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Stability Analysis of Relay Access Protocol (RAP) using Fuzzy Logic in Wireless Sensor Networks

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Abstract. Cluster Head (CHs) determination is critical whereas the combination of input parameters is expected to play an important role. However, each WSN's protocol uses a different combination of input parameters based on residual energy and several other input parameters, which produce different amount of energy consumption. Besides, most of the previous works on cluster heads selection do not take received signal strength indication (RSSI) into consideration. As a result, the sensor nodes with bad RSSI can be elected as CHs which lead to an increase in energy consumption. Moreover, the CHs use single-hop communication to forward their sensed data to the Base Station (BS). This results in high energy consumption and consequently, decrease the network lifetime. In this case, the inter-node distances may degrade the performance of the network due to long distance. Thus, this paper proposed a Relay Access Protocol (RAP) in order to reduce energy consumption in cluster-based wireless sensor networks (WSNs). The RAP protocol is a 2-tier protocol used for energy efficiency by selecting Cluster Heads (CHs) based on Fuzzy Logic (FL). The performance of the proposed protocol was evaluated under two different scenarios and compared with existing protocols through simulations. The experimental results show that the proposed scheme outperformed the existing protocols in terms of First Node Dead (FND) and Last Node Dead (LND) in all of the scenarios.

1. Introduction

The WSNs give focus on energy consumption and stability to provide longer network lifetime. This is due to the limited battery lifetime of the sensor nodes which cannot support long operational hours for some WSN's applications. Motivated by that, some research works have used fuzzy approach for CHs selection with the aim to prolong network lifetime and reduce energy consumption [1]. Fuzzy logic approach uses a combination of fuzzy logic input parameters enable efficient CHs selection and helps in reducing sensors battery power. Common works in the scope of CHs selection always consider the sensor nodes that having the highest number of neighbors and the highest remaining energy is elected as CH. However, the signal quality of the sensor nodes is negligible, hence it potentially drains sensor nodes energy even faster. By exploring previous researches in the area of energy consumption reduction, it reveals that more effort has been made towards CHs selection but a few works focus on noise and signal strength in a fuzzy descriptor perspective. For instance, MAP employs a fuzzy logical-based method to select CHs. Its fuzzy system considers three input parameters such as residual energy, centrality and communication cost. Nevertheless, it does not consider received signal strength indicator (RSSI) in which it may select CHs with badly received signal strength. In each sensor node, different sensor nodes receive different RSSI that affecting energy consumption besides data processing and control tasks. In particular, the effect of noise and interference in the WSNs compromises the data transmission due to numerous data transmission that leads to high energy consumption and low received



signal strength [2],[3]. In the literature, the researchers rely only on the residual energy which is not suitable for CHs selection [4],[5]. This is due to the residual energy input parameters rely on other important attributes to reduce energy consumption. Consequently, CHs consume more energy as compared to non-CH nodes. In an inter-cluster transmission for single and multi-hop transmission, the problem of energy imbalance among sensor nodes could arise [6]. For single-hop transmission, CHs which are far away from BS drain out their energy faster due to long distance transmission. Also, for multi-hop transmission, CHs far away from the BS deplete their energy quickly because of the long distance transmission and also extra burden caused by traffic relaying. As a result, imbalance partitioning of the network occurs and thus affect the performance and energy consumption of the network. The work in [5] has demonstrated that if the relay nodes are distributed randomly and far away from the BS in the network, the sensor nodes die rather quick according to First Node Dead (FND) and Last Node Dead (LND) criteria.

In this paper, a protocol called Relay Access Protocol (RAP) is proposed based on MAP protocol. The MAP used a combination of residual energy, centrality and communication cost as input parameters for CHs selection using the Fuzzy approach [12]. The main idea of our proposed protocol was that CHs selection would be based on not only the centrality and node's residual energy as used in the MAP, but also the received signal strength factor. This signal strength indication (RSSI) was considered as one of the input parameters. Another key idea used in our protocol was during the selection procedures of relay nodes. The cost involved in relaying in terms of distance threshold was incorporated as the criteria for selecting the relay node instead of the random selection used in MAP [3]. Furthermore, the idea of extending the data transmission phase by clustering CHs with the nearest relay nodes was combined with the proposed relay nodes selection based on the K-Optimal approach. The clustering process of CHs with the relay nodes used the K-Means approach which can provide balanced energy to the relay nodes. Also, this proposed approach can reduce the transmission burden at the relay nodes, thereby minimizing energy consumption. The performance of our proposed enhancement protocol was compared with the existing protocols using FND, LND, and network lifetime as the performance metrics. The contributions of this paper are summarized as follows:

