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Data Aggregation Algorithms with Multiple Sensors in Clustered-Based WSN/IoT

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Abstract: In wireless sensor networks (WSN), data aggregation algorithms are used to extend the network lifetime. The size of data packet transmitted from the cluster head (CH) to the base station (BS) seriously affected energy consumption in a CH. In this paper, three types of data aggregation algorithms are evaluated. These techniques are coding schemes based relative difference (CS-RD); adaptive data aggregation method (ADAM); coding schemes based on the factor of precision (CS-PF). The performances of the algorithms are compared based on 15 different scenarios. The algorithms are applied separately with the following parameters: (1) Mean; (2) Median; (3) Mode; (4) Geometric mean; (5) Harmonic mean. Experimental efforts are taken on each scenario separately for the multiple sensors recording the temperature, humidity, and light. The performance metrics studied are energy consumption, average of absolute error and data compression ratio. The simulation results showed that the best performance is shown by the CS-RD algorithm. The ADAM produces an intermediate performance for all sensors. Overall, it can be said that the accuracy of CD-PF is better in comparison with other algorithms. Nevertheless, it displays worst performance in energy consumption and data compression ratio for all scenarios. From the results, it was noted that the selection mechanism suitable to determine the central point effect is based on the performance of the three aggregation algorithms. For temperature (T) and humidity (H) sensors the best performance in terms of energy consumption is the CS-RD, which is less than 800 uJ and compression ratio of more than 90%. ADAM and CS-FP algorithm with Mean /Gmean /Hmean methods showed better performance with energy consumption of less than 1000 uJ and compression ratio of 91%. Mode method negatively affected the performance of all algorithms, with CS-RD energy consumption reaching 2500 uJ. Finally, for light sensor, the CS-RD shows best performance with all central point methods, where the energy consumption goes below 1400 uJ. The CS-PF and ADAM with mode showed the highest energy consumption higher than 4200 uJ and 2400 uJ, respectively.

Keywords: WSN, Data Aggregation, Performance Measure, Clustered WSN, Energy Consumption, Reduction Algorithm

1. Introduction

In a large-scale WSN, data collected from multiple sensor nodes is generally aggregated at an intermediate node before transmitting to a collection point, known as gateway, base station or fusion center. The data collection mechanism is done to avoid repeated flows of information in the network, reducing unnecessary use of network resources, such as energy and bandwidth of the network [1In general, when using clusters, the three main elements in the WSN can be identified as sensor nodes (SNs), base stations (BSs), and cluster heads (CHs) as shown in Figure1. The SN is a set of nodes with sensors that exist in the network to detect the environment and collect data. The main task of the SN in the sensor field is to detect events, perform fast local data processing, and then transmit data. The BS is a data processing point for the data received from the sensor nodes , before uploading to the cloud, where the raw data is accessed by the end user [2].

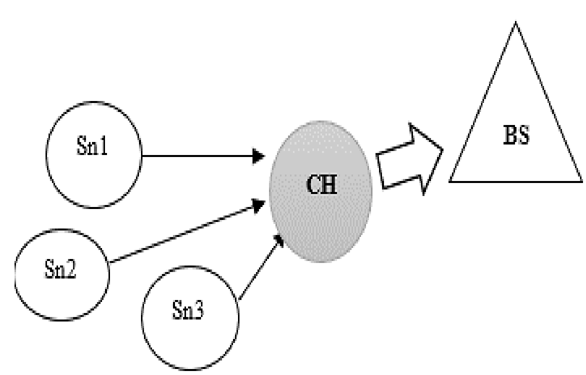

Figure 1. Structure of CH based WSN

In hierarchically structured WSN networks, data collection mechanisms are different types of networks,

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such as tree-based, cluster-based or hybrid structure based data aggregation. In an environment where sensor nodes have large spatial links, the mechanisms of data collection based on groups have been shown to be more efficient [3]. In the cluster-based data collection mechanism, the CH receives data from its cluster members. The CH then received the collected data in a single packet before sending them to the BS. The amount of data collected depends on the number of nodes in the cluster, which in turn depends on the clustering protocol used [4]. CH node packet size of the sensed data aggregation through clustering is the most common issue. The number of nodes that transmit sensed data to the CH will normally affect the size of data payload of the CH. Furthermore, the cluster packet size is limited, where the aggregation data from the nodes must be equal or less than the payload data size. Reducing the packet size will also decrease energy consumption by the CH, hence will prolong its lifetime[5]. This paper investigates the performance of different data aggregation algorithms for different types of sensors. In addition, the outcome of the performance evaluation different data aggregation algorithms for different types of sensors in a wireless sensor network based cluster head nodes will help in selecting which is the better algorithm for each sensor as well as show the limitations of those algorithms.

