International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075, Volume-8 Issue-8 June, 2019

Empirical Validation for Energy Efficiency of DEAR routing protocol over AODV in IEEE802.15.4 based Wireless Sensor Networks

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Abstract: Energy conservation has been a priority research concern for embedded electronics and wireless sensor nodes. The major issues and challenges in WSNs have constrained resources, reliability and fault tolerance. Physically damaged and failed sensor nodes should not hinder the performance of the sensor network, and reliable data routing to the receiver determines the degree of network fault tolerance. Reducing energy consumption at the network layer can be achieved by incorporating energy efficient routing protocols for data dissemination and retrieval. One such solution was reported wherein a distributed energy aware routing (DEAR) protocol is incorporated with a localized cooperative caching algorithm CCZ for data retrieval with minimum latency and higher accuracy. The empirical validation of the same is required to authenticate the use of the proposed algorithm. In this paper, we choose AODV as the standard routing protocol and based on that a validation study is established to prove the efficacy of the proposed DEAR protocol with CCZ cooperative caching scheme. The Student's two-tailed t-test is used as a statistical tool to validate the system. The t-test is a statistical hypothesis test in which the test statistic follows the student's t-distribution under the null hypothesis.

Index Terms: Empirical Validation, CCZ, Cooperative Caching, AODV, DEAR, t-test

I. INTRODUCTION

With the development of Wireless Technologies and embedded electronics, there is an enhancement in the power consumption in Wireless Sensor Networks. IEEE 802.15.4 based WSNs are Low Rate Wireless Personal Area Network standard in which efficient use of resources is the prime concern. Energy efficiency can be achieved by incorporating energy efficient routing algorithms. As an intermediary, multihop routing is preferred over long-range communications in a sensor network environment primarily so as to reduce the energy costs for long-range communications. Further, the energy can also be minimized by reducing the number of packet overheads and this can be achieved by inducing a suitable reliability algorithm. Using such schemes in a wireless network improves the Quality of Service (QoS). The data transmitted from the source must be received at the receiver with minimal latency and energy consumption should be as low as possible.

Revised Manuscript Received on June 05, 2019

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Cooperative caching is an appropriate solution to improved QoS by reducing the packet overheads and also by providing the requested datum to the sink node with minimal delay. Caching will not only serve data request with minimal latency but is also responsible for enhanced energy efficiency in mobile wireless environments. In cooperative caching, the cache management is the crux of the system and is of utmost importance. The cache management scheme provides, cache discovery, cache admission control, cache replacement and cache consistency.

II. RELATED WORKS

Today, researchers describe the performance of the IEEE 802.15.4 standard with different topologies and use many techniques. However, in order to compare the performance between the two topologies for better utilization, it is still rarely done.

A caching scheme was proposed by T.P Sharma et al. [1] that utilize collaboration between various SNs within a designated area. In addition to its own local storage, nodes also use storage from motes of other clusters around them to form larger temporary storage, known as the cumulative cache. They demonstrated a token-based cache admission control (CAC) scheme to cater the need to store or replace the data in the cache by a particular node holding the token. One of the biggest snags in the proposed model is that a greater amount of packet overhead is generated to retain and rotate the token.

Then, N. Dimokas et al. [2] had recognised targets that need to be optimized such as energy consumption, access latency, and the replicated data items to be placed in different locations. The main drawback of this technique was that the node importance (NI) index considers only the one hop neighborhood of a particular mote.

M. Udin Harun Al Rasyid et al.[3], conducted a performance comparison by analyzing throughput, latency, and energy consumption in the beacon enable modes of the IEEE 802.15.4 standard for star and cluster topologies to achieve maximum efficiency as needed to apply the appropriate topology model. They analyzed each topology model using the number of nodes from 10 nodes to 100 nodes to analyze performance metrics as mentioned above. The simulation results show that the lifetime of nodes and throughput of the cluster topology are higher than the star topology.

