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Toward Interference Aware IoT Framework: Energy and Geo-Location-Based-Modeling

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ABSTRACT In multi-hop wireless communication, a sensor node should consume its energy efficiently for relaying of data packets. However, most IoT-devices are equipped with limited battery power and computing resources for wireless communications, and thus energy optimization becomes one of the major concerns in wireless sensors routing design. The wireless technologies usually use unlicensed frequency bands of 2.4 GHz to transmit the data. Due to the broadcasting medium, the wireless transmission interferes with the reception of surrounding radios. As a result, data transmission failure increases resulting in low-communication quality. Therefore, one of the best solutions to this problem is to select the hop distance node that has a few neighbor nodes to disseminate packets until it reaches the ultimate receiver. The proposed routing selects the node that has few neighboring nodes and thus less interference. In another word, the scheme finds a better load balancing, and thus minimizes the probability of overload on a sensor node. It also introduces a new clustering algorithm around a single base station to shorten the transmission distances. This approach periodically selects the cluster heads (CHs) according to its location based distance from the final destination. The extensive simulation studies reveal that the proposed algorithm finds the best routing node and clustering formation to forward the traffic and thereby minimizes the interference ratio. In addition, the proposed protocol achieves low-energy consumption and longer network lifetime than other popular protocols.

INDEX TERMS Internet of Things (IoT), routing protocol, path selection, link quality, green computing, link reliability, interference, wireless sensor network (WSN).

I. INTRODUCTION

The vision of the Internet of Things (IoT) offers a wide range of applications and thus allows the internet to penetrate in embedded computing [1]. It is widely used in intelligent transportation, environmental monitoring, medical care, smart city concept, etc. [2]. IoT enables the development of low cost and low power wireless communication. Thus, it becomes one of the hottest topics in the current research field and has revolted extensive interest both in academic and industries [3]. To realize this vision, millions or even billions of physical embedded sensors cover a large fraction of the region. It needs to sense their environment, collect the information and share it among themselves and with human as well. The smart objects are highly constrained devices with strict limitations in terms of processing capabilities and battery consumption. Therefore, energy is considered as a scarce resource for IoT applications [3]. Sometimes it can be costly to exchange energy source or impossible to replace it in the target field. For example, networks positioned deep inside the ocean, near an active battlefield or volcano [4] or simply because of the large amount of nodes making it logistically impossible.

Within this complex environment, data delivery is usually achieved within multi-hop technology along with a sequence

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of nodes. The IoT-connectivity relies with short-range communications such as radio frequency identification (RFID), IEEE 802.15.1/Bluetooth, IEEE802.15.4/Zigbee, IEEE802.11/ Wi-Fi [5]. This means that each node plays a dual role as a data router and sender. These wireless technologies usually use unlicensed frequency bands 2.4 GHz to transmit the data. However, this frequency is shared with the microwave ovens and Bluetooth/WiFi devices, among others. Therefore, the smart devices regularly suffer from interference generated by surrounding devices. It also causes more congestion in this unlicensed frequency which may cause the bandwidth limitation. This leads to loss of connections and thus resulting in packet drops leading to degraded communication link quality.

Routing algorithms play a very important role for every single node and is a key functionality for direct and indirect communication over a network [6]. It controls the decision in order to travel the data across multiple networks from its source to its destination based on the routing metric. In large networks, the design of scalable and adaptive multi-hop routing schemes is highly recommended. Most of the routing techniques attempt to find the shortest path with the minimum energy path and balance the load within the network [7]. Certainly, direct communication is not only the best way for data dissemination. However, the design of routing protocol is multifold, since it involves not only less energy consumption from the source to the destination. It also requires load balancing and the quality of a link in the whole network. Also, the interference happens during the transmitting and receiving packets on the same frequency [8]. Therefore, it increases the probability of packets collision and reduces the performance of wireless communications. This will affect the quality of service parameters such as throughput, congestion, interference, delay, reliability, and contributes further to the power depletion in the nodes [9]. In order to achieve these goals, data communication techniques used in IoT applications should be optimized.

To eliminate data transmission wireless interference and prolong network lifetime, energy and Geo-location-based modeling route selection has been implemented. The proposed technique greatly improves the performance of a typical IoT network. It also accurately measures the interference among the nodes based on surrounding neighbor nodes that belong to each node. In another word, it reduces the communication traffic and thus energy overhead. This approach differentiates between the nodes on the path and takes intelligent decision to select the next hop. It chooses a node that has fewer neighboring nodes to deliver it packets and thus less interference. The technical novelty also focuses on a new way to select the cluster heads (CHs) among other nodes. The proposed approach involves a group of sensor nodes into clusters. Each sub-group has a CH node that elects based on the transmission distances to the ultimate receiver. The close node represents as a CH node for its sub-group. Therefore, CHs collect the fuse of data and forward it to the final destination. By doing so, the scheme balances the load throughput in the network and minimizes the probability of overloading on a node. Our contribution reveals many interesting observations that are summarized below:

- We first introduce the main theoretical study between the interference and number of neighbour nodes and their relationship with the transmitting power. It shows that increasing the number of surrounding nodes maximizes the transmission power and thus, increases the interference.
- Based on the number of neighbour nodes, estimated interference of each sensor node and shortest transmission distances, the proposed algorithm makes an intelligent decision for creating routing structure.
- The important feature of the proposed technique is a well-balanced network traffic minimizing the probability of collision packets and increasing the performance of the overall network.
- We define the concept of energy and Geo-location routing selection to conduct the strategy of our proposed protocol based on a path with less interference.
- We adopt a new clustering architecture depending on multi-hop concept and less transmission distances to reduce the energy used for each node and therefore elongating the network lifetime of wireless networks.

The rest of this paper is organized as follows: Section II describes the related work for both routing and clustering algorithms which are used in the wireless networks. Section III introduces the relationship between the interference and transmission power which affects the performance of the overall system. It also demonstrates the system model and the radio dissipation model in detail. Moreover, the proposed routing algorithm and the energy efficient clustering methods are also depicted in this section. Section IV delineates the simulation results and discussions. Finally, the conclusion of the work is drawn in Section V. Preliminary results were reported in [12].