2. Data Aggregation Algorithm

A. Related Works

In [4], the authors developed a novel and adaptive method of data aggregation that exploits the spatial correlation between the sensor nodes (ADAM). The main feature of the proposed aggregation method is that in addition to reducing the cost of redundant data transfer in the network, it also optimally utilizes the available space in a packet at each CH. The proposed method, which encodes all the collected data within the space available in the packet by taking differentials of the correlated data, is based on the correlation factor that reflects the degree of correlation between the two sensor nodes. ADAM algorithm used two bits for coding the data packet.

In [5], the authors presented a novel approach to minimize the CH packet size by considering the accuracy of prediction of sensed data at the base station. The proposed coding scheme is based on relative difference and also on the factor of precision as CS-RD and CS-FP, respectively [4][5]. Table 1 illustrates the characteristics of different data aggregation algorithms in WSN based cluster.

B. Methodology

The methodology is divided into four steps; the first step focuses on analysis of the original aggregation algorithms CS-FP, CS-RD and ADAM with different central point methods (or averages) as shown in Figure 2.

TABLE 1. COMPARISON BETWEEN DIFFERENT DATA AGGREGATION ALGORITHMS IN WSN BASED CLUSTER

Algorithm	**Center point**	**Determine the difference between member nodes and Central point**	**Number of bits for sign**	**Sensor**
CD-RD	Median	Relative Difference $\mu_i = \left(\frac{D_i - M_D}{(D_i + M_D)0.5}\right) \times 100$	1 bits	T / H
CD-PF	Median	Absolute change with precision factor $u_i = [\lvert D_i - M_D \rvert \times \omega]$	1 bits	T / H
ADAM	Median	Absuotr change $u_i = Round\ (D_i - M_D)$	2 bits	T / H

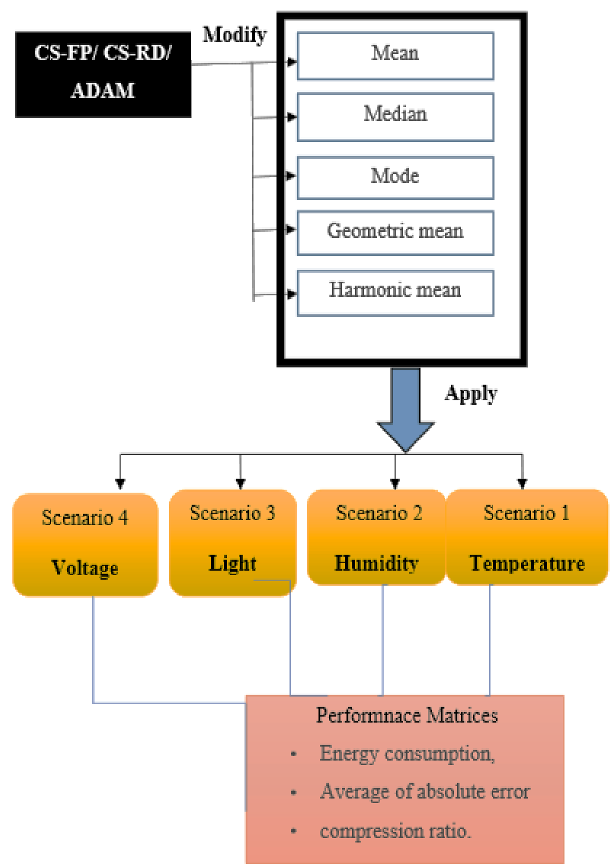

Figure 2. The steps taken to realize the algorithm implementation

// The proposed flow//

1. **Stage1:** Cluster Head receives the cluster members sensed value for Temperature / Humidity /Light / Voltage
2. **Stage2:** Calculate the **Central Point (CP)** for received data from all cluster members. These methods are explained in detail in Chapter 2 in this project report.
3. **Stage 3:** Coding the data based on **CS-FP/ CS-RD/ ADAM** algorithms. // These algorithms are described in detail in Chapter 2 in this project report.
4. **Stage 4:** Calculate the size of transmitted data and performance matrices
5. **End**

3. Evaluation of the Aggregation Algorithm

A. Performance of CS-RD, ADAM and CS-FP algorithms with a temperature sensor

In this scenario, the CH aggregated the sensor data from six (6) nodes in 14 epochs, in which all nodes sensed the temperature value to the CH. The CH sends the sensor node values after collecting the temperature values from all cluster members. In order to evaluate CS-RD, ADAM and CS-FP algorithms real-time dataset have been used as the temperature sensor. The algorithms are applied separately with (1) Mean (2) Median (3) Mode (4) Geometric mean (5) Harmonic mean.

Figure 4 shows the Average absolute error between the actual temperature sensor values and approximated data by applying 15 different scenarios for the aggregation algorithms. The results represent that the minimum error occurs in the case of CS-PF with all scenarios which are located between 0.01 and 0.031. The algorithm CS-RD and ADAM show an intermediate error rate. The Average absolute error for CS-RD is located between 0.02 and 0.2. The highest Average absolute error occurred by application of ADAM algorithm, which is located between 0.1 and 0.32. For CS-RD, the maximum error occurs in case of CS-RD with Harmonic mean over all others. Similarly, for ADAM algorithm, the maximum error occurs in case of ADAM with Harmonic over all others.

