# Lifetime Optimization of Sensor-Cloud Systems


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***Abstract*—Sensor-Cloud is an emerging technology and popular paradigm of choice in systems development for various real-life applications. It consists in integrating wireless sensor networks with cloud computing environment. In fact, the cloud provides new opportunities of massive data storage, processing and analysing that wireless sensor networks can not offer. Despite the fact that the cloud have helped to overcome many wireless sensor networks limitations, there are other challenging issues that need to be addressed. The major problem that can significantly affect Sensor-Cloud performance is the short lifetime due to limited energy supply of sensors and sometimes some sinks. In this work, we propose a Sensor-Cloud Optimization problem (SCL-OPT) that maximizes lifetime as well as increases energy efficiency of sensors and sinks layers.**



***Keywords—Wireless sensor networks; Cloud; Optimization; Lifetime; Energy***


## I. INTRODUCTION

Wireless sensor networks (WSNs) have been considered as an invaluable element for realizing the vision of the Internet of Things (IoT). They are composed of high number of small-size sensor devices with low capabilities in terms of storage, computation and energy. In recent years, WSNs have been used in many applications domains such as healthcare, military, environmental monitoring, agriculture and manufacturing. To overcome WSNs shortcomings, and allow a greater computing and storage capabilities, the cloud was proposed. Indeed, the cloud offers a scalable high performance computing and massive storage infrastructure for real-time processing and storing of data.

By integrating wireless sensor networks with the cloud, the concept of *Sensor-Cloud* was born [1]. Sensor-Cloud has become an emerging technology in the recent days and a popular paradigm of choice in system development for various real-life applications like environmental monitoring, disaster monitoring, telemetric, agriculture, irrigation and healthcare. As an example, the Sensor-Cloud system can help to monitor patients in need of medical care by allowing to report and store everyday vital signs such as oxygen saturation, blood sugar level, blood pressure, body temperature, weight, heart rate and respiratory rate. The collected data can be analysed later by physicians. When an anomaly is detected in physiological data, physicians may request extra data in a higher temporal resolution to better determine the patient's disease and give the appropriate diagnostic and drugs. As a second example of sensor-cloud application is public beaches monitoring. The environmental sensors, scattered in the beach and the water, collect information about bacteria, pH, humidity, pressure, dissolved oxygen, water temperature, wind speed and direction. The collected data is then periodically sent to the cloud to allow the local government officials for public health to analyse it. When dangerous conditions properties are detected, local government officials can request extra sensor data in a higher spatio-temporal resolution to get more information and take the appropriate decision regarding closing the beach or warning the tourists.

Sensor-Cloud offers new opportunities of huge sensor data storage and processing. However, it is subject to energy constraints since the sensor devices are battery-powered. In addition to that, it is usually not feasible to replace the sensors batteries because sensors may be deployed to monitor inhospitable and inaccessible environments. In some applications, sinks may also have limited energy supply. These two problems could significantly affect Sensor-Cloud system performance. In this work, we propose a Sensor-Cloud Optimization problem (SCL-OPT) that enhances lifetime as well as increases energy efficiency of sensors and sinks layers. To our knowledge, no studies have yet investigated Sensor-Cloud to maximize its lifetime.

The remainder of this paper is organized as follows. In Section 2, an overview of Sensor-Cloud is presented. In Section 3, the power consumption model of sensors layer is described. Section 4 proposes an optimization problem (SCL-OPT) that maximizes the lifetime of Sensor-Cloud systems. Section 5 evaluates the performance of the proposed optimization problem and presents the simulation results. Section 6 reviews the main works that have been proposed for Sensor-Cloud to optimize its performance. Section 7 concludes the paper.

## II. SENSOR-CLOUD OVERVIEW

Sensor-Cloud [1] is an extended form of cloud computing to manage sensors scattered throughout a network. By integrating wireless sensor networks with cloud computing environment, several limits of sensor devices like low processing and memory capacity can be resolved. In fact, the cloud offers a huge storage capacity and processing capabilities. Sensor-Cloud enables collecting a huge amount of sensor data by linking WSN and cloud through gateways or sinks. Sinks collect information from various sensor nodes and send it to the cloud in order to be stored. The cloud provides users access to these data through Internet. Sensor-Cloud has a three-tier architecture divided in three layers as shown in the Figure 1.

