IJCSE International Journal of Computer Sciences and Engineering Open Access
Research Paper Vol.-7, Issue-12, Dec 2019 E-ISSN: 2347-2693

Analytic Network Process-Based Cluster Head Selection Mechanism for Extending the Network Lifetime

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DOI: https://doi.org/10.26438/ijcse/v7i12.2734 | Available online at: www.ijcseonline.org

Accepted: 06/Dec/2019, Published: 31/Dec/2019

Abstract— The role of wireless sensor networks is considered to be evolving ubiquitous in the present day life due to its suitability and applicability in surveillance, weather forecasting and implantable sensors used for the purpose of health monitoring and other diversified number of applications. The use of tiny sensor nodes in WSN results in the crucial issues of restricted energy, limited energy and computation time. In this context, the network lifetime expectancy purely depends on the efficient and effective utilization of available resources in the network. However, the organization of sensor nodes into clusters is essential for the potential management of each and every cluster as well as the complete network. In this paper, Analytic Network Process-based Cluster Head Selection Mechanism (ANP-CHSM) is proposed for the objective of the cluster head selection with the view to enhance the network expectancy. This proposed ANP-CHSM considered the parameters that are associated with Residual Energy of Sensor Nodes (RESN), Distance between Nodes (DBN), merged node, Frequency Count in Cluster Head Role (FC-CHR) and Centroid Distance of Sensor Nodes (DSN) for modelling the process of cluster head selection. This proposed ANP-CHSM scheme aided in the optimal cluster head selection process by tackling the aforementioned parameters that attribute towards multi criteria decision making processes. The simulation results of the proposed ANP-CHSM was also considered to be significant over the compared cluster head selection frameworks contributed for effective clustering-based lifetime improvement processes.

***Keywords*—**Analytic Network Process (ANP); Cluster head selection;network lifetime expectancy; Consistency Measure; Eigen Value.

I. INTRODUCTION

The wireless sensor network comprises of numerous sensor nodes which need to collaborate for data communication. The sensor node is an ultra-small power device that has four components. First part is for sensing the voltage, current, temperature, etc of the computer. Second part is the controlling system for data processing and storage activities [1]. Third is the communication system for sending and receiving data from other connected devices. Last is the power supply system that provides energy to carry out the expected tasks. This power supply system has a battery with limited capacity. If a node fails to work due to limited work, it results in serious failure of protocol [2]. However, it is not possible to recharge the battery because the nodes are separated and are at different locations in the other environment or other interested areas or at damaged areas where required information are available [3]. In order to fulfil the requirements the nodes should have sufficient and lengthy lifetime, even up to months or years. There is a possibility of using the energy from external sources [4]. For instance, the solar system can be used as the power source. Since the external power sources are not continuous, it is essential for the buffer to enhance it [5]. From this we incur that for systems on WSN energy is the main factor. For handling the failures efficiently, distributed protocols are the best solution [6]. For providing efficient energy to a network system we use clustering based routing protocols which are also capable of aggregating the scattered data [7]. In a cluster, delay can be reduced because the cluster functions based on the localized algorithm without waiting for the control messages [8]. In comparison with centralized computers, localized algorithms have more stability and throughput [9]. In clustering, some nodes are specified as Cluster Heads (CHs). These heads spend more energy on some specific time frames than other nodes. The sensor nodes send the information to the CHs which are responsible for transmitting the information to the base station (BS) placed at a far distance [10].

In this paper, Analytic Network Process-based Cluster Head Selection Mechanism (ANP-CHSM) is contributing to the cluster head selection in order to improve the network expectancy. This proposed ANP-CHSM utilizes Residual Energy of Sensor Nodes (RESN) , Distance Between Nodes (DBN), merged node, Frequency Count in Cluster Head Role (FC-CHR) and Centroid Distance of Sensor Nodes (DSN) for the selection of cluster head selection. This proposed ANP-CHSM scheme concentrates on optimal cluster head selection process by handling multiple parameters that focuses on multi criteria decision making. The simulation results of the proposed ANP-CHSM was also considered to be significant over the compared cluster head selection frameworks contributed to effective clustering-based lifetime improvement processes.

