Connectivity Re-establishment in the Presence of Dumb Nodes in Sensor-Cloud Infrastructure: A Game Theoretic Approach

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***Abstract*—In this work, we consider the presence of dumb nodes in the underlying physical networks of Sensor-Cloud infrastructure. The dumb nodes get isolated from the network and degrade the network performance. Consequently, a Cloud Service Provider (CSP) is unable to use Wireless Sensor Networks (WSNs) in an efficient manner, as the dumb sensor nodes cannot use as a virtual sensor. Thus, in this work, we propose a scheme, *Connectivity Re-establishment in the Presence of Dumb Nodes in Sensor-Cloud Infrastructure* (CoRDS), that facilitates the re-establishment of the connectivity between dumb nodes and the sink. Using the proposed scheme, CoRDS, the CSP is able to provide the services efficiently as per end-users requirements. In order to re-establish connectivity between the dumb nodes and the sink, we use a single leader multiple follower Stackelberg game. Additionally, theoretical characterization of CoRDS has been shown.**

***Index Terms*—Dumb Node, Sensor-cloud, Wireless Sensor Networks, Connectivity, Stackelberg Game.**

I. Introduction

The rapid development of Micro-Electro-Mechanical Systems (MEMS) technology has spawned adaptive, and high fault tolerant Wireless Sensor Networks (WSNs). Wireless sensor networks consist of a set of sensor nodes that sense some physical phenomena, and transmit the sensed data to the sink. Currently, WSNs are used widely in different fields of application such as habitat monitoring, wild-life monitoring, health monitoring, and target tracking [1]. Sensor nodes in WSNs transmit their sensed data to the sink through single or multi-hop connectivity [2]–[4]. Therefore, each sensor node in the network needs to work in a collaborative manner. The sensor nodes in a WSN are light-weight, and resource-constrained, and thus, the nodes are vulnerable to adverse environmental effects, Denial of Service (DoS) attack, and misbehavior. The adverse environmental effects cause the reduction in communication range of a sensor node, and consequently, the nodes become dumb [5], [6]. These dumb nodes have detrimental effect on the network performance, as with other node misbehaviors.

Of late, *Sensor-Cloud Infrastructure* (SCI) has been recognized as the future substitute of conventional WSNs [7]–[10]. The main advantage of SCI over traditional WSNs is that it enables the end-users to use the services of the physical sensor nodes without owning the same. It allows the common people to enjoy the service of sensor nodes without having to deal with the maintenance overhead. In this infrastructure, sensor owners provide the sensor nodes on a rental basis to the cloud, and earn the profit as per utilization of sensor nodes. On the other hand, the end-users register themselves to the cloud for using those sensor nodes as per demand. The services of the deployed sensor nodes are assigned as virtual sensor services to the end users. End-users need not concern about which physical sensors they are provisioned with. They simply pay for the sensor utilization. In a SCI, the virtualization of the sensor nodes takes place in the cloud.

We consider the presence of dumb nodes [5] within such an infrastructure. If a node becomes dumb in a Sensor-Cloud, it is unable to communicate with any other node in the network. Therefore, the data sensed by a dumb node can not be transmitted to any other node or sink. Consequently, the cloud services of that region will be disrupted.

A. Motivation

In a SCI, the CSP pays rent for the sensor nodes for achieving efficient services from the WSNs, so that the profit from those resources can be maximized. We consider that the problem of the presence of dumb nodes in SCI degrades the performance of not only the associated WSN, but also the cloud. A dumb node gets isolated from the network, subsequently. These remedial steps should be taken so that the connectivity between a dumb node, and the sink can be re-established. The sensor nodes in WSN are resource-constrained. Therefore, if the connectivity re-establishment algorithm runs within the sensor nodes, the nodes get depleted of their energy very soon. Thus, the mechanism of connectivity re-establishment is motivated to be executed within cloud in order to increase network life-time, and enhance the efficacy of resource utilization.

B. Contribution

In the present work, we consider the presence of dumb nodes within the underlying physical network of SCI. The

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main *contributions* of this work are summarized as follows:

(i) This work is one of the first attempts that considers the existence of dumb nodes within Sensor-Cloud and subsequently proposes a scheme named – *Connectivity re-establishment in the presence of Dumb nodes in Sensor-Cloud Infrastructure* (CoRDS).
(ii) The problem of re-establishing of connectivity between the dumb nodes and the sink is modeled as a single leader multiple follower Stackelberg game. The corresponding theoretical analysis is also done.
(iii) Proof of the equilibrium for the proposed game formulation is derived.

