ETOP: Energy-efficient Transmission Optimization Protocol in Sensor Networks of IoT

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Abstract. In the past few years, smart devices have been rapidly increased due to their ever-increasing use in different real-world applications. Most of these devices are sensor nodes that represents the basic element in the Internet of Things (IoT). This increasing number in sensor devices will lead to an increase in the size of transmitted sensed readings across the internet, spending energy of sensor nodes, and decreasing the lifetime of the network. Therefore, to tackle this problem, an Energy-efficient Transmission Optimization Protocol (ETOP) is proposed to optimize the transmission and the lifetime of Sensor Networks of IoT. ETOP achieves this mission by using a simple reduction algorithm-based correlation clustering at the sensor stage to remove the redundant data before transmitting it to the gateway or sink. The results are conducted using the OMNeT++ simulator which show that the ETOP protocol can optimize the transmission and the lifetime of Sensor networks better than other methods.

Keywords: IoT**,** Sensor Networks, Transmission Optimization, Data Reduction, Energy Efficiency.

1 Introduction

Smart sensor nodes in the IoT network are used in various applications ranging from health care, military, smart home, safety, agriculture, smart transportation, and so on [1]. These smart devices will keep on rapidly increasing in the near future. These sensor devices represent the basic element in the IoT and the biggest data generator on the IoT network [2]. Therefore, the huge number of IoT sensor nodes leads to massive traffic that must be transmitted over the IoT network. A great part of this transmitted data by the sensor nodes are temporally correlated or similar data. Since the smart sensor devices have limited memory, energy, processing, and communication and since the sending and receiving aspects of the traffic are the ones spending the most energy [3,4,5], it is therefore necessary to process this data and remove the unnecessary data before transmitting it to the next destination [6]. It is important to design energy-efficient protocols that reduce similar correlated data to save power, thus enhancing the lifetime while saving the data integrity at a suitable level [7]. The contribution of this paper is summarized as follows.

I. This paper suggests an Energy-saving Transmission Optimization Protocol (ETOP) to optimize the transmission and the lifetime of Sensor Networks of IoT. It is implemented in a distributed way at each sensor node and it achieves data collection, data processing and then transmission. During the collection, the sensor gathers the sensed readings and saves them a period of time. After that, the sensor applies a simple reduction algorithm-based correlation clustering to remove the redundant data before transmitting it to the gateway or sink.

II. Some experiments are performed using OMNeT++ simulator [8]and based on real reading from the sensor nodes deployed in the Intel Lab [9]. The simulation results explain the that the proposed ETOP protocol outperforms the other methods PFF [10] and ATP [11] in terms of energy consumption, data accuracy, and data reduction ratio.

The rest of the paper is arranged as follows. Next Section explains the related works. Section 3 introduces the ETOP protocol in more details. Section 4 introduces the simulation results. Section 5 is assigned to the conclusion and future work.

2. Literature review

This section introduces several related works using different technique to reduce the data collected and improve the lifetime. In [10], the PFF method is executed in the sensor device and aggregator node. The authors use the Jaccard similarity to reduce redundant data in the sensor node while they employ set similarity at the aggregator node to reduce the redundant sets of data. The authors in [11] present a technique called ATP at the sensor device to decrease the data before transmitting it to the sink. They remove the redundancy at the sensor node and then apply some methods different to reduce the spatially correlated data in the gateway. The work in [12, 13] presents a DaT method for lowering the size of sensed data in WSN. The authors suggest a method to cluster the data using a modified K-nearest neighbour. After that, it forwards only one data from each group. Then, they further reduce the data at the second level of the network using the clustering approach. The authors in [14] suggest a TLDA method to enhance the sensor network lifetime. They apply the time series methods in the sensor and aggregator nodes to diminish the redundant data in the WSN.

The works in [15, 16, 17, 18] focus on the data gathering and sampling approaches using different similarity techniques to reduce the redundant data during sensing in the same conditions for long periods. The authors in [19, 20, 21] propose several data mining techniques and algorithms to reduce similar data either on the sensor nodes and/or aggregators.