Sensors Layer: It contains one or more wireless sensor networks. Each network can be composed of different types of sensors for instance temperature, humidity and pressure. Each sensor device has an owner who can register or delete its


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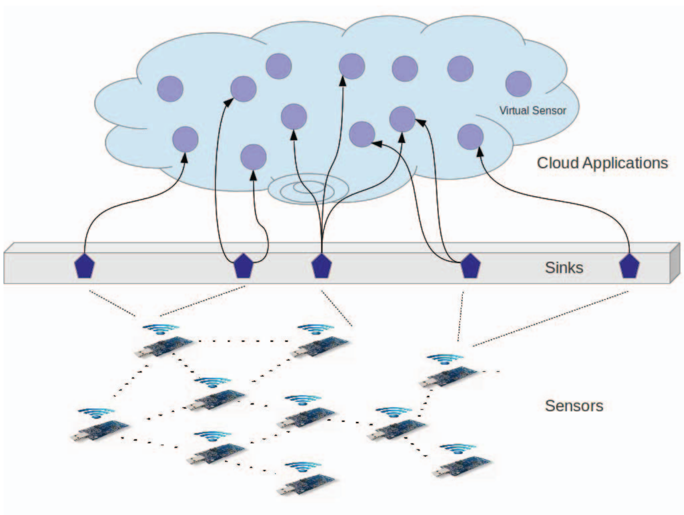



Fig. 1: Sensor-Cloud layers

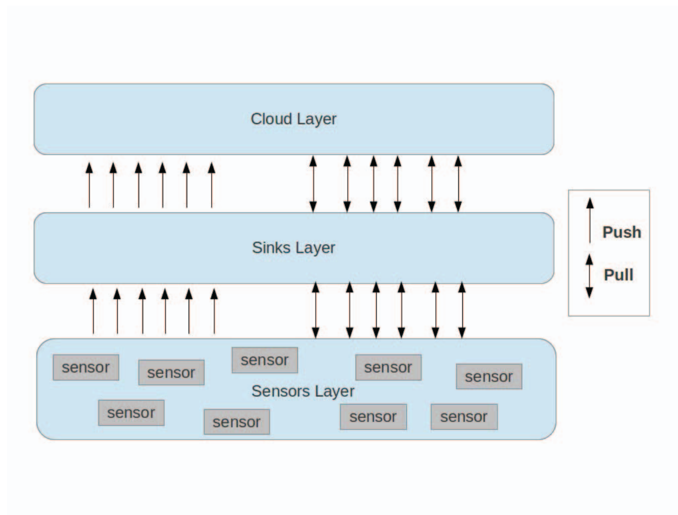



Fig. 2: Push and Pull mechanism in Sensor-Cloud system

device. The sensor devices have limited energy supply because they are battery-operated. The sensors send their acquired data in a hop-by-hop way through a given network topology towards a collection point *i.e.,* sink. Different routing protocols can be adopted to forward data packets [2].

Sinks Layer: It is composed of many sinks which are responsible of collecting data from individual sensors in the network. The sinks store received sensor data in their memory space and transmit it periodically to the cloud layer by using the same or different transmission rate. The sinks play the role of mapper between physical sensors and virtual sensors at the cloud since they know the origins and destinations of sensor data. Contrarily to the sensors which are very constrained in energy, the sinks are often considered resource-rich since they are most frequently plugged on wall. However in some applications, some sinks may be limited in terms of energy because they are powered by batteries or solar panels. When an information required by applications is missing, the sink receives a request from the cloud. Then, it issues a query to the sensor that has the requested data. Upon receiving the query, the sensor acquires the data and returns the needed information.

Cloud Layer: It is composed of one or more clouds that host and manage services of end-user applications. Applications are performed on virtual machines in clouds. Users request virtual sensors via cloud applications in order to supervise the physical environment. If a virtual sensor already has information that the user requests, it returns that information. Otherwise, the virtual sensor issues a query and sends it to the sink node.

In Sensor-Cloud, the way of collecting data from sensors can be divided into two mechanisms: **Push** and **Pull** (see Figure 2). In Push mechanism, the sensors periodically send the collected data to the sinks layer. In Pull mechanism, there is a round trip for requesting sensor data and receiving that data.

The main problem to be addressed in the Sensor-Cloud are the low energy capacity of sensors. In the section IV, the model used to determine the power consumption of sensors layer is presented.

