Energy-efficient Fog Computing-enabled Data Transmission Protocol in Tactile Internet-based Applications

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ABSTRACT

Sensor nodes are one of the basic elements in the Tactile Internet-based fog computing architecture. They provide a huge amount of data to the network due to the widespread real-world applications that use these types of wireless devices. This huge number of data, transmitted by the sensor devices to the fog gateway and then to the cloud, leads to high communication costs, increased power consumption, and high latency at the fog gateway. These challenges would be considered as a hurdle in the Tactile Internet-based fog system. To tackle these challenges, this paper proposes an Energy-efficient Fog Computing-enabled Data Transmission (EFoCoD) protocol in Tactile Internet-based Applications. The protocol works on sensor devices level in the Tactile Internet-based fog computing architecture. EFoCoD protocol executes a Lightweight Data Redundancy Elimination (LiDaRE) Algorithm at the sensor level to reduce the collected data before transferring them to the smart fog gateway. To study the performance of the EFoCoD, it was compared to its counterpart protocols in the literature just like ATP and PFF. Simulation results show that EFoCoD outperforms these protocols in terms of energy consumption, transmitted data, and data accuracy.

KEYWORDS

Tactile Internet, Fog Computing, Data Reduction, Clustering, Smart Sensor nodes, Energy-efficiency.

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1 INTRODUCTION

Smart wireless devices such as sensors, wearable devices, smart objects, and cameras are used by several practical applications like health care, smart cities, smart home, smart transportation, agriculture, and so on [7]. They generally represent the basic elements in the Tactile Internet-based fog computing architecture [10]. These smart devices produce a large number of data readings that required to be transmitted to the fog gateway across this architecture[8].

The data transmission redundancy resulted from the temporal and spatial correlation represents a big challenge in the Tactile Internet-based fog computing network [11]. The increased volume of data transmission leads to an increase in the power consumption at both smart devices and fog gateway, it also increases the latency and the overhead on the network. Therefore, it is important to remove the redundant data measurements at both the fog gateway and smart devices to minimize the sent data and save energy at these devices while preserving an adequate ratio of data accuracy. In addition, the decreased amount of data at the fog gateway can decrease the requirements of latency and provide fast decisions. This is an essential measure for Tactile-based applications [1]. This paper includes the following contributions.

- An Energy-efficient Fog Computing-enabled Data Transmission (EFoCoD) protocol in Tactile Internet-based Applications. The protocol works on sensor devices level in the Tactile Internet-based fog computing architecture. A Lightweight Data Redundancy Elimination (LiDaRE) Algorithm is proposed and executed at the sensor level by EFoCoD protocol to remove the temporally correlated data measurements before sending it to the fog gateway. This can conserve energy and reduce the latency while keeping the accuracy of data at an adequate level.
- Extensive experiments using OMNeT++ simulator are performed to confirm the improved performance of the EFoCoD protocol. Real readings of smart sensor nodes are used during the simulation. A comparison is made with some existing approaches such as PFF scheme[3] and ATP technique[4].

The results demonstrate that the proposed EFoCoD protocol enhances the performance of the network compared to other methods.

This paper has the following structure. In the next section, the related work is introduced. The proposed EFoCoD protocol is introduced in section III. The results are provided in section IV. The conclusions and future work are given in Section V.

2 RELATED WORKS

One big challenge in the Tactile Internet-based fog computing system is to decrease the huge number of data, conserve power, and reduce the latency while maintaining the accuracy of the received data at the final destination at a suitable level. Nowadays, several methods for data reduction are proposed by researchers. The Prefix-Frequency Filtering (PFF) method in [3] executes 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. This approach is enhanced by the introduced methods in [5] to decrease data redundancy in the sensed data before transferring it to the next level of the network. The authors in [4] present a technique called Aggregation and Transmission Protocol (ATP) at the sensor device to decrease the number of data before transmitting it to the sink. They remove the redundancy at the sensor node and then apply some different methods to reduce the spatially correlated data in the gateway. The work in [7] suggests a DaT technique to lower the amount of collected data in sensor networks. A modified K-nearest neighbor is implemented at the sensor nodes to reduce the size of data by selecting one reading for each group to send it to the next level of the network. In the gateway, a hierarchical clustering algorithm is executed to cluster the data sets into groups, then one data set is transmitted to the next level in the network. In [2], the authors introduced a TLDA approach to enhance the network lifespan. It applies techniques of time series to eliminate the unnecessary data from the network. The data correlation (temporal and spatial) between acquired data on both levels of the sensor network. In [8], the authors proposed a lossless compression approach based on the combination of two efficient techniques: Huffman encoding and clustering. The data are clustered into groups. Then each group of data is compressed using Huffman encoding.