II. RELATED WORK

Initially, Bhuyan et al. [11] contributed a clustering algorithm is a distributed clustering algorithm which works very similar to the HEED-based clustering scheme. The core objective of clustering algorithm completely concentrates on the enhancement of HEED algorithm through the construction of balanced cluster sizes. This balancing potential of this QoS improving clustering scheme is also suitable for optimizing the topology intra-cluster based on the sensor nodes location awareness. Then, an Energy Efficient Reliable Routing (E2R2)-based cluster head selection scheme was proposed with likely characteristics which does not consider any assumptions related to the density, network size and residual energy during the process of the CH selection process [12]. E2R2-based clustering algorithm is potent in constructing a multi-level structure for the purpose of intra-cluster communication which limits the number of child nodes associated with a parent sensor node. It only uses the benefits of weights which computed locally for the objective of CH selection. The main merits of the E2R2-based clustering algorithm lies in the utilization of the complete distributed clustering approach which uses the function of the neighbouring node proximity and energy reserve of sensor nodes for clustering process. A Hierarchical and Role-based clustering scheme was proposed for highly maintaining well-balanced distribution of CHs for attaining a potentially minimized energy consumptions in the inter and intra-cluster routing process compared to HEED [13]. This HRCS scheme is independent to the network topology. However, HRCS and E2R2 schemes generate a comparatively high degree of control message overhead due to its iterative nature during the process of cluster construction. It is also not suitable for large region network applications. Secure Trust-Aware Energy Efficient Adaptive Routing (STEAR) was proposed as a distributed and competitive clustering algorithm which selects the CHs through the method of localization [14]. It facilitates the sensor nodes with a proactive competitive range, which diminishes when the sensor nodes move towards the base station. An unequal clustering process for the objective of balancing the energy consumptions between the CHs for resolving the issue of hot spots [15]. In STEAR, each individual sensor node utilizes a random number during the CH selection process.

Further, an improved LEACH-based secure trust-based clustering algorithm was proposed for distributing the energy load uniformly in the network [16]. This secure trust-based clustering scheme concentrates on the process of enforcing each and every sensor node to communicate only with the neighbouring sensor nodes which lie in a close proximity. In this secure trust-based clustering algorithm, the sensor nodes are potent in wireless communication, data detection, data positioning and data fusion with randomized. Trust-Aware Opportunistic Clustering scheme was proposed for attaining the organization of sensor nodes into chains which could be assigned by the sink or accomplished by the greedy algorithm [17]. It assumes that all the sensor nodes are potent in acquiring global knowledge during the employment of greedy algorithm. An Energy-LEACH is an enhanced version of LEACH-based clustering algorithms which change the procedure of cluster head selection depending on the parameters that could be extracted in a particular environment [18]. In E-LEACH, the complete set of nodes in the network is considered to possess an equal probability of being selected as the cluster head. The energy is considered as the major factor for the selection of cluster heads after the first round of implementation. Then, HEEC is proposed for determining cluster head based on the determination of core focus junction of network communication with which its lifetime is responsible for influencing the communication among the sensor nodes of the network [19]. This HEEC facilitates the option of cluster heads based on maximum residual energy or maximum working potential which attains stability in the network.

III. PROPOSED ANALYTIC NETWORK PROCESS-BASED CLUSTER HEAD SELECTION MECHANISM (ANP-CHSM)

The proposed Analytical Network Process-based Adaptive Cluster Head Selection Mechanism (ANP-CHSM) is a reliable option for identifying a potential Cluster Head selection scheme among the proposed Scheme1, Scheme2 and Scheme 3 for the objective of efficient Cluster Head of the network by incorporating the merits of Analytical Network Process (ANP). The Analytic (space) Network Process is used in the proposed ANP-CHSM framework as it is the most predominant multi-criteria decision making methods that includes the support in handling the dependencies and feedback between different entities and parameters of the network from higher level elements to lower level elements. This ANP is also one of the most suitable methods for facilitating decisions in the field of sensor networks, since individual performance of each existing dependency of higher level entities is characterized by the optimal choice of the lower level elements. In this context, the objective of Cluster Head selection depends on the parameters of residual energy, the number of times a specific sensor node was selected as the Cluster Head, the distance of the sensor nodes from the centre of the cluster, distance of each sensor node from its interacting neighbour nodes of the network and the node that has been removed from the low density neighbouring zone of the network, but all the parameters need play a vital role in the process of Cluster Head selection. Hence, the process of Cluster Head prediction need to be changed for optimal selection of cluster heads with the view to improve the lifetime expectancy of the network.