Piyush Charan et al [5] proposed a Cooperative Caching scheme for LR-WPAN based on IEEE802.15.4 standard and found through successive simulations that the Energy Consumption in Grid based network model is less as compared to Star based network model with the

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DEAR routing protocol in collaboration with the localized algorithm for Caching in Cooperative Zones (CCZ). Finally, the purpose of this paper is to validate the simulation of the LR-WPAN by using NS2 and compares the performance of the grid based topology in terms of energy consumption with AODV and DEAR routing protocol with the presence of the localized caching algorithm through standardized test statistic tools.

A. Caching in Cooperative Zones

Caching facilitates storing of data items that are frequently accessed in an on-board cache provided in a sensor node. In WSNs based on IEEE802.15.4 an adaptive technique caching in Cooperative Zone (CCZ) is incorporated for data retrieval. It is always favourable for a sensor node (SN) under this scheme to extend cached data to its one hop neighbour available in its zone. The sensor mote which is a member of a particular zone of a mote forms a collaborative cache system for that particular node because link costs or communication costs with them are very low in terms of consumption of energy and the exchange of data. This mechanism of data retrieval through cooperative caching was earlier incorporated in a network that was simulated with AODV routing protocol by Charan et al [5] and found that AODV with CCZ is more beneficial in a grid based network rather than a cluster or star based network. Later, Charan et al proposed the distributed energy aware routing (DEAR) protocol [6] and the simulation results showed that more significant energy efficiency is achieved when the routing protocol is used with the localized caching algorithm for data retrieval in grid based network comprising of sixteen IEEE802.15.4/ ZigBee based wireless nodes.

B. AODV_CCZ

The IEEE 802.15.4 based grid network model was simulated with adhoc on-demand distance vector (AODV) routing protocol in which a localized caching algorithm complimented the energy efficiency of the network. A network of sixteen nodes in star/ cluster arrangement and grid based arrangement were simulated separately. The simulation results showed that when the caching policy is used with the AODV routing protocol then the energy consumption is reduced from 3.19mWh to 2.43mWh when a star based network is simulated whereas; the energy consumption gets reduced from 2.13mWh to 1.92 mWh when a grid based network was chosen [5]. The overall Quality of Service (QoS) of the system is enhanced based on the byte hit ratio. The simulation results show that the Byte Hit Ratio in Grid Connected Network is better than that in the Star Based Network model. This is because more number of data items are found in the local cache as the cache gets larger. The local byte hit ratio increases with the increase in cache size because with larger cache storage more data can be cached locally in the one hop neighbors as in the case of grid connected devices as all the devices are one hop neighbors to each other in such an arrangement.

C. DEAR_CCZ

The distributed energy aware routing (DEAR) protocol is an extension to the conventional AODV routing protocol which endorses a specific feature via which only those nodes will be included in the routing path which have a residual energy of 80% or more of the total link cost to send the requested datum from the source node to the destination node. As previously used with the AODV routing protocol, a localized caching algorithm is used to compliment the efficacy of the network model. The caching in cooperative zones (CCZ) algorithm is used to retrieve the requested data from the neighboring nodes in various zones. The simulation results show that the energy consumption gets minimized when the grid based network model is used with such parameters.

III. EMPIRICAL VALIDATION

A. Empirical Validation of the proposed CCZ Model

The significance of the proposed study is authenticated by testing the hypothesis for minimal energy consumption. The performance of the DEAR routing protocol with CCZ Cooperative Cache scheme is tested using the two-tailed test on the basis of the total energy consumption against the standard energy consumption of AODV routing protocol with CCZ cooperative caching. The empirical validation is essential for acceptance. The two-tailed t-test is carried out using sample data sets.

B. Data set for the empirical validation of the proposed CCZ model

The simulation results are provided in the following data set shows that the energy consumption in grid or peer-to-peer network model is better so we consider the data set for energy consumption of the grid model. In the proposed grid model, figure 3.14 there exist two scenarios one in which AODV is simulated with CCZ caching scheme and in the other DEAR is simulated with the CCZ caching algorithm. The Energy consumption in both these scenarios is considered as data sets for the empirical validation of the system. The data set for five different scenarios is considered wherein energy consumption is tabulated for various simulations and for data rates in the range (1pps~ 5pps) as shown in table 1.