3 THE EFOCOD PROTOCOL

This section presents the EFoCoD protocol in more detail. Figure 1 demonstrates the EFoCoD protocol. It works in a periodic way. The lifespan of the network comes from the overall periods in the network. The EFoCoD protocol applies efficient data reduction algorithm at sensor device. The main goal of this algorithm is to get rid of repetitive data readings before transmitting them to the next network level. It decreases the cost of communication, extends the lifetime, and decreases the latency while keeping the accuracy at an adequate level in the Tactile Internet-based fog computing system.

The sensor device senses the surrounding environment periodically. The period is composed of a number of slots and the sensor device captures a reading in every time slot. The collected

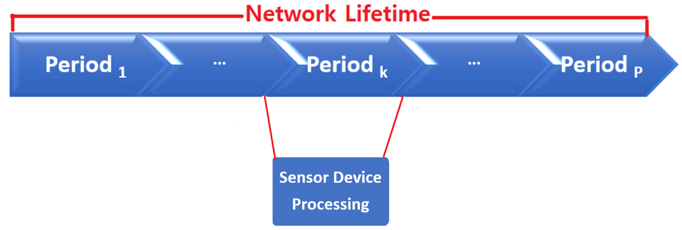

Figure 1: The EFoCoD protocol.

data readings during the period constitute the data readings set $S = \{r_1, \ldots, r_\rho\}$, where ρ is the entire number of data readings in the period. These data readings in the collected data set S are mostly similar or alike especially when the surrounding environmental conditions have not been changed for a long time. Therefore, this increased number of redundant readings should be reduced and cleaned from the data readings set S at this smart node level. Accordingly, a Lightweight Data Redundancy Elimination (LiDaRE) Algorithm is proposed and executed at the sensor device by EFoCoD protocol to remove the redundant data readings before forwarding them to the fog gateway. Algorithm 1 shows the LiDaRE algorithm.

Algorithm 1: *LiDaRE Algorithm*

Require: *S:data reading set, ρ: size of data reading set, α: threshold*
Ensure: *D: the encoded final reduced vector*
1: $B \leftarrow \phi$;
2: $B \leftarrow B \cup S_1$;
3: **for** $i \leftarrow 2$ to ρ **do**
4: $Dif \leftarrow 0$;
5: $j \leftarrow 1$;
6: **while** $j \leq Length(B)$ **do**
7: $Dif \leftarrow |S_i - B_j|$;
8: **if** $(Dif > \alpha)$ **then**
9: $j \leftarrow j + 1$;
10: **else**
11: $j \leftarrow Length(B)$;
12: **end if**
13: **end while**
14: **if** $(Dif > \alpha)$ **then**
15: $B \leftarrow B \cup S_i$;
16: **end if**
17: **end for**
18: $D \leftarrow \phi$;
19: $D \leftarrow D \cup ENCODING(Length(B))$;
20: **for** $k \leftarrow 1$ to $Length(B)$ **do**
21: $D \leftarrow D \cup ENCODING(B_k)$;
22: **end for**
23: return D;

In this algorithm, steps 1-17 focuses on producing the reduced data set after removing the redundant data from the collected data set S. The reduced data set B is initialized to an empty set, then the first data reading from S is allocated to B. After that, each data reading S_j (j $\geq \rho$) is compared with the data readings in the reduced set B according to a certain threshold α fixed by the application. If S_j is similar to one of the readings in B (i.e, the difference between S_j and at least one reading of B less than or equal to α), then it will be discarded. Otherwise, the data reading will be added to the reduced set B. The difference function can be defined as follows.

Definition 3.1. *The Difference function refers to the difference between two data readings S_i and $S_j \in S$ gathered by the node is calculated as:*

$$Dif(S_i, S_j) \leftarrow \begin{cases} 1 & if\,|S_i - S_j| \leq \alpha \\ 0 & Otherwise. \end{cases} \quad (1)$$

Where α refers to the threshold chosen by the user of application. Hence, if the difference between S_i and S_j is less than or equal to α, they are assumed to be similar.