## III. Related Work

Many architectures and research frameworks have been recently proposed to integrate wireless sensor networks to the cloud [3][4][5][6]. The majority of these works study three-tier architecture and focus on publish/subscribe communication between the sinks and cloud layers and push communication between sensors and sinks layers. Only in [6], the authors propose a two-tier architecture composed of sensors and cloud layers without considering an hybrid push-pull communication.

In wireless sensor networks, optimization methods to balance push and pull communication mechanisms have been extensively studied like in [7][8]. However, none of these strategies fit perfectly to Sensor-Cloud systems because each layer has been optimized separately. These reasons have led research to investigate push and pull communications in Sensor-Cloud infrastructures. There are two studies closely related to our work in the sense that they seek to improve Sensor-Cloud performance by proposing an optimization problem [9][10].

In [9], the authors propose a three-tier architecture called CEB (Cloud, Edge and Beneath). CEB enhances scalability and increases energy efficiency via two algorithms optimizing data transmission rates between cloud and edge layers and between edge and sensor layers, respectively. The optimization is performed with respect to energy consumption of sensor nodes. In [10], the authors study push-pull hybrid communication between the sensor and cloud layers through the edge layer. They propose an optimization algorithm for sensor and sink nodes with respect to multiple objectives. The aim is to seek the optimal transmission rate of each node. The optimization is performed with respect to data yield, bandwidth and energy consumption.

Unlike existing works which focus on data transmission rate configurations, this paper formulates an optimization problem that maximizes sensor-cloud lifetime with respect to energy constraints of sensors and sinks layers.

## IV. POWER CONSUMPTION MODEL OF SENSORS LAYER

To calculate the power consumption at sensors layer, the same model used in [11] is considered. Therefore, the power expended in J/s to receive $a_1$-bit/s in the radio model is:

$$P_{Rx}(a_1) = a_1 \; E_e \tag{1}$$

where $E_e$ (J/bit) is the energy spent per bit in the electronic circuits at the transceiver.

The power expended in J/s to transmit $a_2$-bit/s to a distance $d$ is:

$$P_{Tx}(a_2, d)) = a_2 \; (E_e + E_{amp} \; d^{\beta}) \tag{2}$$

where $E_{amp} \; d^{\beta}$ (J/bit) is the energy consumed per bit at the amplifier. $d$ is the distance between the transmitting and the receiving sensor. $\beta$ is the path loss exponent.

Thus, the total power consumed by a sensor node in (J/s) is:

$$P_{Rx}(a_1) + P_{Tx}(a_2, d)) = a_1 \; E_e + a_2 \; (E_e + E_{amp} \; d^{\beta}) \tag{3}$$

Notice that the energy spent by any sensor when it is idle is assumed negligible (*i.e.,* an ideal scenario is assumed where the transceiver is turn off when not used). An ideal MAC layer with no collisions and retransmissions is assumed. The routing protocol used is the shortest path algorithm [2].

## V. SENSOR-CLOUD LIFETIME OPTIMIZATION

This section proposes an optimization problem (SCL-OPT) that maximizes the lifetime of Sensor-Cloud systems. This is achieved by optimizing Push and Pull periods. The parameters and variables used to describe the problem are:

Parameters:

- $S$ represents the set of sensor nodes.
- $\mathcal{K}$ represents the set of all sink nodes.
- $\mathcal{K}'$ is the set of battery-powered sink nodes $\mathcal{K}' \subset \mathcal{K}$.
- $m$ is the communication mechanism used in the Sensor-Cloud. It is composed of two types *Push* or *Pull*, which are noted respectively $p$ and $pp$.
- $T_m$ (s) is the minimum duration time of data collection period where the communication mechanism $m$ is used in the Sensor-Cloud.
- $e_0(i)$ (J) is the initial energy of the sensor node $i$.
- $b_0(k)$ (J) is the initial energy of the battery-powered sink $k$.
- $g_{ik}$ (bit/s) is the data generation rate of sensor node $i$ to push data to sink $k$ in Push mechanism.
- $v_{ki}$ (bit/s) is the data rate of queries received from cloud and sent by sink $k$ to sensor $i$ during the Pull mechanism.
- $y_{ik}$ (bit/s) is the data rate of packets sent by sensor $i$ to answer query received from the sink $k$ during the Pull mechanism.
- $r_{ij}$ (bit/s) is the data transmission rate from sensor $i$ to sensor $j$ where the push mechanism is used.
- $N_i$ is the set of $i$'s neighbors.
- $Q_i$ is the set of sensor nodes that the node $i$ forwards their queries since it is located in their path towards the sink $k$.
- $p_i^m$ (J/s) is the power consumed in sending and receiving data by sensor node $i$, where the communication mechanism $m$ is used in the Sensor-Cloud.
- $c_k^m$ (J/s) is the power consumed in sending and receiving data by sink node $k$, where the communication mechanism $m$ is used in the Sensor-Cloud.
- $\alpha_1$ (J/bit) is the energy spent per bit by each sink node in reception.
- $\alpha_2$ (J/bit) is the energy spent per bit by each sink node in transmission.

