag{15}$$

- The marginal value of the utility function is, therefore, considered to be non-increasing in nature.

$$\frac{\partial^2\big(\mathcal{U}((\mathcal{E}^{norm}_{\mathbb{S}_i^j})_{j\in n}, \Re_j, \mathcal{D}_{ab}, \psi_j^\tau)\big)}{\partial\big(\mathcal{E}^{norm}_{\mathbb{S}_i^j}\big)^2} < 0 \tag{16}$$

- The utility function is considered to be decreasing with the increase in the distance between the physical sensor nodes and the base station.

$$\frac{\partial\big(\mathcal{U}((\mathcal{E}^{norm}_{\mathbb{S}_i^j})_{j\in n}, \Re_j, \mathcal{D}_{ab}, \psi_j^\tau)\big)}{\partial \mathcal{D}_{ab}} \leq 0 \tag{17}$$

- The utility function is considered to be non-increasing with the increase in the number of times the physical sensor nodes are rented.

$$\frac{\partial\big(\mathcal{U}((\mathcal{E}^{norm}_{\mathbb{S}_i^j})_{j\in n}, \Re_j, \mathcal{D}_{ab}, \psi_j^\tau)\big)}{\partial \psi_j^\tau} \leq 0 \tag{18}$$

The utility function is mathematically defined as:

$$\mathcal{U}_{\mathcal{T}_i} = exp\Bigg[\tan^{-1}\Bigg(\frac{\mathcal{E}^{norm}_{\mathbb{S}_i^j} - \Re_j}{\mathcal{D}_{ab}}\Bigg)\psi_j^\tau\Bigg] \tag{19}$$

Theorem 1. *The utility function, $\mathcal{U}_{\mathcal{T}_i}$ for the formation of multiple virtual sensors from the active, physical sensor nodes is concave in nature.*

Proof: The *Hessian* matrix of the function at a particular point, $\tilde{x}$, at any time instant is negative semidefinite, which is mathematically represented as,

$$x^T\mathbb{H}(\tilde{x})x \leq 0, \text{ where}, \tilde{x} \in \mathcal{U}_{\mathcal{T}_i} \tag{20}$$

The second order partial derivatives of the function wrt $\mathcal{E}^{norm}_{\mathbb{S}_i^j}$, and wrt $\mathcal{D}_{ab}$, provided the first order derivative is derived wrt $\mathcal{E}^{norm}_{\mathbb{S}_i^j}$ is:

$$\frac{\partial^2(\mathcal{U}_{\mathcal{T}_i})}{\partial\big(\mathcal{E}^{norm}_{\mathbb{S}_i^j}\big)^2} \text{ and } \frac{\partial^2(\mathcal{U}_{\mathcal{T}_i})}{\partial\big(\mathcal{E}^{norm}_{\mathbb{S}_i^j}\big)\partial(\mathcal{D}_{ab})}.$$

Similarly, the Hessian matrix of the utility function is derived as:

$$\mathbb{H}(\tilde{x}) = \begin{pmatrix} \frac{\partial^2(\mathcal{U}_{\mathcal{T}_i})}{\partial\left(\mathcal{E}^{norm}_{\mathbb{S}_i^j}\right)^2} & \frac{\partial^2(\mathcal{U}_{\mathcal{T}_i})}{\partial\left(\mathcal{E}^{norm}_{\mathbb{S}_i^j}\right)\partial(\mathcal{D}_{ab})} & \cdots\cdots & \frac{\partial^2(\mathcal{U}_{\mathcal{T}_i})}{\partial\left(\mathcal{E}^{norm}_{\mathbb{S}_i^j}\right)\partial(\psi_j^\tau)} \\ \frac{\partial^2(\mathcal{U}_{\mathcal{T}_i})}{\partial(\mathcal{D}_{ab})\partial\left(\mathcal{E}^{norm}_{\mathbb{S}_i^j}\right)} & \frac{\partial^2(\mathcal{U}_{\mathcal{T}_i})}{\partial(\mathcal{D}_{ab})^2} & \cdots\cdots & \frac{\partial^2(\mathcal{U}_{\mathcal{T}_i})}{\partial(\mathcal{D}_{ab})\partial(\psi_j^\tau)} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial^2(\mathcal{U}_{\mathcal{T}_i})}{\partial(\psi_j^\tau)\partial\left(\mathcal{E}^{norm}_{\mathbb{S}_i^j}\right)} & \frac{\partial^2(\mathcal{U}_{\mathcal{T}_i})}{\partial(\psi_j^\tau)\partial(\mathcal{D}_{ab})} & \cdots\cdots & \frac{\partial^2(\mathcal{U}_{\mathcal{T}_i})}{\partial\left(\psi_j^\tau\right)^2} \end{pmatrix} \tag{21}$$