The bar graph in Figure 5 shows the energy dissipation comparison for CS-RD, ADAM and CS-FP algorithms. It can be seen that the CS-FP algorithm shows maximum energy compression for temperature sensor with different methods for determining the central point when applied separately with Mean, Median, Mode, Geometric mean and Harmonic mean. In addition, CS-FP with Mode shows the worst performance in terms of energy dissipation. This is because the nature of the Mode method is to determine the central point as well as the methodology of CS-FP compression algorithm to process, and then compresses the aggregated data with a larger number of bits. The comparison shows that the ADAM compression type shows intermediate energy consumption for temperature sensors for all central point methods. The comparison shows that the CS-RD compression algorithm shows minimum energy consumption for temperature sensors for all central point methods. This ratio indicates that the CS-FP with Mode algorithm shows a maximum dissipation of 6800 uJ, while the CS-RD algorithm shows a minimum energy consumption of 750 uJ.

The outcome of various aggregation algorithms used to reduce the size of collected temperature data that is sent is shown in Figure 6. The results show the comparison of how the aggregation algorithms reduce the transmissions from the from CH to the base station. The data compression ratio for the algorithms CS-RD, ADAM and CS-PF are 90%, 85% and [30%-55%], respectively. From the results, it is clear that the data compression ratio affects the energy consumption as discussed previously.

Figure 3 shows the average absolute error between the actual temperature sensor values and approximated data for all algorithms. The results illustrate the effect of different central point methods for different algorithms. For CS-RD algorithm the minimum error occurs in the case of applied CS-RD with Mode, which is 0.0750. The CS-RD with Mode also showed a better performance in terms of energy consumption and data compression. For CS-FP algorithm, the minimum error occurs in the case of applied CS-FP with Mode, which is 0.018507143. The CS-FP with Mean also showed a better performance in terms of energy consumption and data compression. For ADAM algorithm, the minimum error occurs in the case of applied ADAM with Mode, which is 0.177902381. The ADAM with Mean also showed a better performance in terms of energy consumption and data compression**.**

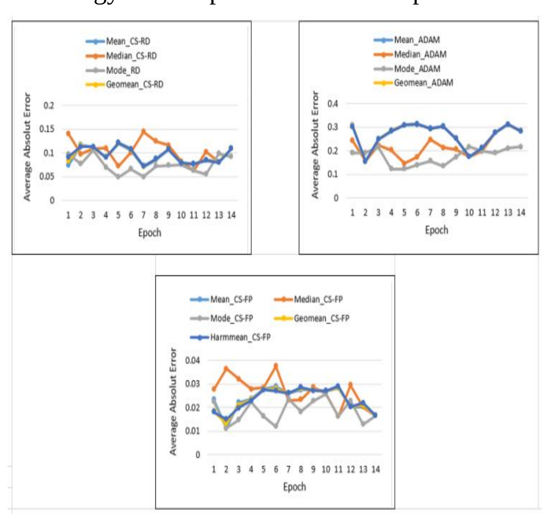

Figure 3. The average absolute error for each algorithm with different type of central point for temperature sensor

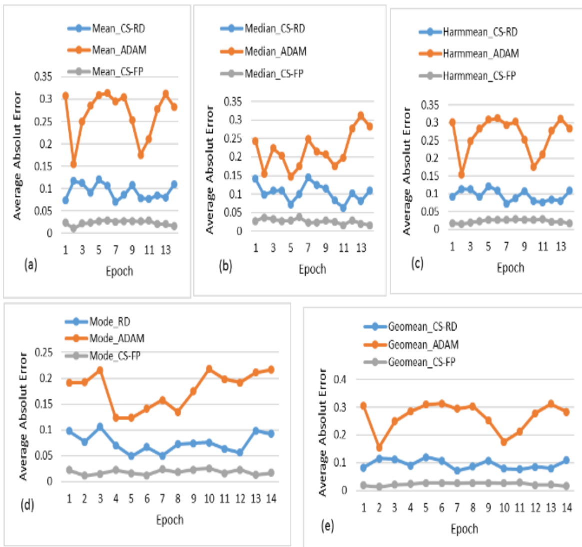

Figure 4. The average absolute error between the actual temperature sensor values and approximated data by applying the algorithms.