II. RELATED WORK

A. ROUTING PATH SELECTION

Routing protocols are a fundamental feature of any network. It has attracted great deal of research interest. The evolution of IoT and the expansion of big data have played a crucial role in the feasibility of smart city concept [13]. Comprehensive data and information are generated by IoT-devices and sent via different routing algorithms via multiple paths to a desirable destination. Thus, one of the most significant current discussions of this rising field is the creation of an unprecedented amount of data [14] and how to send it with optimal resources to the final destination. Radio link quality has a fundamental impact on the network performance, thus, intelligent selection of the next hop based on the high link quality to avoid packets drop is important. Wireless networks implement CSMA/CA protocol which provides an efficient media access control that avoids packets collision. In fact, most of the IoT-connectivity standards use the CSMA/CA method to determine if the channel is clear to send a packet or not. When the channel is busy, the transmitter node waits for a backoff period to transfer the packet. In case, if the channel is still busy after four attempts (default value), then the packet is dropped [15]. Therefore, the intelligent routing technique may play a vital decision for these miniature devices while forwarding packets. This article presents an exhaustive review of these studies and suggests the best direction and solution for future networks developments. A considerable amount of literature has been published on the routing protocols. These studies use routing metric of minimum hops and shortest path to the ultimate receiver without considering the quality of link and interference. It means some nodes afford very heavy traffic while for others load is very light [16]. Therefore, this will not be an efficient and economical way to allocate within WSNs.

In the wireless ad-hoc networks, it is a set of nodes that communicates with each other wirelessly with a shared common channel. It does not need any particular infrastructure such as access point, backbone, etc. One of the standard protocols in wireless ad-hoc networks is called ad hoc on-demand distance vector (AODV). It uses to establish routes between more than two nodes only when it requires by source nodes (on demand) [17].

In another study [18], authors show a simple and efficient routing protocol designed mainly for mobile ad-hoc networks. Dynamic source routing (DSR) is similar to AODV protocol where it forms a route on demand when transmitting packets. However, it uses source routing instead of relying on the routing table at each intermediate node. Hence, as the size of the network grows, both protocols are not scalable and various performance metrics begin decreasing. They require high processing demand and increases the congestion in the active route when a link breakage occurs.

With the rapid technological development of sensors, several attempts have been made to create routing techniques that could reduce network traffic and thereby no overhead on the nodes. Wireless sensor networks (WSNs) are merely a subset of IoT technology. Therefore, we consider the related work from the WSNs aspect. In the work [19], power efficient gathering in sensor information systems (PEGASIS) is formed like a chain among the SNs to make transmission. So, each node receives the data from and transmit it to a close neighbor. Two nodes at the end of the chain routing structure will send the data through the intermediate nodes to the leader node and then the leader transmits it to the BS. A leader node is randomly selected to dispatch the collected data to the ultimate receiver. The main purpose of PEGASIS is to shorten the transmission distances between nodes, and thus the energy consumption of each node is minimized. However, there is only one node is elected as a CH per round. It may be the bottleneck of the network that causes delay and retransmission of a chunk of packets. In addition, it does not consider the transmission distance and energy level of a node when it selects a head of the node.

Similarly, authors [20] introduce one of the modifications of LEACH protocol called energy aware multi-hop multi-path hierarchy protocol (EAMMH). This scheme shows a new routing technique and clustering formation to deliver the data. The proposed algorithm partitions the sensing field into sub-clusters and each sub-cluster has a child-CH node. The main CH should be an optimum distance from these child-CH nodes. This means the distance between them should be balanced to reduce energy usage and thus elongate network lifetime. However, the CH nodes are overloaded with many surrounding nodes and thus it drains out their energy quickly.

In a different study [21], authors examine tree based mobile sink (TBMS). The proposed protocol outperformed many other existing methods. It adopts the sorting algorithm and using the multihop concept to create the routing structure. The idea of TBMS is to reduce the hop distances and thereby the lifetime is extended.

However, this has been implemented in smaller sensing field ($500m^2$) and a few numbers of nodes (100). The authors also assumed that the mobile sink is moving randomly in the sensing field. Therefore, there is no guarantee that the MS can cover all the sensing field or it might take too long when the sensing sensors are extended. Further, if the speed of the mobile sink is too fast or slow, then it will cause high packets loss and more delay.

Although a large and growing body of literature has introduced this area, the authors of this paper believe that a comprehensive and in-depth theoretical energy analysis of sensor nodes based on interferences and creating CH nodes are still missing in the previous work. Therefore, we proposed a new routing technique that selects the next hop with less interference node and thus high residual energy. Also, the proposed scheme introduces a new clustering formation that could save the energy nodes by taking into account of interference and thus and achieve longer network lifetime.

B. CLUSTERING FORMATION FOR WIRELESS SENSOR NETWORKS

Clustering procedure plays a prominent role in changing routing algorithms reaction and increasing network control traffic. One promising approach to address clustering formation in wireless networks environments is to build hierarchies routing and cluster heads selection among the nodes. The clustering method ensures effective routing and support quality of service. As well as it considers the relevant power constraints remain and bandwidth. The concept of clustering in WSNs is not new. There have been several studies in the literature reporting different metrics and focussing on clustering formation to optimize energy usage.

Low-energy adaptive clustering hierarchy (LEACH) is the popular and first clustering scheme for WSN [22]. In this protocol, a sequence of nodes is divided into sub-groups. For each group, a node is selected as a CH node based on a predetermined probability. Selecting the node randomly to become as a cluster head is the main drawback of LEACH protocol. Many various hierarchical LEACH protocol improvements are mentioned by [23]. With the same objective, authors in [24], [25] show an extension of LEACH protocol called energy balanced-LEACH. The proposed algorithm improves the CH selection procedure by considering the energy level as the main metric. This means a node with higher residual energy assigns first priority to become a CH node. Also, the proposed approach provides master cluster heads (MCHs) technique for the CH nodes that locate far from the BS. It can use relaying packets to deliver their data. While other close CH nodes can communicate directly to the BS. A new clustering algorithm is proposed in [26], [27] to reduce the energy consumption and prolong the network lifetime. Authors divide the sensing field into cells and each cell selects one node as a cell head among them. The cell head accepts the data disseminated from the connected nodes and removes the redundant data and then deliver it to the final destination. Even though LEACH and its derivative protocols paved way for implementing energy efficient routing protocol, all of them suffer from one fundamental problem. The node that is selected to become a cluster head does not guarantee that high energy resources nodes always be chosen. Furthermore, it is not applicable to large region networks.