Therefore, by substituting the value of $\mathbb{H}(\tilde{x})$ in Equation (20), we observe that the utility function is concave in nature. ■

B. Existence of Equilibrium

The equilibrium condition of the $\mathcal{N}$ players to form coalition, in order to form virtual sensor for the application requested by end-users, is mathematically represented as:

$$\mathcal{U}((\mathcal{E}^{norm}_{\mathbb{S}_i^j})^*_{j\in n}, \Re_j, \mathcal{D}^*_{ab}, \psi_j^{\tau *})_{\mathcal{T}_i} \geq \mathcal{U}((\mathcal{E}^{norm}_{\mathbb{S}_i^j})_{j\in n}, \Re_j, \mathcal{D}_{ab}, \psi_j^\tau)_{\mathcal{T}_i} \tag{22}$$

By Theorem 1, the utility function is proved as concave in nature. Therefore, in order to obtain the optimal solution, the utility function is maximized, as depicted in Equation (23).

$$\text{Maximize} \quad exp\Bigg[\tan^{-1}\Bigg(\frac{\mathcal{E}^{norm}_{\mathbb{S}_i^j} - \Re_j}{\mathcal{D}_{ab}}\Bigg)\psi_j^\tau\Bigg] \tag{23}$$

subject to,

$$\begin{aligned} \mathcal{E}^{norm}_{\mathbb{S}_i^j} &\geq \frac{\mathcal{E}^{th}_{\mathbb{S}_i^j}}{\mathcal{E}^{init}_{\mathbb{S}_i^j}} \\ \mathcal{D}_{ab} &\leq R_c \\ \Re_j &\geq 0 \\ \psi_j^\tau &\leq {\psi_j^\tau}^{max} \end{aligned} \tag{24}$$

where $\mathcal{E}^{th}_{\mathbb{S}_i^j}$ is the lower threshold value of energy of a physical sensor node, below which the node is unable to transmit data, R_c is the communication range of the sensor node, ${\psi_j^\tau}^{max}$ is the maximum number of times the sensor node can be rented.
The Lagrangian function of the Equations (23)–(24) at time instant, τ, is mathematically represented as:

$$\begin{aligned} \mathbb{L}_\tau = -exp\Bigg[\tan^{-1}\Bigg(\frac{\mathcal{E}^{norm}_{\mathbb{S}_i^j} - \Re_j}{\mathcal{D}_{ab}}\Bigg)\psi_j^\tau\Bigg] - \mu_1\Bigg(\mathcal{E}^{norm}_{\mathbb{S}_i^j} - \frac{\mathcal{E}^{th}_{\mathbb{S}_i^j}}{\mathcal{E}^{init}_{\mathbb{S}_i^j}}\Bigg) + \\ \mu_2(\mathcal{D}_{ab} - R_c) - \mu_3\Re_j + \mu_4(\psi_j^\tau - {\psi_j^\tau}^{max}) \end{aligned} \tag{25}$$

where μ_1, μ_2, μ_3 are the *Lagrangian* multipliers.