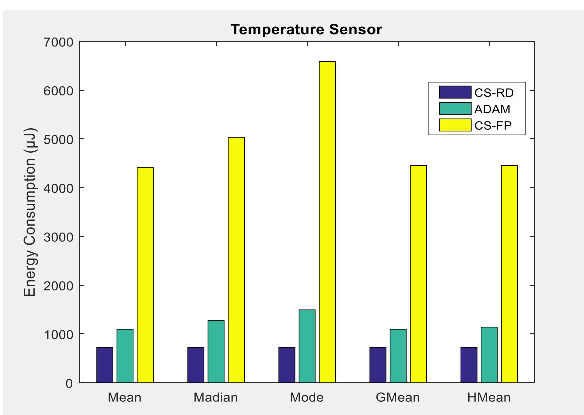

Figure 5. Energy consumption (µJ) by applying the algorithms for the temperature sensor

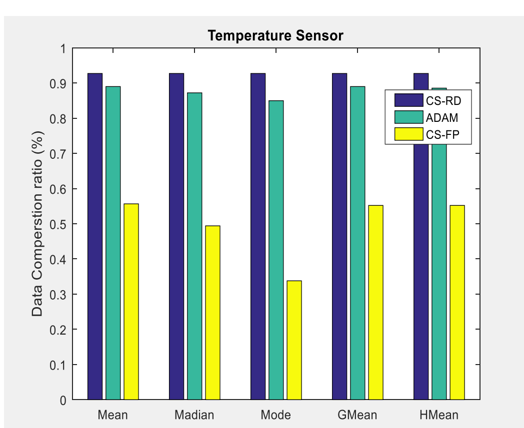

Figure 6. Data compression ratio by applying the algorithms for the temperature sensor

B. *Performance of CS-RD, ADAM and CS-FP algorithms with humidity sensor*

In this scenario, the cluster head aggregated the sensor data from six (6) nodes in 14 epochs, in which all nodes sensed the humidity and transmit to the CH. The CH sends the data after combining values from all cluster members. In order to evaluate CS-RD, ADAM and CS-FP algorithms, real-time dataset has been used as the humidity sensor values. The algorithms are applied separately with (1) mean (2) median (3) mode (4) geometric mean (5) harmonic mean.

Figure 7 shows the average absolute error between the actual humidity sensor values and approximated data for all algorithms. It illustrated the effect of different central point methods for different algorithms. For CS-RD algorithm, the minimum error occur with median value of 0.067. The CS-RD with median also shows better performance in terms of energy consumption and data compression. For CS-FP algorithm, the minimum error occurs in case of applied CS-FP with mode of 0.012. For ADAM algorithm, the minimum error occurs in the case of applied ADAM with Median of 0.19. The ADAM with Median also showed a better performance in terms of energy consumption and data compression.

Figure 8 illustrates the Average absolute error between the actual humidity sensor values and approximated data by applying 15 different scenarios for the aggregation algorithms. The results show that minimum error occurs in the case of CS-PF with all scenarios which are located between 0.026 and 0.035. The Average absolute error for CS-RD is located between 0.067 and 0.2452. The highest Average absolute error occurred by applied ADAM algorithm, which is located between 0.128 and 0.269. For CS-RD and ADAM, the maximum error occurs in the case of CS-RD/ADAM with Geometric mean higher than all others.

The bar graph in Figure 9 shows the energy dissipation comparison for CS-RD, ADAM and CS-FP algorithms. It can be seen that the CS-FP algorithm shows maximum energy compression for humidity sensor with different methods for determining the central point with Mean, Median, Mode, Geometric mean and Harmonic mean applied separately. In addition, CS-FP with Mode shows the worst performance in terms of energy dissipation. This is due to the nature of the Mode method to determine the central point as well as the methodology of CS-FP compression algorithm to process and then compress the aggregated data with a larger number of bits. The comparison shows that the ADAM compression type shows intermediate energy consumption (1300 uJ) for humidity sensors for all central point methods except Mode method, which was 5300 uJ. The comparison shows that the CS-RD algorithm shows minimum energy consumption (650 uJ) for humidity sensors for all central point methods. This ratio indicates that the CS-FP with Mode algorithm shows a maximum dissipation of 5800 uJ, while the energy consumption of CS-FP with other central point methods is approximately 3300 uJ.

The results of various aggregation algorithms used to reduce the size of the collected data (humidity) are shown in Figure 10. The result is provided as a comparison of how the aggregation algorithm reduces transmissions from the CH to the base station. The data compression ratios of the algorithms CS-RD, ADMA and CS-PF are 92%, [87% - 90%] and [40%-65%], respectively. The effect of data compression on energy consumption can be clearly seen as described below. For both CS-PF and ADMA algorithms, the lowest reduction ratio occurs in the case of applying CS-PF / ADMA with Mode method.

