Fuzzy Logic Method for Enhancement Fault-Tolerant of Cluster Head in Wireless Sensor Networks Clustering

Farnaz Pakdel [1], Mansour Esmaeilpour [1]

[1] *Department of Computer Engineering, Hamedan Branch, Islamic Azad University Hamedan , Iran*

Abstract **- Wireless sensor network is comprised of several sensor nodes. The retaining factors influence the network operation. In the clustering structure the cluster head failure can cause loss of information.The aim of this paper is to increase tolerance error in the cluster head node. At first, paying attention to the producing balance in the density of the cluster cause to postpone the death time of the cluster head node and lessen the collision due to the lack of the energy balance in clusters. The innovation in this stage is formed by using two fuzzy logic systems. One in the phase of evaluation of the cluster head chance, and the other in the phase of producing balance and the nodes migration to the qualified clusters to increase balance, Then the focus is on recognizing and repairing the cluster head fault.**

Keywords **- Wireless sensor networks; clustering, Cluster head selection, Fuzzy logic system, Fault-Tolerant.**

1. Introduction

In recent years, wireless sensor networks are widely improved. The sensor nodes arecapable of wireless communication and computing capabilities [1]. The recent advances in the electronic industry and communication have made possible the production of multi-purpose, low cost and low energy-consuming sensor nodes in small dimensions and the feasibility of connection in the short distance.Wireless sensor network is transferred to an area in order to sense the different types of physical data from the environment. Sink assesses the information that is sensed by the sensor. Properties of the nodes are too restricted computational, storage and power capabilities. A technique that makes the network longevity longer is clustering. In a clustering protocol, the nodes that are near to each other geographically are organized into virtual groups named "clusters".A node that is chosen as a cluster head lies in its neighboring nodes as a cluster member [2]. The nodes have restriction of energy and cannot be recharged. One of the important and significant challenges in the wireless sensor network is fault–tolerant. Fault tolerance is an equally important issue for the long run operation of the Wireless sensor network [3]. One of the most signification wireless sensor networks requirement is referred to as fault tolerance. It ensures the correct network continuation performance even when some components fail. As a matter of fact, due to sensor node feature, radio communications and hostile environment in which these networks are transferred, the fault tolerance is necessary in this type of network [4]. Furthermore, within many Wireless sensor networks, the cluster heads are usually selected among the normal sensor nodes that can die because of this additional work load. Many researches [5],[6],[7] have suggested the use of some special nodes called gateways or relay nodes. This gateway and relay nodes provided with extra energy, are regarded as the cluster heads and have the responsibility of the same performance of cluster heads. But the gateways are also operated by battery and therefore have power limitations. When a sensor is ruined due to lack of energy, knock up with the surrounding objects by the diffusion of the first signal in the environment;The management of its covering environmentmust be assigned to another sensor [8,9, 10]. Nodes that die quickly lead to less precise information in that area [2]. In such case, the basic problem is which neighboring sensor is elected

DOI: 10.18421/TEM53-03
https://dx.doi.org/10.18421/TEM53-03

Corresponding author: Mansour Esmaeilpour
Department of Computer Engineering, Hamedan Branch, Islamic Azad University Hamedan , Iran
Email: esmaeilpour@iauh.ac.ir

for the dropped sensor management to choose the adjacent sensor, a fuzzy Logic system can be used so that backing up the fault-tolerant could maximize the reliability of the network. Fault management can be divided in three groups: the fault-discovery, the fault result recognition and fault correction. The rest of the paper is organized as follows: Section 2 depicts the review of the related work in the field of Fault-tolerant Clustering Algorithm for Wireless sensor networks. Section 3 defines the proposed protocol and its phases. Section 4 contains simulation and results and the comparison of the proposed protocol with the existing protocol. Finally, section 5 illustrates the conclusion. In this article, we have used a fuzzy logic system in such a way that the inputs enter the fuzzy system and the rules are implemented upon them, and finally a fuzzy output consisting of a figure between 0 and 1 is produced [11,12].

