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Article *in* IEICE Transactions on Communications · July 2016

DOI: 10.1587/transcom.2015EBP3453

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IEICE TRANSACTIONS

on Communications

VOL. E99-B NO. 7
JULY 2016

A PUBLICATION OF THE COMMUNICATIONS SOCIETY
The Institute of Electronics, Information and Communication Engineers
Kikai-Shinko-Kaikan Bldg., 5-8, Shibakoen 3chome, Minato-ku, TOKYO, 105-0011 JAPAN

PAPER

Power Aware Routing Protocols in Wireless Sensor Network

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SUMMARY Wireless Sensor Networks (WSNs) have gained importance with a rapid growth in their applications during the past decades. There has also been a rise in the need for energy-efficient and scalable routing along with the data aggregation protocols for the large scale deployments of sensor networks. The traditional routing algorithms suffer from drawbacks such as the presence of one hop long distance data transmissions, very large or very small clusters within a network at the same moment, over-accumulated energy consumption within the cluster-heads (CHs) etc. The lifetime of WSNs is also decreased due to these drawbacks. To overcome them, we have proposed a new method for the Multi-Hop, Far-Zone and Load-Balancing Hierarchical-Based Routing Algorithm for Wireless Sensor Network (MFLHA). Various improvements have been brought forward by MFLHA. The first contribution of the proposed method is the existence of a large probability for the nodes with higher energy to become the CH through the introduction of the energy decision condition and energy-weighted factor within the electing threshold of the CH. Secondly, MFLHA forms a Far-Zone, which is defined as a locus where the sensors can reach the CH with an energy less than a threshold. Finally, the energy consumption by CHs is reduced by the introduction of a minimum energy cost method called the Multi-Hop Inter-Cluster routing algorithm. Our experimental results indicate that MFLHA has the ability to balance the network energy consumption effectively as well as extend the lifetime of the networks. The proposed method outperforms the competitors especially in the middle range distances.
key words: *Load-Balancing, Wireless Sensor Network, routing protocol, Far-Zone, clustering*

1. Introduction

Wireless Sensor Networks (WSNs) have gained importance motivated with applications such as physical parameter measurement, emergency event detection with applications in many civil and military fields, object tracking, battlefield surveillance, health monitoring, and smart home applications [1], [2]. A WSN is comprised of various elements known as sensor nodes (SN) which are distributed in the coverage area of the related application. WSNs can be deployed on a large-scale consisting of hundreds or even thousands of SNs. Generally, a SN consists of a power supply typically in battery form, a sensing unit (i.e., transducer) responsible for physical parameter sensing, a simple processing unit and transceiver unit for wireless communications. The data from the sensing unit is transmitted to a specialized central node in a centralized architecture, or alternatively local processing is done on it in a decentralized network. Eventually, a satellite or a microwave link is used for dispatching the information from the WSNs. The research on WSNs includes studying topics such as cost-efficient designs, potential derivation of energy from the environment, designing communication protocols to conserve energy, networks with a self-organizing capability, node failure and information fusion management and many more. To ensure the effective flow of information there must be a pathway which connects every node to the network. The connection among two nodes in a WSN is based on the supplied power of transmission and their geographical positions. The greater the level of transmission power, the more connectivity will be present between the nodes. Thus, the connectivity or topology of the network is dependent upon the transmission power and the node location. However, the optimum utilization of energy is necessary to ensure the long-term running of the entire network. Energy consumption of a WSN can be decreased through communication protocols which conserve energy by using regular intervals of sleep/wakeups, and simpler programming. Nodes in centralized deployments usually transmit their measurements to a more complex and smart unit called the fusion centre (FC), which gathers all the information of the network and conducts the final processing. The efficient organization of nodes, the utilization of medium access control (MAC) and the creation of routes for the protocols to transfer the information to the FC is essential in centralized networks. The flow of information to the FC in case of an event is significantly higher and may cause congestion. Furthermore, whenever a node fails, turns to sleep mode or is incorporated in the network, MAC re-organization is needed. The cost of the devices may increase due to the hardware needed for wireless communication, consequently increasing the cost of the network which are the reasons why a centralized WSN is ineffective and costly in terms of the energy usage, scalability and reply to applications stimulated by specific events. A decentralized network or a system in which every node has the same capabilities and has the potential to perform identical tasks is an alternative where the nodes organize themselves through local interactions without forwarding information to a FC. Results obtained from a decentralized network are considered to be dependable and provide a solution that can be implemented globally. The global information is required to be present at every node. Decen-

Manuscript received October 22, 2015.
Manuscript revised February 29, 2016.
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DOI: 10.1587/transcom.2015EBP3453

tralized networks may also be arranged in forms of clusters in which the present node determined as the CH performs the function of the local FC. These nodes form connections with different CHs and develop a top layer of the network which may be linked to other devices to form a decentralized network having a hierarchical structure [3], [4]. In a centralized WSN, the FC is responsible for the computations whereas, in decentralized architectures, the computation is distributed by utilizing parallel and distributed functionalization tools [5], [6]. Global information is needed in a distributed system; however, the data available is the only information that can be retrieved from the nodes and their one-hop neighbours. Resource scarcity, final decision dependability, node failure resistance and intervals of sleeping are some crucial factors to be considered during the design of distributed algorithms for WSN [4], [7]. Thus, the intelligent design of hardware, energy-efficient algorithms and communication protocols are essential to design simple and reconfigurable WSNs which utilize all the resources available. The purpose of this study is to minimize energy usage and optimize the performance of WSNs. Our method aims to create a balanced consumption of power within the WSNs while preserving other performance parameters. Moreover, we present a new clustering technique, which helps to carry out the load balancing process. This paper has the following organization. In Sect. 2 we review the previous works done. Section 3 introduces our method in detail. Section 4 presents the experimental results and finally, in Sect. 5, we draw our conclusions and present future directions.