The performance of a clustering based Wireless Sensor Network (WSN) wholly depends on the selection of Cluster Head (CH), since it is indispensable to choose the node that promises the efficient use of resources in the network [20-21]. The choice of appropriate CH improves the lifespan anticipation of the network.

The steps involved in the ANP-CHSM are listed below.

Step 1: The main issue prevalent in the Dynamic Cluster Head Selection Scheme using Analytical Network Method (ANP-CHSM) is classified into sub problems by systematically recognizing the aim, major and minor benchmarks and promising options as shown in Figure 1. The main aim of the proposed scheme is to select appropriate major and minor benchmarks which are an assortment of factors and feasible options are the significant elements based on which decisions are to be made. In the proposed ANP-CHSM, the main goal is the proficient choice of CH that relies on major and minor benchmarks like Residual Energy, the frequency of a node elected as a CH, distance of a node from the centre of a Cluster, distance of a node from its cooperating adjacent nodes and the node that was detached from the low density adjacency zone.

Step 2: The choices and benchmarks are executed on scaling based on the substantial qualitative scale as propounded by Saaty[22]. The qualitative scale is transformed into a computable scale ranging from 1 to 9 as shown in Table 1.

Table 1. Saaty Qualitative Scale used for Scaling in the Proposed ANP-CHSM

Scale of Importance	Description
1	Equally important
2	Equal to Moderately high importance
3	Moderate high importance
4	Moderate to maximum importance
5	Highly important
6	High to very high significance
7	Very high significance
8	Very strongly to more significant
9	High priority

Step 3: Pair wise evaluation is done once the process of scaling is accomplished. Pair wise comparison is used for instituting the relative significance of diverse benchmarks conforming to a specific node. Pair wise evaluation is a consistent tool for examining the quantifiable impact of elements over selection of CHs.

Step 4: A matrix showing the criteria is built. An alternative comparison method based on benchmarks is executed for all probable alternate elements that are associated with each other. The comparison matrix is obtained after exhaustive comparisons of choices.

Step 5: Suitable CHs are to be based on 3 stability measures like Consistency Ratio and Index. The Random index used in the proposed model is shown in Table 2.

Table 2. Random Index of ANP-CHSM

Number	Related Random Index (RI)
1	0
2	0
3	0.52
4	0.89
5	1.11
6	1.25
7	1.35
8	1.40
9	1.45

The mean in the consistency measure vector is shown in the following Equations.

$$CM_{v(i)} = \frac{RI_{(i)} * PV}{PV_{(i)}} \quad (1)$$

$$CI_{Measure} = \frac{\alpha_{MAX} - n}{n-1} \quad (2)$$

$$CR_{Measure} = \frac{CI_{Measure}}{RI} \quad (3)$$

$$PV_{(i)} = \frac{1}{n}\sum_{j=1}^{n} a_{ij} \quad (4)$$

Step 6: The outputs of the comparison matrix in the unweighted super matrices are estimated to find the Eigen vectors. The unweighted super matrices are transformed into a weighted one by adding each column to 1.The weighted super matrices are obtained from the cluster and unweighted super matrix.

Step 7: The power of weighted super matrix is raised to obtain the limit matrix, unless there is a convergence that aid in estimating major stable weight sets. The best choice is given based on the maximum priority value called the Eigen value.

Step 8: Finally, Sensitivity analysis is performed to ensure steadiness and determine the ranking of results connected with the choices assisted by the whole analytical process.

IV. SIMULATION RESULTS AND DISCUSSIONS

The simulation results of the proposed ANP-CHSM are conducted using MATLAB. The simulation parameters used in the implementation of the proposed ANP-CHSM framework is listed in Table 3.