Variables:

- $T$ (s) is the network lifetime of the Sensor-Cloud when using mixed push and pull mechanism.
- $l_p$ is an integer variable which represents the number of periods when the Push mechanism is used.
- $l_{pp}$ is an integer variable which represents the number of periods when the Pull mechanism is used.

$$\max \; T \;\; = T_p l_p + T_{pp} l_{pp} \tag{4}$$

$$T_p \; l_p \; p_i^p + T_{pp} \; l_{pp} \; p_i^{pp} \leq e_0(i), \;\; i \in S \tag{5}$$

$$T_p \; l_p \; c_k^p + T_{pp} \; l_{pp} \; c_k^{pp} \leq b_0(k), \;\; k \in \mathcal{K}' \tag{6}$$

$$l_p \geq 0, \; l_{pp} \geq 0 \tag{7}$$

The equation (4) maximizes the network lifetime. The equation (5) assures that the energy consumed in receiving and transmitting data by each sensor does not exceed its initial energy. The equation (6) guarantees that the energy consumed by each battery-powered sink does not exceed its initial energy.

The power $p_i^p$ expended in Push mechanism is computed as follows:

$$p_i^p = E_e \sum_{j:i \in N_j} r_{ji} + (E_e + E_{amp} \; d^{\beta}) \sum_{j \in N_i} r_{ij}, \tag{8}$$

At each node in Push communication mechanism, the total of packets sent is equal to the total of received packets plus the data packets generated at sensor node $i$ towards sink $k$:

$$\sum_{j:i\in N_j} r_{ji} + g_{ik} = \sum_{j\in N_i} r_{ij},\ i\in S,\ k\in\mathcal{K} \tag{9}$$

Using the two equations (8) and (9), the power $p_i^p$ is computed as follows:

$$p_i^p = E_e \sum_{j:i\in N_j} r_{ji} + (E_e + E_{amp}\, d^{\beta})(\sum_{j:i\in N_j} r_{ji} + g_{ik}),\quad i\in S,\ k\in\mathcal{K} \tag{10}$$

The power $p_i^{pp}$ expended in Pull mechanism contains power consumption in receiving queries from the sink node $k$, transmitting answers and power consumed in receiving and transmitting queries destined to other sensors. It is computed as follows:

$$\begin{aligned} p_i^{pp} = E_e\, v_{ki} + y_{ik}\,(E_e + E_{amp}\, d^{\beta}) +\ E_e \sum_{j\in Q_i} v_{kj} \\ + \sum_{j\in Q_i} v_{kj}\,(E_e + E_{amp}\, d^{\beta}),\ i\in S,\ k\in\mathcal{K} \end{aligned} \tag{11}$$

The power $c_k^p$ consumed in Push mechanism by the battery-powered sink $k$ is equal to power expended in reception and transmission of incoming sensor data. It is computed as follows:

$$c_k^p = \alpha_1 \sum_{i\in S} g_{ik} + \alpha_2 \sum_{i\in S} g_{ik},\ k\in\mathcal{K}' \tag{12}$$

The power $c_k^{pp}$ expended in Pull mechanism by the battery-powered sink $k$ is equal to power consumed in reception and transmission of queries received from the cloud and reception and transmission of sensor data answers. It is calculated as follows:

$$c_k^{pp} = \alpha_1 \sum_{i\in S} v_{ki} + \alpha_2 \sum_{i\in S} v_{ki} + \alpha_1 \sum_{i\in S} y_{ik} + \alpha_2 \sum_{i\in S} y_{ik},\ k\in\mathcal{K}' \tag{13}$$