The rest of the paper is organized as follows. Section II describes the prior art related to this work. Section III describes the system model. An elaborate discussion of the Stackelberg game formulation for the problem is discussed in Section IV. Section V-A provides simulation design of CoRDS. The analysis of results is discussed in Section V-B. Finally, we conclude our work in Section VI.

II. Related Work

Our work is motivated from different misbehaviors, faults, and attacks in WSNs, as reported reported in the existing literature [11]. Environmental factors such as temperature, rainfall, and fog cause reduction in communication range of sensor nodes. These factors reduce the signal strength, as a consequence of which, the communication ranges of the sensor nodes reduce [12]–[14]. Bannister *et al.* [12] experimented with Telos-class motes in hot region and observed that during the hottest time of the day there is highest reduction in the signal strength of the motes. Boano *et al.* [14] experimented with outdoor sensor networks, which show that communication get affected by temperature. Markham *et al.* [13] reported that rainfall affects the link quality in a WSN. Finally, Misra *et al.* proposed a new misbehavior of a sensor node– the "dumb" behavior [5], considering the environmental impacts in the WSN. A node becomes dumb when the communication range reduces below a certain threshold due to the presence of adverse environmental effects. The authors revealed the fact that a dumb node in the network affects the network performance, as does other misbehaving and selfish nodes.

WSNs are largely used in various fields of applications. The nodes in WSN deployed may not be used during the entire life-time. If a WSN is not used efficiently, there is drainage in battery power that results in the quick depletion of sensor nodes. Thus, for efficient use of WSN, the cloud is combined with WSNs and a new term is given as *Sensor-Cloud* [7]–[9]. The authors describe the architecture of Sensor-Cloud, where different registered owners of sensor nodes give the nodes on a rent basis to the Cloud. End users register to cloud for utilizing the services of the sensor nodes through the cloud. Users request for the sensor nodes as per their requirements. Cloud assigns virtually from the available sensors. The user may de-register from the cloud, if the service of the sensor is not needed further. SCI is a newly introduced approach, in which the sensor-owner, CSP, and end users all are benefited in terms of cost-effectiveness and efficient resource utilization.

The existing literature, viz., [7]–[10], introduce the concept of SCI and dumb nodes. However, the authors did not consider the presence of dumb nodes in SCI. In this architecture, the health of the node is monitored before allocating to any user. If a dumb node is present in a WSN, the CSP is unable to reach the node. Consequently, it is difficult to get any information from that dumb node. This problem results in loss of revenue for both the CSP and the sensor owner. Thus, in this work, we consider the presence of dumb nodes in SCI. We provide solution for re-establishing the connectivity between a dumb node and sink.

III. System Model

We consider the SCI consisting of multiple WSNs and a single cloud service provider. Traditional WSNs sense some physical phenomena, in which each sensor node transmits the sensed data to a centralized unit, i.e., the sink. We assume that a set of sensor nodes is deployed randomly over a region, and few of the deployed nodes are activated to covered the entire-region. The sensed data from the monitored region are ported into a server, and the users can access the data as per their requirements. The entire infrastructure is controlled by the CSP. This architecture enables different users to access the same or different types of sensed-data by the activated sensor nodes deployed in that region at any time. A user need not bother about the ownership, and the deployment of the sensor nodes to get the required services. The CSP is responsible for the maintenance of the WSNs in the entire-region.

A. Dumb nodes in WSN

We assume N number of sensor nodes to be deployed over a region of interest. Each sensor node is Global Positioning System (GPS) enabled and homogeneous, i.e., each node has the same ability to sense and transmit, the maximum communication range being R_C^{max}. The adverse effects of environment, such as temperature, rainfall, and fog, reduce the communication range of sensor nodes. Due to these adverse effects, if the communication range of a node shrinks below the distance to its nearest active neighbor node, $\mathscr{D}$, that sensor node is unable to communicate with any other nodes in the network, which is termed as *dumb behavior* [5], and is defined in definition 1. A sensor node with dumb behavior is called as a dumb node. A dumb node can sense its surroundings but unable to transmit the data packet to any other nodes. Hence, the CSP is responsible for establishing the connectivity between the dumb nodes and the other activated nodes in the network in order to maintain the Quality of Service (QoS).

