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***Abstract*—In the Tactile Internet-based fog computing architecture, the sensor devices represent the basic elements for sensing the surrounding environment. They gather a large amount of data due to their use in various real-world Tactile Internet applications. The huge amount of transmitted data from sensor devices to the fog gateway then to the cloud would lead to high data traffic over the network, increased consumed energy, and increased delay to provide the decision at the Fog gateway. These challenges represent a hurdle in the Tactile Internet-based fog system. This paper suggests a Data Transmission Optimization Scheme (DaTOS) in Tactile Internet-based Fog Computing Applications. The protocol works on two-level devices in the Tactile Internet-based fog computing architecture: sensor devices and fog gateway. The DaTOS implements a Lightweight Redundant Data Removing (LiReDaR) Algorithm at the sensor devices level to lower the gathered data before sending them to the fog gateway. In fog gateway, it executes a Data Set Redundancy Elimination (DaSeRE) approach to discard the repetitive data set resulting from the spatial correlation among the data readings sets of sensor nodes. To evaluate the performance of the DaTOS, it was compared to its counterpart methods in the literature like ATP, PFF and Harb. Simulation results indicate that DaTOS outperforms these methods in terms of transmitted data, energy consumption, and data accuracy.**

***Index Terms*—Tactile Internet, Fog Computing, Data Reduction, Clustering, Energy-efficiency.**

I. Introduction

The fast evolution of high-performance computing, sensing, networking, and communication technologies would make the paradigm of the Tactile Internet (TI) become a reality. Tactile Internet is an innovative concept that supports ultra-responsive, high-fidelity and widely available human-to-machine interactions . Several emerging applications are supported by TI like road traffic, autonomous driving, mobile augmented video content, smart grid, healthcare, smart building, remote education, smart cities, and remote immersion/interaction among others. The smart wireless devices generally represent the essential component in the Tactile Internet-based fog computing architecture (see Figure 1) [1]. These smart devices produce a large number of data readings that are required to be transmitted to the fog gateway and then to the cloud platform across this architecture. The data transmission redundancy resulted from the temporal and spatial correlation represents a big challenge in the Tactile Internet-based fog computing network [2].

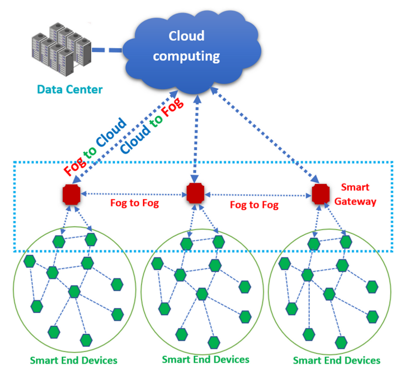


Fig. 1. Tactile Internet-based fog computing architecture.

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. To lower data transmission latency and mitigate internet congestion, data transmission reduction has been approved as a significant element of the Tactile Internet [3]. Therefore, it is important to remove the redundant data measurements at both the fog gateway and smart devices to minimize the sent data, save energy at these devices, and reduce data transmission latency while preserving an adequate ratio of data accuracy. In addition, the decreased amount of data at the fog gateway can decrease the requirements in terms of latency and provide fast decisions. This is an essential measure for Tactile-based applications [4]. This paper includes the following contributions.

- We propose a Data Transmission Optimization Scheme (DaTOS) in Tactile Internet-based Fog Computing Applications. The protocol works on two-level devices in the Tactile Internet-based fog computing architecture: sensor devices and fog gateway. The purpose of DaTOS scheme is to decrease the volume of transmitted data at both smart devices and gateway to conserve energy and reduce the data transmission latency while keeping the accuracy of data at an adequate level.
- A Lightweight Redundant Data Removing (LiReDaR) Algorithm is suggested and implemented at the sensor

level by DaTOS to eliminate the temporally correlated data readings before transmitting them to the fog gateway.
- A Data Set Redundancy Elimination (DaSeRE) Algorithm is proposed and implemented by DaTOS at the fog gateway to further discard the redundant data reading sets of the received data sets of sensor devices before forwarding them to the data centers of the cloud.

This paper has the following structure. In the next section, the related work is introduced. The proposed DaTOS scheme is presented in section III. The performance evaluation is provided in section IV. The conclusions and perspectives are given in Section V.