## VI. Simulation Results

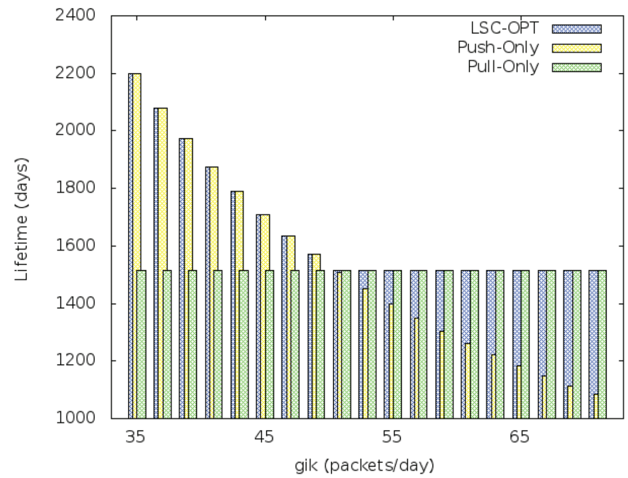
To evaluate the performance of the proposed optimization problem for Sensor-Cloud infrastructures, simulations are configured with a set of parameters as shown in Table I. A network with hundreds of sensor nodes is simulated to connect to a cloud through a sink node. The sensors are randomly distributed in a 50mx50m square network. They may periodically send data towards the cloud through the sink or answer the received queries. The data transmission rate of sensors and sinks is assumed constant. The sink has an infinite energy supply. It is located at a random position inside the network. Cloud applications issue complex and simple queries per day. Simple queries can be answered by virtual sensors in the cloud without a need of collection from sensors layer.

To get a deeper understanding of the efficiency of SCL-OPT solution, the lifetime of Sensor-Cloud is investigated and compared with two other approaches: Push-Only and PULL-Only. In the former, sensors data is only pushed to the cloud through the sink. In the latter, sensors receive queries from the cloud through the sink and send answers. To determine the Sensor-Cloud lifetime and the optimal periods of Push and Pull, the proposed optimization problem SCL-OPT is solved with GLPK [12]. The calculation of the power consumed by each sensor node was provided by simulations.

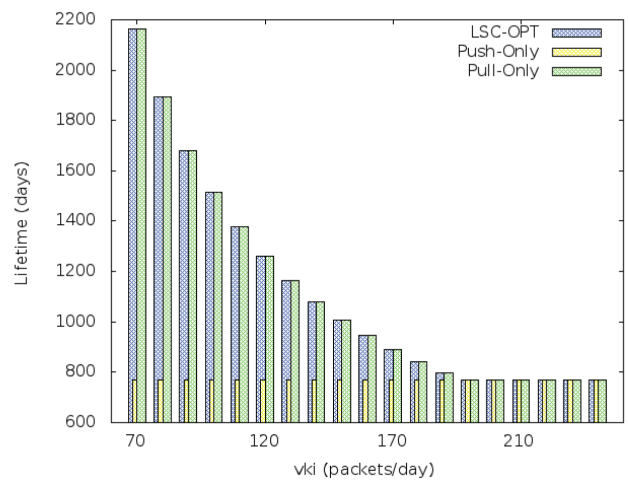
In Figure 3, the lifetime obtained with the resolution of SCL-OPT problem is analysed for increasing values of

TABLE I: Parameters values

| Parameter | Value |
|---|---|
| Number of sensors $\vert S\vert$ | 100, 200 |
| Packet size | 120 Bytes |
| Query size | 60 Bytes |
| $E_e$ | 50 nJ/bit |
| $\beta$ | 2 (free space) |
| $E_{amp}$ | 100 pJ/bit/m$^2$ |
| $e0$ | 500 joules |
| Confidence level | 95 % |