Definition 1. *Dumb Behavior: If a sensor node senses the physical phenomena in its surroundings, and is able to transmit the sensed data neither to the any activated sensor nodes nor to the sink at a certain instant of time due to presence of adverse environmental effects, but is able transmit at a later instant of time, with the resumption of favorable environmental* *conditions, is termed as a dumb node. Such behavior is called as dumb behavior, i.e., denoted by Ψ_d. Mathematically [5],*

$$\Psi_d = \begin{cases} 1, & \{(0 < \mathscr{D} \leq r_c(\tau_i) \leq R_C^{max})\} \\ & \wedge\{(0 \leq r_c(\tau_j) < \mathscr{D} < R_C^{max})\} \ \forall \tau_i, \tau_j \ \ \tau_i \neq \tau_j \\ 0, & otherwise \end{cases}$$

B. Sensor-Cloud Infrastructure

In this work, we consider the concept of Sensor-Cloud Infrastructure (SCI) which facilitates the users by providing the services from the different WSNs without any intervention of the users. In this architecture, CSP plays an important role for providing services and maintaining the WSNs. We assume that a large number of sensor nodes are deployed over a region. These deployed sensor nodes with different functionality form multiple WSNs. The architecture considered in this work depicts in Fig. 1. This figure shows that the sensor-cloud architecture consists of a set of different type of sensor nodes which are connected to the sink through wireless connectivity. The sink is further connected to the cloud, which is responsible for providing the sensed-data of the WSNs. Among these deployed sensor nodes, few nodes are activated to cover their respective region of interest. Due to the presence of adverse environmental effects, the sensor nodes behave as dumb, and are unable to communicate their sensed-data to any other node in the network. Therefore, the cloud has to play a significant role to re-establish the connectivity between dumb nodes, and other activated nodes.

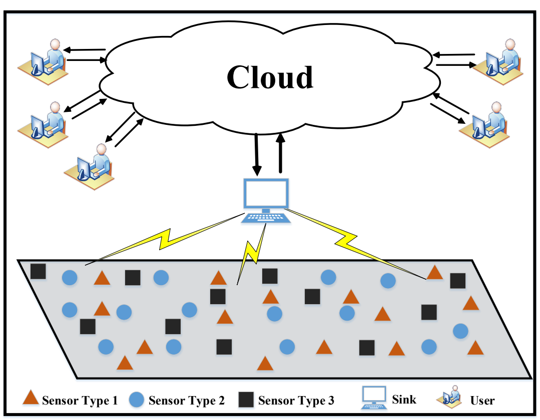

Fig. 1: Sensor-Cloud Infrastructure

IV. Game Model

In the proposed scheme, CoRDS, we use a single leader multiple followers game theoretic approach. In the proposed scheme, the cloud acts as a leader, and needs to decide the optimum number of sleep nodes to be activated in order to maintain full-connectivity of the WSNs through cloud service. On the other hand, the deployed sensor nodes, those are in sleep mode, act as the followers in the proposed scheme. Each follower in CoRDS calculates the number of dumb nodes connected to the sink through it, and tries to maximize the number of connected dumb nodes to improve its payoff and the QoS of the overall network. In the network, N_{tot} number of sensor nodes are deployed over a region, and $\mathcal{N}$ number of sensor nodes are activated to cover the entire region of interest. As the sensor nodes are GPS-enabled, the cloud knows about their positions. Among these $\mathcal{N}$ number of sensor nodes, we consider that the number of dumb nodes in the network is D_n, where $D_n \in \mathcal{N}$. The cloud knows the position of each dumb node $n \in D_n$ in the network. $\hat{S}$ is the number of nodes in the sleep mode, where $\hat{S} \in (N_{tot} - \mathcal{N})$. The cloud needs to activate the set of sleep nodes from the total available sleep node, i.e., $\hat{S}$. In order to increase the lifetime of the energy-constraint WSNs, defined in Definition 2, the cloud tries to activate less number of nodes from the available sleep sensor nodes, $\hat{S}$.