In this paper, an Energy-efficient Transmission Optimization Protocol is introduced to optimize the transmission and the lifetime of Sensor Networks of the IoT. ETOP is used in a distributed way at each sensor node and it achieves the data collection, data processing and then the transmission. During the collection, the sensor gathers the sensed readings and saved them for a certain period of time. After that, the sensor implements a simple reduction algorithm-based correlation clustering to remove the redundant data before transmitting it to the gateway or sink.

3. Network Model

In most sensor networks based IoT, the sensor nodes are sending their sensed data periodically, are called periodic sensor networks. The proposed ETOP protocol is based on this type of network. Each sensor device k captures new reading r_i at a slot of time s. After that, the device k constructs a vector of sensed readings $R^k = \{r_1^k, r_2^k, \dots, r_N^k\}$ at every period p, where R is the number of readings captured during period p and transmits them to a certain gateway or node leader [23, 24]. Figure 1 exhibits an example of periodic sensor nodes where each sensor device captures one reading every five minutes where s = 5 minutes, and transfers its collected vector of data which includes five readings where N =5, to the gateway at the end of each period.

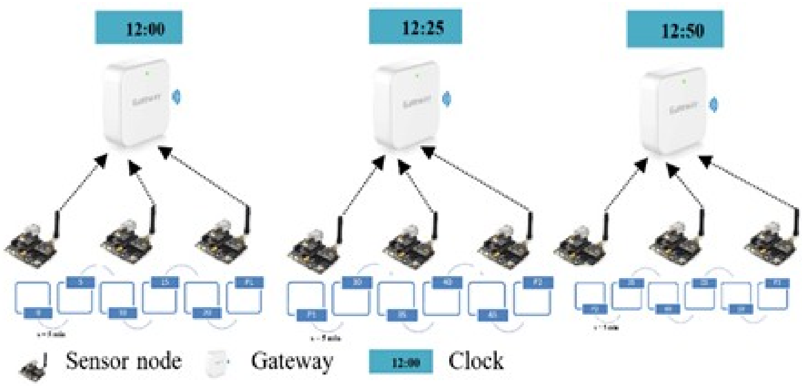

Figure 1 Periodic sensor network model with illustrative example.

In the periodic data sensing model, it is important to take into account the dynamic changing of the conditions of the monitored area of interest. These conditions can either speed up or slow according to the situation of the surrounding environment [25, 26]. It is expected that the sensor device captures similar or close readings many times especially when the time slot period s has decreased. This can make the sensor device transmit large redundant data during every period. These huge collected readings can highly participate in reducing the energy of the sensor battery. Therefore, it is important to remove the redundant data before forwarding them to the gateway.

4. ETOP protocol

This section illustrates the ETOP protocol for sensor networks of IoT. The lifetime of the network in this protocol is divided into periods and each period includes sensing the reading, processing it, and finally transmitting it to the gateway. The sensor transmission reduction algorithm is implemented to remove the readings redundancy and to decrease the traffic transmission to the next level of the network (sink or gateway). Figure 2 shows the ETOP protocol.

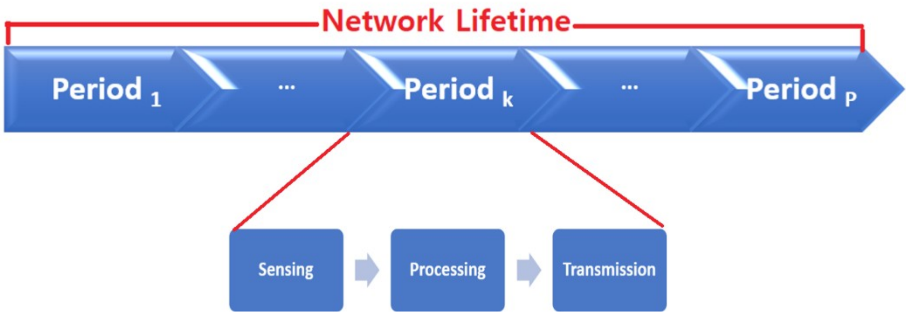

Figure 2: ETOP protocol.