- 1) A new combination of fuzzy input parameters was proposed, which incorporates residual energy, centrality and RSSI.
- 2) The K-Optimal and K-Means techniques were used in a two-tier strategy network to efficiently deploy the relay nodes.
- 3) The effectiveness and stability of the proposed combination of input parameter were compared with other combination of input parameters on the basis of FND, LND under various scenarios.
- 4) The energy efficiency of RAP was evaluated and compared with existing protocols in terms of FND, LND and network lifetime under various scenarios.

The rest of the paper is organized as follows. In Section 2, we present related works. Section 3 presented the energy model. Then, the optimal relay selection technique is presented in Section 4. Next, Section 5 presents simulation settings. The simulation results of the proposed approach are presented in Section 6. Finally, Section 7 concluded this paper.

2. Related Works

The WSN is a collection of the connected sensors, embedding software and hardware through the base station to the Internet. The architecture of WSN consists of three main components known as sensor node, a base station (BS) or gateway, and user. It is commonly installed in the form of a cluster consist of a large number of sensor nodes to cover a wide area network. Compared to the current wireless standard network (i.e., IEEE 802.11a/b/g/ac), WSN aims to respond to the users where sensors collect and gather information to forward sensor/actuator data from/to the user via the base station in a small amount of data. The sensors are usually dependent upon non-rechargeable or replaceable power. Nevertheless, power consumption is a challenge due to the drawbacks of battery life.

CHs selection is one of the crucial aspects for prolonging network lifetime and reducing energy consumption. The right combinations of input to be used as fuzzy descriptor play a role to determine the CHs that can contribute to energy reduction. Previously, many WSNs protocols consider the conventional method using different algorithm approaches for CHs selection [4],[5],[6],[7]. The

computational cost is high and complex to use traditional approaches whereas most of the works rely on the residual energy of the nodes to select the CHs.

The several numbers of works that consider the fuzzy logic approach has been explored to gain insights for obtaining the energy consumption efficiency in WSNs. Early work by [8] improved CHs selection in LEACH by adopting a fuzzy logic approach. Instead of considering the random number for CHs selection, three input parameter were used such as residual energy, concentration, and centrality. During the setup state, the fuzzy inference system estimates the residual energy and location information, and centrality for CHs selection. The remaining processes are the same with LEACH protocol such as advertisement message and join request. Similarly, work in [9] uses the same approach whereby the selection of the CHs based on residual energy and centrality. The authors claim that this proposed approach outperforms Fuzzy Gupta approach although their fuzzy approach does not consider concentration as a fuzzy descriptor. It means that the combination of residual energy and centrality has a strong correlation as opposed to the combination of residual energy, concentration, and centrality.

The work in [10] proposed a super-CH (SCH) that can send the information to the mobile BS. The CHs was selected based on residual energy, mobility of BS, and centrality. Mamdani fuzzy inference was used to select the SCH. The proposed clustering follows the LEACH in which each node generates a random number between 0 and 1. Also, the fuzzy K-Mean Algorithm (FKM) was used to partition data point into K clusters and the number of clusters were represented as a cluster center. Although the complexity is low, the mobility of the BS considerations is not really significant toward CHs selection. Another work in [11] proposed fuzzy-based unequal clustering which used residual energy, distance from the BS, node degree and competition radius as input parameters for CHs selection. This work attempt to overcome the overburden problem of CHs due to inefficient clustering. To mitigate such issue, the authors consider the distance from the BS to avoid hotspot problem. Two membership functions were used which is trapezoid and triangular. The trapezoid membership function is applied at the boundary variables and triangular membership function. The drawback of the proposed protocol is that when the CHs are placed far away from the BS, those particular nodes might suffer from quick energy depletion due to long transmission range. The work in [12] proposed an adaptive fuzzy clustering protocol called as LEACH-SF which used a fuzzy c-mean algorithm for clustering. The selection of CHs was using the Sugeno fuzzy inference system based on residual energy, distance from the BS, and centrality. The novelty of this work is that the fuzzy rules table is defined by a bee colony algorithm instead specify it manually. However, the placements of the nodes were not discussed in detail where this aspect is important for energy balancing.