Definition 2. *Lifetime of the Network: The lifetime of a network, i.e., $\mathcal{L}$, is defined as the duration of time until the last sensor node deployed in wireless sensor network dies in the sensor cloud infrastructure. We define the lifetime of the network as the maximum time-elapsed by the sensor nodes deployed over the terrain. Mathematically,*

$$\mathcal{L} = \arg\max\{L_1, L_2, \cdots, L_n, \cdots, L_{\mathcal{N}}\} \tag{1}$$

where L_n is the lifetime of the node $n \in \mathcal{N}$.

We define the overall strategic form $\mathcal{G}$ of CoRDS as follows:

$$\mathcal{G} = [D_n^P, D_n^C, \mathcal{N}, \widehat{N}, cloud, \mathcal{U}(\cdot)]$$

The components of strategic form $\mathcal{G}$ are as follows:

i) Due to environmental effect, the number of dumb nodes present in the network is defined as $D_n^P(\cdot) \in D_n$
ii) D_n^C: Number of dumb nodes connected in the network
iii) $\mathcal{N}$: Initially activated nodes in the network
iv) $\widehat{N}$: Total number of nodes activated in the network
v) *cloud*: Cloud acts a leader of the game
vi) $\mathcal{U}(\cdot)$: Utility function of the cloud in the network

The utility function of the *cloud*, $\mathcal{U}(\cdot)$, is defined as a concave function signifying the satisfaction level of the *cloud*. The net payoff of $\mathcal{U}(\cdot)$ is derived as the difference between the revenue function ($R(\cdot)$) and the cost function ($C(\cdot)$), defined in Definitions 3 and 4, respectively. Mathematically,

$$\mathcal{U}(\cdot) = R(\cdot) - C(\cdot) \tag{2}$$

Definition 3. *Revenue function: The revenue function, $R(\cdot)$, of the cloud is considered to be a concave function. The revenue function is dependent on the ratio of the number of dumb nodes present in the network, i.e., D_n^P, and the number of dumb nodes connected to the sink in the network, i.e., D_n^C. We define the revenue function, $R(\cdot)$, as a function of ratio of the number of dumb nodes connected to the sink, D_n^C, and the number of dumb nodes present in the network, D_n^P. Mathematically,*

$$R(\cdot) = f\left(\frac{D_n^C}{D_n^P}\right) \tag{3}$$

Definition 4. *Cost function: The cost function, $C(\cdot)$, of the cloud is also defined as a concave function, and depends on the* *initially activated nodes in the network, $\mathcal{N}$ and total number of nodes activated in the network, $\widehat{N}$. With the increase in total number of activated nodes, the energy consumption of the network increases, and the duration of service provided by the cloud to the users reduces. Therefore, the cost to the cloud increases. Mathematically,*

$$C(\cdot) = f\left(\frac{\widehat{N}}{\mathcal{N}}\right) \tag{4}$$

As we assume that the utility function of the cloud signifies the satisfaction factor of the cloud for proving better QoS, the cloud tries to maximize its satisfaction factor by maximizing the payoff of the utility function of the cloud. The satisfaction factor of the cloud, i.e., $\mathscr{S}(\cdot)$ is defined in Definition 5.

Definition 5. *Satisfaction factor ($\mathscr{S}(\cdot)$): Satisfaction factor of the cloud is defined as the ratio of the total number of dumb nodes connected to the sink in the network ($D_n^C(\cdot)$) to newly activated nodes for establishing the connectivity between the dumb nodes and previously connected nodes to the sink in the network, i.e., $\eta(\cdot)$, where $\eta(\cdot) = \widehat{N}(\cdot) - \mathcal{N}(\cdot)$. Mathematically,*

$$\mathscr{S}(\cdot) = \frac{D_n^C(\cdot)}{\eta(\cdot)} = \frac{D_n^C(\cdot)}{\widehat{N}(\cdot) - \mathcal{N}(\cdot)} \tag{5}$$