Too many researchers have been carried out regarding clustering and fault-tolerance so far. The most significant and applied clustering protocols lie upon the wireless sensor network of the LEACH protocol which puts emphasis on election cluster heads randomly with a fixed probability. In the LEACH protocol, the sensors are accidentally distributed in one area. The time duration of the network activity is divided into some rounds. In the beginning of each round, the number of nodes is selected randomlyas the head node and each node produce a casual figure between 0 and 1.In the equation 1 if the figure is less than the quantity of *T(n)* the mentioned node is elected as the cluster head, and then the cluster heads transfer a message toward all nodes, and then the nodes choose the considered cluster based on the received signal from the cluster heads. P is the proportion of the number of clusters to the number of nodes. R is the figure of the present round and G is the number of the nodes that have not been selected as cluster heads in the previous round. [13]

$$T(n) = \begin{cases} P/(1 - p \times (r \bmod (1/p))) \;\; , \;\; fn \in G \\ 0, \qquad\qquad Otherwise \end{cases} \qquad (1)$$

In LEACH protocol, a node won't have any chance to become a head node unless all of the nodes become cluster head or the external circle is accomplished. Moreover, it won't have any mechanisms to tolerate the cluster head fault. Cluster head election also will take place accidentally and it doesn`t have any other parameters. Thus it is possible that a node with the least energy to become cluster head and the elected clusters, because of their casual nature maybe elected close to each other or elected on the surrounding edges. Cluster Head Election mechanism using Fuzzy Logic (CHEF) protocol uses fuzzy logic to select cluster head with inputs such as: remaining energy of the node and the local distance(total of distance between a specific node and its neighbors within a specified radius) [14]. CHEF doesn't take inter cluster communication cost for cluster head selection into consideration. Cluster head selection protocol uses distance of cluster centroid from sink, residual energy of node and network traffic as inputs fuzzy logic [15]. CHUFL is the clustering algorithm and it is the best cluster head election. This algorithm selects the best cluster head of fuzzy logic System with three inputs: remaining energy, distance from sink and an accessible ability to the neighboring nodes with radius of R. To focus on the inputs is in order to select the cluster head leads to a better function of this algorithm than the different algorithms, like the CHEF algorithm.In this algorithm no attention has been paid to the cluster density and balance maintenance in the clusters [16].Although clustering algorithms have lot of advantage; they have usually paid no attention to the fault-tolerant. All members of the cluster will also lose their connection to sink when an error maybe committed. A mechanism must be considered to discover and repair the fault [17,18]. The algorithm of FTCD is one of algorithms in the fault-tolerant area thatincludes two steps of fault recognition and fault finding of the cluster head. In the first step, the clustering inadequacy and defect are identified. In the next step, the repair and maintenance of the cluster are carried out. This algorithm uses the LEACH base, protocol for clustering.In the fault-recognition phase, an evaluation process of the cluster head situation has been added to TDMA timing that check the vitality of the cluster head in the determined time intervals.In the event of making an error, the nearest node lies in the distance of *r/2*from the cluster head and it is selected as the replacing cluster head. The challenge of this algorithm is that it has no other mechanism for selecting the substitute cluster head node; there is also an election probability of substituting node among from the nodes with the less energy [18]. One of the algorithms of fault-recognition is DFCA. In this protocol, maintaining the cluster nodes energy is the major preference. This protocol is of the recognition phase and fault tolerant of the cluster head nodes. In DFCA, the mechanism of the cluster head election is on the basis of cluster head cost function which has a direct relationship with the remaining energy along with a distance between the sensor node and the cluster head and the distance of the cluster head from the base station. The main challenge of this algorithm is that there is no mechanism for a suitable choice of the cluster head in the first phase. Furthermore, there is no mechanism for filtering worthless cluster head nodes in respect to the density and disbanding the cluster head nodes which have attracted more nodes than threshold.In the phase of the node election that is carried out by the coverless nodes, the remaining energy of the target node is the only considered criterion [3]. The next algorithm is the above-mentioned algorithm in which there are a number of homogeneous sensors with a unique identifier and a rate of identical transfer all of which are interrelated in a network based on radio interchanges. The proposed algorithm calculates and extracts the fault-tolerant extent for each node. Meanwhile, each node possesses a current nerve network installed on it. The algorithm ensures that each sensor recognizes the identity of its own neighboring sensor. This algorithm doesn`t have any effectiveness in the environment with higher density [19]. Another presented algorithm in this study is the mentioned algorithm that proposed a distribution method to fight the node fault and uses the movable nodes for recovery. Determining the type and the movement route in this study is innovative and it could have been useful for the heterogeneous movable networks [20]. Another algorithm has been presented to increase the fault-tolerant using fuzzy logic within the wireless sensor networks. In the proposed algorithm when a sensor encounters a problem, the space covered by the sensor remains uncovered. A missing space is given a cover due to the sensor destruction by the faulty neighboring sensors. In this algorithm, one of the faulty neighboring sensor that is of higher priority to cover the lost space moves toward the faulty sensor so that it would cover the missing boundary.The fuzzy logic has been used to calculate the priority arrangement of the neighboring nodes. The fuzzy inputs are the faulty: node distance from its neighbors, the distance from the cluster head and the remaining energy amount. His algorithm is proposed in a network that is not clustered, its nodes are movable and the purpose is to cover the lost area. It also has no mechanism to choose the substitute when the sensor is faced with problems [21].