Initially, the proposed ANP-CHSM is investigated using the number of rounds until the death of the first node death, the number of rounds until the death of half of the nodes, the number of rounds until the death of the last node under increase in the sensor nodes. Figure 2, 3 and 4 exemplars the number of rounds until the death of the first node death, the number of rounds until the death of half of the nodes, the number of rounds until the death of the last node under increase in the sensor nodes.

The number of rounds until the death of the first node death, half of the nodes' death and last node death in the proposed ANP-CHSM framework is determined to be superior even when the number of sensor nodes is increased from 100 to 1000 systematically.

This predominant sustenance in prolonging the number of rounds before the death of the first node, half of the nodes' death and last node death is mainly due to the Analytical Network process-based multiple criteria decision making process in the cluster head selection framework. Thus, the number of rounds before the death of the first node is determined to be enhanced by 9%, 12% and 15% excellent to the compared CHSM-FMADM, CHSM-TREMADM and CHSM-TOPSIS frameworks used for comparison.

The number of rounds before the death of the half of the nodes of the network is determined to be enhanced by 11%, 14% and 16% excellent to the compared CHSM-FMADM, CHSM-TREMADM and CHSM-TOPSIS frameworks used for comparison. Moreover, The number of rounds before the death of the last node in the network is determined to be enhanced by 13%, 16% and 18% excellent to the compared CHSM-FMADM, CHSM-TREMADM and CHSM-TOPSIS frameworks used for comparison.

Further, Figure 5, 6 and 7 demonstrates the predominance of the proposed ANP-CHSM is investigated using the percentage increase in network lifetime, percentage increase in throughput and percentage decrease in energy consumptions. The percentage increase in network lifetime facilitated by the proposed ANP-CHSM framework was determined to be improved at an average by 8%, 11% and 14% compared to the CHSM-FMADM, CHSM-TREMADM and CHSM-TOPSIS frameworks used for investigation. The percentage increase in throughput facilitated by the proposed ANP-CHSM framework under a different number of sensor nodes was determined to be improved at an average by 10%, 13% and 16% compared to the CHSM-FMADM, CHSM-TREMADM and CHSM-TOPSIS frameworks used for investigation.

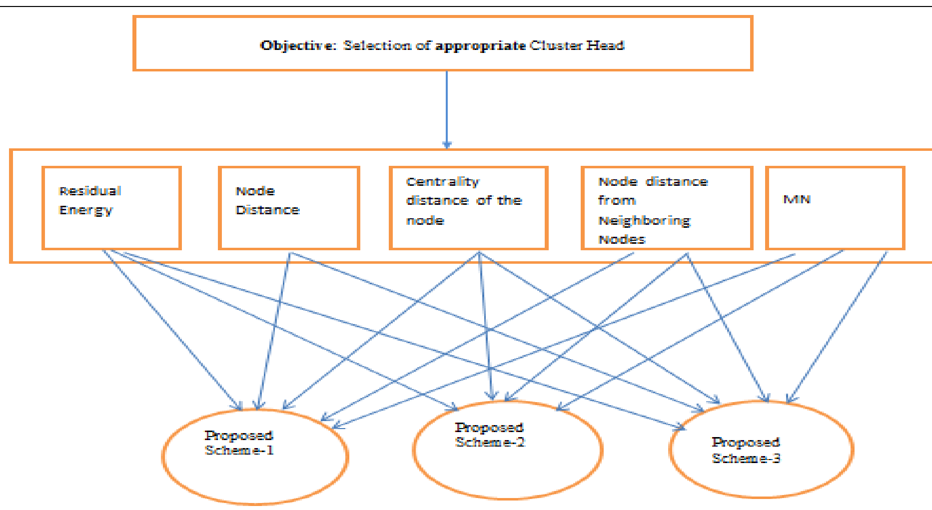

Figure 1: The Analytical Hierarchical Model of the Proposed Framework

Table 3: The simulation setup used for implementing the proposed ANP-CHSM

Simulation parameters	Values
Area of the network	1000*1000 meters
Initial Energy (Joules)	1.0
Number of nodes	300
Size of the packets(bits)	2000
Number of grids	16
Primary weight (w_1)	0.3
Secondary weight (w_2)	0.5
Tertiary weight (w_3)	0.2
Energy used for amplification	100 pJ/ bit /square meters
Energy used for amplification	100 pJ/ bit /square meters
Energy used for amplification	100 pJ/ bit /square meters