II. Related Works

One of the principle challenges 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. There are two main approaches focused on reducing the collected data in the network such as data compression [2], [5] and data reduction [6]–[10]. In the compression based approaches, Rajasekar and Pushpalatha [5] suggested a lossless compression technique using Huffman based discrete cosine transform to decrease the complexity of data and to enhance data privacy. In [2], 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.

In the data reduction based approaches, the Prefix-Frequency Filtering (PFF) method in [6] operated on both sensor and aggregator nodes. They utilize Jaccard similarity in the sensor node to eliminate duplicate data, and set similarity in the aggregator node to decrease duplicated sets of data. In [7],the researchers explain an Aggregation and Transmission Protocol (ATP) approach to minimize the amount of captured data at the sensor device before transferring it to the sink. They eliminate redundancy of spatially correlated data in the gateway using some techniques. Harb et al. [8] proposed a two-level approach to data reduction to save power and maximize the lifetime of the network. It removes redundant data at the sensors. Then, it implements the sets-similarity algorithm to eliminate duplicate data sets at the cluster head. The work in [9] introduced a two-level data reduction method. It applies a modified K-nearest neighbour at the sensors while it implements the hierarchical clustering at the gateway for removing redundant data.

III. The DaTOS scheme

This section presents the DaTOS scheme in more detail. Figure 2 demonstrates the DaTOS scheme. The DaTOS scheme applies two algorithms at both fog gateway and sensor devices. It works periodically. The main goal of both algorithms is to decrease the cost of communication, extends the lifetime, and decrease the latency while keeping the accuracy at an adequate level in the Tactile Internet-based fog computing system.

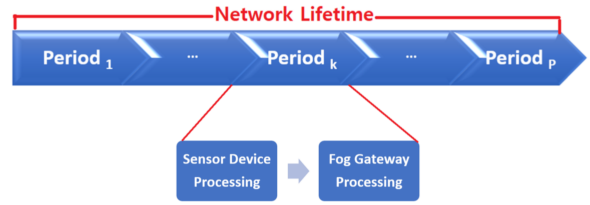


Fig. 2. The DaTOS scheme.

A. Data processing at sensor device:

The sensor device senses the surrounding environment in the area of interest periodically. The period includes several slots, and the sensor device catches a data measurement in each time slot. The gathered data measurements throughout the period comprise the set of data measurements $\delta = \{s_1, \ldots, s_\rho\}$, where ρ refers to the total number of data measurements in the period. These data measurements in the set δ are mostly similar or alike particularly when the conditions of the monitored environment have not been varied for a long time. Hence, it is necessary to remove this increased number of redundant measurements from the set of data measurements δ at this smart device level. Therefore, a Lightweight Redundant Data Removing (LiReDaR) Algorithm is suggested and executed at the sensor device by DaTOS scheme to eliminate the redundant data measurements before forwarding them to the fog gateway. Algorithm 1 shows the LiReDaR algorithm.

Algorithm 1: *LiReDaR Algorithm*

Require: *δ:Set of data measurements, ρ: Number of data measurements, α: threshold*
Ensure: *E: the encoded reduced data vector*

1: $\beta \leftarrow \phi$;
2: $\beta \leftarrow \beta \cup \delta_1$;
3: **for** $k \leftarrow 2$ to ρ **do**
4:   $i \leftarrow 1$;
5:   **while** $i \leq Size(\beta)$ **do**
6:     $\varphi \leftarrow |\delta_k - \beta_i|$;
7:     **if** $(\varphi > \alpha)$ **then**
8:       $i \leftarrow i + 1$;
9:     **else**
10:       $i \leftarrow Size(\beta) + 1$;
11:     **end if**
12:   **end while**
13:   **if** $(\varphi > \alpha)$ **then**
14:     $\beta \leftarrow \beta \cup \delta_k$;
15:   **end if**
16: **end for**
17: $E \leftarrow \phi$;
18: $E \leftarrow E \cup COMPRESSOR(Size(\beta))$;
19: **for** $j \leftarrow 1$ to $Size(\beta)$ **do**
20:   $E \leftarrow E \cup COMPRESSOR(\beta_j)$;
21: **end for**
22: return E;

In algorithm 1, steps 1-17 construct a new set of reduced data measurements after eliminating the data measurement redundancy from the set of sensed data measurements δ. The set of reduced data measurements β starts with an empty list, then the first measurement of δ is assigned to β. After that, the comparison is done for each measurement δ_j (j $\geq \rho$) with the data measurements in β according to a particular threshold α specified by the application. If the condition of comparison is satisfied (i.e., the difference between δ_j and at least one measurement of β less than or equal to α), it means that the δ_j is similar to one of the data measurements in β and it will be discarded. Otherwise, the data measurement will be appended to the set β. The function Size() returns the size of the list. The difference function can be defined as follows.