2. Proposed protocol

2.1 Clustering and creating balanced cluster

The problems of the probable clustering algorithm and the weakness in choosing an appropriate and balanced cluster head in the network has assigned one part of our idea to itself in this study. In the proposed protocol, the existence probability of a cluster head with a small number of members approximately reaches to zero. At first, the clusters are created in equilibrium in order to increase the network longevity and prevent its breaking into pieces. In the each period, CH_{opt} is number of Optimal cluster head and we will select 2 CH_{opt} . The phases of the head node election are as follows:

- In each period, each node creates a random figure between 0 and 1.
- If the random figure is less than, P_{opt} the sensor node calculates chance of becoming luster head through a fuzzy system no1.
- Then, the node sends other nodes a message including its own identifier and a chance obtained from the first fuzzy logic System.
- Then, the node waits for the next message of other nodes, if the mentioned node chance is greater than the chance of the other nodes; the node is elected as the cluster head.
- The elected cluster head nodes as to their head clustering and member admittance send their own publicity message.
- After receiving the publicity message of the cluster head in terms of the most powerful received signal, the normal nodes of the network elect the appropriate cluster head which has the nearest distance from them, and then send themtheir own request of membership message.
- The cluster head nodes send their own identifier list of their own cluster member nodes to the sink [8].
- The next phase is the disbanding of the sparse clusters. The definite number of cluster heads is obtained through $K = K'/2$ equation. In this way, we will have no cluster head with a number of members less than threshold. Innovation in this phase is the election of the suitable and balanced cluster heads in the network.
- Then, the migration of the disbanding cluster nodes to the appropriate clusters is obtained through fuzzy logic System no2.

2.2 Determining the substitute node

After appropriate cluster formation and definite cluster heads election, determining the backup node is performed through fuzzy logic System no 3.This process is repeated in each period using TDMA, because it is possible that the elect backup node in the previous time slot to have lost its own energy in the next time slot due to the energy consuming or a reason of this sort. Therefore, it can`t be a good election as the cluster head substitute in term of the fault appearance

2.3 Evaluation fault recognition

Anetwork collision which is mainly occurs due to the simultaneous transfer of several nodes. As well as, the use of hierarchy transfer is to diminish the cost of package transition as to the sink. Another way to fight the cluster head nodes defeat in the present article is using the backup nodes. In this mechanism, the candidate node of the cluster head (backup) can substitute the faulty cluster head node when the cluster head node is defeated. In the proposed algorithm, the status of cluster heads isexamined in different time's slot.If there is no response from the cluster head, the nodes close to the cluster head become sensitive to its performance and send their request if it has not made any mistake. Otherwise, the mentioned nodes can recognize that the cluster head node is faced with a problem.

2.4 Fault repair

In the event of the cluster head fault, the node or the deciding nodes introduce the substitute node as the new cluster head, the list of the previous cluster head members is sent to the new cluster head; the system is asked for table scheduling in table schedule TDAM. Then, the new cluster head sends a message to the new cluster head. Again, the phase of determining the substitute cluster head for the new cluster head is carried out.

2.5 The First fuzzy logic System: Determining the proposed protocol cluster head

In order to determine the head clustering chance among from the candidate nodes, the first fuzzy logic System with three inputs are used. The inputs: The remaining energy of the node *n* (first input), the distance from the sink (second input), the output: the head clustering chance of the node *n* .The distance parameter depends on the mean of the nodes distance in the neighboring radius are shown in the Figures 1 to 4 [16].

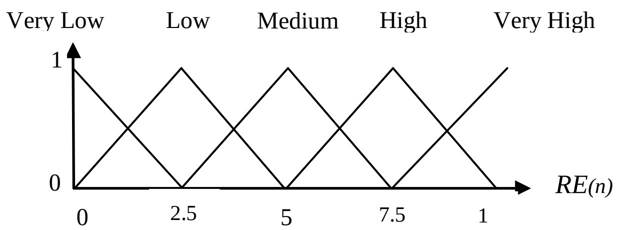

Figure 1.Remaining energy of node.