Table 1: Data Set for Paired Sample *t*-Test for Energy Consumption in IEEE 802.15.4 grid-based network model

Data Rate	*AODV_CCZ (Energy Consumption when AODV with CCZ cooperative caching is used)*	*DEAR_CCZ (Energy Consumption when DEAR with CCZ cooperative caching is used)*
pps	**mWh**	**mWh**
1	2.221	1.217
2	1.980	1.154
3	1.871	1.061
4	1.794	1.102
5	1.742	1.087

IV. TWO TAILED T -TEST FOR ENERGY CONSUMPTION IN WSNS BASED ON IEEE802.15.4

A two-tailed *t*-test is performed on data set as given in table 1. This is done so as to assign half of the alpha to test statistical significance in one direction and the other half of alpha to test statistical significance in the other direction, where alpha ($\alpha = 0.05$) when 95% level of significance is

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considered. This means 0.025 at each tail of the test statistic distribution. When using a two-tailed test, the possibility of a bidirectional relationship is tested, regardless of the direction of relationship being hypothesized. Since two different routing protocols are examined in the grid-based scenario where all nodes are based on the IEEE 802.15.4 MAC and PHY standard therefore, a student's two-tailed *t*-test is performed on the data set as provided in table 1, wherein one sample contains data for energy consumption by the nodes when the standard AODV with CCZ cooperative caching scheme is employed for data rates in the range (1pps~ 5pps) and the other sample contains data for energy utilization by the motes when the DEAR protocol with CCZ cooperative caching scheme is employed for similar data rates.

To analyze the performance of AODV and DEAR routing protocols respectively with Cooperative Caching strategy using two-tailed *t*-tests we re-write the hypothesis statements as below:

A. *Hypothesized Statement*

The performance and Quality of Service in IEEE 802.15.4/ZigBee based Wireless Sensor Networks based on the Energy Consumption is improved when the proposed DEAR protocol is used with cooperative caching scheme.

B. *Null Hypothesis (H_0)*

The performance of DEAR routing protocol with CCZ caching scheme for nodes in IEEE 802.15.4 based WSNs is less than or equal to the standard AODV protocol when analyzed with the same caching scheme. This also means that the energy consumption of nodes in a sensor network routing data by the standard routing protocol AODV with CCZ caching (μ_1) is less than or equal to the energy consumption of nodes routing data by DEAR protocol with CCZ caching (μ_2).

$$\Rightarrow \quad \boldsymbol{H_0\colon\ \mu_1 \le \mu_2}$$

C. *Alternative Hypothesis (H_A)*

The performance of sensor nodes simulated with DEAR protocol and CCZ caching scheme is better with respect to the standard AODV protocol when analyzed with the same caching scheme. This also means that the energy consumption of nodes in a sensor network routing data via the standard AODV protocol with CCZ caching algorithm (μ_1) is greater than the energy consumption of nodes routing data by DEAR routing protocol with CCZ caching (μ_2).

$$\Rightarrow \quad \boldsymbol{H_A\colon \mu_1 > \mu_2}$$

V. Data Analysis

The Analysis Toolpak of Microsoft Excel 2013 and Minitab v14 are used as tools for data description and analysis. The table 5.1 contains two samples for energy consumptions in IEEE 802.15.4 based WSNs wherein one sample is for the standard adhoc on demand distance vector (AODV) routing protocol and the other for the distributed energy aware routing (DEAR) routing protocol respectively with Caching in Cooperative Zones (CCZ) cache scheme.

A. *Description of AODV_CCZ*

The sample with name AODV_CCZ is basically data for Energy Consumption in the sensor motes based on the IEEE 802.15.4 MAC/PHY Wireless Sensor Networks arranged in a Grid or peer-to-peer network model wherein the data packets are routed using the standard AODV routing protocol[4] with CCZ cooperative caching algorithm. The sample mean of the data provided is M = 1.92160, the Standard Deviation of the sample is SD = 0.18983, the sample size of the data is n = 5, and the Standard Error for the sample Mean is SE = 0.08490.