Definition 3.1: The Difference function refers to the difference between two data measurements δ_i and $\delta_j \in \delta$ gathered by the node is calculated as:

$$\varphi(\delta_i, \delta_j) \leftarrow \begin{cases} 1 & \text{if } |\delta_i - \delta_j| \leq \alpha \\ 0 & \text{Otherwise.} \end{cases} \tag{1}$$

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

Steps 18-22 are responsible for compressing the resulting set β of reduced data at the sensor device using a simple encoding method. Each data measurement in β is encoded using the COMPRESSOR function in two bytes, and then the encoded data measurement is appended to the file E. Figure 3 refers to the 16-bits representation of data measurement. The sign bit utilizes the binary values "1" and "0" for the negative and positive numbers respectively. The integer part is the next part of the data measurement representation that takes 8-bits. The last part is the fraction part of the data measurement that takes 7-bits.

Fig. 3. The 16-bits representation of data measurement.

The COMPRESSOR function plays an important role in reducing the size of the reduced data set β using a simple encoding method. This results in further lowering the volume of data, saving energy, and maintaining data integrity. Finally, the compressed file E is forwarded to the fog gateway. The time requirement of Algorithm 1 is O(ρ $Size(\beta)$) . The space requirement is O(ρ + $Size(\beta)$). The Compressor function in Algorithm 1 requires O(log n) of time complexity, where n refers to the number of digits of the given input.

B. Data processing at fog gateway:

This section is focused on applying DaTOS at the fog gateway. The DaTOS will execute the proposed Data Set Redundancy Elimination (DaSeRE) Algorithm to eliminate the redundant data set resulted from the spatial correlation between the received data sets of sensor devices. The DaSeRE algorithm of DaTOS scheme is responsible for removing the unnecessary data sets at the fog gateway before delivering them to the sink. The DaSeRE algorithm first decodes the received encoded data of each sensor node j using DECOMPRESSOR function, and saves it in vector $X^j = \{x_1^j, x_2^j, ..., x_T^j\}$, where T is the total number of data measurements of sensor device j. Then, the variance of each data measurement set X^j is computed. The result is a set of variance values is expressed as $R \leftarrow \{r_1, r_2, ..., r_M\}$, where M refers to the number of sensor devices.

Definition 3.2: Variance function refers to a statistical measure of the spread between the sensed data measurements in a data measurement set of sensor device j and defined as follows

$$R^j \leftarrow \frac{\sum_{i=1}^{T^j}(x_i^j - \mu^j)^2}{L^j - 1}. \tag{2}$$

where μ^j refers to the mean value of the data measurements set X^j of sensor device j.

The DaSeRE algorithm employs the Mini-batch k-Means (see Algorithm 2) to cluster the data measurements sets of the sensor devices according to their variance values into groups of data measurement sets. This algorithm is the modified version of the k-means algorithm and it reduces the processing time in the large datasets by using mini-batches. Hence, it is faster than the k-means algorithm and produces better solutions [11]. Algorithm 2 requires $O(T.(b + K))$ of time complexity.

Algorithm 2: *Mini-batch k-Means clustering*

Require: K*:number of clusters, b: size of mini-batch,* Y*: dataset, M: size of dataset*
Ensure: C*: set of centroids*

```
for j ← 1 to K do
    C_j ← Y_i; //randomlyselectY_i fromY(1 ≤ i ≥ M)
    S_j ← Y_i;
    N_j ← 1;
end for
while Stoping Creterion is not satisfied do
    L ← b samples selected randomly from Y;
    for Each i ∈ L do
        A_i ← argmin_{j∈K} ||Y_i − C_j||;
        S_{A_i} ← S_{A_i} + Y_i;
        N_{A_i} ← N_{A_i} + 1;
    end for
    for Each i ∈ K do
        C_j ← S_j/N_j;
    end for
end while
return C;
```

One data measurement set is elected as a representative set for each group. The results are a group of data measurement sets, each one represents at least one or more of the data measurements sets of sensor devices. Algorithm 3 refers to the DaSeRE Algorithm.