2. Power-Aware Routing Algorithms

Energy efficiency should always be considered when carrying out routing, data dissemination or any kind of general network management, which affects the lifetime of the network. Control packets, retransmitting collided packets, extra overhead and idle listening may lead to the waste of energy. The requirement for several WSN routing protocols like [8]–[10] is to bring forward a route to the base station, which needs low overhead and extremely low control packets. The networks' lifetime can be extended and scalable architecture can be attained through clustering [2], [11]. The WSNs consider routing as a challenge mainly due to the presence of the various characteristics of the contemporary ad-hoc wireless networks. Limited physical resources, data collected from various sources and missing global addressing schemes are the main characteristics differentiating WSNs [12].

2.1 Overview of WSN's Routing Protocols

The routing taxonomy, protocol classification and its subcategories have been presented in [13]. Routing protocols can be classified based on the structure of the underlying network(s), or the operations performed by the routing protocol. If classified based on the network structure, the protocols are divided into location-based routing, flat routing, and hierarchical routing protocols [20]. In the flat routing technique, the sensor nodes perform the same role such as the collection of data and communication with the sink [13]. In hierarchical routing there is a cluster of the routing sensors in the network where the CHs are responsible for collecting all data and communication with it [13]. In location-based routing, location is used to address the sensor nodes. The distance of the nearest neighboring node can be calculated on the basis of the incoming signal strength. The signal strength becomes weaker due to various obstacles in the networks, which is the reason why it becomes difficult to determine the nearest neighboring node. In such situations, the small minimum energy communication networks (SMECN) seem to perform more efficiently as they are able to establish a sparse graph of the network nodes before the next node transmits. Since energy is a key factor in routing protocols, the location-based schemes require the nodes to alter their state from active to sleep mode when no action is being performed. Various location-based schemes are present, such as GEAR (Geographic and Energy-Aware Routing) and GAF (Geographic Adaptive Fidelity) [13].

2.1.1 Operation Based Routing Protocols

The operation based routing protocols are divided into coherent-based, quality-of-service (QoS) based, query-based, negotiation-based and multi-path based routing protocols. In the coherent-based algorithm, the sink or the nearest neighbor is sent the data collected by the sensor nodes in the WSN after processing them. This protocol supports coherent and non-coherent data processing. In the non-coherent data process routing, the nodes conduct all the processing, reducing the energy consumption and total time, which explains why it is energy efficient [17]. For the QoS-based routing protocol, it is important to secure quality and energy within the network. When a sink sends queries for data from the sensed nodes within the network, the transmission has to fulfill some QoS requirements such as bandwidth consumption and bounded latency [16]. In the query-based algorithm, the queries presented by the base station are used to request specific information from the network nodes. The data sensing and collection are the responsibility of each node, which would read the query, and if a match were observed with the data being requested, would then send out the data to the node or to the base station. This is known as the Directed Diffusion process [15] in which interest messages are sent by the base stations to the network. Here, the data aggregation is carried out on a route and less energy is consumed. The redundant data transmissions are removed through the negotiation-based protocol which makes use of high level descriptors having high level coding. Negotiation protocols, for instance SPIN [14], help in restricting the duplicate information and do not allow repetitive data to be transferred to the neighboring node or the base station [15].