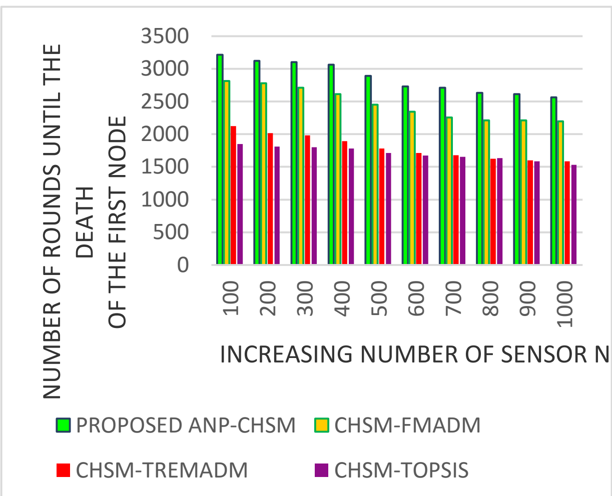

Figure 2: Proposed ANP-CHSM -Number of Rounds until first node death under increase in sensor nodes

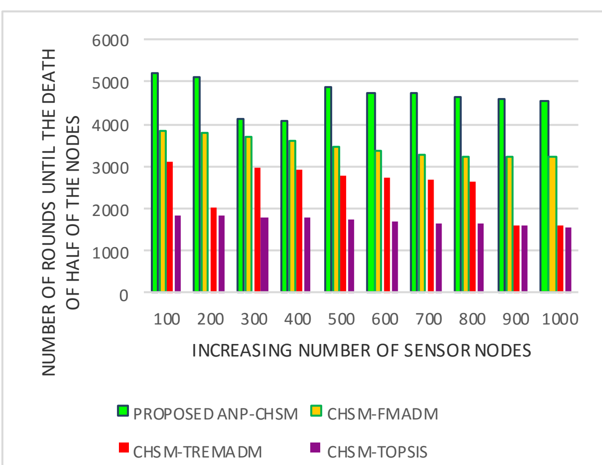

Figure 3: Proposed ANP-CHSM -Number of Rounds until half of the nodes' death under increase in sensor nodes

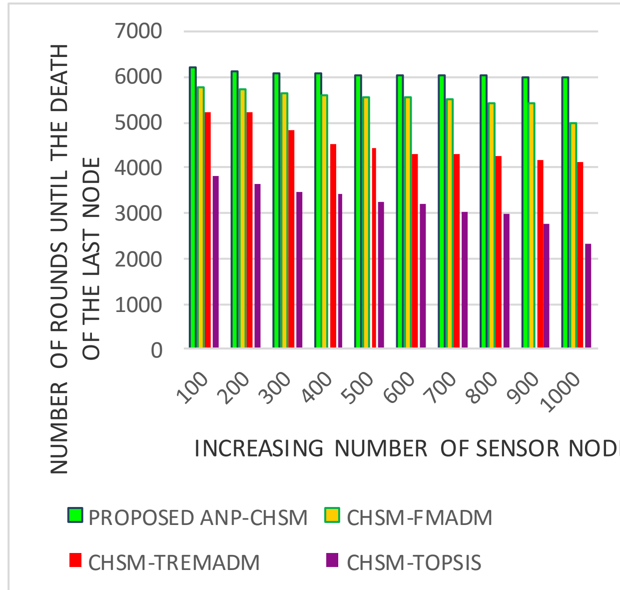

Figure 4: Proposed ANP-CHSM -Number of Rounds until all the nodes death under increase in sensor nodes

The percentage decrease in energy consumptions facilitated by the proposed ANP-CHSM framework under a different number of sensor nodes was determined to be improved at an average by 7%, 11% and 14% compared to the CHSM-FMADM, CHSM-TREMADM and CHSM-TOPSIS frameworks used for investigation.