In this algorithm, the function DECOMPRESSOR() is responsible for decoding the received file D^j of sensor device j

Algorithm 3: *DaSeRE Algorithm*

Require: K*:number of clusters, b: size of mini-batch, D: encoded reduced vectors, M:number of reduced vectors in D*

Ensure: EDS*: Encoded data reading sets*

1: **for** $j \leftarrow 1$ to M **do**
2: $\quad X^j \leftarrow DECOMPRESSOR(D^j)$;
3: $\quad R^j \leftarrow Variance(X^j)$ *using Eq.* 2;
4: **end for**
5: $C \leftarrow Mini-batch\ k-Means\ clustering(K, b, R, M)$;
6: $EDS \leftarrow \phi$;
7: $EDS \leftarrow EDS \cup COMPRESSOR(K)$;
8: **for** *Each* $i \in K$ **do**
9: $\quad DS^i \leftarrow BringRepresentativeDataSet()$;
10: $\quad EDS \leftarrow EDS \cup COMPRESSOR(Length(DS^i))$;
11: $\quad$ **for** $k \leftarrow 1$ to $Size(DS^i)$ **do**
12: $\quad\quad EDS \leftarrow EDS \cup COMPRESSOR(DS^i_k)$;
13: $\quad$ **end for**
14: **end for**
15: return EDS;

into a set of data readings X. The function COMPRESSOR() is responsible for encoding each reading (see Figure 3) into 16 bits for appending each one to the encoded file before transmitting it to the next level of the network. The function BringRepresentativeDataSet() brings the representative data set according to its centroid. The fog gateway sends the encoded file of the representative data sets with the identifications (ids) of sensor devices to the next level of the network. The DaSeRE Algorithm removes the repetitive data reading sets to reduce the volume of the transmitted data, save energy, reduce the latency, and preserves the accuracy with an acceptable level. Moreover, it further reduces the transmitted data by encoding them before sending them to the next level of the network. In DaSeRE Algorithm, steps 1-4 require time complexity for is $O(M.Len(X))$. The time complexity of step 5 is $O(T.(b+K))$ while the steps 6-14 require $O(K.Len(DS))$. Hence, the time requirement for the algorithm 3 is $O(MAX((T.(b+K)), (M.Len(X)), (K.Len(DS))))$, where $Len(X)$ and $Len(DS)$ refer to the lengths of vectors X and DS respectively.

IV. Performance Evaluation

This section introduces the performance assessment of the proposed DaTOS scheme using a network simulator called OMNeT++. Many simulation experimental results have been conducted using real sensed data measurements from the sensor nodes that distributed in the Lab of the Intel Berkeley that used by [7]. This Lab includes 47 nodes that collect the data measurements (e.g., light, temperature, voltage, and humidity) every 31 seconds from the surrounding climate of the laboratory building. In these simulation experiments and for the sake of simplicity, the DaTOS scheme uses just the temperature data measurements. Figure 4 illustrates the network architecture utilized during this simulation. The fog

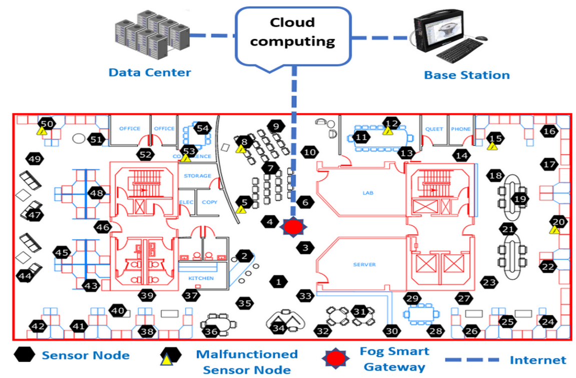


Fig. 4. The sensor network of Intel Berkeley Lab.

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 5) is used as an energy consumption model by the DaTOS scheme as in [7]. The length of the data measurement is assumed to be 64 bits. Therefore, the size of the data packet is the number of data measurements that are required to be transmitted to the fog gateway multiplied by the length of the data measurement.