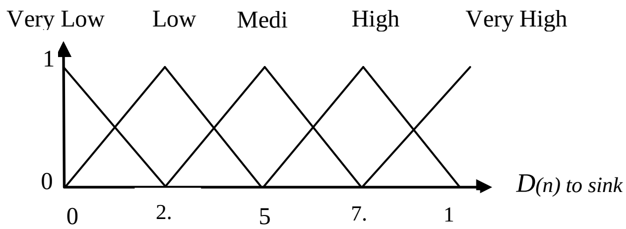

Figure 2. Distance from the sink.

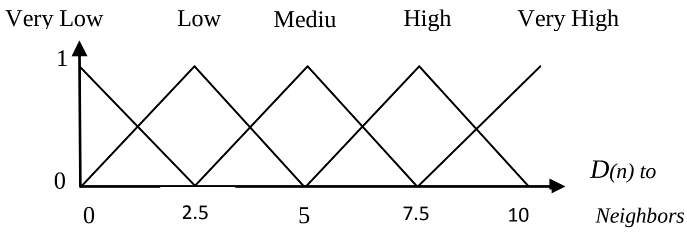

Figure 3. Distance from the Neighbors.

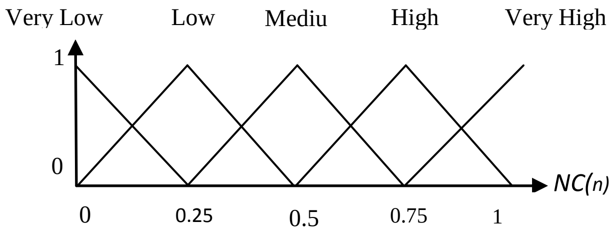

Figure 4.Head clustering chance ofnode n.

The fuzzy logic System inputs are demonstrated in form of the following fuzzy diagram and each sensor node cost is calculated by equation 2 and 3 [22]. The cost of each sensor node in time slot is [0,1]. In this way, the head clustering chance for the entire candidate node is calculated and the node with the greater node cost (more chance)and highest $f(n)$would be selected as the cluster head.

$$NC = \frac{\sum Rule_i \times C_i(NC)}{\sum Rule_i} \qquad (2)$$

$$f(n) = NC \qquad (3)$$

2.6 The Second fuzzy logic System: The stable status of the proposed protocol

After disbanding the private nodes, the nodes resulted from the protocol nodes disbanding use the second fuzzy logic System in order to migrate to the existing clusters and to select the best cluster. The usable fuzzy logic System in this stage comprises three inputs and one output. The inputs: The most remaining energy and the distance from the cluster and the density (the number of the clusters numbers).The output: the cost for electing the best cluster head, are shown in the Figures 5. to 7. As it is inferred from the fuzzy logic System and the proposed triangle model, each input parameter of fuzzy logic System consists of a triangle diagram. In each diagram, regarding the existing triangles, other values in y axis can be assigned to the behavior of one parameter in variable values of X axis. Each point on the axis contains two values on Y axis. In the density diagram, the density ratio can be placed in 5 levels: very low, low, medium, high, and very high. The densityof each cluster can be put in one of these levels or at least in the two respective levels. NC(n) and $f(n)$ will be calculated from equations 2 and 3 [22].The greater node cost (more chance) and greater f(n) causes the node to the cluster with the highest chance to migrate.

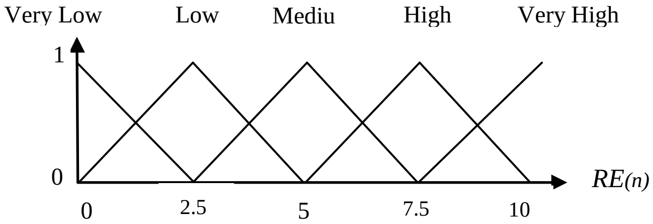

Figure 5. Remaining energy of node.

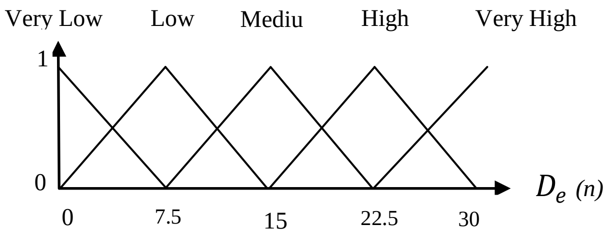

Figure 6. The density of the clusters.

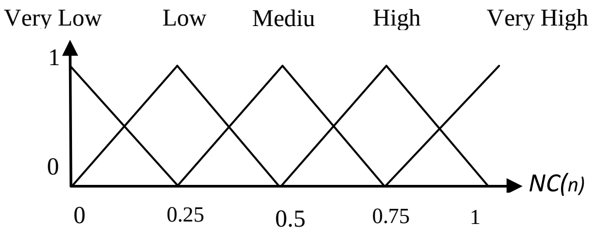

Figure 7. Node Cost.