To compute the optimum solution, we have used *Karush-Kuhn-Tucker* conditions [14], which are as follows:

$$\frac{\partial \mathbb{L}_\tau}{\partial \mathcal{E}^{norm}_{\mathbb{S}_i^j}} = -exp\Bigg[\tan^{-1}\Bigg(\frac{\mathcal{E}^{norm}_{\mathbb{S}_i^j} - \Re_j}{\mathcal{D}_{ab}}\Bigg)\psi_j^\tau\Bigg]\frac{1}{1+\Bigg[\Bigg(\frac{\mathcal{E}^{norm}_{\mathbb{S}_i^j} - \Re_j}{\mathcal{D}_{ab}}\Bigg)\psi_j^\tau\Bigg]^2}\frac{\psi_j^\tau}{\mathcal{D}_{ab}} - \mu_1 \tag{26}$$

$$\frac{\partial \mathbb{L}_\tau}{\partial \mathcal{D}_{ab}} = exp\Bigg[\tan^{-1}\Bigg(\frac{\mathcal{E}^{norm}_{\mathbb{S}_i^j} - \Re_j}{\mathcal{D}_{ab}}\Bigg)\psi_j^\tau\Bigg]\frac{1}{1+\Bigg[\Bigg(\frac{\mathcal{E}^{norm}_{\mathbb{S}_i^j} - \Re_j}{\mathcal{D}_{ab}}\Bigg)\psi_j^\tau\Bigg]^2}\Bigg(\frac{\mathcal{E}^{norm}_{\mathbb{S}_i^j} - \Re_j}{\mathcal{D}^2_{ab}}\Bigg)\psi_j^\tau + \mu_2 \tag{27}$$

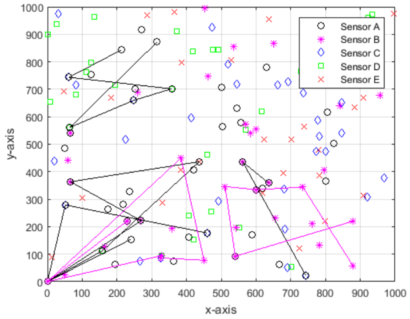

Fig. 2: Coalition Formation by DIVISOR

$$\frac{\partial \mathbb{L}_\tau}{\partial \Re_j} = exp\Big[\tan^{-1}\Big(\frac{\mathcal{E}^{norm}_{\mathbb{S}^j_i} - \Re_j}{\mathcal{D}_{ab}}\Big)\psi^\tau_j\Big] \frac{1}{1+\Big[\Big(\frac{\mathcal{E}^{norm}_{\mathbb{S}^j_i} - \Re_j}{\mathcal{D}_{ab}}\Big)\psi^\tau_j\Big]^2} \frac{\psi_\tau}{\mathcal{D}_{ab}} - \mu_3 \tag{28}$$

$$\frac{\partial \mathbb{L}_\tau}{\partial \psi^\tau_j} = -exp\Big[\tan^{-1}\Big(\frac{\mathcal{E}^{norm}_{\mathbb{S}^j_i} - \Re_j}{\mathcal{D}_{ab}}\Big)\psi^\tau_j\Big] \frac{1}{1+\Big[\Big(\frac{\mathcal{E}^{norm}_{\mathbb{S}^j_i} - \Re_j}{\mathcal{D}_{ab}}\Big)\psi^\tau_j\Big]^2} \Big(\frac{\mathcal{E}^{norm}_{\mathbb{S}^j_i} - \Re_j}{\mathcal{D}_{ab}}\Big) + \mu_4 \tag{29}$$

$$\begin{aligned} &-\mu_1(\mathcal{E}^{norm}_{\mathbb{S}^j_i} - \frac{\mathcal{E}^{th}_{\mathbb{S}^j_i}}{\mathcal{E}^{init}_{\mathbb{S}^j_i}}) = 0 \\ &\mu_2(\mathcal{D}_{ab} - R_c) = 0 \\ &\mu_3 \Re_j = 0 \\ &\mu_4(\psi^\tau_j - \psi^{\tau max}_j) = 0 \\ &\mu_1, \mu_2, \mu_3, \mu_4 \geq 0 \end{aligned} \tag{30}$$

Therefore, the solution of the maximization function satisfies the equilibrium condition.

On solving the Equations (26) – (30), we find the optimum set of physical sensor nodes, which form the virtual sensor, $\mathcal{V}_i$. Fig. 2 shows the coalition formation by homogeneous types of sensor nodes in order to form virtual sensor nodes. The algorithm, DIVISOR, for the formation of virtual sensors is given in Algorithm 1.