2.2 WSNs Hierarchical (Clustering) Routing Protocols

LEACH (Low Energy Adaptive Clustering Hierarchy) [21], which is one of the earliest hierarchical clustering protocols, has been used to increase the life span of the WSNs. The sensor nodes form clusters where, one node functions as the cluster-head (CH). The base station (BS) can only be contacted by the CHs. The energy in individual nodes is saved when the LEACH adopts a randomized rotation of the CHs. Cluster forming and CH selection is performed in the setup phase. Multiple clusters are formed for all nodes even if there are various nodes that may identify themselves as CHs regardless of the rest of the nodes. A suggested percentage (P) is used for the election of the CH nodes, considering their earlier record as a CH. A random number between 0 and 1 is generated by all nodes which are not part of the CH in the preceding *1/p* rounds. If the value generated is less than a threshold T(n), then the node is selected as the CH. With the help of the CSMA/CA protocol, the status is broadcast by the elected CHs. Non-CH nodes select their corresponding CH by comparing the Received Signal Strength Indication (RSSI) of multiple CHs. The data sent by the sensor nodes is aggregated and forwarded to the BS. The steady state phase is normally longer than the setup phase. The main drawback of the LEACH is that the random selection of the CH does not guarantee its optimal distribution. The node with low energy has the same possibility of becoming a CH as the node with high energy. This can lead to the degradation of the network lifetime. LEACH-Centralized (LEACH-C) [22] includes an improvement for CH selection. During the setup phase, the energy status is sent by the sensor nodes along with the nodes' IDs and location information to the BS. Using the central control algorithm, the BS designates a node as CH. It then forwards the node IDs of the selected CHs to all network nodes. The distance between the CHs and other nodes is also minimized by the BS. There are certain assumptions for LEACH-C such as the nodes' capability to compute energy, determining the node location and transferring this information to the BS even if the BS is far from them. The main drawback of LEACH-C protocol is the necessity to send information to the BS in the setup phase which consumes part of the node energy. The Power Efficient Gathering in Sensor Information Systems (PEGASIS) [24] addresses the dynamic clustering issue in LEACH by forming chains rather than clusters. Nodes communicate with the nearest nodes in PEGASIS and this communication continues to take place untill the aggregated data is received by the BS. The lifetime of the network is thus improved as the power consumption for each round is reduced. Random selection of the leader node is performed at the beginning of each round which makes the network more robust. Once the leader has been chosen, a token is passed to the end node to commence the collection of data. This leader node is then responsible for transmitting the fused data to the BS. However, the location and energy of the nodes are not considered by PEGASIS when choosing the leader nodes. LLs (long links) are a major issue of PEGASIS since Greedy algorithm is applied to the chain construction. The closest node is the one that is the locally closest; however, it may not be globally closest or near at all. Hence, there may be greater delay in transmission. Chain Cluster-Based Mixed Routing (CCM) algorithm has been proposed by Tang et al. [23], which includes the chain clustering followed by the cluster routing steps. In the first stage, on a horizontal basis, a number of chains are formed and each of these chains has a chain head. In parallel, each node in the chain passes data to the chain head. Following this process, a cluster is created where only chain heads are present. Lastly, the chain heads transmit all the aggregated data to an agreed upon CH. The Energy-Efficient Clustering Protocol (EECPL) proposed by Bajaber and Awan [25] chooses a CH and a cluster sender. The CH establishes and disseminates the time division multiple access (TDMA) schedule, while the cluster sender aggregates the data from the sender nodes and forwards them to the base station. The EECPL then decomposes the network into several clusters from which it extracts the cluster senders and the CHs. Within each cluster, a ring is formed to allow each node to send and receive data from a single neighbor. The aggregated data is sent to the cluster sender which transmits it to the BS. The Energy-Efficient Weight Clustering (EWC) protocol [26] uses a different CH election method. Several metrics such as distance, node degree (number of neighbours of the node) and residual energy are taken into account when the CH is chosen, assuming that the nodes are location unaware, static, homogenous, and distributed randomly. Both channel nodes are used along with free space with multipath fading power loss. The weight metrics used for the CH selection are residual energy, the distance between CHs, BS and nodes, and node degree. The method imposes extra processing to select the CH. To manage the drawbacks of LEACH, Katiyar et al. [27] put forward the Far-Zone LEACH (FZ-LEACH) method. A cluster is separated into two regions which are determined by the distance between the CH and cluster members (CM). The group of nodes located at a distance from the CH are known as a Far-Zone region. Through the average minimum reachability power (AMRP), the FZ-LEACH determines the nodes that are located in the Far-Zone. The AMRP is the measure of the expected intra-cluster communication energy used for communication with the CH. The minimum power level of CM is calculated by the CH. The Far-Zone is the minimum power level below the AMRP. The most powerful node in the Far-Zone is chosen as ZH; however, the FZ-LEACH protocol does not consider the distance between the Far-Zone member nodes and ZH. In addition, it does not take into account the fact that the Far-Zone Member Nodes are not owned by ZH. In [18] ZH is elected by using quadrant method and finding the average coordinate values. The energy-efficient adaptive clustering routing algorithm (EEACRA) was put forward by Jia et al. [28]. This algorithm helps overcome the issues in the LEACH CHs, such as the irrational distributions, over-accumulated energy consumption, and the noneoptimal proportion. EEACRA assumes that the CH is the node which has more energy through considering the energy condition in the CH electing process. Moreover, the distribution of the CHs and the collision probability is reduced through an energy weighted strategy which is present in the CH broadcasting phase. Also, the CH energy consumption is reduced through the minimum energy cost multi-hop routing mechanism which prolongs the network life-cycle; the entire network energy consumption is balanced effectively. The only issue with EEACRA is that the selection of the optimum relay CH during the inter-cluster multi-hop routing algorithm requires additional overhead. An improvement to the multi-hop routing algorithm was proposed by Ranga et al. [19] where the authors combine the Far-Zone clustering with mltihop routing. They proposed an energy efficient clustering protocol called Multi-hop Far-Zone Leach Protocol (MFZLP) which uses multi-hop technique in Far-Zone (FZ) LEACH to improve the lifetime of the network. There are also newer studies to extend the lifetime of the sensors with the same amount of initial power. Banerjee et al. [35] offered a mechanism to replace the random CH election protocol used in LEACH into an energy-aware clustering algorithm over the whole network. The authors assumed that the following critical information should be available at nodes: (i) The nodes shall be eligible to determine their current energy level, and the strength of the transmission signal, (ii) All nodes shall be aware about the signal strength of the other nodes. Although having knowledge in the former is possible, having knowledge on the latter needs sophisticated signal measurements or knowledge of the locations. However, in [35] the authors stated that the locations of the sensors are not known. For a node, knowing the signal strength is directly related to knowing the location of itself relative to the other nodes. The authors stated that their average lifetime performance is 32.8% better than the standard LEACH with offered modifications. Sony et al. [36] renewed the studies of [35] for small networks, and offered a modified multi-hop LEACH method for the very large networks. The assumptions were similar to the assumptions in [35]. In the second part of their experiments, the authors increased the number of nodes from 100 to 1000 while the area where the sensors were perfused increased from 10,000 meter-square to 1,000,000 meter-square. The authors stated that, the offered multi-hop model performs 25% better than the original LEACH. Although the authors in [35] and [36] stated that it consumes less than 1% more energy to transfer the relative signal strengths, they do not mention how and with what cost they build the relative strength map for the whole network.