2.7 The Third fuzzy logic System: electing the substitute node

Performing an affective clustering and creating a balanced cluster as much as possible, the appropriate substitute cluster head with a fuzzy system is elected immediately in order to replace the backup node with faulty cluster head when a fault appears in the cluster head. Within the tome intervals of TDMA, the fuzzy system is implemented so that the best substitute cluster head is elected. The target fuzzy logic System in this phase includes four inputs and one output. The inputs: the remaining energy of the node n, the distance to the sink, the distance extent from the cluster head, the distance means to other cluster heads and the output: the cost is for electing the best substitute cluster head, shown in Figures 8 to 12.

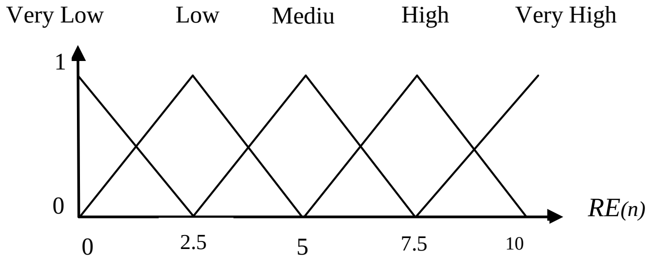

Figure 8. Remaining energy of node.

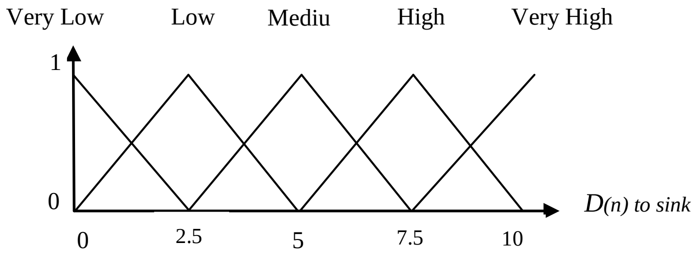

Figure 9. Distance from the sink.

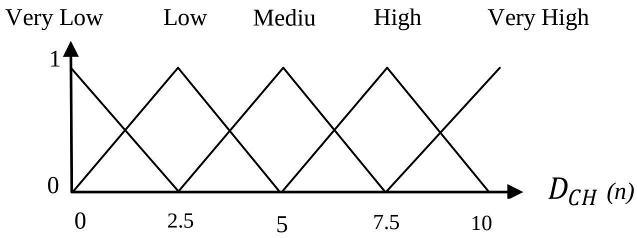

Figure 10. Distance extent from cluster head.

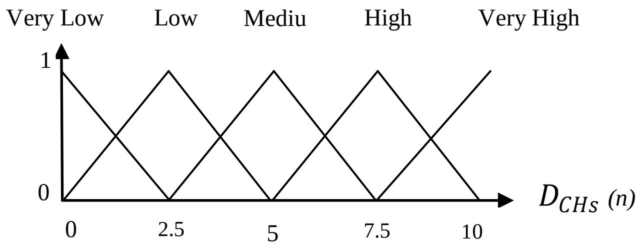

Figure 11.Distance extent from the cluster head.

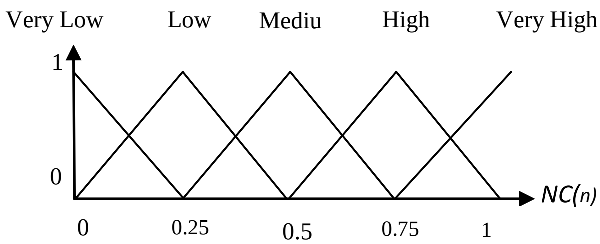

Figure 12. Node Cost.

The distance parameter is dependent upon the distance extent which is calculated from the equation 4.

$$\Delta_x = v.\Delta_t \qquad (4)$$

Δ_x is the distance of the node from the sink, that is the same $D_{(n)}$ in the fuzzy diagram. The parameter v is a fixed variable that is equal to the light speed and is considered as the genuine amount of 299792458*m/s*and an estimated amount of 300*km/s*. The speed of signal is equal to the light speed; the sameamount is applicable in our equation.But the parameter Δ_t is equal to the difference of time of one package transition and its received time. In this way, the more the mount of Δ_t, the more distance between the sender and the receiver will be. The average of the distance amount from other cluster head is estimated for the reason that the accessibility extent of the cluster head to the sink is to be considered. For sending information when the node has a great distance from the sink and has also low energy and cannot send information, it sends the information by the help of other cluster head. These four Parameters, after entering the proposed fuzzy logic System and performing fuzzy operation and adapting with the rules, change into the fuzzy logic System output that will be regarded as the node cost or the same *NC(n)*; and it will be calculated from equations 2 and 3 [22] and Fuzzy rule base shown in Table 1.