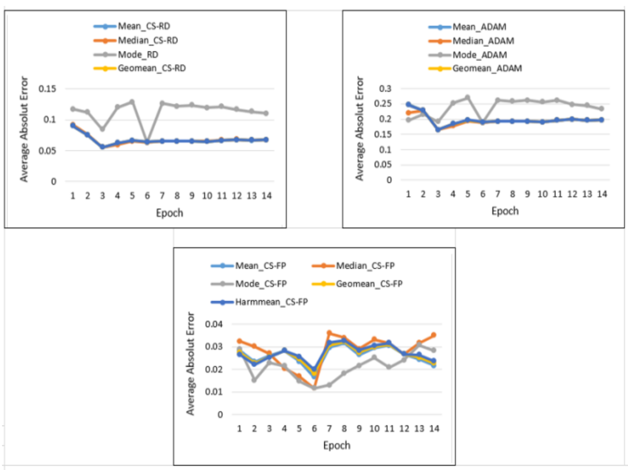

Figure 7. The Average absolute for each algorithm with different type of central point for humidity sensor

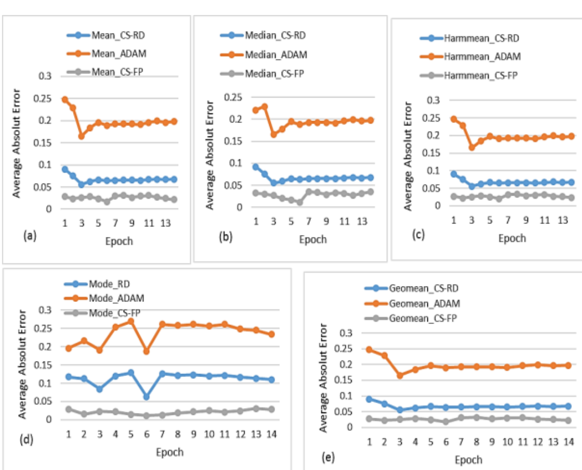

Figure 8. The Average absolute error between the actual humidity sensor values and approximated data by applying the algorithms

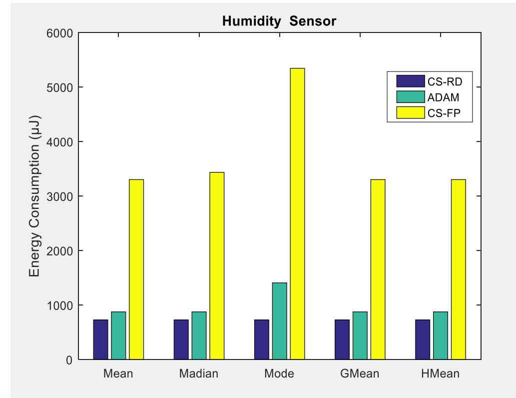

Figure 9. Energy consumption (µJ) by applying the algorithms for humidity sensor

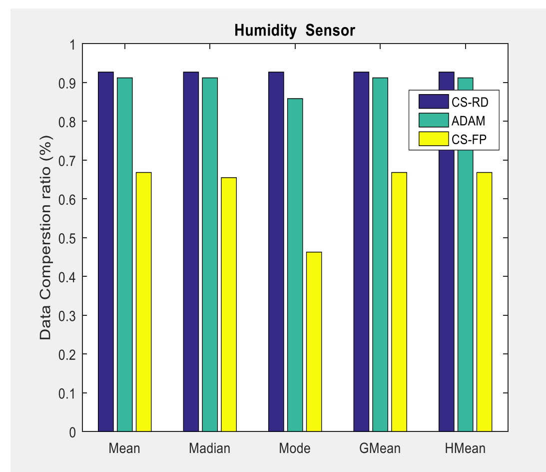

Figure 10. Data compression ratio by applying the algorithms for humidity sensor

C. Performance of CS-RD, ADAM and CS-FP algorithm with a light sensor

In this scenario, the cluster head aggregated the sensor data from six (6) nodes in 14 epochs, in which all nodes sensed the light value to the cluster head. Cluster head sends the sensor nodes values after collecting the light values from all cluster members. In order to evaluate CS-RD, ADAM and CS-FP algorithms, real-time dataset has been used as the light sensor. The algorithms applied separately with (1) Mean (2) Median (3) Mode (4) Geometric mean (5) Harmonic mean.

Figure 11 shows the average absolute error between the actual light sensor values and approximated data for all algorithms. The results illustrated the effect of different central point methods for different algorithms. For CS-RD algorithm, the minimum error occurs in the case of applied CS-RD with Mode of 1.083. The CS-RD with Mode also showed a good performance in terms of energy consumption and data compression. For CS-FP algorithm, the minimum error occurs in the case of applied CS-FP with Mode of 0.019. The CS-FP with Mean also showed a better performance in terms of energy consumption and data compression. For ADAM algorithm, the minimum error occurs in the case of applied ADAM with Mode of 0.211. The ADAM with Mean also showed a better performance in terms of energy consumption and data compression.

Figure 12 shows the Average absolute error between the actual light sensor values and approximated data by applying 15 different scenarios for the aggregation algorithms. The result shows that minimum error occurs in the case of CS-FP with all scenarios that are located between 0.0 and 0.2. The algorithm CS-RD and ADAM show an intermediate error rate. The Average absolute error for CS-RD and ADAM is located between 0.1 and 3.6. The maximum error occurs in the case of ADAM with Geometric mean.