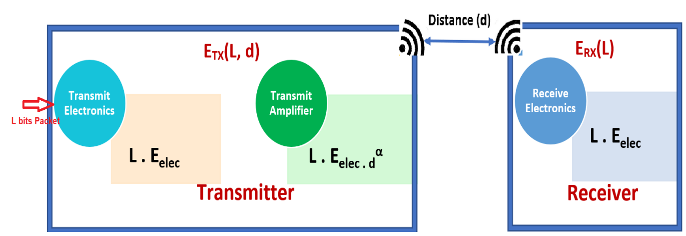


Fig. 5. The First Order Radio Model.

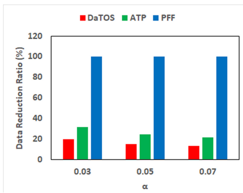
The results of the DaTOS scheme are compared to some existing techniques such as PFF [6], ATP method [7], and Harb (FISHER, TUKEY, and BARTLETT) approach [8] to confirm the high performance of the DaTOS scheme. In this paper, the number of clusters (K) is selected according to the Elbow Curve Method. Table 1 introduces the parameters values of the simulation.

TABLE I
Parameters values for simulation.

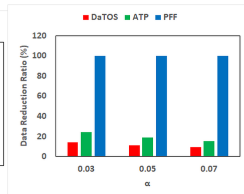
Parameter	Value
No. of nodes (M)	47 nodes
ρ	20, 50 and 100, 200, 500, 1000 readings
E_{elec}	50 nJ/bit
β_{amp}	100 pJ/bit/m^2
α	0.03, 0.05, 0.07, and 0.1
K	15

A. Data Reduction Ratio

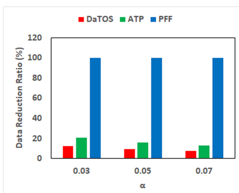
The principal task of the sensor device is to gather the data measurements and send them to the next level of the network in an energy-saving way. This experiment investigates the performance of the DaTOS scheme in decreasing the redundant data at the sensor device. Figure 6 demonstrates the reduction ratio of data measurements after implementing the LiReDaR algorithm of the DaTOS scheme.



(a) ρ = 20



(b) ρ = 50



(c) ρ = 100

Fig. 6. Data Reduction Ratio.

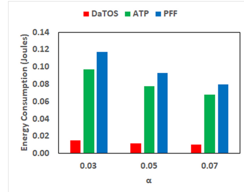
The DaTOS scheme decreases the unnecessary measurements before transferring them to the fog gateway from 80.41% up to 92.16% and 38.18% up to 39.86% compared to PFF and ATP respectively. It can be seen from the results the effectiveness of the DaTOS in removing the useless data readings to save energy and improve the performance of the network.

B. The power consumption of sensor node

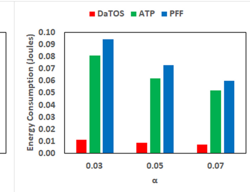
The energy consumption of sensor devices represents one significant challenge that should be considered when developing a technique for a Tactile Internet-based fog computing system. The DaTOS scheme investigates the consumed energy in this experiment. Figure 7 presents the consumed energy of the sensor device utilizing various data measurements sizes. It can be regarded that the presented DaTOS scheme reduces 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 methods respectively. Therefore, the DaTOS scheme outperforms the other methods in conserving the energy of sensor devices due to its ability in eliminating the unnecessary measurements as indicated in Figure 6.

C. Data Loss Ratio

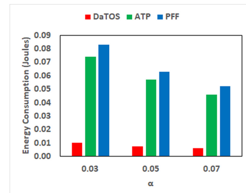
This experiment studies the impact of diminished data measurements on the quality of received measurements at the fog gateway. Since it is crucial to minimize the size of transmitted data before transferring them to the gateway to conserve energy, but at the same time, it is necessary to maintain a sufficient rate of data quality at the gateway. The ratio of lost data measurements in the received measurement



(a) ρ = 20

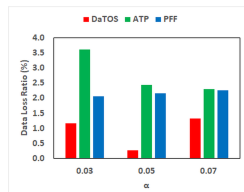


(b) ρ = 50

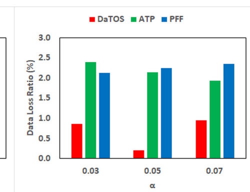


(c) ρ = 100

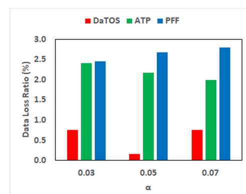
Fig. 7. The power consumption of sensor node.