At last, the sensor node which has the maximum $f(n)$ amount of the node will be elected as the bestcandidatenode for acquiring the substitute cluster head role.

Table 1.Fuzzy rule base for the third fuzzy logic system.

Antecedent					***Consequent***
Rules	***Remaining Energy*** $RE_{(n)}$	***Distance to BS*** ***D(n) to sink***	***Distance to CH*** $DCH_{(n)}$	***Distance to other CH*** $DCHs_{(n)}$	C_i $NC_{(n)}$
Rule1	*Low*	*Medium*	*Very Low*	*Low*	*Medium*
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
Rule16	*Medium*	*Medium*	*Very Low*	*Medium*	*Medium*

3. Simulation and results

In this study, we presented a clustering protocol on the basis of fuzzy logic System with a trend of fault tolerant. We have put the intended idea into practice in the simulation environment of the network that is the NS simulation software 2.34 version, and then we have evaluated this study results with the base and similar algorithms. That we have considered the parameters dependent on the clustering mechanism in the network and have tried to balance the cluster head pressure on the highly valuable nodes, it is evident that the death time of the first and the last network node is postponed. In the tests, we have had some sensor nodes make mistakes accidently in the simulation. We want to evaluate to what extent the proposed method and the similar ones can discover this fault and can repair it in the clustering structure. The death tie of the first and the last network node is generally and directly related to the life time of the sensor network. The simulation conditions are shown in Table 2.

Table 2. Simulation conditions.

PARAMETERS	*DFCA,FTCD*	*PROPOSED*
Network size	*1000*1000*	*1000*1000*
Antenna	*All the way*	*All the way*
Time simulation	*1000*	*1000*
The number of sink	*1*	*1*
Location sink	*Fixed*	*Fixed*
Primary energy sink	*1000*	*1000*
The number of nodes	*100*	*100*
Position nodes	*Random*	*Random*
Status groups	*Fixed*	*Fixed*
Primary energy	*10 Jules*	*10 Jules*
Energy model	*Battery*	*Battery*

The results obtained from the administered tests on the proposed protocol showed that the proposed protocol in the important parameters like the remaining energy, the death time of the first node, the number of the network routing packets, the number of dropped packets of the network and the comparison test of the network Throughput in terms of the number of the network current and the packet delivery rate,have better performance than the two protocols of FTCD and DFCA. In the first phase, the appropriate cluster head election creating balance in the cluster, and appropriate election backup cluster head causes can increase in the fault-tolerant and network longevity. The reason of superiority of the proposed protocol regarding the death time parameter of the first node as to its compared protocols lies in the fact that the longer this time is, the network responsibility load and clusters have been distributed more effectively.The proposed method could have achieved one of its goals, that is to delay the death time of the network node. The number of the dropped packets represents the achievement degree of fault-tolerant performance in the network. The less number of the dropped network packets indicates the best performance of the network in confronting occurred node fault. The proposed protocol presented a better performance in this regard. Increasing the fault-tolerant and electing appropriately the cluster head inducesbetter information transferring in the network and through put increasing and the high extent of this parameter in the proposed algorithm in comparison to the two other algorithms demonstrates the best network output. The received data over the sent data in terms of the percentage represents the delivery rate of the packets. Surely, the more this percentage rate is, the better network outputand performance will be in the cluster head election and fault-tolerant controversy. The proposed algorithm has had better performance in this regard. Chart simulation results for the proposed protocol and protocol FTCD and DFCA are shown in Figures 13. to 18.

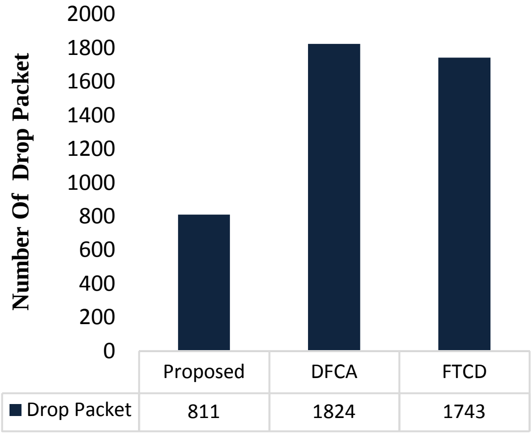

Figure13. Number of dropped packets.