Each sensor at this stage senses its surrounding environment and sends the sensed readings periodically to the gateway. Therefore, during one period the sensor device collects a vector of readings R = $\{r_1, r_2, ..., r_N\}$, where N is the number of readings during one period. The gathered data are similar or very close to each other due to the slow change in the environmental conditions. This temporal correlation can be treated and eliminate the similar reading before transmitting it to the gateway to save energy thus enhancing the lifetime of the network.

Therefore, a simple lightweight reduction algorithm based on correlation clustering algorithm was used to remove the redundant readings to reduce transmitted traffic to the gateway. This saves the energy of sensor nodes and maximizes the life of the batteries of sensor nodes. This algorithm will cluster the readings in the R vector into groups of similar readings, and only one reading for each group will be sent to the gateway. This clustering algorithm is quick and needs one passing over the collected readings R. This algorithm is implemented in a distributed way in each IoT sensor in the network. Algorithm 1 exhibits a Transmission reduction-based correlation clustering algorithm. This algorithm used a different function *DiffrenceFunc* (see step 8 in Algorithm 1) to allow the close readings to belong to the same group if the difference between them is less than or equal to threshold T. The difference function can be defined as follows

Definition 1 (*DiffrenceFunc*). We define the difference function between two readings r_i and $r_j \in R$ captured by the sensor device as:

$$DiffrenceFunc(r_i, r_j) = \begin{cases} 1 \; if \; |r_i - r_j| \le T \\ 0 \quad Otherwise. \end{cases}$$

Algorithm 1 **Transmission reduction-based correlation clustering**

Require: R: set of gathered readings. N: number of readings, T: distance threshold
Ensure: X: reduced data after removing redundancy.

$F_i \leftarrow$ false; // i $\leftarrow$ 1,…, N
g $\leftarrow$ 1;
$DS_1^g \leftarrow R_1; DS_0^g \leftarrow 1;$
$F_1 \leftarrow$ true;
QuickSort (R) ; // sort the readings in R
$for\ k \leftarrow 1$ ¿ $N\ do$
  $if\ F_k = false\ then$
    $if\ DiffrenceFunc(DS_1^g, R_k, T) = 1\ then$
      $DS_0^g \leftarrow DS_0^g + 1;$
      $DS_{DS_0^g}^g \leftarrow R_k$
    else
      $g \leftarrow g + 1;$
      $DS_0^g \leftarrow R_k$
    endif
    $F_k \leftarrow$ true;
  endif
endfor
$for\ k \leftarrow 1$ ¿ $g\ do$
$X_k \leftarrow Average(DS^k, DS_0^k);$ // average of group DS^k of length DS_0^k
: endfor
$return\ X;$

In Algorithm 1, the time complexity required to implement this algorithm is O(NlogN). Each sensor node will execute this algorithm at each period to eliminate the redundant readings, save energy, and extend the sensor network's lifetime.

5. Performance Evaluation and Analysis

The proposed ETOP protocol has been evaluated using the OMNeT++ network simulator [8]. Several experiments have been achieved using real readings from sensor devices which are deployed in the Intel Berkeley Lab. [9]. This Lab. includes 47 sensor devices which are responsible for gathering the values of temperature, voltage, humidity, and light every 31 seconds (see Figure 3). Table 1 shows the simulation parameters.

Table 1. Parameters values for simulation.