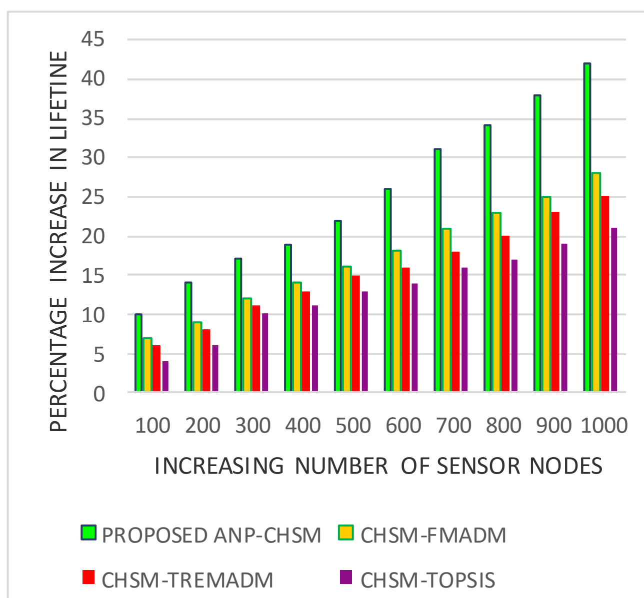

Figure 5: Proposed ANP-CHSM -percentage increase in network lifetime with increase in sensor nodes

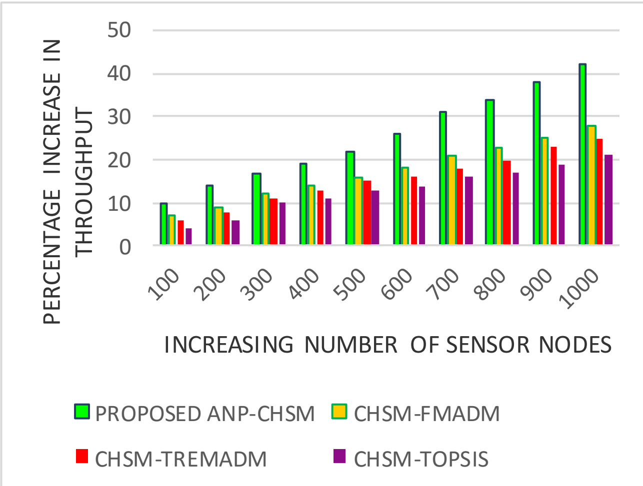

Figure 6: Proposed ANP-CHSM -percentage increase in throughput under increase in sensor nodes

Furthermore, Figure 8 and 9 glorifies the performance of the proposed ANP-CHSM using mean throughput and standard deviation in throughput under a different number of sensor nodes in the network. The mean throughput and standard deviation in throughput under a different number of sensor nodes in the network facilitated the proposed ANP-CHSM framework was determined to be predominant to the compared CHSM-FMADM, CHSM-TREMADM and CHSM-TOPSIS frameworks used for comparison independent to the systematic increase in the number of sensor nodes in the network, since it explores all possible criteria for alternating the decision of the cluster head selection chosen a a particular context.

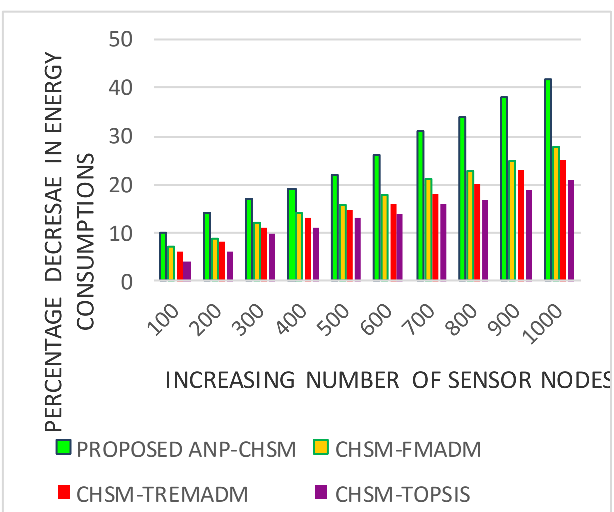

Figure 7: Proposed ANP-CHSM -percentage decrease in energy consumptions under increase in sensor nodes

