Dynamic Duty Scheduling for Green Sensor-Cloud Applications

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***Abstract*— In this paper, we propose a dynamic duty scheduling scheme for minimizing the energy consumption of the on-field sensor networks in a sensor-cloud application framework. The conjugation of cloud framework with Wireless Sensor Networks (WSNs) adds enhanced processing and storage capacity to the on-field WSN applications. However, the WSN applications performing periodic information update to the cloud exhibit low network lifetime, low resource utilization, and high cost. In this regard, the advent of the sensor-cloud technology facilitates dynamic duty scheduling of the on-field WSNs. As a result, the on-field WSNs attain improved energy-efficiency and cost-effectiveness. The simulation results show the effectiveness of the proposed scheme over the traditional scenarios.**

***Index Terms*—Sensor-cloud, Energy-efficiency, Duty scheduling, Wireless sensor network**

I. Introduction

The sensor-cloud framework refers to the advent of cloud computing [1] for enhanced monitoring of on-field distributed WSNs [2], [3]. This integrated framework empowers the typical WSNs in terms of improved processing power and storage capacity. Sensor-cloud provides efficient data management and access in a WSN deployment spanning a vast geographical area. Also, the sharing of computing resources in a cloud computing framework increases the resource utilization. This facilitates the development of real-time decision support system for use with multiple WSN applications at the same time. The potential applications of sensor-cloud span over various domains such as health-care [4], [5], multimedia streaming [6], precision agriculture, environmental monitoring, and even the military [7], [8].

A. Motivation

The on-field WSNs periodically update the sensed information in the cloud framework. However, frequent update of information increases energy consumption, and at the same time, increases the bandwidth requirement. In resource constrained networks such as WSNs, it is desirable to minimize energy consumption to maximize the sensor lifetime, while maintaining the delay constraint. In such a problem scenario, *dynamic* duty scheduling of the sensor nodes can significantly minimize the energy consumption of the on-field WSNs. Overall, the advantages of dynamic duty scheduling are as follows.

- Increased operational lifetime.
- Suitability for the use with bandwidth constrained networks.
- Facilitating optimal resource utilization.
- Quality-of-service preservation.
- Low overhead and high utility.
- Cost-effectiveness.

However, in the traditional WSNs, optimal duty scheduling is performed at the local gateways depending on the sensed information of the corresponding WSNs. Therefore, the energy consumption of the gateways, which, in turn, are energy-constrained, increases significantly. Additionally, the local gateways decide the duty schedule, based on the local observations only. Thus, we need to have a duty scheduling scheme which takes into account the global observations by different WSNs, while supporting the distributed architecture of multiple WSNs.

B. Contributions

In this paper, we propose a *dynamic* duty scheduling scheme for minimizing the energy consumption of the on-field sensor networks in a sensor-cloud application framework. The on-field sensor networks, which are typically distributed over a vast geographic area, periodically update their sensed information in the cloud storage. Thus, the sensor-cloud framework helps in reducing the computational and processing load of these on-field WSNs. We present the optimal time-interval selection strategy by forming an optimization problem in the sensor-cloud framework, in which the sensor-cloud estimates the duty time-interval based on the uploaded information from each WSN. Therefore, the proposed scheme facilitates dynamic duty scheduling for each of the on-field WSNs. Additionally, this dynamic scheduling is performed in such a manner that the optimized time-interval for any WSN is independent of the other WSNs' time-intervals. An algorithm is also devised for the proposed dynamic duty scheduling of the on-field WSNs.

The paper is organized as follows. In Section II, we briefly discuss the existing literature in the area of sensor-cloud. The proposed system architecture, with an example application scenario, is presented in Section III. The proposed framework of dynamic duty scheduling is described in Section IV. We

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present and discuss the simulation results of the proposed scheme in Section V. Finally, in Section VI, the paper concludes by citing directions for future work.