Recently, the work in [13] proposed a multi-clustering based on Fuzzy Logic (MCFL) by reusing the previous CHs as the current CHs. The election of the CHs based on residual energy and communication cost of CHs and its child nodes. Though the fuzzy approach was used, the proposed two combinations of input parameters commonly is not sufficient enough to produce a high number of CHs' output chances. Moreover, the distance between CHs and the BS is not considered for CHs selection. Later than that, the researchers attempt to utilize the multi-tier network for the scalability in the network. For example, two-tier Distributed Fuzzy Logic Based Protocol (TTDFP) is a multi-hop clustering protocol in which CHs is selected based on a combination of distance (CHs to the BS), residual energy and relative node connectivity [14]. Besides electing the CHs using such input parameters, the routing phase also considers a fuzzy logic approach to determine the type of route such as very low, low, moderately high, extra low, normal, extra high, moderately low, high and very high. It means that, if the route has high residual energy and close distance, then the chance value of the particular route is very high. In fact, this approach increases the complexity and computational cost due to the fuzzy system has to double the process in order to determine the CHs and the best route. The route can be simply determined by the shortest distance based on Euclidean distance calculation. MAP protocol fairly distributes all the sensor nodes according to the circle geometry calculation results in sensor nodes in 2-tier with three times more nodes [15]. The selection of the CHs in MAP based on residual energy, centrality, and communication cost. However, the RRSI was not considered for CHs selection and the relay nodes are randomly deployed in the network. Simulation results showed that this approach is more energy-efficient than LEACH and SEP.

3. Energy Model

Some performance metric in [14] have been used to evaluate the energy consumption. The energy consumption model which have been proposed in [15] rely on the transmitted packet with (k) bits over the distance (d). The energy consumption model is given by:

$$E_{TX}(k, d) = \begin{cases} k * E_{elect} + k * \epsilon_{fs} * d^2, & d \leq d_o \\ k * E_{elect} + k * \epsilon_{mp} * d^4, & d \geq d_o \end{cases} \quad (1)$$

where ϵ_{fs} is the amplifier's value per bit during data transmission if the distance $d \leq d_o$, E_{elect} is energy dissipated per (k) bit to run the transmitter, ϵ_{mp} is the amplifier's value per bit for data transmission if the distance $d \geq d_o$. The energy consumption of each node is calculated as:

$$E_{RX} = k * E_{elect} \quad (2)$$

As sensor nodes communicate with their respective CHs, the energy dissipation occur in CHs. The energy dissipation of the CHs can be obtained as follow:

$$E_{CH} = \left(\frac{N}{L} - 1\right) * k * E_{elect} + \frac{N}{L} * k * E_{DA} + k * E_{elect} + k * \epsilon_{fs} * d^2 \quad (3)$$

4. Network Model

The network model was based on 2-tier network model. The BS was placed in the centre of the network due to it has an effect on the energy consumption. The position of the BS can affect the energy consumption of the network. For that reason, the BS has been placed in the center of the network to reduce energy consumption [10].