According to the application requested by the end-user, the virtual sensors, $\mathcal{V}_i$ are formed. To serve different applications, VSGs are formed. We have,

$$\begin{aligned} VSG_j = \{\mathcal{V}_1, \mathcal{V}_2, \mathcal{V}_3, \cdots, \mathcal{V}_N\} \quad &\text{where} j \in I \\ \text{such that, } \mathcal{V}^{type}_i \neq \mathcal{V}^{type}_j \quad &\forall i, j \in \{1, 2, \cdots, z\} \end{aligned} \tag{31}$$

where $\mathcal{V}^{type}_i$ denotes the type of the virtual sensor formed. Here, the *type* signifies the type of virtual sensor based upon the hardware specifications of the physical sensor node from which it is formed.

V. RESULT

In this Section, we discuss the performance of the proposed scheme, DIVISOR. The problem is newly explored and is unique with respect to the existing state-of-the-art. Therefore, comparative study of the proposed scheme, DIVISOR, is out of scope. For evaluating the performance of DIVISOR, we consider $150 - 270$ nodes in an area of $1000 \times 1000\ m^2$ simulation area. The simulation parameters used in this work are listed in Table I.

We rigorously experimented the proposed scheme, DIVISOR, and evaluated the performance, considering the following metrics:

- *Average residual energy*: Total average remaining energy of the nodes in network after the formation of coalitions.
- *Average number of participating nodes*: Average number of nodes participated per coalition.
- *Average number of times rented*: Average number of times a particular type of sensor node of respective sensor owners is rented.

Algorithm 1 DIVISOR

```
INPUTS:
    • $\mathcal{E}^{norm}_{\mathbb{S}^j_i}$ : Normalized residual energy of the physical, sensor node.
    • $\Re_j$ : Reputation rating of the physical sensor node.
    • $\mathcal{D}_{ab}$: Distance between the physical sensor node and the base station.
    • $\psi^\tau_j$: Number of times the sensor node is rented.
OUTPUTS: $\mathcal{V}_i$ : Virtual sensors formed from homogeneous sensors (Coalition formed).
for $i$ = 1 to $\mathcal{N}$ do                                  ▷ $\mathcal{N}$ : Total no. of sensors
    while $s^{type}_i == s^{type}_j$ do                          ▷ $s^{type}_i$:type of sensor
        if $\mathcal{E}^{norm}_{\mathbb{S}^j_i} \geq \frac{\mathcal{E}^{th}_{\mathbb{S}^j_i}}{\mathcal{E}^{init}_{\mathbb{S}^j_i}}$ and $\Re_j \geq 0$ and $\mathcal{D}_{ab} \leq R_c$and $\psi^\tau_j \leq \psi^{\tau max}_j$ then
            $s_j$ is chosen                                      ▷ 1 ≤ j ≤ n
            $\mathcal{U}_{\mathcal{T}_i}$=$exp\Big[\tan^{-1}\Big(\frac{\mathcal{E}^{norm}_{\mathbb{S}^j_i} - \Re_j}{\mathcal{D}_{ab}}\Big)\psi^\tau_j\Big]$   ▷ Utility function of the selected sensor node is calculated
        else if
            then   Select the next nearest sensor node
        end if
        Calculate the utility function
    end while
    if $\mathcal{U}^{af}_{\mathcal{T}_i} > \mathcal{U}^{bf}_{\mathcal{T}_i}$ then     ▷ $\mathcal{U}^{af}_{\mathcal{T}_i}$ and $\mathcal{U}^{bf}_{\mathcal{T}_i}$ : Utility after and before coalition respectively
        $s_i$ merges with the $\mathcal{U}_{\mathcal{T}_i}$
    else
        $s_i$ splits from $\mathcal{U}_{\mathcal{T}_i}$
    end if
end for
```

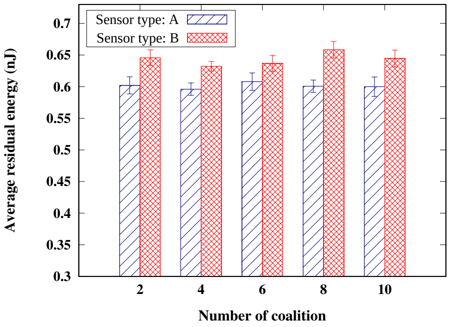

Fig. 3: Average residual energy

TABLE I: Simulation Parameters

Parameter	Value
Simulation area	$1000\ m \times 1000\ m$
Sensor deployment type	Random
Number of nodes (N)	100-700
Number of types of sensor nodes	5
Number of sensor owners	4
Earth's radius ($\mathbb{E}_r$)	6731 m