II. Related Works

Recently, several works are proposed for the sensor-cloud framework with various application domains such as health-care, multimedia streaming, agricultural irrigation management. Alamri *et al.* [2] presented a detailed survey of the sensor-cloud framework, applications, and its pros and cons. The inception of cloud computing [1] brings several advantages to the sensor network applications in terms of improved data management, higher resource utilization, scalability and cost-effectiveness. The sensor-cloud infrastructure, which facilitates virtualization of on-field sensors in a cloud framework, was proposed by Yuriyama *et al.* [3]. The end-users are able to control and access the physical sensors through the virtual sensors.

Nkosi *et al.* [9] proposed a cloud-based framework for efficient health-care delivery to the mobile users. The authors proposed a framework, which enables the execution of multimedia and security protocols in the cloud, thereby, exempting the mobile devices with heavy computations. The design of BodyCloud architecture for the management of body sensor information based on the cloud framework is described in [10]. The BodyCloud architecture facilitates scalability and flexibility of resources, and supports heterogeneous sensor deployment. The work is further extended in [11] catering programming abstractions for smart and enhanced development of body-sensor based applications. Furthermore, the authors include case studies featuring real-time cardiac sensor data streaming. Doukas and Maglogiannis [12] presented the design of a wearable system which collects health-care related data from a patient and uploads the same to the cloud. The system enables continuous health monitoring of patients and elderly persons. Misra *et al.* [5] and Das *et al.* [4] proposed optimal gateway selection techniques in a sensor-cloud framework for health-care applications.

Misra *et al.* [13] formulated the problem of bandwidth shifting and redistribution in a mobile sensor cloud environment. However, the authors argue that mere bandwidth shifting is not sufficient for maintaining Quality of Service (QoS) in such environments. Thereafter, bandwidth redistribution is applied. The issue of limited bandwidth availability in multimedia streaming was studied by Lai *et al.* [6]. In this work, the authors proposed a device and network-aware approach to provide QoS over different multimedia applications. Misra *et al.* [14] proposed a learning automata-inspired QoS framework for addressing the problem of optimal utilization of resources in a cloud computing framework.

The detailed analysis of the existing literature (such as the ones discussed above) reveals various sensor-cloud applications such as health-care, multimedia, irrigation management. The issues of resource utilization [4]–[6], QoS [6], [13], [14], and security [9] have also been addressed in the context of the sensor-cloud. However, the problem of minimizing the energy consumption of on-field sensor-cloud applications is still open. Towards this goal, we propose a dynamic duty scheduling scheme for sensor-cloud applications.

III. Proposed System Architecture

We consider a sensor-cloud framework, in which n number of on-field sensor networks ($\mathcal{W}$) are deployed at n different locations. Here, $\mathcal{W} = \{W_1, W_2, \cdots, W_i, \cdots, W_n\}$ denote the set of all the on-field WSNs. The on-field sensor nodes (S_i) in any WSN $W_i \in \mathcal{W}$, communicate the sensed information to a gateway node $G_i \in \mathcal{G}$, where $\mathcal{G}$ is the set of all the gateway nodes. A gateway node is responsible for providing communication between the on-field sensor network ($\mathcal{W}$) and the sensor-cloud. On the other hand, the sensor-cloud provides support for efficient decision making based on the large-scale on-field sensor data. The proposed system architecture is shown in Figure 1.

Each WSN W_i can be represented as a graph $G(S_i, E)$, where S_i is the set of sensor nodes present in W_i such that any sensor node $j \in S_i$. E represents the set of communication links between the nodes such that $\overline{j,k} \in E$ *iff* $d_{jk} \leq r_i$, where r_i is the transmission range of any sensor node $j \in S_i$. For the simplicity of the problem, we consider all the on-field nodes to be homogeneous types. The on-field sensors ($j \in S_i$) communicate their data to the gateway G_i at periodic time-interval $\tau^*_{i,t}$. The time-interval $\tau^*_{i,t}$ is dynamically decided in the sensor-cloud framework in our proposed scheme. The gateway G_i, upon collecting the on-field information, communicates to the sensor-cloud for storage and further processing.