Parameter	Value
N	20, 50, and 100 readings
Nodes Number	47 nodes
E_{elec}	50 nJ/bit
B_{amp}	100 pJ/bit/m^2
T	0.03, 0.05, and 0.07

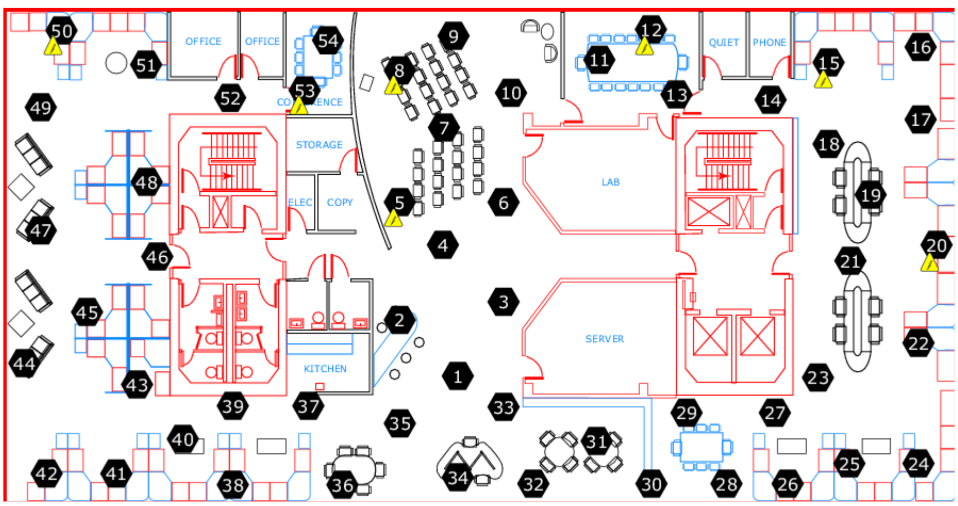

Figure 3. Intel Berkeley Lab.

The ETOP protocol uses Heintzelman's model [22] for energy consumption, and this model only considers the sending and receiving consumed energy during the simulation (see Figure 4). The packet size is the number of readings in the period multiplying by 64 bits.

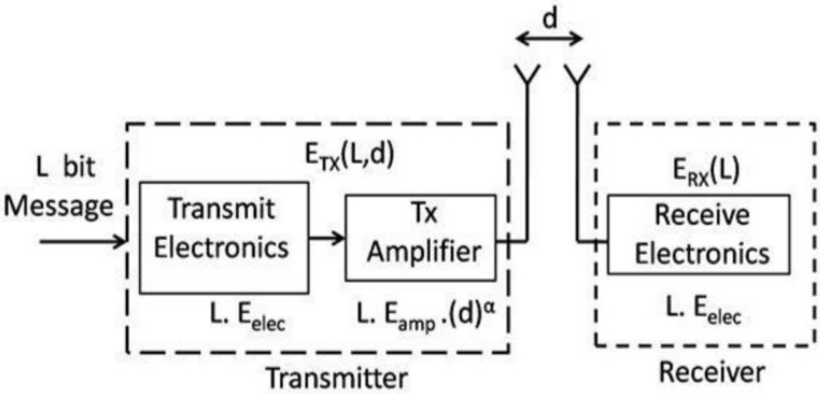

Figure 4: Heintzelman's model for energy consumption

The proposed ETOP protocol assessed using different performance metrics like energy consumption, transmitted readings, accuracy. It is compared with ATP method [11] and the PFF algorithm [10] results.

5.1 Readings Reduction ratio

The elimination of unnecessary readings represents one of the essential missions in the IoT sensors. This experiment shows the ratio of data readings after applying the ETOP protocol inside the IoT sensor for Transmission reduction. Figure 5 illustrates the ratio of readings reduction. The ETOP protocol achieves from 94% up to 97% and from 75% up to 81% of transmission reduction by each IoT sensor compared to PFF and ATP respectively. It can be observed that the ETOP protocol decreases the number of transmitted data when N or T increases, because of increasing similar readings (data redundancy) that were removed during each period.