Steps 18-22 are responsible for compressing the resulted reduced set B at the sensor node. Each data reading in B is encoded using the ENCODING function in two bytes and then appended to the file D. Figure 2 refers to the 16-bits representation of data reading. The sign bit uses binaries "0" and "1" for the positive and negative numbers respectively. The next part of the data reading representation corresponds to the integer part that takes 8-bits. The last part is the fraction part of the data reading that takes 7-bits.

Figure 2: The 16-bits representation of data reading.

This encoding process for the reduced data readings B participates in decreasing further the volume of data, save energy, and keeping the data integrity. Finally, the encoded file D is sent to the fog gateway. The time complexity of Algorithm 1 is O(ρ $Length(B)$) . The space complexity is O(ρ + $Length(B)$). The ENCODING function in Algorithm 1 requires O(log n) of time complexity, where n refers to the number of digits of the given input.

4 PERFORMANCE EVALUATION

The performance of the proposed EFoCoD protocol has been evaluated using the OMNeT++ network simulator [12]. Several experiments have been accomplished using real data readings from the nodes which are fixed in the Lab of the Intel Berkeley [9]. This Lab contains 47 nodes that collect the data readings (e.g, light, temperature, voltage, and humidity) every 31 seconds from the surrounding climate. In this experiment, the EFoCoD protocol only uses just the temperature readings for the sake of simplicity.

The fog gateway is located at the center of the Intel Berkeley Lab and sends its data to the cloud data center across the Internet. The First Order Radio Model (see Figure 3) is applied as an energy consumption model by the EFoCoD protocol [6]. It is assumed that the length of the data reading is 64 bits, and the data packet size is the number of data readings that are required to be sent to the fog gateway.

The results of the EFoCoD protocol are compared to some existing methods such as PFF [3] and ATP method [4] to confirm the high performance of the EFoCoD. In this paper, the number

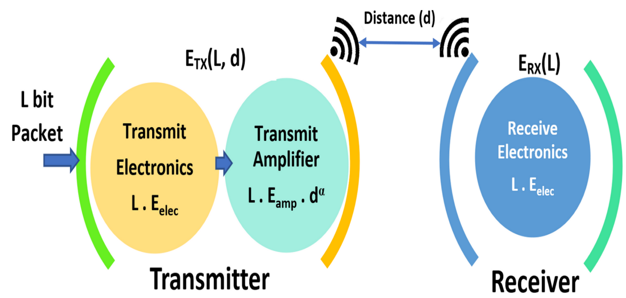

Figure 3: The First Order Radio Model.

of nodes (M) is 47 nodes. The ρ takes different sizes like 20, 50 and 100, 200, 500, 1000 readings. The threshold α takes 0.03, 0.05, 0.07, and 0.1. The E_{elec} and β_{amp} takes 50 nJ/bit and 100 pJ/bit/m^2 respectively.

4.1 Data Readings Reduction Ratio

The main task of the sensor device is to collect the data readings and to transmit them to the next level in an energy-efficient manner. This experiment studies the performance of the EFoCoD protocol in reducing the redundant data at the sensor node. Figure 4 presents the data readings reduction ratio after applying the LiDaRE algorithm of the EFoCoD protocol. The EFoCoD could reduce the

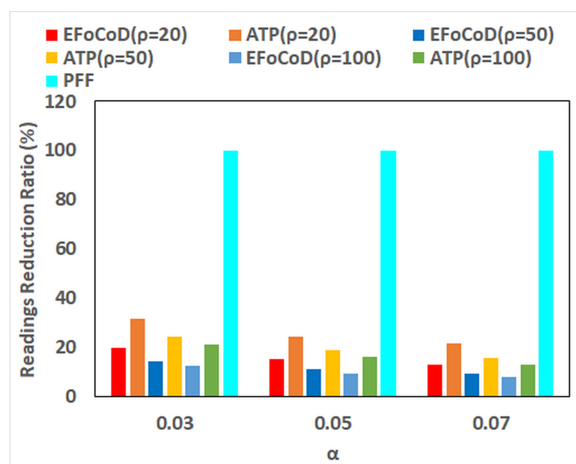

Figure 4: Data Readings Reduction Ratio.

redundant readings before sending them to the fog gateway from 80.41% up to 92.16% and 38.18% up to 39.86% compared to PFF and ATP respectively. It can be seen from the results the effectiveness of the EFoCoD in removing the useless data readings to save energy and improve the performance of the network.