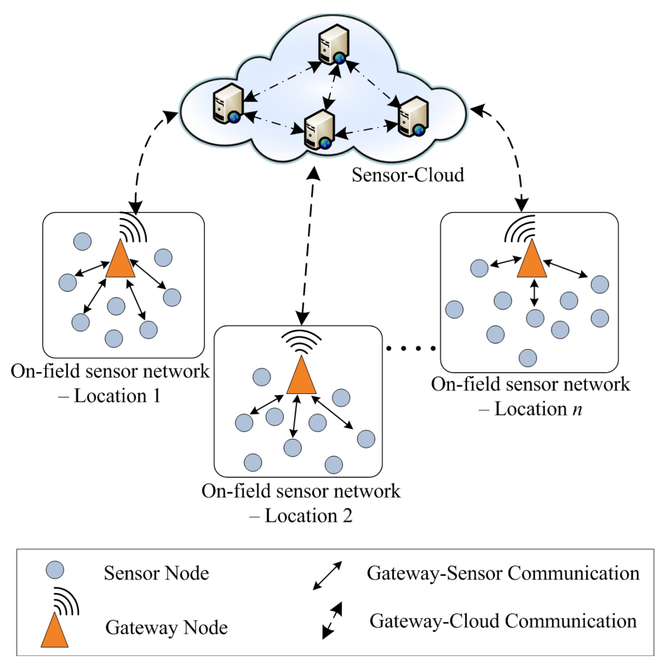


Fig. 1: The proposed system architecture

A. Application Scenario

A example application scenario of the proposed sensor-cloud framework is shown in Figure 2. The on-field WSN is deployed in an agricultural field for the monitoring of soil moisture, soil temperature, ambient temperature, and humidity. The sensed information is then stored and processed in the cloud for optimal decision of irrigation management. The intended end users of this application framework are the farmers. The farmers are able to control the total process of irrigation management by choosing an automated (or any preferred) schedule from their cell phone application (app). In Figure 2, we show the deployment of the soil-related sensors (i.e., soil moisture, temperature) sensors under ground, and the deployment of the environmental measurement sensors (i.e., ambient temperature, humidity) over ground.

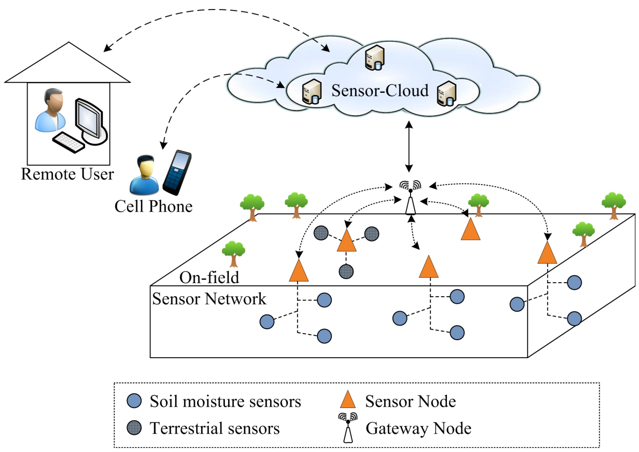


Fig. 2: Typical application scenario of on-field sensor-cloud

B. Energy Consumption of On-field Sensor Network

In this section, we show the total energy consumption ($\mathcal{E}_{W_i}(t)$) of the on-field sensor network (without the cloud framework) $W_i \in \mathcal{W}$ at time t. In Figure 1, we depict the deployment hierarchy of any on-field WSN considered in our work. As explained in Section III, the on-field sensor nodes periodically update the sensed information in the cloud. Thus, the energy consumption of any on-field sensor network at any time t depends the following factors — energy consumption due to communication between the sensor and gateway node ($E_{s,g}(t)$), and that due to the processing taking place inside any node ($E_p(t)$). Therefore,

$$\mathcal{E}_{W_i}(t) = E_{s,g}(t) + E_p(t) \tag{1}$$

The total energy consumption in the on-field WSN W_i incurred due to communication between any node $j \in S_i$ and the gateway G_i is represented in Equation (2). We have,

$$E_{s,g}(t) = \sum_{j \in S_i} \mathcal{D}_j^{\tau}(t) e^j_{s,g} \tag{2}$$

In Equation (2), $e^j_{s,g}$ denotes the energy consumption of any node j for communicating to the gateway, $\mathcal{D}_j^{\tau}(t)$ denotes the the information sensed by the j^{th} sensor node for the time-interval τ at any time instance t, and τ is decided by the gateway node, based on the local observations only.