The mean throughput enabled by the proposed ANP-CHSM Framework was determined to be improved at an average by 10%, 13% and 16% compared to the CHSM-FMADM, CHSM-TREMADM and CHSM-TOPSIS frameworks used for investigation. The standard deviation in the throughput facilitated by the proposed ANP-CHSM Framework was determined to be improved at an average by 12%, 15% and 18% compared to the CHSM-FMADM, CHSM-TREMADM and CHSM-TOPSIS frameworks used for investigation.

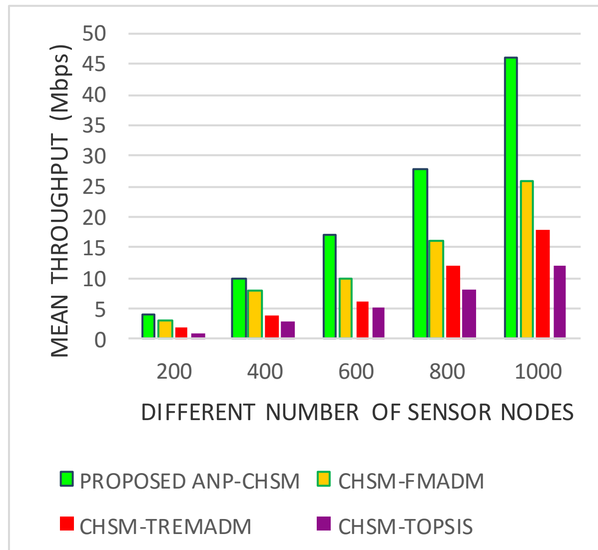

Figure 8: ProposedANP-CHSM -Mean Throughput-Number of sensor nodes

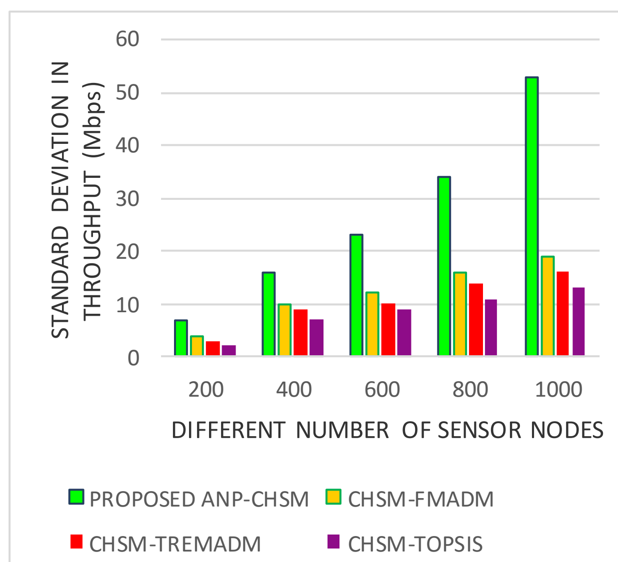

Figure 9: Proposed ANP-CHSM -Standard Deviation in Throughput-Number of sensor nodes