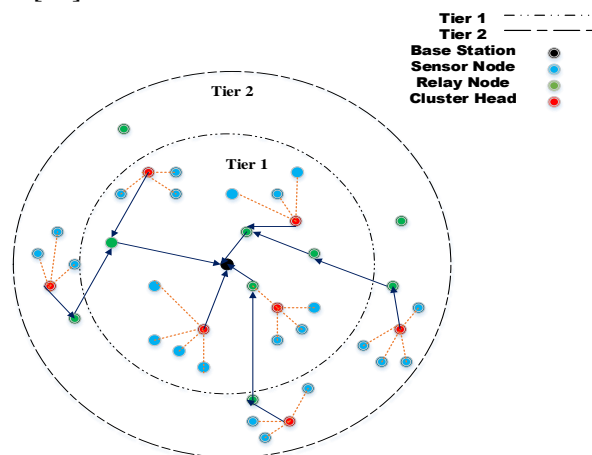


Figure 1. Data transmission of RAP

As shown in Figure 1, the circle area has been partitioned into 2 smaller areas. The diameter of each tier were 25 meters and 50 meters. The sensor nodes in 2-tier have three times more sensor nodes which is 75 according to the the circle geometry calculation. The sensor nodes obtained in 1-tier was 25. For data transmission, sensor nodes in 1-tier sent data to its respective CHS. Then, the aggregated data were sent to the relay nodes. In 2-tier, the relay nodes of 2-tier pass the data in 1-tier before reaching to the BS. The K-Optimal technique is used to obtain the relay nodes in respective tier. The optimal number of relay nodes is written as:

$$RN_{opt} = \left(\sqrt{\frac{U_i}{2\pi}} \right) * \sqrt{\left(\frac{\epsilon_{fs}}{\epsilon_{mp}} \right)} * \frac{U}{d^2} \tag{4}$$

The energy model takes ϵ_{fs} as the energy radio dissipates (d^2 power loss) and ϵ_{mp} is the amplifier energy of multi-path fading loss (d^4 power loss). U represents the total number of nodes and d represents the average distance between nodes and the BS. The value of ϵ_{fs} and ϵ_{mp} were considered as $10 * 0.000000000001$ which indicate as free space model and $0.0013 * 0.000000000001$ represents as multi-path fading [39, 40,41]. The optimal number of relay nodes is obtained depending on average distance to the BS, the path of the nodes and total number of nodes deployed in the network. Thus, the number of relay nodes for 1-tier and 2-tier respective tier was obtained as:

In 1-tier,

$$RN_{opt}^{1-tier} = \left(\sqrt{\frac{U_{1-tier}}{2\pi}} \right) * \left(\sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \right) * \frac{U}{d^2} \tag{5}$$

$$RN_{opt}^{1-tier} = \left(\sqrt{\frac{25}{2\pi}} \right) * \left(\sqrt{\frac{10 * 0.000000000001}{0.0013 * 0.000000000001}} \right) * \frac{100}{d^2} = 7 \tag{6}$$

In 2-tier,

$$RN_{opt}^{2-tier} = \left(\sqrt{\frac{U_{2-tier}}{2\pi}} \right) * \left(\sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \right) * \frac{U}{d^2} \tag{7}$$

$$RN_{opt}^{2-tier} = \left(\sqrt{\frac{75}{2\pi}} \right) * \left(\sqrt{\frac{10 * 0.000000000001}{0.0013 * 0.000000000001}} \right) * \frac{100}{d^2} = 12 \tag{8}$$

According to Equation (5) and Equation (6), the number of relay nodes obtained was 7 and 12 at the initial state. Figure 2 shows the distribution of the nodes in 1-tier and 2-tier.

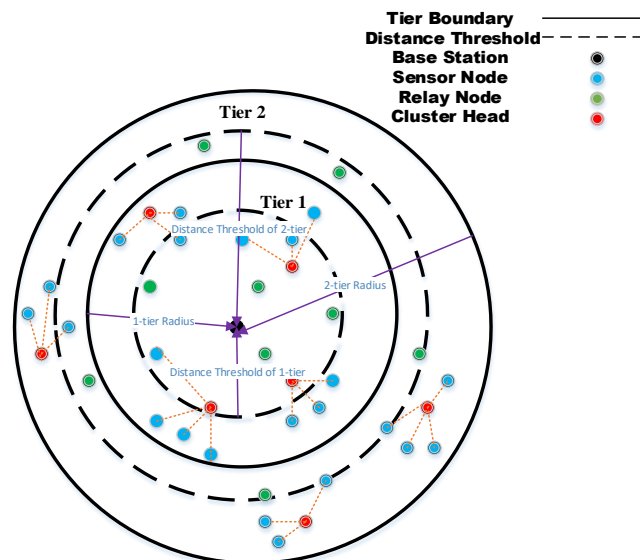


Figure 2. The position of optimal relay nodes

According to K-Means approach, the number of optimal relay nodes obtained can be used to determine the number of clusters that can be formed with the CHs. This is because the number of relay nodes can be used as a centre point to find the nearest CHs. There are five steps in K-Means clustering technique as follows:

- 1) Determine the optimal number of relay nodes.
- 2) The distinct data points which is the optimal number of relay nodes is obtained.
- 3) Calculate the distance between the CHs and relay nodes based on Euclidean distance calculation.
- 4) Assign the nearest CHs to the distinct point to form a cluster.
- 5) Calculate the mean and center of each cluster.

The distance threshold creates an upper bound so that the transmission distance between relay nodes and CHs can be minimized. Figure 2 shows the setting of distance threshold in the network. The distance threshold of 1-tier and 2-tier were set as $d_1 = 15m$ m and $d_2 = 30m$ m respectively. Consequently, the selected relay nodes form a cluster with the nearest CHs. The cluster formation in RAP can be divided into two types which is cluster formation of the CHs with the sensor nodes and cluster formation of the relay nodes with the CHs. For data transmission, in 1-tier, the data transmission journey start from child nodes in the cluster sent the data to its respective CH. Data aggregation is in a bottom-up manner from the child nodes. The sensed data from the child nodes are aggregated and compressed by the CHs. CHs collect the aggregated data from the child nodes to be sent to the relay nodes. Then, relay nodes forward the data to the BS. The transmission flow in 1-tier is shown in Figure 3.

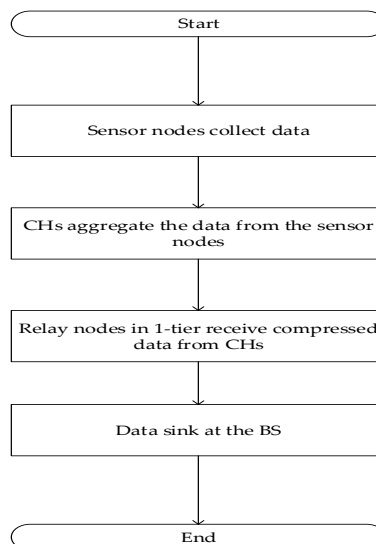


Figure 3. Data Communication in 1-tier

Similarly, in 2-tier, whereas the sensor nodes of 2-tier pass the data to its CHs. Then, CHs forward data to the nearest relay node in 1-tier. The transmission flow in 2-tier is shown in Figure 4.

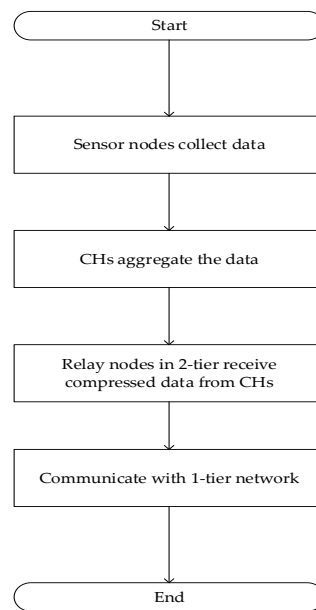


Figure 4. Data Communication in 2-tier

Since the network consists of 1-tier and 2-tier, the transmission occurs across these two tiers. In 2-tier, the CHs find the nearest relay node, R_2 to visit next. Then, R_2 forwards the data to the nearest relay nodes, R_1 in 1-tier (i.e., based on the certain criteria). Consequently, the R_1 forwards the data to the BS. Hence, establishing a connection from CHs to the relay nodes across 1-tier results in the larger hop (i.e., quad-hop) to the BS. The data aggregation is in a bottom-up manner from the child nodes in tier-1 and tier-2 and forwarded then to the BS for further processing.

5. Simulation Settings

The WSN network was simulated by employing MATLAB with the aim to evaluate its energy consumption. The proposed protocol known as Relay Access Protocol (RAP) protocol was compared with Stable Election Protocol (SEP) and MAP protocol in term of First Dead Node (FDN), Last Dead Node (LDN), and Total Dead Node (TDN). The simulation parameters setting in experiments are presented in Table 1.