The total energy consumption of the nodes in WSN W_i for their own computations is shown in Equation (3).

$$E_p(t) = \sum_{j \in S_i} \mathcal{D}_j^{\tau}(t) e^j_p \tag{3}$$

where e^j_p denotes the energy consumption in node $j \in S_i$ for its own computations.

Therefore, based on Equations (1), (2), and (3), the overall energy consumption of any on-field WSN W_i is computed as shown in Equation (4).

$$\mathcal{E}_{W_i}(t) = \sum_{j \in S_i} \mathcal{D}_j^{\tau}(t) \left(e^j_{s,g} + e^j_p \right) \tag{4}$$

Based on Equation (4), we can formulate the energy optimization problem for any on-field WSN $W_i \in \mathcal{W}$ as follows,

$$\text{Minimize} \tag{5}$$

$$\mathcal{E}_{W_i}(t) = \sum_{j \in S_i} \mathcal{D}_j^{\tau}(t) \left(e^j_{s,g} + e^j_p \right)$$

subject to

$$e^j_{s,g}|_{min} \leq e^j_{s,g} \tag{6}$$

$$e^j_p|_{min} \leq e^j_p \tag{7}$$

$$\tau \leq \Gamma \tag{8}$$

Consequently, the overall energy consumption of all the on-field WSNs (except the cloud framework) is calculated as

$$\mathcal{E}(t) = \sum_{W_i \in \mathcal{W}} \mathcal{E}_{W_i}(t) \tag{9}$$

IV. Dynamic Duty Scheduling Framework

A. Optimization of Energy Consumption in the Sensor-cloud Framework

In this section, we present the energy consumption in the sensor-cloud framework as an optimization problem. In the sensor-cloud framework, the overall energy consumption depends on the information uploading (sensor to gateway and gateway to cloud) and in-cloud processing. Therefore, the energy optimization problem for any on-field WSN $W_i \in \mathcal{W}$ is presented as follows.

Minimize

$$\mathcal{E}^*_{W_i}(t) = \sum_{j \in S_i} \mathcal{D}_j^{\tau^*}(t) \left(e^j_{s,g} + e^u_{g,c} \right) + \sum_{j \in S_i} \bar{\mathcal{D}}_j^{\tau^*}(t) e^p_c \tag{10}$$

subject to

$$e^j_{s,g}|_{min} \leq e^j_{s,g} \tag{11}$$

$$e^u_{g,c}|_{min} \leq e^u_{g,c} \tag{12}$$

$$e^p_c|_{min} \leq e^p_c \tag{13}$$

$$\tau \leq \Gamma \tag{14}$$

where $\mathcal{D}_j^{\tau^*}(t)$ denotes the information sensed by the j^{th} sensor node for the time-interval τ^* at any time instance t. $\bar{\mathcal{D}}_j^{\tau^*}(t)$ is the subset of the information collected by the cloud. Mathematically, $\bar{\mathcal{D}}_j^{\tau^*}(t) \subseteq \mathcal{D}_j^{\tau^*}(t)$, where $\tau^* = \tau^*_{i,t}$ is the optimal time-interval computed by the cloud for the on-field WSN W_i at any time instant t. $e^j_{s,g}$, $e^u_{g,c}$, and e^p_c denote the energy consumption for uploading from sensor to gateway, gateway to cloud, and in-cloud processing, respectively. Equations (11), (12), and (13) present the lower bounds for all the energy consumption constraints. Additionally, the delay constraint is presented in Equation (14), in order to take into account the delay-sensitive information.