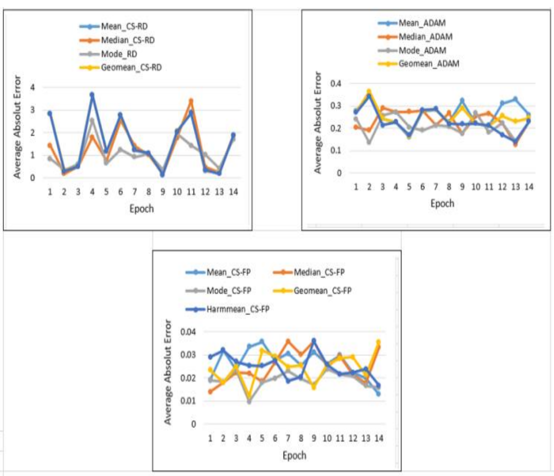

Figure 11. The Average absolute for each algorithm with different type of central point for light sensor

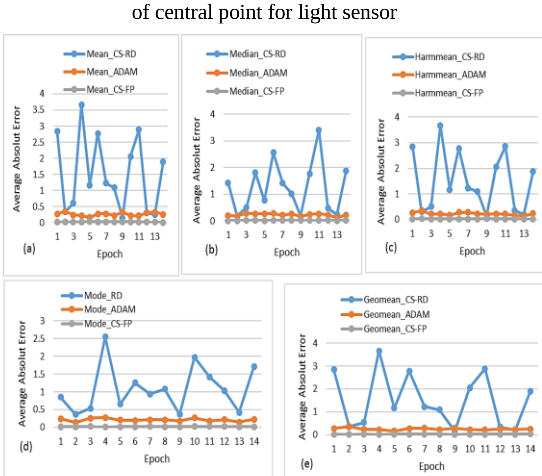

Figure 12. The Average absolute error between the actual light sensor values and approximated data by applying the algorithms

Figure 13 shows the energy dissipation comparison for CS-RD, ADAM and CS-FP algorithms. It can be seen that the CS-FP algorithm shows maximum energy compression for a light sensor with different methods for determining the central point by separate application with Mean, Median, Mode, Geometric mean and Harmonic mean. In addition, CS-FP with Mode shows the worst performance in terms of energy dissipation. This is due to the nature of the Mode method to determine the central point as well as the methodology of CS-FP compression algorithm to process and then compress the aggregated data with a larger number of bits. The comparison shows that the ADAM compression type shows acceptable performance in energy consumption for light sensors for all central point methods. The comparison shows that the CS-RD compression algorithm shows minimum energy consumption for light sensors for all central point methods. This ratio indicates that the CS-FP with Mode algorithm shows a maximum dissipation of 4700 uJ, while the CS-RD algorithm shows a minimum energy consumption of 1450 uJ. The ADAM shows energy consumption of 2200 uJ. The CS-RD /ADAM with Mode show the highest energy consumption over all other methods. The outcome of various aggregation algorithms used to reduce the size of collected light data transfer is shown in Figure 14, which indicates the results as a comparison of how the aggregation algorithms reduce transmissions from CH to the base station. The data compression ratio for the algorithms CS-RD, ADMA and CR are 88%, 78% and 55%, respectively. From the results, it is clear that the data compression ratio affects the energy consumption as discussed previously.

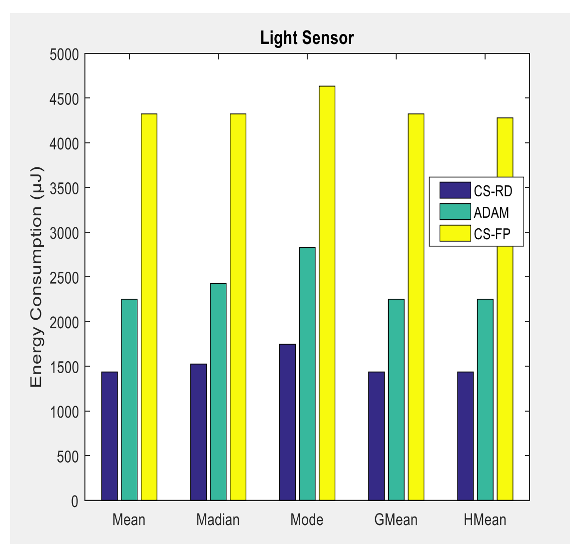

Figure 13. Energy consumption (µJ) by applying the algorithms for light sensorSome Common Mistakes

D. Performance of CS-RD, ADAM and CS-FP algorithm with a voltage sensor

In this scenario, the cluster head aggregated the sensor data from six (6) nodes in 14 epochs, in which all nodes sensed the Voltage value to the cluster head. Cluster head sends the sensor nodes values after collecting the light values from all cluster members. In order to evaluate CS-RD, ADAM and CS-FP algorithms, real-time dataset has been used as the Voltage sensor. The algorithms are applied separately with (1) Mean (2) Median (3) Mode (4) Geometric mean (5) Harmonic mean.