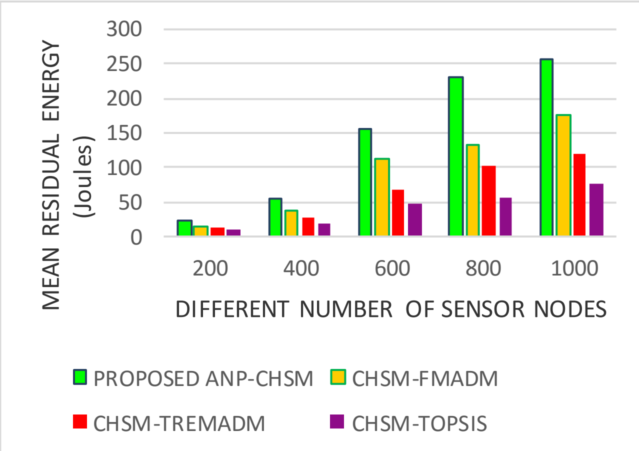

Figure 10: Proposed ANP-CHSM -Mean Residual Energy-Number of sensor nodes

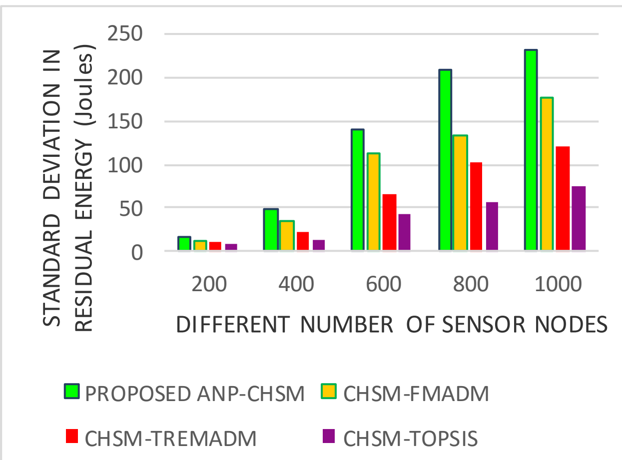

Figure 11: Proposed ANP-CHSM -Standard Deviation in Residual Energy-Number of sensor nodes

In addition, Figure 10 and 11 demonstrates the predominance of the proposed ANP-CHSM using mean residual energy and standard deviation in residual energy under a different number of sensor nodes in the network. The mean residual energy and standard deviation in residual energy under a different number of sensor nodes in the network facilitated the proposed ANP-CHSM framework was determined to be predominant to the compared CHSM-FMADM, CHSM-TREMADM and CHSM-TOPSIS frameworks used for comparison independent to the systematic increase in the number of sensor nodes in the network, since it inherits the benefits of pair wise comparison matrix of analytical network process to quantify the influence of each criteria over the selection of appropriate cluster head selection strategy.

The mean residual energy ensured by the proposed ANP-CHSM framework was determined to be improved at an average by 11%, 14% and 17% compared to the CHSM-FMADM, CHSM-TREMADM and CHSM-TOPSIS frameworks used for investigation. The standard deviation in the residual energy facilitated by the proposed ANP-CHSM framework was determined to be improved at an average by 13%, 16% and 19% compared to the CHSM-FMADM, CHSM-TREMADM and CHSM-TOPSIS frameworks used for investigation.

IV. CONCLUSIONS

The application of the wireless sensor networks in the field of surveillance, weather forecasting and in health monitoring has increased the importance of wireless sensor networks. Even though there are impeding challenges in the WSN namely limited energy and computational time. These are managed effectively by the use of clustering mechanism. The proposed clustering mechanism framework, Analytic Network Process-based Cluster Head Selection Mechanism (ANP-CHSM) is designed for enhancing the network lifetime. This proposed ANP-CHSM considered the parameters that are associated with Residual Energy of Sensor Nodes (RESN), Distance between Nodes (DBN), merged node, Frequency Count in Cluster Head Role (FC-CHR) and Centroid Distance of Sensor Nodes (DSN) for modelling the process of cluster head selection. The simulation experiments of the proposed ANP-CHSM framework proved its efficacy in terms of residual energy, throughput and lifetime expectancy. The residual energy ANP-CHSM framework was determined to be highly sustained and balanced with 8%, 10% and 13%, compared to the CHSM-FMADM, CHSM-TREMADM and CHSM-TOPSIS frameworks used for investigation. The throughput of the proposed ANP-CHSM framework was estimated to be improved by 11%, 14% and 16%, compared to the CHSM-FMADM, CHSM-TREMADM and CHSM-TOPSIS frameworks used for investigation. In addition, the lifetime expectancy of the proposed ANP-CHSM frameworkis also identified to be enhanced by 9%, 11% and 14%, compared to the CHSM-FMADM, CHSM-TREMADM and CHSM-TOPSIS frameworks used for investigation. As the plan of the future, Electre Method of Multiple Attribute Decision Making is decided to be utilized of implementing the cluster head selection framework and compared with the proposed framework.

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