Therefore, using Equation (10), the overall energy consumption of all the on-field WSNs is shown in Equation (15).

$$\mathcal{E}^*(t) = \sum_{W_i \in \mathcal{W}} \mathcal{E}^*_{W_i}(t) \tag{15}$$

B. Optimal Duty Scheduling

According to Section III, the information sensed by the on-field sensor nodes is fetched to the sensor-cloud. The sensor-cloud, empowered by its inherent computational capability, processes the information and compute the desired time-interval based on the received information.

The computation of the desired time-interval ($\tau_{i,t}$) by the cloud is shown in Equation (16). In this work, we limit our discussion on information processing in the cloud for the simplicity of the proposed scheme.

$$\tau_{i,t} = \mathcal{F}(\mathcal{D}^*_t) \tag{16}$$

where $\mathcal{D}^*_t$ is the set of the received information from the on-field WSNs which send their information at any time t. Mathematically,

$$\mathcal{D}^*_t = \bigcup_{W_i \in \mathcal{W}} \mathcal{D}_i(t) \tag{17}$$

$$\text{or, } \mathcal{D}^*_t = \bigcup_{W_i \in \mathcal{W}} \bigcup_{j \in S_i} \mathcal{D}_j^{\tau^*}(t) \tag{18}$$

Assumption 1. *The sensor-cloud framework is capable of computing the desired time-interval ($\tau_{i,t}$) for information update for any on-field WSN $W_i \in \mathcal{W}$, based on the received information [15].*

After performing the computation of the desired time-interval ($\tau_{i,t}$), the cloud determines the value of the optimal time-interval $\tau^*_{i,t}$ as follows.

$$\tau^*_{i,t} = \alpha\tau_{i,t} + (1-\alpha)\tau^*_{i,t-1} \tag{19}$$

where $\alpha \in [0,1]$ is a weightage determining factor, which is user defined. τ^*_{t-1} is the optimal time-interval for time $t-1$.

C. Algorithm

In Algorithm 1, we present the corresponding optimal duty scheduling algorithm in a step-wise manner. We consider user-defined threshold values for duty scheduling delay, namely — lower threshold delay (δ^{low}_{th}) and higher threshold delay (δ^{high}_{th}), δ^{low}_{th} is chosen for bounding the optimal time-interval such that the energy consumption of the nodes is limited. On the other hand, δ^{high}_{th} is used for maintaining the delay-sensitivity constraint.

Algorithm 1: Algorithm for Optimal Duty Scheduling

Input: Number of on-field WSNs ($W_i \in \mathcal{W}$), Total received information ($\mathcal{D}^*_t$), optimal time-interval ($\tau^*_{i,t-1}$), Lower-threshold delay (δ^{low}_{th}), Higher-threshold delay (δ^{high}_{th})
Output: Optimal time-interval ($\tau^*_{i,t}$)

```
Receive information from the on-field WSNs W_i ∈ 𝒲 at
  time t;
Compute the desired time-interval τ_{i,t} according to
  Equation (16);
Get the optimal time-interval τ*_{i,t-1} for time t − 1;
Compute the optimal time-interval τ*_{i,t} for time t
  according to Equation (19);
if τ*_{i,t} ≤ δ^{low}_{th} then
    Update τ*_{i,t} = δ^{low}_{th};
if τ*_{i,t} ≥ δ^{high}_{th} then
    Update τ*_{i,t} = δ^{high}_{th};
Update τ*_{i,t-1} = τ*_{i,t};
Return τ*_{i,t};
```

V. Results and Discussions

A. Simulation Settings

We simulated the proposed scheme using the NS-3 (http://www.nsnam.org/) simulator. The simulation parameters are listed in Table I. We present the simulation results according to the following metrics — selected duty value, energy consumption, network lifetime, and utility to the sensor gateway. In the following, the results are presented and analyzed.

B. Results and Analysis

1) Duty Scheduling: The optimal time-interval computed by the cloud for the on-field WSNs are shown in Figure 3. The results indicated that the duty schedule is dynamically allocated to the on-field WSNs. The optimal duty value determined for any WSN is independent of the duty values allocated to the other on-field WSNs.