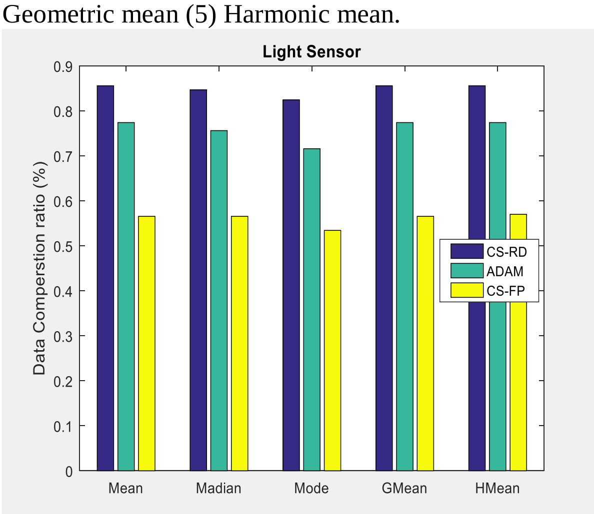

Figure 14. Data compression ratio by applying the algorithms for light sensor

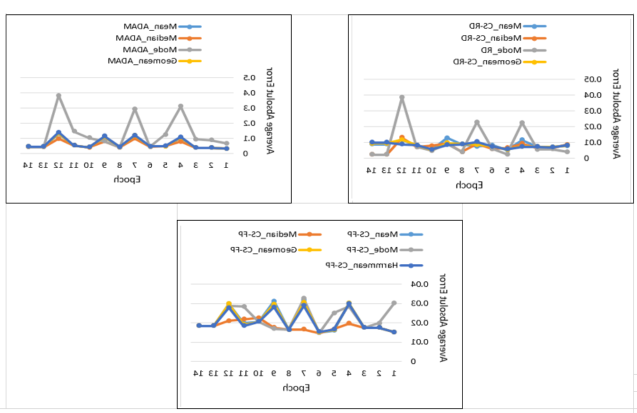

Figure 15. The Average absolute for each algorithm with different type of central point for voltage sensor

Figure 15 shows the average absolute error between the actual voltage sensor values and approximated data for all algorithms. The results illustrated the effect of different central point methods for different algorithms. For CS-RD algorithm, the minimum error occurs in the case of applied CS-RD with Median of 0.007098714. The CS-RD with Median also showed a better performance in terms of energy consumption and data compression. For CS-FP algorithm, the minimum error occurs in the case of applied CS-FP with Median of 0.018216071. The CS-FP with Mean also showed a better performance in terms of energy consumption and data compression. For ADAM algorithm, the minimum error occurs in the case of applied ADAM with Median of 0.056514524. The ADAM with Median also showed a better performance in terms of energy consumption and data compression.

Figure 16 shows the Average absolute error between the actual Voltage sensor values and approximated data by applying 15 different scenarios for the aggregation algorithms. The results show that minimum error occurs in the case of CS-PF with all scenarios which are located between 0.0 and 0.026. The algorithm CS-RD and ADAM show an intermediate error rate. The Average absolute error for CS-RD and ADAM is located between 0.1 and 3. The ADAM with Mode shows the highest error above 0.3.

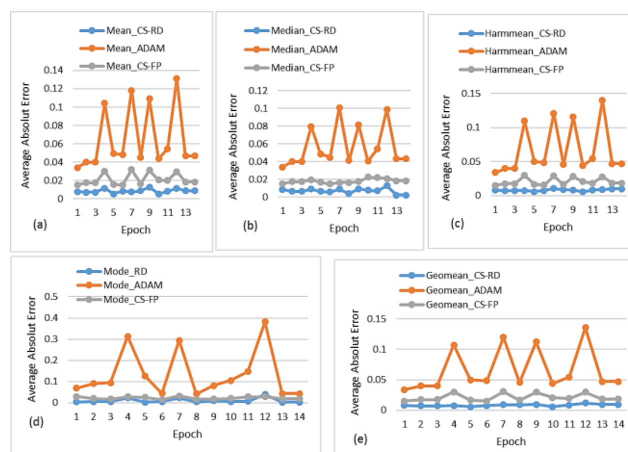

Figure 16. The Average absolute error between the actual Voltage sensor values and approximated data by applying the algorithms