4.2 The power consumption of sensor node

Power consumption represents one important challenge that should be considered when designing the protocol for a Tactile Internet-based fog computing system. The consumed energy by the EFoCoD protocol is investigated in this experiment. The consumed power of the sensor node is explained in Figure 5 using different data reading sizes.

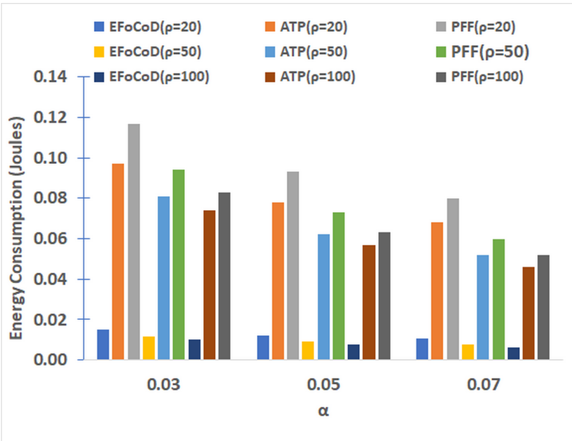

Figure 5: The power consumption of sensor node.

It can be observed that the suggested EFoCoD protocol decreases the energy consumption of the sensor device from 87.23% up to 87.94% and from 84.60% up to 86.37% compared with PFF and ATP approaches respectively. Hence, the EFoCoD protocol outperforms the other methods in saving the energy of sensor nodes due to its ability in discarding the unnecessary readings as shown in Figure 4.

4.3 Data Loss Ratio

This experiment investigates the effect of reduced data readings on the quality of received readings at the fog gateway. Since it is necessary to minimize the transmitted data size before transmitting them to the gateway to save energy, but at the same time, it is important to keep an adequate rate of data quality at the gateway. The ratio of lost data readings in the received reading at the gateway represents the data reading accuracy. Figure 6 exhibits the data loss ratio (data accuracy). It can be mentioned from Figure 6 that the EFoCoD protocol minimizes the amount of lost data from 52.83% up to 91.77% and from 63.31% up to 91.21% compared with PFF and ATP approaches respectively. Therefore, the EFoCoD protocol minimizes the amount of transmitted data, saves power, and enhances the network's lifespan while preserving an adequate accuracy level.

5 CONCLUSION AND PERSPECTIVES

This paper proposes an Energy-efficient Fog Computing-enabled Data Transmission (EFoCoD) protocol in Tactile Internet-based Applications. The protocol works on sensor devices level in the Tactile Internet-based fog computing architecture. The EFoCoD protocol implements the LiDaRE algorithm at the sensor devices to eliminate the data readings redundancy in this device. Several experiments have been implemented to show the efficiency of the proposed protocol. It can be observed that the EFoCoD protocol reduces the amount of transmitted data from 80.41% up to 92.16% and 38.18% up to 39.86% compared to PFF and ATP respectively. It decreases the energy consumption of the sensor device from

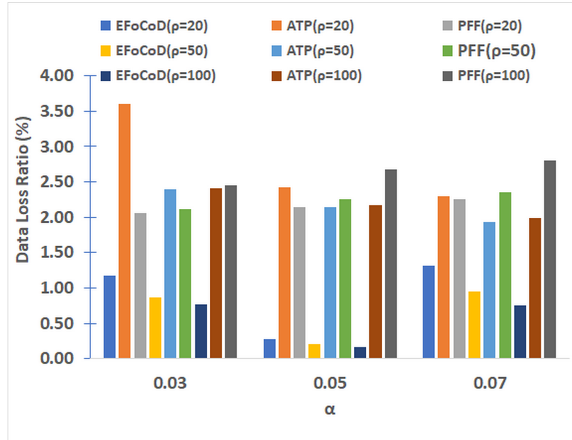

Figure 6: Data Loss Ratio.

87.23% up to 87.94% and from 84.60% up to 86.37% compared with PFF and ATP approaches respectively. In the future, we plan to add a decision-maker at the fog gateway to provide suitable decisions for sensing-based applications and based on machine learning techniques.

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