Table 1. The simulation parameter settings

Parameter	Value
Number of Sensor Nodes	100 and 200
Network Area	100 M x 100 M
Base Station Coordinate	Center (50,50)
1-tier Diameter	25 M
2-tier Diameter	50 M
Energy (J)	1 J, 0.5 to 2 J
Number of bits	2000, 4000, 6000, and 8000

The experiments were divided into three sets, while the first and second sets observe the FDN and LDN that consists of a combination of input parameters i.e., ResCen, ResRSSI, and ResCenRSSI. This is to test the stability of RAP protocol, where the various number of bits were used as 2000, 4000, 6000 and 8000 bits. The initial energy (J) were carried to have 1 J and 0.5 to 2 J with 100 nodes which indicated as scenario 1 and scenario 2 respectively. Thirdly, performances of improved MAP 1 and improved MAP 2 were evaluated in terms of the number of dead nodes, FDN and LDN. For that, the proposed protocols are categorized into two types. For the first type, namely the improved MAP 1, the proposed protocol used the combination of input parameters (ResCenRSSI) without incorporating the relay

selection approach. For the second type, namely improved MAP 2, the method of relay selection along with CHs fuzzy based selection technique was incorporated.

6. Simulation Results

6.1 The Stability of the RAP in Scenario 1

This section explains the FND, LND, and number of the dead node when the residual energy of the 100 sensor nodes is 1 J. There is a very strong correlation between FND and LND, where the longer the LND or network lifetime is, and the more slowly the FND is going to appear. Figure 5 and 6 show the FND of ResCenRSSI, ResCen and ResRSSI with 2000, 4000, 6000 and 8000 bits.

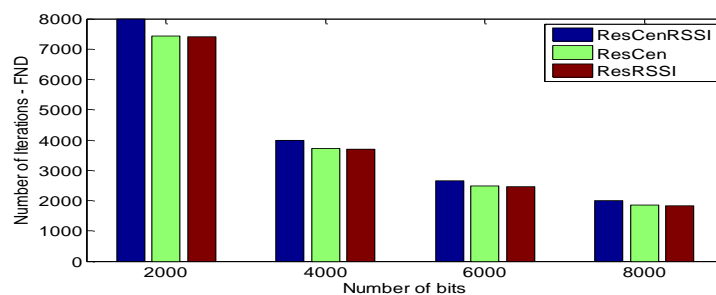


Figure 5. FND of improved MAP with 1 J energy of 100 sensor nodes

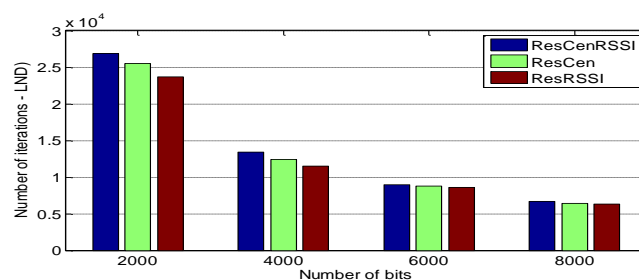


Figure 6. LND of improved MAP with 1 J energy of 100 sensor nodes

As shown in Figure 5 and 6, the results show that the FND appears with ResCenRSSI is much later than that in ResCen, and ResRSSI with all number of bits. The FND of ResCenRSSI was reported at 7997th, 3993th, 2877th, and 2438th iterations which is the highest value compared to the other input combinations for 2000, 4000, 6000, 8000 bits. ResCen and ResRSSI is following behind ResCenRSSI as 7722th, 3711th, 2474th, 1856 and 7712th, 3705th, 2465th, 1832th for 2000, 4000, 6000, and 8000 bits respectively, and ResRSSI has the lowest value of FND. Also, the LND of ResCenRSSI is much longer than ResCen and RSSI which indicate the longest network lifetime. Since inclusion of RSSI avoid low received signal strength to be elected as CHs, ResCenRSSI perform well with initial energy of 1 J. ResCen gives no considerations to the RSSI of sensor nodes, and their performance is much worse than that ResCenRSSI because low residual energy would deplete energy more quickly with bad RSSI as the number of bits are increased. On the other hand, ResRSSI does not consider centrality where this input parameter influences energy consumption as well.