Although clustering formation has been widely used in the area of wireless communications, there has been limited research on hop distance between the CH nodes and the ultimate receiver. In this paper, a clustering scheme is taken as the main criteria and dependence on different parameters and objectives is studied. Thus, it improves the efficiency and monitors the unnecessary traffic and thereby reduces the change of interference.

III. SYSTEM MODEL

The objective of the presented work is to implement a new heuristic routing algorithm and clustering formation that can reduce the power used for wireless sensors and thus maximizes the network lifetime. Most of IoT-devices communicate wirelessly with the limited power. It generates a substantial amount of interference. In some cases, the interference increases the probability of drop packets and thereby it requires to retransmit the packets to the target. Retransmission of packets add more complexity and overhead transmission to the network. To overcome this interference, it is important to study the relationship between interference and transmission power. This could improve the quality of service of the overall system and thereby extend the network lifetime.

A. INTERFERENCE ESTIMATION

This section proposes the relation between the wireless transmission distance and energy consumption for WSNs that enables IoT technology. Regardless of the WSN architecture, the transmission range has direct proportional relation with energy consumption. Most of these nodes are powered with the nonchargeable battery power. Therefore, the transmission range shrinks with other neighbor nodes, and thus reducing the lifetime of sensors. In short-range communications with a few numbers of neighbor nodes, the problem related to the energy consumption and interference is not significant as compared to long-range communications with more neighbor nodes. The main impact of long-range communications performance is wireless interference and energy resources. It is possible that wireless transmission from one radio can affect with the reception of surrounding radios. This can lead to low communication quality and data transmission failure. Furthermore, this will add more load on the already constrained network, end-to-end delay, and affects the lifetime of the network. To correctly estimate interference $I(i)$ generates in a node belongs to a path, the power produces by each neighbor node to this node should take into consideration based on (1) [28].

$$I(i) = \frac{N(p)}{N(P_{max}) + \beta} \sqrt{\frac{P^2 + P_{max}^2}{2P_{max}^2}} \tag{1}$$

where the current transmit power (P) to reach the neighbor nodes. P_{max} is the maximum power level that uses to reach maximum nodes $N(P_{max})$. A number of neighbor nodes $N(P)$ that can be used certain power P to link with them. β is the dimensionless correction factor needed to differentiate nodes that use higher transmission power but it has a different number of neighbors. This factor has been fixed to a value greater or equal to 1.

In multi-hop communications, with limited transmission range, a source node depends on other intermediate nodes to send it packets to the destination that locates it out of transmission range. These intermediate nodes act as relays for packets. Each relay node has plenty of neighbor nodes connect to it. In some situation, this might be caused collision of signals and increased drop packets. It also maximizes energy consumption and interference. Therefore, the cost in term of interference for a path $I(path)$ can be summarized as:

$$I(path) = \sum_{\forall (i,j) \in path} I_{i,j} \tag{2}$$

where $I_{i,j}$ is the summation of interference that generates from each node in a path. Based on (1) & (2), there are two important properties preserved by the interference, compared to the real interference phenomena, are the number of neighbor nodes $N(P)$ and transmit power level (P). A formal definition of this property is defined as below:

- The smaller power (P) uses to transmit a packet from node i to j, the minimum interference produced. We assumed that the number of neighbor nodes on a path is constant "i.e. $\forall N(P_i) = N(P_j)$", a path with $P_i < P_j$ has less interference than other "i.e. $I(Path_i) < I(Path_j)$".
- The interference decreases when the number of neighbor nodes through a path is a few. We assumed that the power of transmitting (P) is constant between two paths "i.e. $\forall P_i = P_j$, then the $N(P_i) < N(P_j)$. In this case, the interference of $I(path_i) < I(path_j)$".

Fig. 1 reveals the estimate interference for an individual node that has a number of surrounded nodes with energy

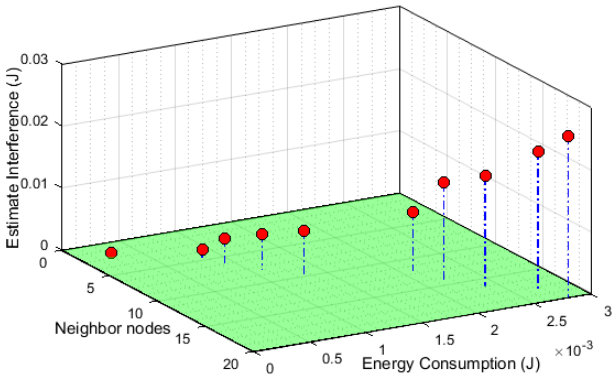

FIGURE 1. Estimated interference by no. of neighbor nodes vs energy.

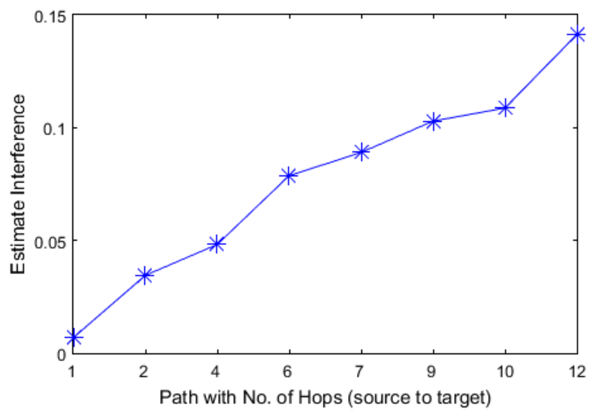

FIGURE 2. Estimated interference for entire path.

consumption based on (1). The presented figure shows that a node with a higher number of neighbors, it depletes the larger amount of energy due to advertising packets between these neighbor nodes to establish the link and thus produce higher interferences "i.e. node with 20 neighbors". On the contrary, a node has a few numbers of neighbor nodes consumes a smaller amount of energy and less interference "i.e. node with 3 neighbors".

Among the plausible explanations for these findings is that a path with fewer neighbor nodes and minimum number of hops have less interference. The interference has been calculated for the entire path from the sender to the receiver. It is apparent from Fig. 2 that the data deliver within two hops has less interference than the one sends within 20 hops.