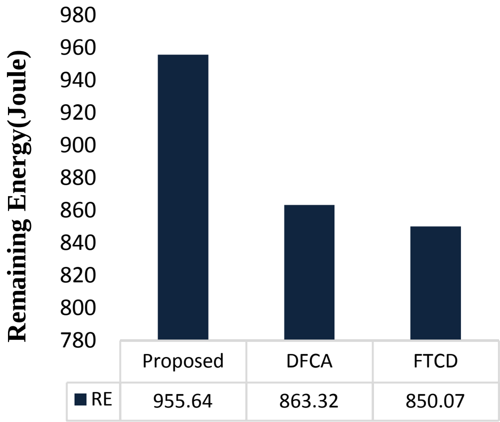

Figure 14. Remaining energy.

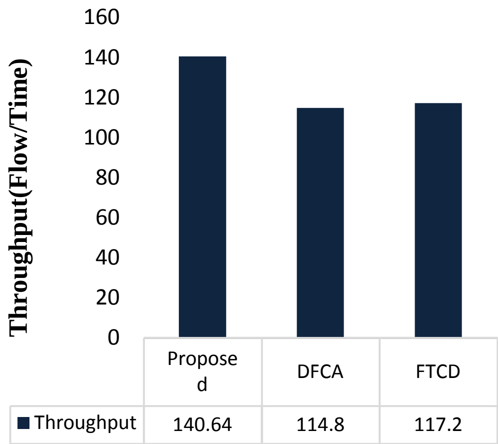

Figure 15. Throughput.

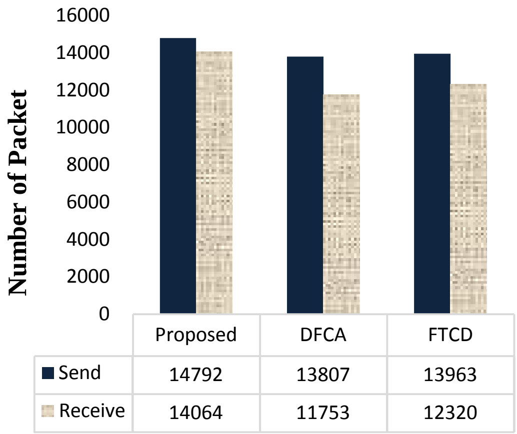

Figure 16. Number of routing packets.

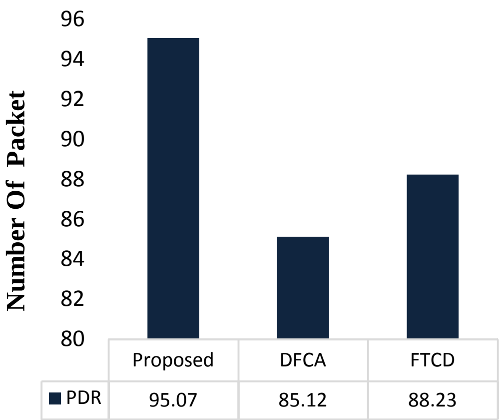

Figure 17. (FND) First Node Die.

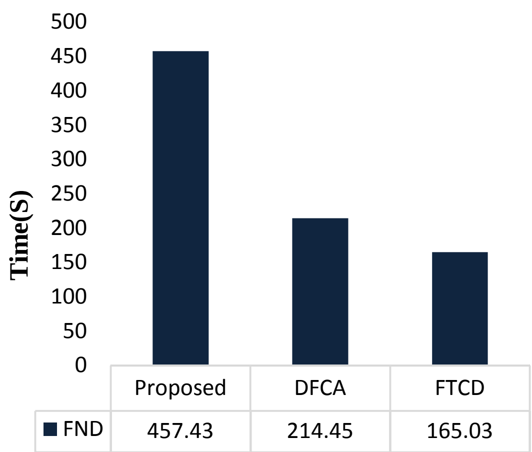

Figure18. (PDR) Packet Delivery Rate.

4. Conclusion

The purpose of the study is to present a new way for balanced clustering with a fault–tolerant trend using fuzzy logic System. The node fault-tolerant in theinduce reliability is maximized in the network and the network longevity. Moreover, the necessity of the network stability, energy consuming balance creation in the cluster nodes population, and management and better access to cluster heads from network source by the proposed protocol. The proposed protocol has been designed on the basis of the present challenges and postpones the death time of the first node in the network, increases the network longevity, and prevents the networks dismantling.The appropriate number of the cluster members not only prevents any delay in information collection in the cluster head but also disbands the worthless and reclusion clusters.