The cloud aims to connect the maximum number of dumb nodes with the sink by activating less number of sleep nodes in the network. To incorporate this, the cloud defines its utility function, $\mathcal{U}(\cdot)$, and tries to maximize the payoff of the utility function, $\mathcal{U}(\cdot)$. The properties of the utility function of the cloud, $\mathcal{U}(\cdot)$, must satisfy the following inequalities as defined below:

i) The utility function, $\mathcal{U}(\cdot)$, of the cloud is considered to be a non-decreasing function, as the cloud tries to increase the number of dumb nodes to connect with sink for maximizing its satisfaction level, $\mathcal{S}(\cdot)$. Let us assume, by increasing the number of dumb nodes connected to sink from D_n^C to $\widehat{D_n^C}$, the payoff of $\mathcal{U}(\cdot)$, also increases. Here, D_n^C and $\widehat{D_n^C}$ are the previous and current number of dumb nodes connected to sink. Mathematically,

$$\frac{\delta\mathcal{U}(\cdot)}{\delta\widehat{D_n^C}} \geq 0 \tag{6}$$

ii) The marginal payoff of $\mathcal{U}(\cdot)$ is considered to be decreasing. Hence, at marginal condition, the cloud does not activate any new sleep node to cover the dumb nodes in the network. There may be different marginal situation — either all the dumb nodes are connected to the sink, or to connect a few dumb nodes, a very large number of sleep nodes to be activated. Mathematically,

$$\frac{\delta^2\mathcal{U}(\cdot)}{\delta\widehat{D_n^C}^2} < 0 \tag{7}$$

iii) With the increase in the number of activated nodes in the network to connect the dumb nodes to the sink, the cloud may provide a better value of QoS. However, the lifetime of the network decreases significantly. Therefore, the payoff of the utility function of cloud, $\mathcal{U}(\cdot)$, varies inversely with the number of activated nodes in the network. Mathematically,

$$\frac{\delta\mathcal{U}(\cdot)}{\delta\widehat{N}} < 0 \tag{8}$$

Hence, considering that the revenue function of the cloud, $R(\cdot)$, follows the concave curve, we define the revenue function of the cloud as follows:

$$R(\cdot) = \tan^{-1}\left(e^{-\frac{\widehat{D_n^C} - D_n^C}{D_n^C}}\right) \tag{9}$$

With the increase in the number of activated nodes from sleep mode, the cloud considers to reduce the lifetime of the sensor network. Therefore, with the initially deployed fixed number of sensor nodes in the region, the ability of the cloud to service the users as per their requirements gets reduced. Therefore, we define the cost function of the cloud as given below:

$$C(\cdot) = \tan^{-1}\left(e^{-\frac{\widehat{N} - \mathcal{N}}{\mathcal{N}}}\right) \tag{10}$$

Considering the revenue and cost functions given in Equations 9 and 10, respectively, we define the utility function of the cloud, i.e., $\mathcal{U}(\cdot)$ as follows:

$$\begin{aligned}\mathcal{U}(\cdot) &= R(\cdot) - C(\cdot)\\ &= \tan^{-1}\left(e^{-\frac{\widehat{D_n^C} - D_n^C}{D_n^C}}\right) - \tan^{-1}\left(e^{-\frac{\widehat{N} - \mathcal{N}}{\mathcal{N}}}\right)\end{aligned} \tag{11}$$

As the cloud makes a trade-off between the dumb nodes connected to the sink, i.e., D_n^C, and the lifetime of the network, the cloud needs to activate less number of sensor nodes from sleep mode to active mode. Hence, the cloud tries to maximize the payoff of the utility function, $\mathcal{U}(\cdot)$, defined in Equation 11.

A. Existence of Nash Equilibrium

In this Section, we evaluate the existence of Nash equilibrium for the proposed scheme, CoRDS, as shown in Theorem 1.

Theorem 1. *Given a fixed number of detected sensor nodes as dumb node, i.e., $\widehat{D_n^C}$, in the sensor cloud infrastructure, there is a Nash equilibrium in activating the number of sensor nodes which are in sleep mode, while satisfying the following inequality:*

$$\mathcal{N}(\widehat{D_n^C}^*, \widehat{N}^*) \geq \mathcal{N}(\widehat{D_n^C}^*, \widehat{N}) \tag{12}$$