3. Proposed Method

Although it is essential to maintain the longevity of the network because of the limited energy supply, it is not possible to replace the sensor nodes since they are randomly deployed in a severe environment, such as being dropped from a helicopter. The network lifetime can be prolonged and a scalable architecture can be achieved through clustering. In order to overcome the drawbacks of LEACH, we propose a Multi-Hop, Far-Zone and Load Balancing Hierarchical Based Routing Algorithm (MFLHA) The proposed algorithm solves several problems inherent in LEACH such as extreme energy use in CHs, the simultaneous presence of extremely large and extremely small clusters in the network, long-distance broadcasting of data in a single hop, etc. that can bring a reduction in the lifetime of the WSNs.

3.1 System Model

The proposed model in this study uses similar assumptions with the proposals in [35] and [36] excluding the knowledge of the signal strength of the other nodes. Knowing the signal strength requires the awareness of the location of a node relative to others contradicts with their location unawareness assumption. The simplicity of our model makes the proposed model still applicable to real life. The single hierarchy network model that is similar to the LEACH [21] has been applied in this study, considering the following assumptions:

1. To support the various kinds of data processing and MAC protocols, the nodes are all the same with sufficient computing capacity [21].
2. The wireless channel is symmetric and identical energy attenuation is present for the radio signals in all directions [21].
3. The nodes including the sink communicate with each other in single hop mode [21].
4. The nodes are aware of their residual energy and adjust transmission power as per the communication distances [35] and [36].
5. Sinks are static in nature and have sufficient power supply [21].
6. Within a given time slot, data is transmitted by the node. Collected data by neighboring nodes are correlative; therefore, the CH is able to combine the collective data [35] and [36].

The radio energy dissipation model which has been applied in [21], [29]. It should be assumed that for each bit, the radio model gives out the following energy $Eelec = 50nJ/bit$ to operate the receiver circuit and transmitter. For data bits to be transmitted over a distance (d) keeping an acceptable SNR in mind, the amplification energy is consumed to manage the loss of multipath (mp) or free space (fs) based on the transmission distances (d). Hence, to transmit k bits, the following energy is used;

$$\begin{aligned} E_{Tx}(k,d) &= E_{Tx} - elec(k) + E_{Tx-amp} \\ &= \begin{cases} KE_{elec} + k\epsilon_{fs}d^2 & if \quad d < d_0 \\ KE_{elec} + k\epsilon_{mp}d^4 & if \quad d \geq d_0 \end{cases} \end{aligned} \tag{1}$$

The distance threshold for exchanging amplification models denoted by d_0 (which is the reference distance between receiver and transmitter) is computed as follows:

$$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \tag{2}$$

The radio will expend the following energy to receive a k-bit message

$$E_{Rx}(k) = E_{elec}k \tag{3}$$

It is assumed that the energy consumed during the transmission of a k-bit message from node A to node B is the same. Additionally, it is also assumed that there is a correlation in the sensed information which is why the CH would always aggregate the data collected from the members into a single length-fixed packet. The energy expended by the CH to aggregate k-bit data from n members is given in Eq. (4)

$$E(k,n) = n \times E_{DA} \times k \tag{4}$$

where E_{DA} is the data aggregation factor.

3.2 Multi-Hop, Far-Zone and Load Balancing Hierarchical Based Routing Algorithm for Wireless Sensor Networks (MFLHA)

There are two phases in the proposed MFLHA operation: the set-up phase and steady-state phase. The clusters are organized and the CHs are selected within the set-up phase. The actual data transmission to the sink is carried out in the steady-state phase. Certain nodes have been selected randomly as the CHs within the proposed algorithm. For all nodes, the CH role has been rotated in order to balance the energy dissipation of the sensor nodes within the networks. In this section, the CH election threshold *T(n)* has been shown, along with the LEACH optimal value K_{opt}. The improved algorithm has subsequently been presented with the following threshold [21]

$$T(n) = \begin{cases} \frac{p}{1-p\times[r \bmod (1/p)]} & if \quad n \in G \\ 0 & otherwise \end{cases} \tag{5}$$

The designed percentage of the CHs is denoted by P, current round is denoted by r and the set of nodes which have not been CHs in *1/p* rounds is G. Through the following equation, the optimal number of CHs can be computed as follows

$$K_{opt} = \frac{\sqrt{N}}{\sqrt{2\pi}} \times \frac{\epsilon_{fs}}{\epsilon_{mp}} \times \frac{M}{d^2_{toBS}} \tag{6}$$

where the total number of network nodes is N; the length of the side of the square region is M; the distance between the nodes and the sink or base station is d_{toBS}; the power amplifier in free space amplification coefficients and multipath fading channel models are ϵ_{fs} and ϵ_{mp}, respectively [29]. Our proposed method outperforms the current methods through (i) the improved threshold for choosing the CH, (ii) a more efficient inter-cluster routing algorithm, and (iii) the intra-cluster far-zone formation as explained in the following sections.