Due to this reason, it is crucial to implement a new heuristic routing technique that takes into account the minimum number of neighbor nodes required to achieve connectivity. This reduces the amount of interference and decreases collision detection. It thereby minimizes the retransmission packets to conserve more energy. The contribution of this study is obvious as the resulting outcomes can be capitalized as guidelines to find a more reliable and efficient path. It also optimizes the power transmission toward the surrounded nodes in terms of packet error rate (*PER*) and interference.

B. PACKET ERROR RATE (PER)

In this section, the analysis and evaluation of simple retransmission packets in multi-hop technique under various *PER* assumptions have been presented. The number of sensor nodes present by IoT is growing exponentially. Most of these devices use radio signals to send and receive their data across networks. An increasing traffic load produces high interference and congestion through the network. Therefore, this leads to increase the packet error rate and thus retransmission of packets raise. Retransmission of lost data is the percentage of data drop with respect to data sent. It affects the throughput of network and quality of service. It also drains the node's battery due to an increase in the overall successful transmission. This finding provides evidence that it may leave the sensing area uncovered and it is a negative impact on network efficiency.

The expected cost of energy $E(c)$ used for the transmission succeed is expressed in (3) [29]:

When a number of hops (N) is equal to 1:

$$E(c)=(1-r_i)*(N*E_h)+r_i*(N*E_h+N*E_h*\frac{1}{(1-r_i)^2}) \quad (3)$$

E_h is the power used in the transmit mode. r_i is the *PER* from source node n_i to the target node n_{i-1}.

The probability of packets loss increases due to the multi-hop packets amongst the nodes. This is because of an increasing number of hops leads to decrease the number of packets that reach their target. Therefore, when the number of hops is $1 < N <= n_{i-1}$, the following equation below denotes the *PER* along the path over each transmission link i, j as:

$$PER(path) = 1 - \prod_{\forall(i,j)\in path} (1 - PER(i, j)) \quad (4)$$

where $PER(i, j)$ is the packet error rate when the sending packets from source node i to the target j belong to the same $path(i, j)$. We can conclude that the expected cost of energy $E(c)$ for a path that has N more than two is:

$$E(c) = \sum_{\substack{i=1\\ j=i+1}}^{N-1} (i - PER(i, j)) * (N * E_n) + PER(i, j)$$
$$(N * E_n * \frac{1}{(1 - PER(i, j))^2}) \quad (5)$$

In order to avoid a path consumes higher energy than others. A simple example is shown in Fig. 3 to prove this conjecture. The plot was generated by randomly picking sixth paths based on the table 1 parameters. Each path uses some intermediate nodes to forward the data from the source to ultimate receiver. We also assume that the *PER* is fixed in each path. The expected route cost gets a higher value of energy consumption when the number of hops and PER increase. The evolution results are done based on (3) & (5). As a result, this reflects our contribution that attempts to improve the energy used and therefore elongate the network lifetime.

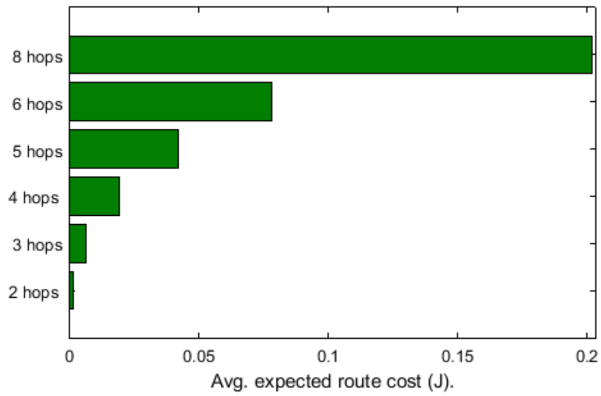

FIGURE 3. Evolution of expected route cost (J).

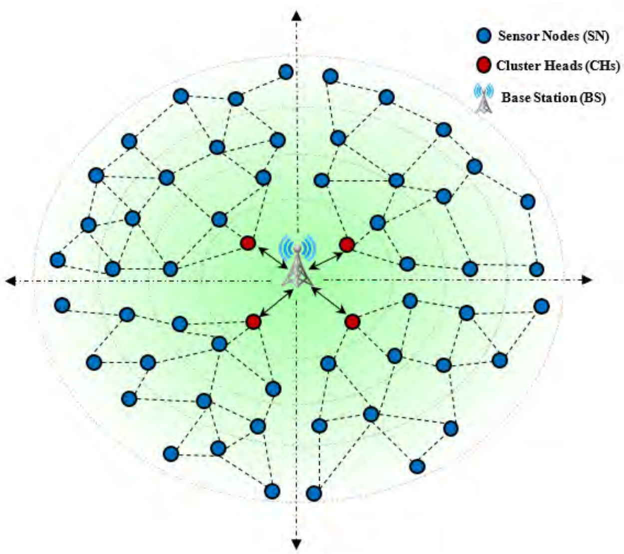

FIGURE 4. Typical internet of things architecture.

C. NODE PLACEMENT

The adopted scheme provides better network coverage on a large number of nodes and sensing area that is more consistent to future IoT applications. The proposed system utilizes a typical system architecture indicated in Fig. 4.

We assume that SNs are positioned randomly in the sensing area. The distance (d_i) between two nodes (N) is given by Euclidean mathematical method as:

$$d_i = \sqrt{((x_i - x) + (y_i - y))^2}, \quad i = 1, 2, 3, \ldots, N \quad (6)$$

where (x, y) is the position of each node. The sensing field is divided into four nested concentric circles where each part has some nodes. The BS in the center of the sensing field and fully powered. It is also surrounded by CH nodes to overcome the limitations of direct links. The multi-hop concept is used to cover a wider geographic area and minimize the transmission distances between nodes. During the packet's journey, the probability of drops increases due to the high number of paths links to a single node, interferences, limitation of the processing unit and bandwidth. Therefore, a suitable routing protocol is highly recommended in term of higher energy utilization and thus maintain a longer network lifetime.