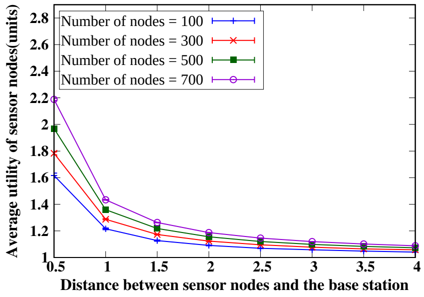

Fig. 4: Variation of utility of sensor nodes with distance

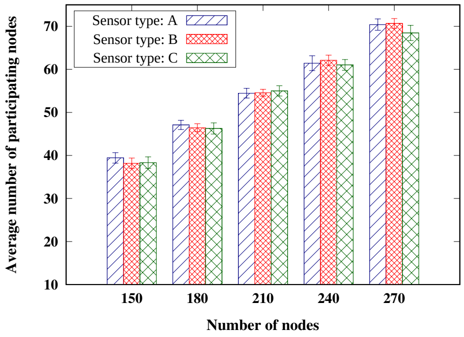

Fig. 5: Average number of participating nodes

- *Average utility of sensor nodes* : The ratio of the sum of the utility of every sensor node to the total number of nodes present in the scenario.

Fig. 3 depicts the average residual energy of the network after the formation of coalitions in the network. In this plot, we select two types of sensor nodes, A and B, among the total number of available nodes in the network. The x-axis depicts the number of coalitions formed by sensor types A and B in the network. However, we observe in the figure that, there is no significant change in the residual energy with the increasing number of coalitions in the network. Thus, from the plot we infer that the proposed scheme, DIVISOR is energy-efficient, even if the number of coalitions changes in the network.

Fig. 4 shows the variation in average utility of the sensor nodes with distance. We analyze the result using total number of nodes 100 - 700, with an interval of 200. In this plot x-axis represents the distance between the sensor nodes and the base station. We observe that with the increase in distance, utility seems to be decreasing.

In Fig. 5, we consider the existence of three types of sensor nodes in the network. Along the x-axis, the total number of nodes present in the network are plotted from the range of 150 to 270, with an interval of 30. In this plot, we observe that, there is an increasing trend in the average number of participating nodes in a coalition, with the increasing number of total number of nodes present in the network.

The average number of nodes which participated for renting is depicted in Fig. 6. In this plot, we consider the presence of three types of sensor nodes and 2 sensor owners. This plots refers to the number of times each of the owners gets opportunity to rent their sensor nodes. We observe that the average number of times the nodes participate in the coalition for each of the sensor owners does not vary significantly in all the cases. Thus, from this plot it is inferred that each of the sensor owners gets almost an equal opportunity to rent their sensors nodes.

VI. CONCLUSION

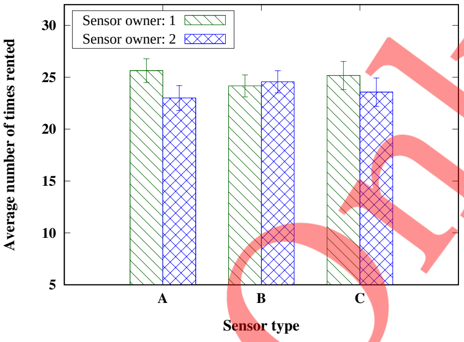

Fig. 6: Average number of times rented

This work studied the problem of formation of virtual sensors in the sensor-cloud platform. We proposed a scheme, DIVISOR, considering the area of overlap of different sensor nodes deployed by the respective sensor owners, and thereafter, form a virtual sensor. DIVISOR provides an equal opportunity to each of the sensor owners for renting their sensor nodes. In order to design the scheme, DIVISOR, we have used a cooperative coalition based game-theoretic approach.

In the future, this work can be extended considering the equal distribution of the profit among the respective sensor owners. We plan to design a scheme to distribute the profit to the different sensor owners by considering the end users' requirements.

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