3.2.1 The Improved Threshold for Electing the CH

The EEACRA [28] has provided the concept of enhanced threshold for CH selection. A low energy node can be elected as the CH within the LEACH distributed algorithm. However, this election can cause an unbalanced use of network energy. In each election round, it may not be able to assure an optimal CH number K_{opt}. If a node exhausts its energy, the K_{opt} cannot be adjusted accordingly. Statistical regularity exists for the energy consumption of the entire network and the CH number. The random election method does not guarantee that within each round, an optimal number of CHs would be elected. Hence, K_{opt} can be used as a reference value for the CH number, signified by K_{ep}. This can be done on the basis of the fact that all nodes are alive and the minimum energy is consumed in the entire network. We use as the expected number of CHs and replace K_{opt} in Eq. (7). It is assumed that N_0 is the initial node number and K_{ep}/N_0 is the optimal CH percentage or probability. The Eq. (7) shows that K_{opt} is proportionate to the square root of the alive node number N, and inversely proportional to $\sqrt{N}$. Hence, the probability of selecting the optimized CH would be as shown in Eq. (7).

$$P_{ep} = \frac{k_{ep}\sqrt{N_0}}{N_0\sqrt{N}} = \frac{k_{ep}}{\sqrt{N_0}\sqrt{N}} \tag{7}$$

Here, N_0 refers to the initial node number and N is the number of alive nodes. If there is no failed node, then N equals N_0. The energy decision threshold and energy weighted factor are based on P_{ep}. Hence, the improved threshold of the CHs becomes:

$$\begin{aligned} T_ep(n) &= \begin{cases} \frac{P_{ep}E_{n\_cur}\sigma}{E_{ch\_av}(r-1)} & \beta \geq 0.5 \\ 0 & \beta < 0.5 \end{cases} \\ &= \begin{cases} \frac{k_{ep}E_{n\_cur}\sigma}{\sqrt{N_0}\sqrt{N}E_{ch\_av}(r-1)} & \beta \geq 0.5 \\ 0 & \beta < 0.5 \end{cases} \end{aligned} \tag{8}$$

where

$$\beta = \frac{E_{n\_cur}}{E_{ch\_av}(r-1)} \tag{9}$$

In this case, the CH selection probability of node n in the present round is P_{ep}; the energy-weighted factor is denoted by β; the residual energy of node n is En_cur; average residual energy of all nodes in the last round is $Ech\_av(r-1)$; the current round number is r; and the correction factor is σ. When clusters are being formed in the set-up phase, the nodes decide if they want to become the CH or not in the current round. The decision depends on a predetermined fraction of nodes and the threshold T(s) present in Eq. (5). With the help of this threshold, each node is expected to be a CH at some point of time within the rounds $1/P_{ep}$. All the nodes become eligible to be CHs after the rounds $1/P_{ep}$. An advertisement message (ADV) is sent by the node that has designated itself as the CH for the current round to the remaining network nodes. On receiving the ADV message, the non-CH nodes decide which cluster they would belong to in the present round. The advertisement message signal strength determines this decision. On receiving all messages by the CH regarding the inclusion of the nodes in the cluster and based on the number of nodes present in the cluster, a TDMA schedule is created by the CH and the time slot is assigned to each node during which the transmission can be carried out.

3.2.2 The Intra-Cluster Far-Zone Formation

In long distance communications most of the energy consumption takes place during the data transmission. In the LEACH protocol, if the energy is to be utilized efficiently, the intra-cluster Far- Zone must be formed in large clusters. The Far-Zone idea was proposed in [27]. The classification of the entire area by the CH is based on the distance. In the proposed algorithm (MFLHA), the CH and node distance is larger than the average since the node is considered to be a Far-Zone member. Four clusters are present (A, B, and C, D). Some of the nodes in cluster D are present far away from their CH. In the MFLHA, the selection of CHs is similar to the LEACH algorithm, with the only difference being that the MFLHA uses the improved threshold for choosing the CH. After the formation of the CHs, the average of minimum reachability power (AMRP) value is computed by each CH as shown in Eq. (10)

$$AMRP = \frac{\Sigma_{i=1}^{N} MinPwr_i}{N} \quad (10)$$

The expected intra-cluster communication energy consumption [34] is explained by the node AMRP. The Far-Zone is a sub-set of the members of a cluster which are far from the CH in terms of AMRP. If the reachability power level of the node is lower than the AMRP, then the distance between the CH and node is longer than the average. For a Far-zone a single ZH is selected which is the Far-Zone member with the highest energy. This is because the ZH is responsible for receiving the messages of the Far-Zone members, and forwarding them to the CH after aggregating them. Hence it spends more energy than other members of the Far-Zone. However, as described in Sect. 3.2.1 the CHs are elected at each round using an improved algorithm. Therefore, the Far-Zones are redefined with the election of new CHs. The redefinition of the Far-Zones provides a chance for other members to be selected as a ZH. The TDMA schedule is established by the ZH in the same way as the LEACH, and the time slots are attributed to the zone members. Data is aggregated by the ZH after the sensing data is received from the zone member nodes and then it is broadcast to the CH.