2) Energy Consumption: We present the results for the energy consumption for two scenarios — without the sensor-cloud framework and the proposed sensor-cloud based scheme. In Figure 4(a), the energy consumption of the on-field WSNs

TABLE I: Simulation Parameters

Parameter	Value
Number of WSNs	10
Number of nodes in a WSN	50 - 100
Simulation Area	1 $Km \times 1\ Km$
Transmission Range of a sensor node (r)	100 m
Initial energy of a node	100 J
Threshold battery level (W_{th})	50 J

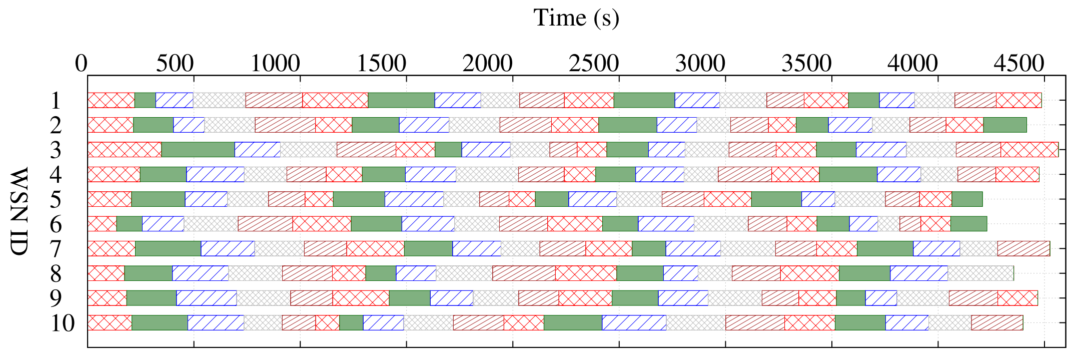
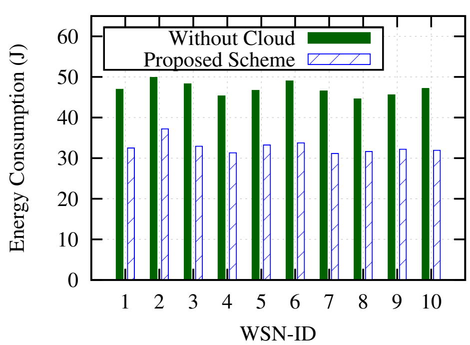
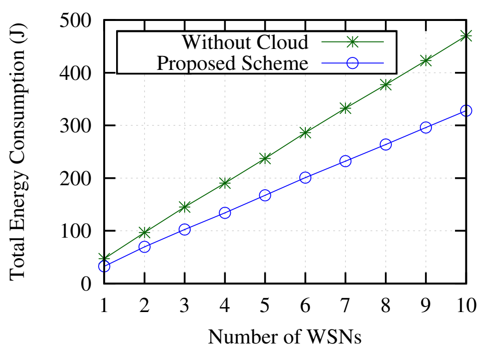


Fig. 3: Duty scheduling in the proposed scheme



(a) Energy Consumption of the On-field WSNs



(b) Total energy consumption of the on-field WSNs

Fig. 4: Energy Consumption

are shown individually. On the other hand, the energy consumption with different number of WSNs are shown in Figure 4(b). The results indicate that with the sensor-cloud framework, the on-field WSNs are able to maintain energy-efficiency in individual as well as with different number of WSNs. The energy consumption of the on-field WSNs vary according to the optimal value of the duty schedule selected by the cloud.