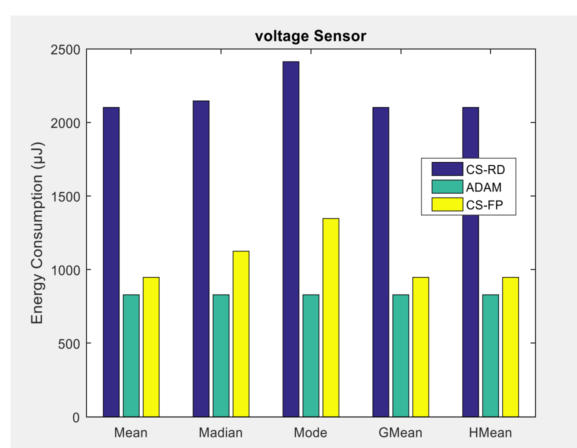

Figure 17. Energy consumption (µJ) by applying the algorithms for the Voltage sensor

The bar graph in Figure 17 shows the energy dissipation comparison for CS-RD, ADAM and CS-FP algorithms. It can be seen that the CS-RD algorithm shows maximum energy compression for Voltage sensor with different methods for determining the central point by separate application with Mean, Median, Mode, Geometric mean and Harmonic mean. In addition, CS-RD with Mode shows the worst performance in terms of energy dissipation. The comparison shows that the CS-FP compression type shows intermediate energy consumption for Voltage sensors for all central point methods. The comparison shows that the ADAM compression algorithm shows minimum energy consumption for Voltage sensors for all central point methods. This ratio indicates that the CS-RD with Mode algorithm shows a maximum dissipation of 2400 uJ, while the ADAM algorithm shows a minimum energy consumption of 820 uJ.

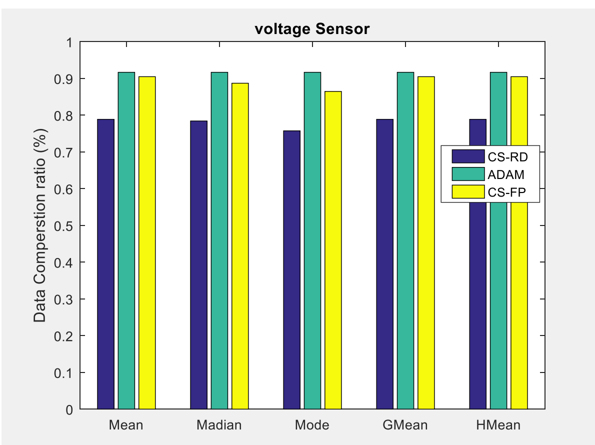

Figure 18. Data compression ratio by applying the algorithms for the Voltage sensor
NOTE: change voltage to Voltage

TABLE 2. SUMMARY OF THE PERFORMANCE OF ALL ALGORITHMS

Algorithm	Performance Metrics	Temperature	Humidity	Light	Voltage
CS_RD	**Average Absolut Error**	Mode	Median	Mode	Median
	Energy Consumption	All central Point	Median	Mode	Median
ADAM	**Average Absolut Error**	Mode	Median	Mode	Median
	Energy Consumption	Mean	All central point	Mean	All central Point
CS_FP	**Average Absolut Error**	Mode	Mode	Mode	Median
	Energy Consumption	Mean	HMean	Mean	Mean

The result of various aggregation algorithms used to reduce the size of collected data (Voltage) sending is shown in Figure 18. Results are shown as a comparison of how the aggregation algorithms reduce the number of transmissions from CH to the base station. The data compression ratio for the algorithms ADMA, CS-PF and CS-RD are 91%, 89% and 78%, respectively.

For more comprehensive review, the summary of the analytical performance results for the four sensors have been arranged critically through Table 2.

4. CONCLUSIONS

First, from the simulation results, it can be concluded that the best performance is shown by the CS-RD algorithm, followed by the ADAM algorithm which has showed intermediate performance for all sensors. Also, as an average result, the CS-PF had the lower performance. However, while it can be said that the accuracy of CS-PF is better than other algorithms, it shows the worst performance in terms of energy consumption and data compression ratio for all scenarios. From the results, it is observed that in order to determine the central point effect in the performance of three aggregation algorithms, the appropriate mechanism should be selected. For temperature and humidity sensors, the best performance is in terms of energy consumption with application of CS-RD with all methods that were below 800 uJ and compression ratio above 90%, which was adjudged to be an acceptable error. On average, CS-PF shows the worst performance, especially with Mode method. For the voltage sensor in this study, the ADAM and CS-FP with Mean /Gmean /Hmean methods showed better performance in energy consumption below 1000 uJ, compression ratio about 91% and acceptable error. Furthermore, the CS-RD performance result was above 85%, which can be considered acceptable in terms of compression ratio that will also affect the energy consumption. Also, it has been strongly concluded that the performance of all algorithms was negatively affected by the mode method. Finally, in terms of energy consumption, the CS-RD with Mode is considered the worst performance, with a result close to 2500 uJ. Finally, for the light sensor, the best performance has been reached by applying CS-RD algorithm with all central point methods, where the energy consumption was below 1400 uJ, and the CS-PF/ADAM with Mode showed the highest energy consumption above 4200 uJ for CS-PF and above 2400 uJ for ADAM.

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