Proof. Taking the first order derivative of the utility function of the CSP, $\mathcal{U}(\cdot)$, we get:

$$\dot{\mathcal{U}}(\cdot) = \frac{1}{\mathcal{N}}\left[\frac{e^{-\frac{\widehat{N}-\mathcal{N}}{\mathcal{N}}}}{1+\left(e^{-\frac{\widehat{N}-\mathcal{N}}{\mathcal{N}}}\right)^2}\right] - \frac{1}{D_n^C}\left[\frac{e^{-\frac{\widehat{D_n^C}-D_n^C}{D_n^C}}}{1+\left(e^{-\frac{\widehat{D_n^C}-D_n^C}{D_n^C}}\right)^2}\right] \tag{13}$$

Hence, by performing Jacobian on the first order derivative of the utility function of the CSP, i.e., $J\dot{\mathcal{U}}(\cdot)$, we get:

$$J\dot{\mathcal{U}}(\cdot) = -\left[\frac{e^{-\frac{\widehat{N}-\mathcal{N}}{\mathcal{N}}}}{\mathcal{N}^2}\right] + \left[\frac{e^{-\frac{\widehat{D_n^C}-D_n^C}{D_n^C}}}{[D_n^C]^2}\right] \quad (14)$$

Hence, we argue that the value of $J\dot{\mathcal{U}}(\cdot)$ is negative, as we know the constraint defined as follows:

$$\mathcal{N} \geq D_n^C \quad (15)$$

where $\mathcal{N}$ denotes the number of sensor nodes deployed in the sensor-cloud infrastructure, and D_n^C denotes the number of dumb node connected to the sink. Hence, from differential mathematics, we conclude the existence of a Nash equilibrium. □

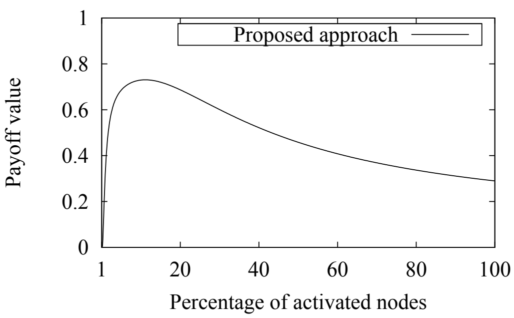

Fig. 2: Equilibrium curve of CoRDS

As shown in Theorem 1, there exists an equilibrium for our proposed approach. Fig. 2 re-establishes the fact that the payoff of the utility function of the cloud. Fig. 2 depicts that activating 15-20% nodes in the network has maximum payoff.

B. The proposed algorithm

In CoRDS, the cloud service provider decides to activate a set of sensor nodes with sleep mode using the proposed algorithm, as discussed in Algorithm 1. Depending on the payoff of the utility function, $\mathcal{U}(\cdot)$, the cloud makes a trade-off between the lifetime of the sensor networks, and the coverage of the network. Therefore, the cloud chooses the strategy, i.e., either to activate a set of sensor nodes to connect a dumb node or not to connect the dumb node, based on the number of sensor nodes in sleep mode needed to active.

Algorithm 1 Dumb node detection

Inputs:
Set of dumb nodes, $\widehat{D_n^C}$
Set of active nodes, $\widehat{N}$
Set of sleep nodes, $\hat{S}$
Output:
Set of newly activated nodes, $\widehat{N}^*$
Steps:
do
1. Activate a new set of sensor nodes, $\mathcal{N}$, to connect a new dumb node
2. $\widehat{N}^* = \widehat{N} + \mathcal{N}$
3. $\widehat{D_n^C}^* = \widehat{D_n^C} - 1$
if $\mathcal{N}(\widehat{D_n^C}^*, \widehat{N}^*) \geq \mathcal{N}(\widehat{D_n^C}, \widehat{N})$
4. The activated nodes do not need to be deactivated
5. $\widehat{N} = \widehat{N}^*$
6. $\widehat{D_n^C} = \widehat{D_n^C} - 1$
else
7. Deactivate the newly activated sensor nodes, $\mathcal{N}$
8. $\widehat{N} = \widehat{N}^* + \mathcal{N}$
9. $\widehat{D_n^C} = \widehat{D_n^C}^* + 1$
end if

V. Performance Evaluation

A. Simulation Design

In this section, we evaluate the performance of the proposed algorithm for re-establishing the connectivity of the dumb nodes in SCI. SCI is a newly introduced infrastructure. Therefore, in existing literature, the concept of dumb nodes in SCI is not considered. Hence, comparative study of our proposed scheme with similar existing scheme is infeasible. Table I depicts the list of simulation parameters used for the proposed scheme. We consider that total 100-350 number of sensor nodes with sensing range 25 m are deployed randomly over an area of 500 $m \times$ 500 m. Among these deployed sensor nodes, some of the nodes are activated, and the remaining nodes are in sleep mode.