D. REVIEW OF THE PROPOSED ALGORITHM

The primary goal of the energy and Geo-location technique is to balance the power usage among the nodes and improve the quality of service and thus elongate the network lifetime for wireless networks. The proposed scheme can be mainly divided into two phases:

- **Phase 1:** This phase assumes that nodes cooperate with each other and each node has sufficient power to communicate with others. Therefore, sensor nodes require to exchange hello message before actual data communication begins. The proposed protocol is designed so that sensors attempt to communicate and negotiate the parameters of the network before transmitting data such as sensors locations, energy level, and other important details. Thus, a sensor node sends *SYNchronize* packet (*SYN*) over an *IP* network to discover all neighbor nodes that belong to it. However, *SNs* are in sleep mode if out of transmission range. Neighbor nodes respond *SYN* packet and store a sensor node information and then return a confirmation receipt $SYNchronize - ACKnowledgement$ (SYN/ACK) packets back to them. Upon completion of this process, the connection is established and *SNs* and *BS* can communicate with each other based on the information table shared between *SNs*. These steps are shown in algorithm 1 from (1-12) lines.
- **Phase 2:** The aim of this phase is to calculate the transmission distances between each node and their neighbor nodes. It also to find the shortest path between the sender and the ultimate receiver. We assume that our protocol is targeted for the scalable dense network. This means each node has plenty of neighbor nodes. While previous routing protocols have only considered a few parameters to compute the path from the sender to the receiver. The proposed protocol takes into consideration some important parameters to share it with other nodes such as the transmission distances from sender to receiver, neighbor nodes and estimate interference based on *phase*1 setup. As previously mentioned, the neighbor nodes are located at different distances (close/far) from a node. Therefore, energy consumption depends on transmission distances between nodes. The higher transmission distance, this means higher energy consumption. This setup is not consistent with the multitude of devices and their diversity of future networks.

  To address these limitations, the proposed scheme has tended on transmission distances and interference between neighbor nodes rather than the only number of neighbor nodes to a single node. The proposed protocol is defined to be the less interference path and minimum distances over the actual number of neighbor nodes.

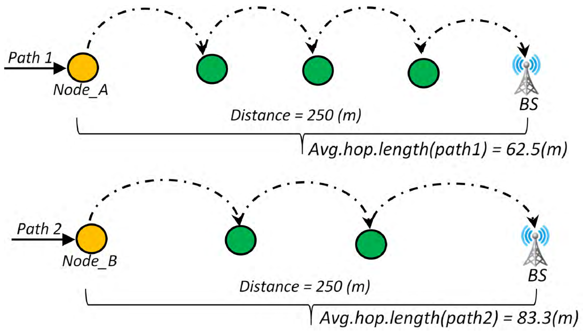

FIGURE 5. Two paths with same distance but different hops.

This is the best way to disseminate the data to the target with minimum congestion. Therefore, the energy and Geo-location method comprehensively characterizes both transmission cost of the entire path and data delivery ratio. We define the proposed protocol of a generic link as follows:

(i) In multi-hop transmission, nodes use intermediate nodes to forward their packets. The power of these nodes is quickly drained, when they transmit data over long distance. Therefore, the proposed protocol takes the shortest path to reach the ultimate receiver based on the following equation:

$$Avg.hop.length_i = \frac{dis(i,j)}{S(i,j)} \tag{7}$$

where $dis(i,j)$ represents the transmission distances from the source to the final destination and $S(i,j)$ is the total number of nodes on the path.
Consider a simplified scenario showed in Fig. 5. A node wants to disseminate its data to the ultimate receiver within two different paths. The transmission distance for each path is equal to 250 meters. However, intermediate nodes in these paths are not similar. *Node_A* sends their packets to the BS via four hops while *node_B* sends it via three hops.
In *path*1, the average length hops that *node_A* packet passes to the *BS* is ($\frac{250}{4}$=62.5 m). In *path*2, however, the average length hops that *node_B* packet access to the *BS* is ($\frac{250}{3}$=83.3 m). This means the transmission distance via *path*1 is lower than *path*2. Basically, a less transmission distances for each node a longer network lifetime. Therefore, we conclude that the transmission packets via *path*1 is the best way to disseminate the data. Based on the above proof, this intuition is adopted in the proposed algorithm and shown in (14 - 15) lines.
In case, if a single node has two forwarder routes to the next hop node with the same value of average transmission distances. This makes it difficult and confusing to select the next hop. Therefore, a node should have different policy and procedure to deliver the data to the next device. Thus, the proposed method takes into consideration the other parameter which is the transmission distances of each neighbor node.

(ii) Energy and Geo-location algorithm calculates the actual transmission cost (Tc_i) between a single node and their surrounding nodes based on the equation below:

$$Tc_i = \frac{\sum_{i=1}^{N} d_i}{N_n} \tag{8}$$

where d_i is the summation of transmission distances between a node and their neighbors and N_n is the total of surrounding neighbor nodes to a specific node in the sensor field. Basically, a node announces the data with an advertisement message to each neighbor. These advertising messages are the one that waste more energy in the wireless network. The sensor nodes are deployed randomly in the region. Therefore, each node has a different number of surrounding nodes which are located at different distances from the node. Many neighbors to an individual node will use this particular node for many routes to forward other packets. Thus, this increases energy consumption and interference for a node. It also increases the processing time and dramatically the packets should wait longer to forward as a result. Neglecting these measures leads to degrading transmission efficiency and thus data retransmission. Therefore, a node with $Tc_{n1} < Tc_{ni}$ has higher residual energy and less interference. Therefore, the proposed protocol strategy pick it as the next hop as described in (23 - 24) lines.
IoT consists of a massive number of smart objects communicate with each other in the sensing field. There will be equal distances between the nodes which makes the transmission distance not an option any more for the selection of the next hop as shown in line 25. In this case, each node computes the interference for every single node which in turn is used to choose the route.