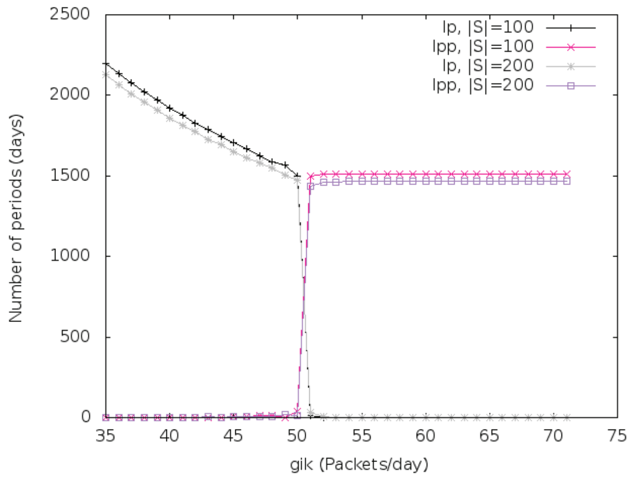



(a) Lifetime with $v_{ki}$ = 100 packets/day and an increasing $g_{ik}$

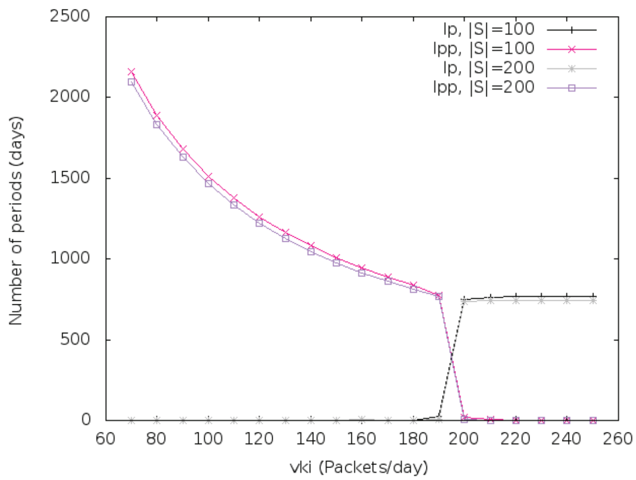



(b) Lifetime with $g_{ik}$ = 100 packets/day and an increasing $v_{ki}$

Fig. 3: Sensor-Cloud lifetime, $|S|$= 100 sensors




(a) Number of $lp$ and $lpp$ with increasing value of $g_{ik}$




(b) Number of $lp$ and $lpp$ with increasing value of $v_{ki}$

Fig. 4: Optimal number of periods $lp$ and $lpp$ determined by SCL-OPT with different values of sensors $|\mathcal{S}|$

data generation rate $g_{ik}$ and data query rate $v_{ki}$. The results show that SCL-OPT maximizes the Sensor-Cloud lifetime and achieves trade-off between lifetimes obtained with Push-Only and PULL-Only approaches. The average lifetime improvement with SCL-OPT with different $g_{ik}$ reaches 10 % against both Push-Only and PULL-Only strategies (see Figure 3(a)).

Figure 4 represents the number of Push and Pull periods respectively $lp$ and $lpp$ determined by SCL-OPT with growing values of data generation rate $g_{ik}$ and data query rate $v_{ki}$. The simulations was performed with 100 and 200 sensors. When data generation rate $g_{ik}$ increases (more than 50 packets per day), the number of $lpp$ grows which means than SCL-OPT behaves as PULL-Only. Otherwise, $lpp$ decreases and SCL-OPT acts as Push-Only (see Figure 4(a)). In Figure 4(b), the same observation can be made. When data query rate $v_{ik}$ issued by the cloud increases (more than 190 queries per day), the number of $lpp$ becomes very low and SCL-OPT behaves as Push-Only. Otherwise, it acts as Pull-Only. This shows that SCL-OPT behaves as PULL-Only when requesting data from sensors tends to be more economical than periodically pushing data and as Push-0nly otherwise leading to a less energy waste at sensors layer.

## VII. Conclusion

This paper explores the problem of energy constraints of Sensor-Cloud infrastructure in order to improve its performance and extend its lifetime, which is really needed in practice. As a solution, a Sensor-Cloud optimization problem is proposed to enhance its lifetime as well as increase its energy efficiency. The problem is formulated as Integer Linear Programming that maximizes lifetime of sensors layer by determining the optimal number of Push or Pull periods for data collection or requesting. The problem optimizes Sensor-Cloud lifetime with respect to energy consumption of sensors and sinks during the different Push and Pull mechanisms. The proposed approach was evaluated by numerical simulations. The results showed that with our proposed approach the network lifetime can be improved about 10 %.

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