TABLE I: Simulation Parameters

Parameter	**Value**
Number of nodes (N)	100-350
Simulation area	500 $m \times$ 500 m
Sensing range	25 m
Communication range	42-58 m

We execute extensive experimentation for the proposed scheme, and evaluate the performances of the proposed scheme by considering the following parameters:

- *Percentage of dumb nodes*: Percentage of dumb nodes represents the number of dumb nodes exists per 100 nodes.
- *Percentage of newly activated nodes*: In the proposed scheme, the sleep nodes are activated for re-establishing connectivity between the dumb nodes and the sink. This parameter represents the percentage of newly activated node for re-establishing the connectivity.
- *Re-connected dumb nodes*: Re-connected dumb nodes signifies the percentage of dumb nodes successfully connected with sink by applying the proposed scheme.

B. Results

Fig. 3 depicts the percentage of dumb nodes with the varying communication range, i.e., 42-58 m, in the network. The communication range is shown along X-axis. We observe

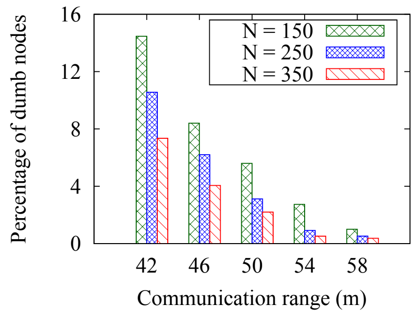

Fig. 3: Percentage of dumb nodes present in the network

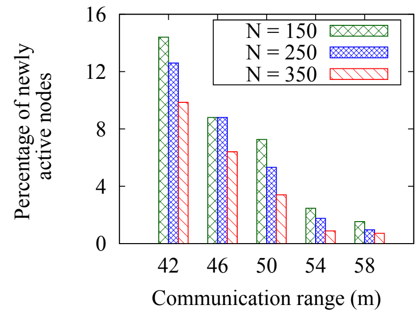

Fig. 4: Percentage of newly activated nodes

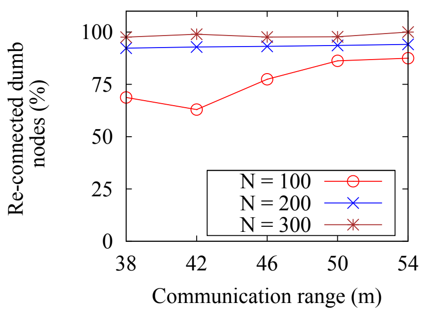

Fig. 5: Percentage of dumb nodes re-connected with the sink

that with the increase in communication range, the percentage of dumb nodes in the network increases. Fig. 4 depicts the percentage of nodes activated for re-connecting the dumb nodes. Considering Figs. 3 and 4, we conclude that with the increase in the number of dumb node in the network, the number of newly activated nodes also increases. In each of the plots, the variation in result is shown considering the total number of 150, 250, and 350 nodes in the network. Fig. 5 shows the percentage of dumb nodes connected with the sink using the proposed scheme. The communication range of the nodes varies within 38-54 m. The total number of nodes present in the network is considered as 100, 200, and 300. In each of the cases, we observe that the percentage of dumb nodes connected with sink achieves at least 85% by applying the proposed scheme.

VI. Conclusion

In this work, we have proposed a scheme for re-establishing connectivity between the dumb nodes and the sink. In this work, we have considered a newly introduced approach of the cloud and the WSN, as the Sensor-Cloud Infrastructure. In such an infrastructure, we addressed the issue of connectivity in the presence of the dumb nodes. The dumb behavior of the node causes due to the shrinkage of its communication range in the presence of adverse environmental effects.

Future extension of this work includes understanding of how the nodes behaving as a dumb node can be detected in SCI, and how the relay nodes can be placed to re-establish the overall connectivity of the network.

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