(iii) Interference adversely affects the wireless networks in the form of packet loss which reduces the efficiency and reliability of WSN devices. The power perceived by each neighbor node should be taken into account. Therefore, the proposed scheme calculates the estimated interference generated in the whole neighbor nodes based on (1). The node that has less interference is selected as the forwarder node. This step is presented in algorithm 1 between(26 - 30) lines.
As illustrated in Fig. 6 as a portion of Fig. 4, some sensor nodes deployed randomly in the sensing field. Multi-hop technique prefers as a type of communication between nodes. We suppose that *node_A* wants to forward a packet to the *BS*. It has

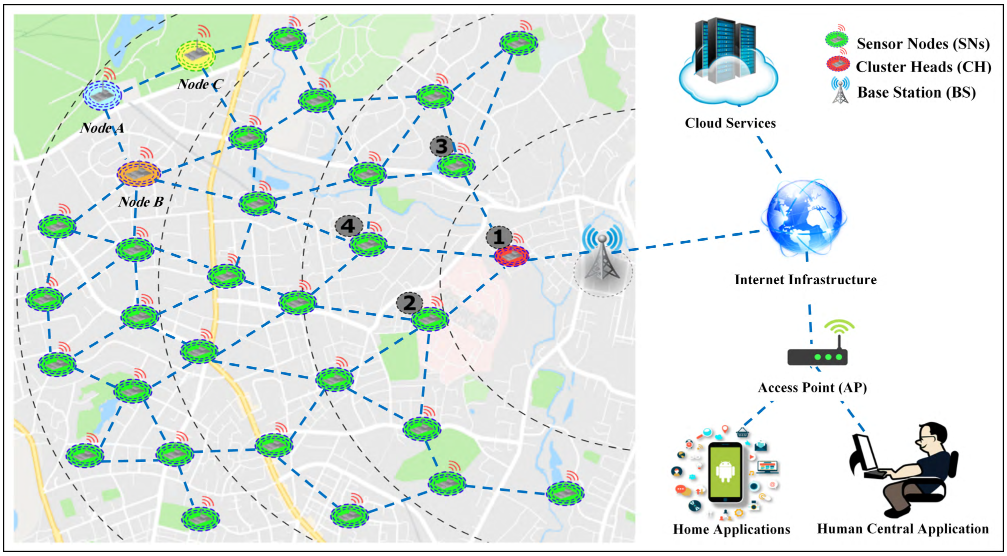

FIGURE 6. The proposed routing structure.

node_B and *C* forwarder paths to select from. However, the immediate neighboring nodes of *C* is less than *B*. In view of that, many links to an individual node lead to use this node to deliver other packets come from surrounding nodes. Thus it leads to quicker energy drainage. Also, a node with a higher number of neighbor nodes has less energy, bandwidth, higher processing time and interference. Therefore, *node_A* delivers it packets to *node_C* and then through the intermediate nodes based on the proposed protocol strategy to reach the ultimate receiver.

When an unknown node joins the network, It starts to send advertisement message to their neighboring nodes to establish a link with them and share the parameters by applying the proposed algorithm from (1 - 36) lines. This helps to get the short distance to the ultimate receiver based on the following equation:

$$d_i = \sum_{i=1}^{N} distance(i, BS) \Rightarrow min \qquad (9)$$

E. CLUSTERING FORMATION

As mentioned above, the CH nodes play a crucial role in transmitting packets and coordinating within its sub-structure. A cluster head acts as a temporary BS within its sub-group and communicates with other CHs or direct to the ultimate receiver [30]. Selecting a specific node as a head of nodes is not arbitrary. It depends on different factors and parameters, such as hop length to the BS, a location of the node, energy, capacity, interference, etc. Therefore, the proposed algorithm introduces a new clustering technique that can reduce energy consumption and constructs the routing tree for efficient data transmission. The objective of this scheme is to consume less energy and create a fair clustering procedure among all nodes and finally extend the lifetime of the network. After advertisement messages between nodes and sharing of the important parameters based on *phase*1 steps, the cluster heads election is based on the distance from the sensor nodes to the *BS*. A node with less transmission distances from the *BS* is selected as a CH node. In another word, the node within $(1 - hop)$ away from BS has a high priority to be selected as a head node of its cluster. Otherwise, a node sends the data to the next hop node as done in (16 - 20) lines of the algorithm 1.

For instance, we assume that smart objects deploy randomly in the sensing field and they use multi-hop communication to deliver their packets. As shown in Fig. 6, $node_1$ acts as a CH node for its sub-group due to its location being closest to the *BS*. Therefore, it receives the data from all sensors that belong to its cluster and then disseminate it to the *BS*. Since *SNs* are typically supplied by batteries hence the amount of energy available at each node is not infinite. Therefore, when the power of $node_1$ is exhausted, a node fails to operate and thus it becomes out of service. The failure node should not affect the overall operation of the entire network. Therefore, another node must be elected as a CH node based on our algorithm. The next $(1 - hop)$ node distance to the *BS* will become the head of the nodes which is responsible for collecting the data and dispatching it to the ultimate receiver. Therefore, $node_2$ is a second cluster head of its sub-group after $node_1$ death. After $node_2$ has depleted its power, $node_3$ will become a CH of its cluster and so on. Fig. 8 further summarizes the proposed algorithm with the aid of a flowchart.

Algorithm 1 : Pseudo-code for the proposed algorithm.

Initialization

Set $N_n(p)$ = neighbor nodes ($N_1(p), N_2(p), \ldots, etc.$)
Set SNs = sensor nodes
Set CH = cluster head
Set $d(i, BS)$ = the distance between the source to the BS
Set $min.dis$ = minimum distance to next hop
Set $Avg.dis.neig$ = average distance to neighbor nodes
Set I_n = the amount of interference for each node

procedure *Phase*1 : Route Discovery
  for all SNs **do**
    if $SN \in N_n(p)$ **then**
      SN send SYN packets
    else
      SN out of coverage area (in sleeping mode)
    end if
  end for
  for all $N_n(p) \in SNs$ **do**
    $N_n(p)$ send SYN/ACK packets to SN
  end for
end procedure

procedure *Phase*2 : Energy & Geo-location route
  Calculate $d(i, BS)$
  Find min.dis from (i, BS)
  if $(1 - hop)$ away from the BS **then**
    a node becomes a hopping cluster member and executes *ClusterFormation*
  else
    sensors gather the data and forward it to the next hop
  end if
  for all $SNs \in N_n(p)$ **do**
    Find min.dis to next hop (Tc_i)
    if $Avg.dis.neig_1 < Avg.dis.neig_2$ **then**
      Select $Avg.dis.neig_1$ as the next hop
    else if $Avg.dis.neig_1 == Avg.dis.neig_2$ **then**
      if $I_n(1) < I_n(2)$ **then**
        Select $I_n(1)$ as the forwarder path
      else
        $I_n(2)$ is the next path
      end if
    else
      Select $Avg.dis.neig_2$ as the next hop
    end if
  end for
  Forward packets to the target node
end procedure

F. ENERGY CONSUMPTION MODEL

The wireless transmission power model [9] is assumed and revealed in Fig. 7. The proposed scheme is implemented to find the path with less number of neighboring nodes and thus higher residual energy to dispatch the packets. The energy consumption [9] can be calculated using the following equations.