3) Network Lifetime: The results for network lifetime of the on-field WSNs are presented in Figure 5. Here, in Figure

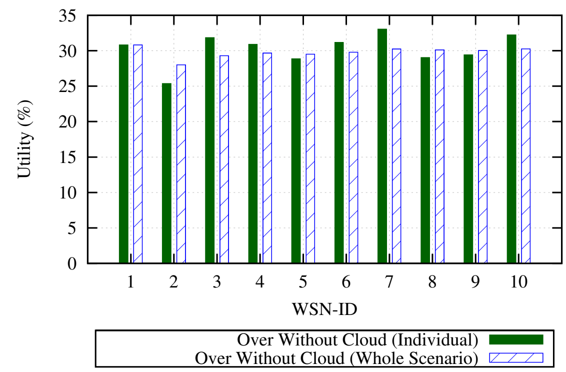


Fig. 6: Utility of the on-field WSNs

5, we denote the two different scenarios — proposed scheme and the framework without cloud as 'w/ Cl' and 'w/o Cl', and 'W1' refers to the on-field WSN W_1. As shown in Figure 4(a), due to the high energy consumption of on-field WSNs, the network lifetime decays quickly in the scenario without cloud. However, with selection of the optimal duty schedule, the network lifetime of the on-field WSNs in sensor-cloud framework remain sustained that that of the scenario without cloud.

4) Utility: In Figure 6, we present the utility of the proposed scheme over the schemes without cloud. Additionally, we also plot the overall utility obtained by the different number of WSNs. The simulation results indicate the effectiveness of the proposed scheme.

VI. Conclusion

The inception of cloud framework attracts several advantages over the existing WSN-based applications in terms of high computational power and information storage capacity. In this regard, the sensor-cloud based applications exhibit performance challenges such as high energy consumption, low resource utilization, and high cost. In this paper, we proposed a dynamic duty scheduling scheme for the on-field WSNs to

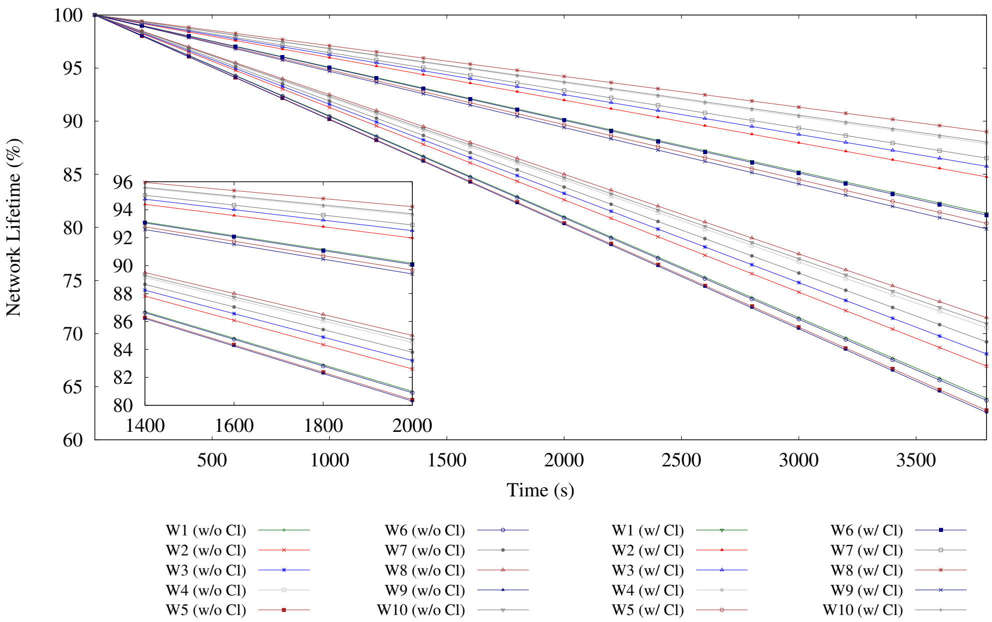


Fig. 5: Network lifetime for individual sensor networks with and without cloud

improve on the said metrics. The scheme facilitates energy-efficiency of the on-fields WSNs in sensor-cloud framework. NS-3 based simulation results indicate the effectiveness of the proposed scheme.

In the future works, we will evaluate the scheme in a real world scenario. Also, the proposed scheme may be extended to attain QoS-guarantee in the bandwidth-challenged scenarios.

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