6.2 The Stability of the RAP in Scenario 2

This sections explains the FND, LND and number of the dead node when the residual energy of the 100 sensor nodes is 0.5 to 2 J.

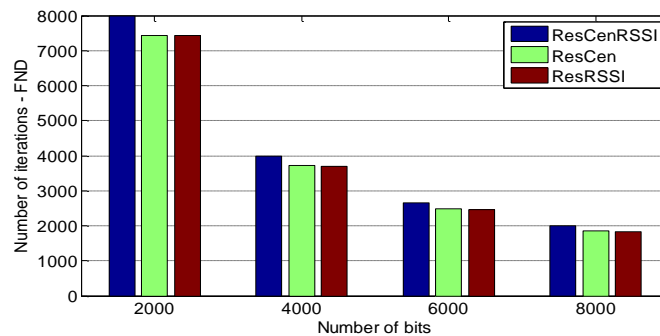


Figure 7. FND of improved MAP with 0.5 to 2 J energy of 100 sensor nodes

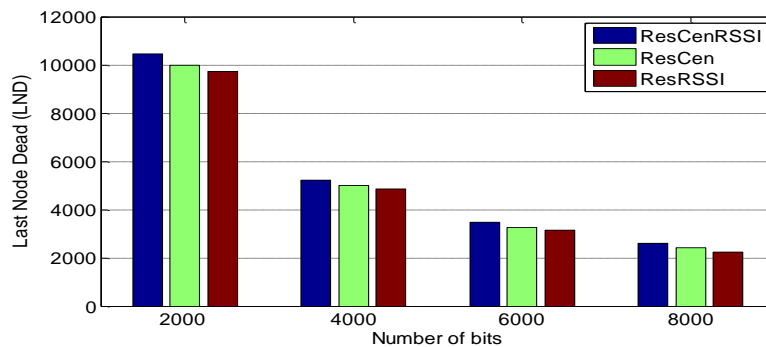


Figure 8. LND of improved MAP with 0.5 to 2 J energy of 100 sensor nodes

Figure 7 and 8 describe the FND and LND for various numbers of data: 2000 bits, 4000 bits, 6000 bits, 8000 bits, and 10000 bits for all combination of input parameters. As shown in the figures, in general, the iterations taken for the first and last node to die is more slowly as data increased from 2000 bits to 8000 bits compared in the first scenario (i.e., initial energy of 1 J). This is because the energy assigned to the nodes is much higher which is 2 J which lead to a longer network lifetime. The death time of the first node with ResCenRSSI is at the 7986th, 3993th, 2662th and 1997th iterations, whose performance increased by about 10% and 12% than ResCen and ResRSSI for 2000 bits, 4000 bits, 6000 bits, and 8000 bits respectively. When the last node dead, the iteration of ResCenRSSI for 2000 bits, 4000 bits, 6000 bits, and 8000 bits are increased about by 12% and 13% than ResCen and ResCenRSSI. Furthermore, the results show that the FND appears in ResCenRSSI is much later than in ResCen and ResRSSI, and the network lifetime is much longer. This is because the higher residual energy of the sensor nodes i.e., 2J, it will take longer iterations to die. Thus, it can be inferred that combination between residual energy, centrality, and RSSI is better energy consumption strategy with an initial energy of 2 J. The higher residual energy provided cause longer network lifetime. This situation corroborates that ResCenRSSI maintain its efficient operation fashion with the various number of bits.

6.3 Number of dead nodes evaluation

This section evaluates the energy consumption of SEP, MAP, improved MAP and improved MAP 2 in term FND, LND and number of dead nodes. The improvement gained through improved MAP protocol is further laid out in each of the two scenarios.