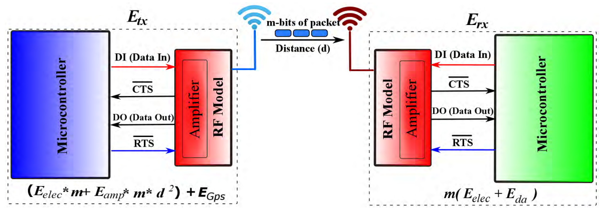

FIGURE 7. Wireless transmission power model.

- To transmit chunk of $S - bits$ of data:

$$E_{Tx} = S(E_{elec} + \epsilon_{amp} * d^2) + E_{gps} \tag{10}$$

- To receive chunk of $S - bits$ of data:

$$E_{Rx} = S(E_{elec} + E_{da}) \tag{11}$$

- Then the total energy used by a particular node is:

$$E_{Total} = F(E_{Tx}) + R(E_{Rx}) \tag{12}$$

where E_{Rx} and E_{Tx} are the energy depleted due to receive and transmit $S - bits$ of data from the sender to the next hop respectively. E_{gps} is the energy consumed by *GPS* receiver and d is the distance between the source and the next hop node.

E_{elec} is the energy dissipated to run the wireless transmission power board. R and F are the number of hops for receiving and transmitting packets on a sensor respectively. E_{da} is the power wasted for data aggregation and compression. ϵ_{amp} is the power consumed by the transmission unit to amplify the signal enough to reach the next target that can be calculated as:

$$\epsilon_{amp} = \begin{cases} \epsilon_{fs} * d^2 & d \leq d_0 \\ \epsilon_{mp} * d^4 & d > d_0 \end{cases} \tag{13}$$

$$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \tag{14}$$

where ϵ_{f_s} is the amplification coefficient of free space signal (d^2 as power loss) and ϵ_{mp} is the multi-path fading signal amplification coefficient (d^4 as power loss). d_0 is a threshold value calculated by (14) [21]. When the d is less than d_0, then a free space propagation method is used else multi-path fading signal amplification is setup. In case, if a node is a quick depletion or addition, this drastically will affect the behavior of energy and Geo-location protocol. Therefore, new routes can be available at the selection time based on *phase*1&2 of the proposed algorithm.

IV. RESULTS AND DISCUSSION

In this section, we discuss the simulation parameters, environment and depict the simulation results. The simulation is performed in *Matlab* environment and compared with other energy efficiency schemes. In TBMS, authors have presented their method to be superior to many other routing algorithms.

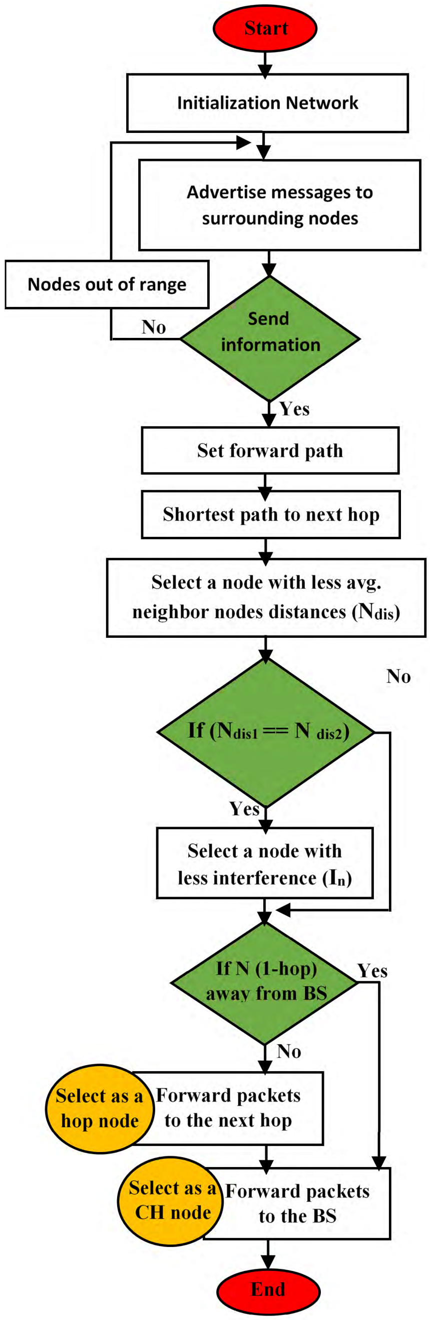

FIGURE 8. Flow-chart of the proposed algorithm.

Therefore, we have taken TBMS protocol as a benchmark for the comparison. In PEGASIS and EAMMH protocols, authors assumed that sensor nodes are distributed randomly in a sensing area and used multi-hop techniques to communicate with each other. Also, they used different techniques to select CHs in a field according to the amount of energy.

Internet of things and smart city concept increase further the number of sensor devices and data collecting. Therefore, we assume that SNs are deployed to be used outdoors and the *BS* is in the center of the sensing field. The parameters and assumption used in the simulation are shown in the table 1.

TABLE 1. Parameters used in the simulation.

Parameter	Value
Initial energy of node (E_{init})	0.25 J
Electronics Energy (E_{elec})	50 nJ/bit
Energy for GPS (E_{GPS})	20 nJ/bit/signal
Energy of data Aggregation (E_{da})	5 nJ/bit/signal
Communication energy (ϵ_{mp})	0.0013 pJ/bit/m^4
Communication energy (ϵ_{fs})	10 pJ/bit/m^2
Threshold value of distance (d_0)	87 m
Header Size + Payload	4000 bits
Advertise message size	8 bytes + header size
Number of nodes (N)	100, 300, 400
Sensing field	$200m^2$, $300m^2$, $800m^2$

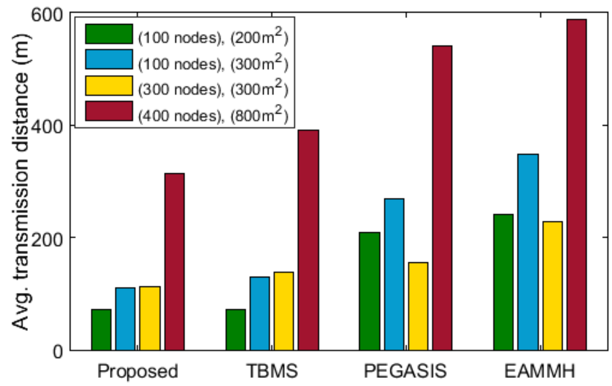

FIGURE 9. Avg. transmission distance (m).