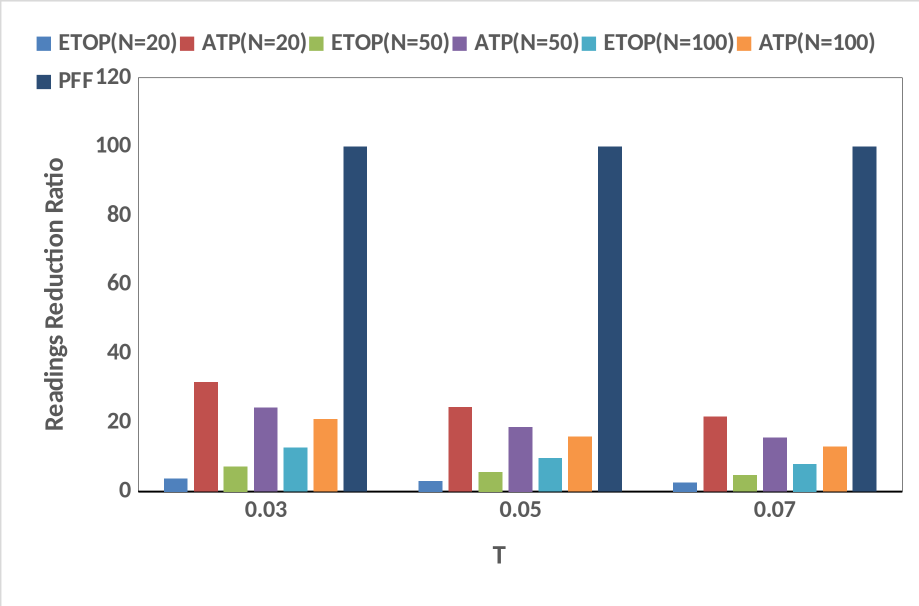

Fig. 5. Readings Reduction ratio.

As shown in these results, the ETOP protocol outperforms the other methods in terms of data readings reduction and it decreases the transmission, saves energy, and extends the IoT sensor network lifetime.

5.2 Energy consumption

Energy saving is one of the most important goals that should be taken into account when designing any protocol for the sensor networks. This section studies the impact of the proposed ETOP protocol on the consumed energy by the sensor nodes. Figure 6 introduces energy consumption by the IoT sensor nodes and uses different sizes of readings. The IoT sensor node reduces the consumed energy by the proposed ETOP protocol from 65% up to 77% and from 58% up to 74% in comparison with PFF and ATP methods respectively. It can be seen that the ETOP protocol increases the amount of saved energy when T or N increases, due to a reduction of transmitted data to the gateway during each period.

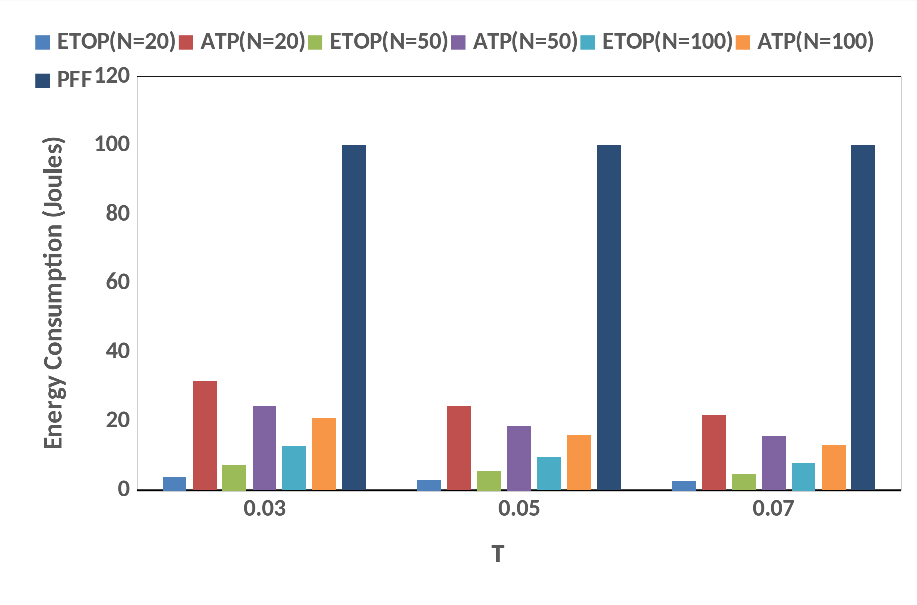

Fig. 6. Energy consumption.