(a) ρ = 20



(b) ρ = 50



(c) ρ = 100

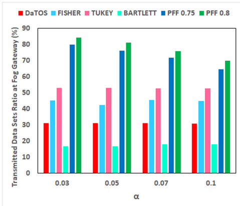
Fig. 8. Data Loss Ratio.

at the gateway represents the accuracy of data measurement. Figure 8 exhibits the data loss ratio (data accuracy).

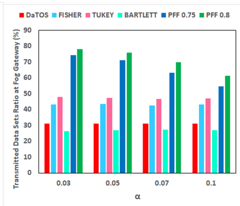
It can be observed from Figure 8 that the DaTOS scheme lowers the amount of lost data from 52.83% up to 91.77% and from 63.31% up to 91.21% compared with PFF and ATP methods respectively. Hence, the DaTOS scheme minimizes the amount of transferred data, preserves power, and improves the network's lifespan while keeping an acceptable accuracy level.

D. Transmitted Data Sets Ratio at Fog Gateway

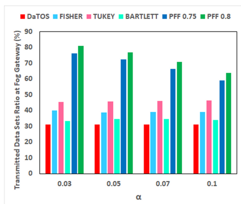
The similarities between the data reading sets received at the fog gateway can be significant. Therefore, it is necessary to eliminate the redundant data sets before transmitting the data to the cloud data center. This experiment explains the effectiveness of the proposed DaSeRE algorithm used by the proposed DaTOS scheme in removing these redundant data sets to save energy, reduce latency, and improve the performance of the network. Figure 9 shows the transmitted data reading set Ratio at Fog Gateway.



(a) ρ = 200



(b) ρ = 500



(c) ρ = 1000

Fig. 9. Transmitted Data Sets Ratio at Fog Gateway.

It can be noted from Figure 9 that the proposed DaTOS scheme decreased the data sets from 49.72% up to 62.91%, from 43.56% up to 60.91%, from 32.15% up to 41.19%, and from 20.51% up to 31.23% compared to PFF 0.8, PFF 0.75, Tukey, and Fisher methods respectively. It can be regarded that the Bartlett gives better results in only one case. However, the DaTOS scheme is better than the other techniques in general by removing the repetitive data readings sets and saving the energy at the gateway.

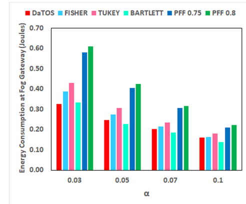
E. Consumed Power of Fog Gateway

Consumed power represents the most critical factor in most limited resources nodes. The performance of the proposed DaTOS scheme in terms of power consumption is studied and compared with some existing methods. Figure 10 shows the fog gateway consumed power .

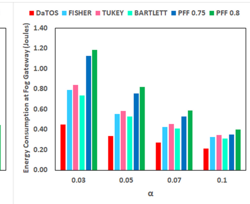
It can be regarded from Figure 10 that the proposed DaTOS scheme minimizes the energy consumption from 28.03% up to 74.23%, from 23.55% up to 73.36%, from 14.95% up to 58.86%, from 11.24% up to 61.90%, and from 1.37% up to 58.02% compared to PFF 0.8, PFF 0.75, Bartlett, Tukey, and Fisher methods respectively. The results show that the DaTOS scheme outperforms the other methods in saving energy at the fog gateway by removing redundant data readings sets after receiving them from the sensor devices.

V. Conclusion and Perspectives

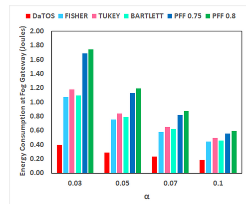
This paper proposes a Data Transmission Optimization Scheme (DaTOS) in Tactile Internet-based Fog Computing Applications. The protocol works on two levels in the Tactile Internet-based fog computing architecture: sensor devices and fog gateway. The DaTOS scheme implements the LiReDaR algorithm at the sensor devices to eliminate the data readings redundancy in this device, while it executes DaSeRE Algorithm eliminate repetitive data sets at the fog gateway. Several experiments have been implemented to show the efficiency of the proposed protocol. It can be observed from the results that the DaTOS introduces a better performance compared with other methods in terms of the amount of transmitted data, energy consumption, data loss ratio, and transmitted data sets ratio at Fog Gateway 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.



(a) ρ = 200



(b) ρ = 500



(c) ρ = 1000

Fig. 10. Energy Consumption at Fog Gateway.

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