References

[1] Sakthidharan, G.R., & Chitra, S. (2012). A survey on wireless sensor network: An application perspective, *In Computer Communication and Informatics (ICCCI). International Conference* ,1-5.

[2] Behboudi, N., &Abhari, A. (2011). A Weighted Energy Efficient Clustering (WEEC) for Wireless Sensor Networks. *International Conference on Mobile Ad-hoc and Sensor Networks (MSN)*, 146-151.

[3] Azharuddin, M., Kuila, P., & Jana, P. K. (2013). A distributed fault-tolerant clustering algorithm for wireless sensor networks. *International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, 997-1002.

[4] Chouikhi, S., El Korbi I., Ghamri-Doudane Y., & Azouz Saidane, L. (2015). A survey on fault tolerance in small and large scale wireless sensor networks. *computer communication*, 69, 22-37.

[5] Low, C. P., Fang, C., Ng, J. M., &Ang, Y. H. (2008). Efficient load-balanced clustering algorithms for wireless sensor networks. *Computer Communications*, 31, 750-759.

[6] Pratyay, K., & Jana P. K. (2012). Improved load balanced clustering algorithm for wireless sensor networks. *ADCONS , LNCS*, 7135, 399-404.

[7] Gupta, G., & Younis, M. (2003). Load-balanced clustering of wireless sensor networks. *International Conference ICC*, 3, 1848-1852.

[8] Han, X., Cao, X., Lloyd, E. L., & Shen, C. C. (2010). Fault-tolerant relay node placement in heterogeneous wireless sensor networks. *IEEE Transactions on Mobile Computing*, 9, 643-656.

[9] Younis, M., Senturk, I. F., Akkaya, K., Lee, S., & Senel, F. (2014). Topology management techniques for tolerating node failures in wireless sensor networks: A survey. *Computer Networks*, 58, 254-283.

[10] Lee, M. H., & Choi, Y. H. (2008). Fault detection of wireless sensor networks. *Computer Communications*, 31, 3469-3475.

[11] Runkler,T. A. (1997). Selection of appropriate defuzzification methods using application specific properties. *IEEE Transactions on Fuzzy Syst*, 5, 72-79.

[12] Wang, L. (1996). A course in fuzzy systems and control. *Prentice-Hall*.

[13] Heinzelman, W.R., Chandarkasan, A., & Balakrishnan, H. (2000). Energy-Efficient Communication Protocol for Wireless Microsensor Networks. *International Conference on System Sciences*. 1-10.

[14] Kim, J. M., Park, S. H., Han, Y. J., & Chung, T. M. (2008). CHEF: cluster head election mechanism using fuzzy logic in wireless sensor networks. *International Conference on Advanced Communication Technology*, 654–659.

[15] Anno, J., Barolli, L., Xhafa, F., & Durresi, A. (2007). A Cluster Head Selection Method for Wireless Sensor Networks Based on Fuzzy Logic, *IEEE TENCON*, 1-4.

[16] Gajjar, S., Sarkar, M., &Dasgupta, k. (2014). Cluster Head Selection Protocol using Fuzzy Logic for Wireless Sensor Networks. *Computer Application*, 97, 38-43.

[17] Alwan, H., & Agarwal, A. (2009). A survey on fault tolerant routing techniques in wireless sensor networks. *International Conference on Sensor Technologies and Applications*. 366-371.

[18] Dhawan, A., Shukla, N., Chapman, C., & Hennion, S. (2011). Fault Tolerant Clustering in Dense Wireless Sensor Networks. *International Conference on Networking and Computing*, 252-256.

[19] Khan, S. A., Daachi, B., &Djouani, K. (2012). Application of fuzzy inference systems to detection of faults in wireless sensor networks. *Neuro computing*, 94, 111-120.

[20] Ould-Ahmed-Vall, E., Ferri, B. H., & Riley, G. F. (2012). Distributed fault-tolerance for event detection using heterogeneous wireless sensor networks. *IEEE Transactions on Mobile Computing*, 11, 1994-2007.

[21] Behzadi, S., Azad, M.(2014). Fault-tolerant in wireless sensor networks using fuzzy logic. *Applied and sciences*, 8, 1276-1280.

[22] Imad, S., Al Shawi, Lianshan Yan. (2012). Lifetime Enhancement in Wireless Sensor Networks Using Fuzzy logic system Approach and A-Star Algorithm. *IEEE Sensors journal*, 12, 3010-3018.