3.2.3 The Multi-Hop Inter-Cluster Routing Algorithm

When there is a large distance between a CH and the sink (BS), the single-hop mode brings about a stark increase in the energy consumed by the CH. The cluster head-energy consumption load is balanced by the MFLHA, based on the multi-hop routing algorithm having the smallest energy cost. The sink node broadcasts beacon messages which are used by the CHs to compute their distance to the sink node. Next, using the distance to sink value each CH computes the energy needed to send data to the sink node in a single hop mode. This value called path cost, is broadcast in an ADV message. After receiving the ADV messages of other CHs, Far-CHs decide which CH can be considered as a relay node for forwarding messages. This decision is made based on the path cost values advertised by other CHs in their ADV messages. The CH with the smallest path cost is considered as the next hop (relay node) on the way to the sink node. The following are the details of the multi-hop routing steps.

a. Calculating initial path cost and selecting Far-CHs

The wireless communication module consumes most of the energy used by the sensors [30]. The energy consumed in receiving status is about 80% of the energy consumed during the transmitting status. As a result, in the calculation of the path cost, receiving energy cannot be disregarded. The Far-Zone nodes idea has been applied in the MFLHA for data routing from CHs to sink. The method suggested in this paper is different from the work of the EEACRA [28] in the following ways:

i) Only the CHs that are situated far from the sink (Far-CHs) would determine their initial path cost to sink and try to update the routing path to sink by selecting another CH as a relay to the sink, provided that its cost is lower. This would bring a decrease in the additional overhead used to compute the initial path cost and update the path for each CH in the network.

ii) Eventually, an even distribution of the load between CHs would be attained and the power consumption of the entire network would decline. The Far-CHs selection algorithm is explained in detail below.

$$\begin{aligned} Cost_0(CH_i) &= E_{Tx}^{i}(l, d_{toSink}) \\ &= \begin{cases} E_{elec}l + \epsilon_{fs} l d_{toSink}^2 & d_{toSink} < d_0 \\ E_{elec}l + \epsilon_{mp} l d_{toSink}^4 & d_{toSink} \geq d_0 \end{cases} \end{aligned} \quad (11)$$

i. Calculating minimum reachability power to the sink for cluster-heads

The transmission distance is calculated by each CH using the beacon message dispatched by the sink. The minimum reachability power or the energy consumption of sending the collected data to the sink within a single-hop mode is also calculated. The initial path cost will be this value and would then be sent together with the ADV as the information field during the phase of the CH declaration. The initial path cost is attained by using the following equation.

ii. Selecting Far-CHs and updating path cost

Multi-hop transmission has the disadvantage of depleting the energy of the relay nodes in a much faster way. Hence, some nodes die very quickly while the other nodes still have their energy preserved. One of the goals of the proposed method is balancing the energy consumption in the entire network. If the energy needed for transmission of a message by a CH is less than the AMRP, the proposed method assumes it spends its energy in a fair and balanced way. Once the ADV is obtained from other CHs, the AMRP of each CH is calculated for all CHs to carry out communication with the sink and make comparisons with the initial path cost. The AMRP would be the threshold for determining which CH is situated at a far zone. If the AMRP is lower than the initial path cost, then the CH is considered far from the sink (Far-CH). Far-CHs are able to estimate the CH distances and to compute the forwarding path cost when the rest of the CHs function as the forwarding node towards the sink. If the initial value were higher than the cost, it would be considered as the updated path cost value. Numerous forwarding paths may be present in the Far-CH, which would have a lower cost compared to the initial value. The minimum cost path is chosen as the default forwarding path and the new path cost is stated in the ADV transmission. A single-hop mode may be used by the other non-far CHs. An optimal multi-hop routing can be established by each of the CHs iteratively. Only one forwarding CH that acts as the forwarding node to the sink is present in the routing table formed by this method. The standby routing table ensures that the corresponding path cost and the suboptimal forwarding CHs are saved. The suboptimal forwarding path would be chosen if the optimal forwarding path fails during the transmission period. For the forwarding node, the path cost of CH i to the CH j, have been presented in the following iterative equation.

$$Cost(CH_i) = E^i_{Tx}(l, d_{ij}) + CostF(CH_j) = \begin{cases} CostF(CH_j) + E_{elec}l + \epsilon_{fs}ld^2_{ij} & d_{ij} < d_0 \\ CostF(CH_j) + E_{elec}l + \epsilon_{mp}ld^4_{ij} & d_{ij} \geq d_0 \end{cases} \tag{12}$$

$$CostF(CH_j) = E^j_{Rx}(l, d_{ij}) + Cost(CH_j) \tag{13}$$

where the distance between two neighbouring CHs, i and j, is denoted by d_{ij}, the energy consumption of the CH is $E^i_{Tx}(l, d_{ij})$. In the case of CHi sending l bit message to CHj, and $E^j_{Rx}(l, d_{ij})$ is the energy consumption to receive l bit message from CHi. The forwarding path cost of CHj is $CostF(CH_j)$. The forwarding path cost is calculated as shown in Eq. (14) assuming CHj is the last forwarding node.

$$CostF(CH_j) = E^j_{Rx}(l, d_{ij}) + Cost_o(CH_j) \tag{14}$$

b. Routing maintenance

The cluster set up phase is used to construct the multi-hop routing table. The routing table is rebuilt again if a new election round initiates. This helps us to eliminate the burden for the routing table maintenance. A sub-optimal forwarding node would be chosen from the standby routing table if the default forwarding CH were unable to forward the data during the transmission process. If data cannot be correctly forwarded by any of the CHs, then the data would be broadcast directly to the sink in one hop. There is a small number of optimal CHs in a middle-size application context and hence the building time of a routing table does not have any impact on the efficiency of the network. The routing table is now convenient to maintain, as it is small. Moreover, the multi-hop routing system in the MFLHA that has been proposed is reliable and has no additional overhead for the routing maintenance. Only the Far-CHs require an estimate of the distance towards other CHs, and so the forwarding path cost is computed using Eqs. (12) and (13) when the rest of the CHs function as forwarding nodes to the sink.