B. *Description of DEAR_CCZ*

The sample with name DEAR_CCZ is data for Energy Consumption in the sensor motes based on the IEEE 802.15.4 MAC/PHY Wireless Sensor Networks arranged in a Grid or peer-to-peer network model wherein the data packets are routed using the DEAR routing protocol with CCZ cooperative caching algorithm. The sample mean of the data provided is M = 1.1242, the Standard Deviation of the sample is SD = 0.06199, the sample size of the data is n = 5, and the Standard Error for the sample Mean is SE = 0.02772.
A tabulated sheet of the above data is produced in table 2 as obtained from Minitab v14.

Table 2: Description of Paired Sample Data Set for two tailed *t*-Test

	Sample Size N	Mean M	Standard Deviation SD	Standard Error for Mean SE
AODV_CCZ	5	1.92160	0.18983	0.08490
DEAR_CCZ	5	1.12420	0.06199	0.02772
Difference	5	0.79740	0.13697	0.06126

A box plot for the above two mentioned samples for Energy consumption in the IEEE 802.15.4 grid based Wireless Sensor Network is also obtained from Minitab as shown in figure1.

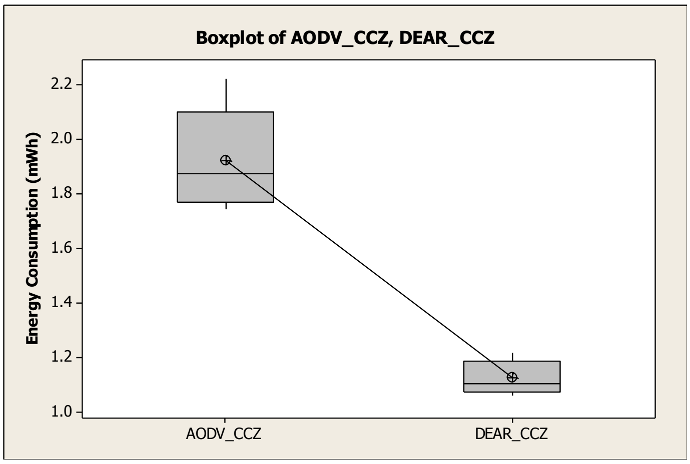

Fig. 1. Box Plot for the Sampled Data of Energy Consumption for AODV_CCZ and DEAR_CCZ

VI. Paired Sample Two Tailed T-Test Analysis

A two-tailed *t*-test is performed on the sample as illustrated in table 1. The test is conducted for 95% level of confidence or 5% level of significance ($\alpha = 0.05$), the hypothesized mean is 0, the degrees of freedom is df = n-1 = 5-1 = 4, and the remaining test results are tabulated in table 3.

Table 3: *t*-Test: Paired Two Sample for Means of AODV_CCZ and DEAR_CCZ obtained on MinitabV14

	AODV_CCZ μ_1	*DEAR_CCZ* μ_2
Mean	1.9216	1.1242
Variance	0.0360373	0.0038427
Observations	5	5
Pearson Correlation	0.897289406	
Hypothesized Mean Difference	0	
df	4	
t Stat	13.02	
P(T<=t) one-tail	0.0001	
t Critical one-tail	2.132	
P(T<=t) two-tail	0.0002	
t Critical two-tail	2.776	

Table 4: *t*-Test: Paired Two Sample for Difference of Means of AODV_CCZ and DEAR_CCZ obtained in Analysis Toolpak of Excel 2013

Data rate	AODV_CCZ μ_1	DEAR_CCZ μ_2	Difference $x_d = \mu_1 - \mu_2$
pps	mWh	mWh	
1	2.221	1.217	1.004
2	1.980	1.154	0.826
3	1.871	1.061	0.810
4	1.794	1.102	0.692
5	1.742	1.087	0.655
sample mean ($\overline{x_d}$)			0.7974
sample std deviation (s)			0.136974
Hypothesized Mean difference			0
Sample Size, n			5
Degrees of Freedom, df=n-1			4
***t*-Stat**			13.02
p-value			0.000201