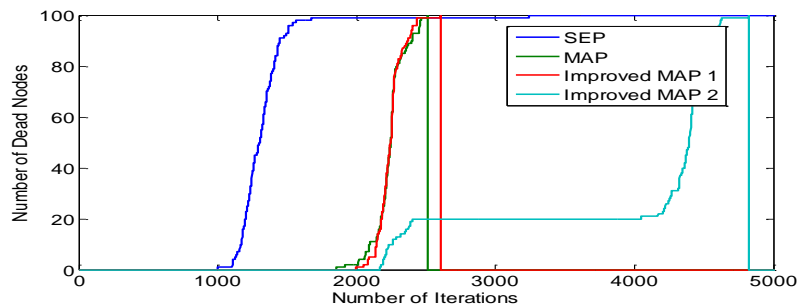


Figure 9. Number of Dead Nodes for Scenario 1

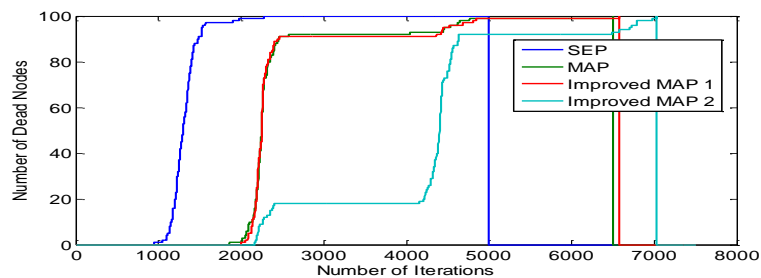


Figure 10. Number of Dead Nodes for Scenario 2

Figures 9 and 10 show the number of dead nodes with respect to iterations for Scenarios 1 and 2. As shown in Figure 9 and Figure 10, the FND of SEP protocol occurred at 1000th and 988th iterations and 60% and 40% nodes died at about the 1200th and 1100th iterations for Scenarios 1 and 2. The network lifetime of SEP was the poorest than other protocols. The reason for this was that the SEP protocol adopted the probabilistic CHs selection method [21]. Moreover, the placement of the BS in SEP was not centered, which may lead to high energy consumption and shorter network lifetime. In MAP protocol, the FND occurred at about the 2401th and 6408th iterations and 80% and 90% nodes died at about 2200th and 3000th iterations for scenarios 1 and 2. The total dead nodes of improved MAP 1 was slightly reduced and also the FND was slightly earlier which was at the 2511th and 6597th iterations compared with MAP for all scenarios.

The average improvement obtained in network lifetime in the improved MAP 2 protocol considering FND as the metric was about 26% for Scenario 1 and 24% in the case of Scenario 2 in comparison with MAP. With reference to LND as the network lifetime evaluation metric, the average improvement in Scenarios 1 and 2 was about 57% and 14%. The reason was that the improved MAP 1 method selects the CHs with high residual energy, high centrality, and with good signal strength. It can also be seen that the total dead nodes in improved MAP 2 dropped significantly during the 2500th and 2400th iterations for Scenarios 1 and 2 respectively. The BS in improved MAP 2 communicated with the relay nodes within the distance threshold, which caused the distance of data transmissions to be reduced and hence saved energy. Furthermore, the relay nodes efficiently formed clusters with the CHs based on the K-Means approach which provided load balancing, especially with the high number of the sensor nodes. As observed, the improved MAP protocol, i.e., MAP 2, achieved better energy efficiency and balancing than the MAP and SEP protocols. The reason was because the improved MAP protocol considered the impact of both intra-cluster and inter-clusters communication loads during operation. From the results, it can be concluded that the improved MAP was able to address the non-efficient CHs selection, heterogeneity of nodes, and quick energy depletion successfully.

7. Conclusions

In this paper, the Relay Access Protocol (RAP) has been proposed in order to improve the network energy efficiency. The FL-based CHs selection approach has been exploited in this work. The CHs selection used a combination of three input parameters which were residual energy, centrality, and RSSI. The CHs were assigned based on high residual energy, closeness to their child nodes, and good signal strength. Furthermore, the relay node selection was adopted to provide energy balancing and reduce the

communication energy consumption of far-end CHs. The simulation results showed that the method of relay selection along with CHs fuzzy based selection technique namely as improved MAP 2 extend the lifetime of wireless sensor network 57% and 14% longer than the original MAP for all scenarios.

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