4. Experimental Studies

Performance evaluation of the proposed MFLHA algorithm has been carried out using the simulation data. The algorithms were implemented using MATLAB. The LEACH and the FZ-LEACH algorithms have been used as bench marks for comparison and performance evaluation. The following metrics were used to evaluate the performance. (i) Energy consumption, (ii) Load balancing, (iii) Network throughput, and (iv) Latency.

4.1 Simulation Setup

The random-distribution network model has been applied within the simulation. Various sink locations have been set and different scenarios were built. Table 1 lists the parameters. The network lifetime performance indexes during the simulation were as follows.

1. *Stability period [31]:* This is an essential performance index for WSNs as it is the time interval from the beginning of the network operation until the first sensor node dies.
2. *Full Coverage period [32]:* This time interval spans from the beginning of the network operation until 50% of the sensor nodes dies.
3. *Network lifetime:* This time interval spans from the beginning of the network operation until 90% of the nodes within the network dies.

4.2 Simulation Results and Performance Analysis

For the different contexts of sink location, the table presented below demonstrates the number of dead nodes in each round. This involves inside as well as outside the

Table 1 Simulation parameters.

Parameter	Value
Number of Nodes	100
Network Size	100m × 100m
Location of Sink (Base Station)	Variable
Initial Energy of Nodes	0.5 J
Energy consumption for transmission (E_{elec})	50 nJ/bit
Data aggregation factor (E_{DA})	5 nJ/bit
Power amplifier coefficient in free space (ϵ_{f_s})	10 pJ/bit/m2
Power amp. coeff. in multipath fading chn. (ϵ_{mp})	0.0013 pJ/bit/m^4
Data Packet Size	4000 bits

Table 2 Percentage of failed nodes vs. number of rounds sink at location (50, 200).

Algorithms	Sink Location is (50, 200)		
	@the first node dies	@50% of nodes die	@90% of nodes die
LEACH	287	538	928
FZ-Leach	346	754	1065
MFLHA	661	960	1191

Table 3 Percentage of failed nodes vs. number of rounds sink at location (50, 175).

Algorithms	Sink Location is (50, 175)		
	@the first node dies	@50% of nodes die	@90% of nodes die
LEACH	431	742	1074
FZ-Leach	487	840	1108
MFLHA	712	1042	1277

Table 4 Percentage of failed nodes vs. number of rounds sink at location (50, 150).

Algorithms	Sink Location is (50, 150)		
	@the first node dies	@50% of nodes die	@90% of nodes die
LEACH	587	840	1110
FZ-Leach	650	981	1189
MFLHA	878	1168	1379

Table 5 Percentage of failed nodes vs. number of rounds sink at location (50, 100).

Algorithms	Sink Location is (50, 100)		
	@the first node dies	@50% of nodes die	@90% of nodes die
LEACH	850	1021	1156
FZ-Leach	925	1060	1181
MFLHA	874	1133	1359

Table 6 Percentage of failed nodes vs. number of rounds sink at location (50, 50).

Algorithms	Sink Location is (50, 50)		
	@the first node dies	@50% of nodes die	@90% of nodes die
LEACH	884	1039	1131
FZ-Leach	924	1076	1173
MFLHA	945	1158	1391

network. Using the random-distribution network model, the outcome, which is the round number, is different for each simulation code execution compared to the earlier one. For the different contexts of sink location, the Tables 2–6 demonstrate the number of dead nodes in each round. With the use of the random-distribution network model, the number of rounds changes at each execution. Table 3 depicts comparison of three algorithms on a popular base station location (50,175). In the given configuration the first node dies on iteration 431 in the LEACH whereas it dies on iteration 712 in the MFLHA. The average lifetime of the nodes in the MFLHA was 79.27% longer than the ones in the LEACH. Since there were no experiments performed on (50,175) in

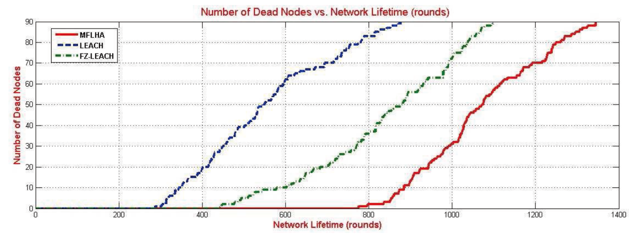

Fig. 1 Numbers of dead nodes over rounds.

[35] and [36], the experiments can only be compared by the average lifetime improvement in the proposed method and the others. The proposed MFLHA algorithm extends the average lifetime of a node 79.27% whereas [35] extends 33% and [36] extends 25%. The network instability of the MFLHA is less, according to the results presented in Tables 2, 3 and 4. In addition, the nodes'failure rate increases as their lifetime ends. Hence, it is possible for the MFLHA to effectively balance the entire network energy consumption. The network performance is most efficient when the sink is located far from the network center. However, the network performance is degraded if the sink is close to the network centre, as it is demonstrated in Tables 5 and 6. This means that there is a decrease in the MFLHA stability period and its performance moves closer to the LEACH and the FZ-LEACH. The main reason for this is that relay energy consumption increases for the multi-hop inter-cluster routing, bringing about an increase in the latency of the MFLHA. This suggests that the MFLHA is more appropriate for large-scale networks, and despite the higher latency of the MFLHA, it exhibits better performance compared to the LEACH and the FZ-LEACH. This can be attributed to the decrease in the energy consumption of the nodes, which brings about an increase in the lifetime of the entire network. In case of node failure, there would be considerably more effective nodes in the MFLHA compared to the LEACH and the FZ-LEACH, which indicates that the MFLHA has greater data accuracy and is more appropriate for full coverage for the requirements in WSN application.