For testing the hypothesis the *t*-values (critical and statistical) are compared with each other in order to select or reject a null hypothesis. The $t_{statistical}$ value is calculated using equation 1 as shown below:

$$t_{statistical} = \frac{\overline{x_d} - hypothesized\ mean}{\frac{s}{\sqrt{n}}} \quad (1)$$

$$or, \quad t_{statistical} = \frac{0.7974 - 0}{\frac{0.136974}{\sqrt{5}}}$$

$$or, \ t_{statistical} = 13.02 \quad (2)$$

On the other hand, the $t_{critical}$ value is calculated from the t-distribution table for 5% level of significance (α = 0.05) and 4 degrees of freedom:

$$t_{critical} = t_{\alpha}(df) = t_{0.05}(4) = 2.776 \quad (3)$$

The statistical analysis for the two tailed *t*-test shows that for $df = 4$, the $t_{critical} = t_{0.05}(4) = 2.776$, and the $t_{statistical} = 13.02$.

The box plot for the difference of samples x_d with H_0 at 95% t-confidence interval for the mean is given below in figure 2.

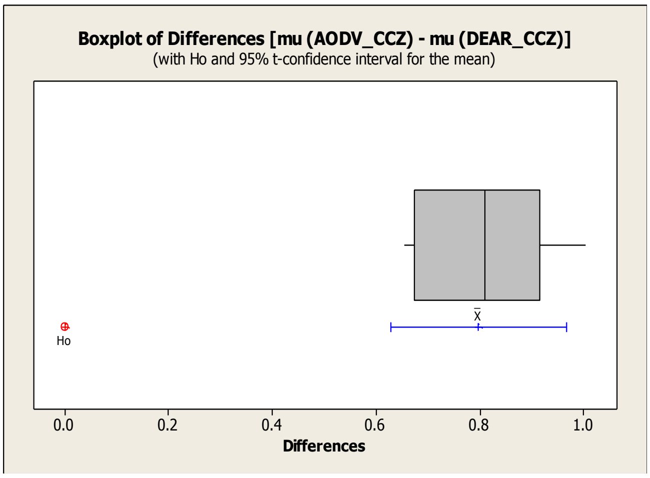

Fig. 2. Box Plot for the difference of samples x_d with H_0 at 95% t-confidence interval for the mean

Since, $t_{statistical} > t_{critical}$ therefore we reject the null hypothesis (H_0) and we may accept the alternative hypothesis (H_A). It means that the energy consumption of nodes in a sensor network routing data via the standard AODV protocol with CCZ caching algorithm (μ_1) may be greater than the energy consumption of nodes routing data by DEAR routing protocol with CCZ caching (μ_2).

So, we finally reject the null hypothesis but to approve the alternative hypothesis (H_A), the p-value needs to be compared with the alpha (α) value.

Since, for 95% level of confidence is considered which means that 5% level of significance is considered, that is:

$$\alpha = 0.05 \quad (4)$$

If p-value is less than α, then we strongly accept the alternative hypothesis (H_A). And according to the statistical analysis the p-value for the two tailed test as illustrated in table 4 is:

$$p - value\ (two\ tailed) = 0.000201 \quad (5)$$

Since, p-value is much less than the alpha (α) value, therefore, we strongly accept the alternative hypothesis.

VII. CONCLUSIONS

In this manuscript we have validated the hypothesis by applying a paired two-tailed *t*-test in which two paired samples are considered for energy consumption in the IEEE 802.15.4 based Wireless Sensor Network wherein the sensor motes are considered to be arranged in a peer-to-peer or grid formation and in one sample the energy consumption is computed with the simulation when the standard AODV routing protocol with CCZ cooperative caching scheme is considered and in the other sample the energy consumption is computed with the simulation when the proposed DEAR routing protocol with the CCZ cooperative caching scheme is considered. The statistical analysis was done and a conclusion is drawn that the DEAR protocol with Caching Scheme performs better than the AODV protocol in terms of the total energy consumption by the sensor nodes. The null hypothesis (H_0) is rejected and the alternative hypothesis (H_A) is strongly accepted.

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ACKNOWLEDGMENT

We would like to thank Integral Information and Research Centre, Integral University, Lucknow, India for providing an opportunity to carry out this research work. The authors acknowledge the Office of Dean, Research and Development for critically reviewing the manuscript and providing the manuscript number (IU/R&D/2019-MCN000614).

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