The results show that the ETOP protocol can reduce the consumed power due to a decrease in the transmission traffics at each IoT sensor node before sending it to the next level of the network.

5.3 Accuracy

Since transmission reduction is an essential factor that affects the performance of the network, then it is necessary to reduce the reading traffics, thus reducing the communication cost before transmitting the readings to the next level of the network. At the same time, it is important to keep the quality of the received readings at an acceptable level in the next level of the network. The percentage of reading loss represents the accuracy of received data readings at the next level of the network. Figure 7 presents the percentage of data readings loss for all methods. It can be seen from the conducted results that the proposed ETOP protocol minimizes respectively the percentage of lost data readings from 41% up to 99.8% and from 54% up to 99.8% in comparison with the PFF and the ATP methods.

It can be concluded from the results that the proposed ETOP protocol reduced the transmission volume efficiently while keeping a suitable level of readings accuracy.

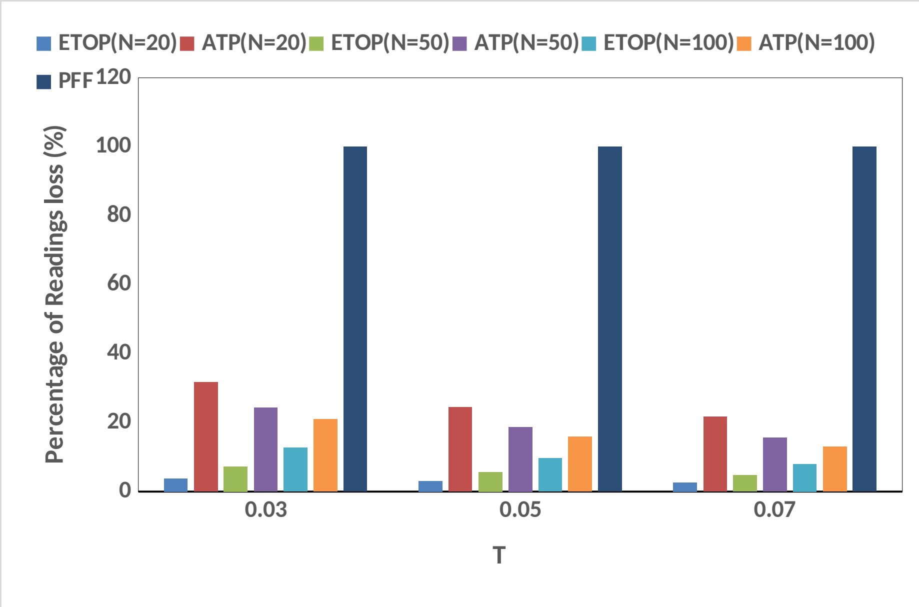

Fig. 7. Percentage of data reading loss.

6. Conclusions and Future Works

This paper proposes an Energy-efficient Transmission Optimization Protocol (ETOP) to optimize the transmission and the lifetime of Sensor Networks of IoT. ETOP accomplishes a simple reduction algorithm-based correlation clustering at the sensor node to remove the redundant data before transmitting it to the gateway or sink. The results show that the proposed ETOP protocol can optimize the transmission of sensor networks better than other methods while maintaining a suitable level of accuracy. In the future, we plan to achieve the transmission reduction on the next level of the network. One could for example, remove the redundant reading resulting from the spatial correlation between the reading of the sensor nodes on the gateway.

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