4.3 Performance Analysis

Load Balancing is considered as the percentage of the energy left in the network when the first node dies. The total remaining energy of the network over the iteration rounds is demonstrated in Fig. 1. A higher percentage of energy is left in the MFLHA since it allocates the load between the CHs through the multi-hop inter-cluster routing algorithm. **The Energy Consumed** by all nodes during the working of the simulation is depicted in Fig. 2. It is observed that the MFLHA uses lower energy than the LEACH and the FZ-LEACH protocols. This amounts to an average increase of 28% in the network lifetime in the MFLHA when compared to the LEACH, and an average increase of 13% when compared to the FZ-LEACH.

The Network Throughput is defined as the total number of packets received at the base station [33]. The net-

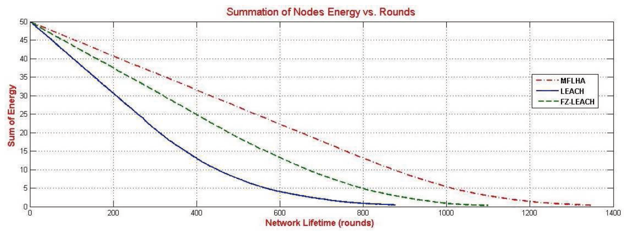

Fig. 2 The remaining energy of the network over rounds.

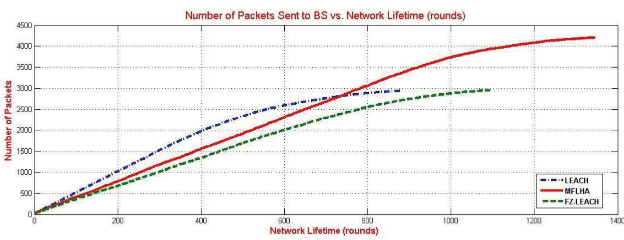

Fig. 3 The number of data messages received at BS over rounds.

Table 7 Latency with respect to the sink locations.

Algorithms	Sink Locations			
	50,200	50,150	50,100	50,50
LEACH	6204	7119	6100	5245
FZ-Leach	4356	5485	5532	3834
MFLHA	5047	6936	8198	4434

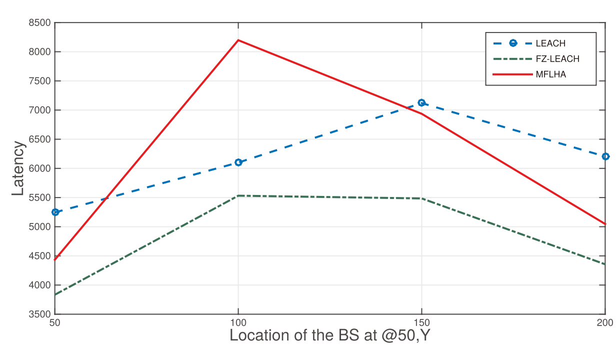

Fig. 4 Algorithms latency in different scenarios of sink locations.

work throughput is depicted in Fig. 3 which indicates that the MFLHA performs better than the other two protocols in terms of the messages received at the sink over rounds. The large cluster size issue has been resolved by the MFLHA which explains how it attains a higher level.

Latency of Algorithms: For the proposed MFLHA, the latency in terms of the number of hops is demonstrated in Table 7 compared to the LEACH and the FZ-LEACH algorithms considering the various scenarios pertaining to sink locations. It can be seen that when the sink is moved closer to the network centre, there is an increase in the latency of the MFLHA in comparison to the LEACH and the FZ-LEACH. This brings about a decrease in the level of network stability of the MFLHA as depicted in Fig. 4.

5. Conclusion and Future Studies

In the present research, an in-depth analysis of the hierarchical routing protocols in WSNs has been carried out. Based on this analysis, a multi-hop, far-zone, load balancing, hierarchical algorithm (MFLHA) has been proposed for the WSNs. The proposed method maximizes the lifetime of the network and optimizes the energy consumption within the sensor nodes of the network. The advantages such as the data fusion mechanism and CH rotation have been incorporated in the MFLHA. It includes improvements such as an energy-weighted factor in the CH election threshold, which solves the issue of the rapid failure of low energy nodes when they are elected as the CH. The far-zone has also been formed through which the issue of large cluster size is solved. The heavy energy consumption of CH is resolved through the minimum energy cost multi-hop inter-cluster routing mechanism.

The simulation results of the MFLHA were compared to the LEACH and the FZ-LEACH. It was observed that a further network balance is present for the entire network energy consumption for MFLHA and it also has the ability to extend the lifetime and stability of the network. In large scale applications, the MFLHA exhibits higher energy efficiency and environmental flexibility. Through the random election process of the CH, it is not possible to obtain the optimal number of CHs. This has an impact on the efficiency of the MFLHA and it is considered a drawback for the protocol. An improvement based on the CH location and its residual energy can be considered as a solution. The method proposed in [35] performs efficiently when sensors are distributed in a very small area while, the proposed method in [36] assumes very long distances with location awareness which increases the complexity of the network organization. On the other hand, the proposed method has simple requirements and yet outperforms the above mentioned proposals for middle distances.

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