Transmission distance is defined as the ability of smart objects to reach the data sink using single or multi-hop communication. So, less transmission distances whenever possible is certainly the best way for data dissemination. Fig. 9 depicts the average transmission distances in a round for four methods when the sensing field $200m^2$ with 100 nodes, $300m^2$ with 100 nodes, $300m^2$ with 300 nodes and $800m^2$ with 400 nodes. It is obvious that the transmission distance for the four schemes increases when the sensing area increases. It also can be seen that the proposed method has less transmission distances than other methods.

Each node can route the packets to the ultimate receiver either through direct or via intermediate nodes. Therefore, optimizing the length of these hops that can minimize the power consumption and thus maximize the network lifetime. In view of Fig. 10 demonstrates the average number of hops for the four algorithms based on table 2 scenarios. It clearly shows that EAMMH protocol has less number of hops than other methods. This is because of multi-hop transmission behavior in this approach. In this technique, some nodes send the packets within one or two maximum hops. It reduces the number of hops but at the same time, it overloads with surrounding nodes. Therefore, it sends through the long distance to the next hop or a CH node and thus shortens the lifespan of these nodes. Also, PEGASIS protocol has a higher number of hops which degrades the function of end-to-end reliability and therefore reduces the lifetime of the network.

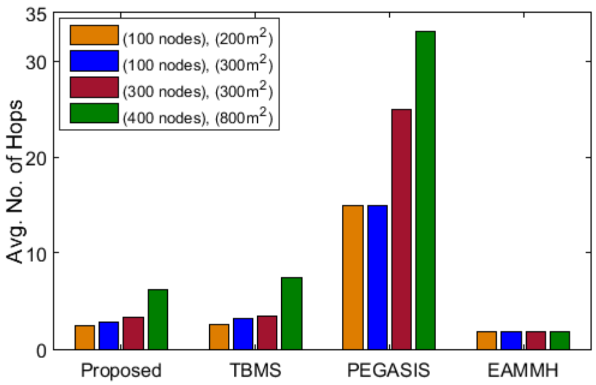

FIGURE 10. Avg. number of hops.

TABLE 2. Different scenarios used in the simulation.

No. of Nodes	Sensing Area
100	$200m^2$
100	$300m^2$
300	$300m^2$
400	$800m^2$

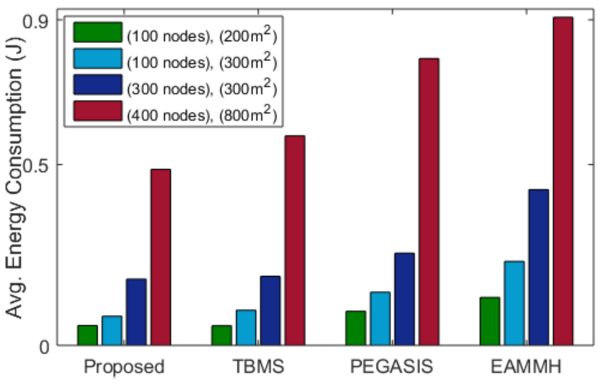

FIGURE 11. Avg. energy consumption (J).

While the proposed protocol and TBMS techniques have the best optimal way to reduce the number of packets traveling and conserve more energy.

The average power consumption is presented in Fig. 11 when the sensing area $200m^2$ with 100 nodes, $300m^2$ with 100 nodes, $300m^2$ with 300 nodes and $800m^2$ with 400 nodes. It is clear that the average energy consumption increases when the number of nodes and sensing area increase. This finding also highlights that the proposed algorithm consumes less power than other methods which extends the lifespan of the network.

Table 3 shows the network lifetime which is calculated based on the death of the last node during the running simulation for the four protocols. The estimation results show that the proposed scheme has the longest lifespan for all the considered scenarios. This is consistent with Figs. [9],[11] results.

TABLE 3. Network lifetime per rounds.

Sensing Area	Proposed	TBMS	PEGASIS	EAMMH
$(100\ nodes),(200m^2)$	594	594	396	262
$(100\ nodes),(300m^2)$	562	533	317	241
$(300\ nodes),(300m^2)$	605	417	392	263
$(400\ nodes),(800m^2)$	447	313	247	161

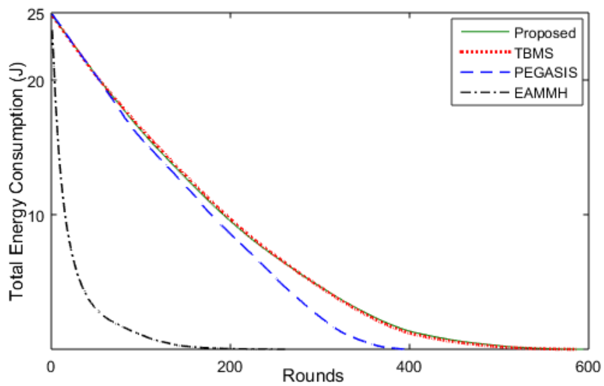

FIGURE 12. Total network energy ($200m^2$ sensing area and 100 nodes).

The total energy is defined as the summation of residual energy at all nodes per iteration. Fig. 12 illustrates the total energy when the sensing field $200m^2$ with 100 nodes. It appears that TBMS and the proposed protocol have almost the same value. This finding is consistent with the results of the past studies by [9], [10], which is a random mobility pattern is suitable for a few numbers of nodes and smaller area. Thus, the TBMS scheme and the proposed method outperform other protocols.

To prove that our protocol is well-designed, sensing area and number of nodes have been extended as illustrated in table 2. It appears from Figs. [13]-[15] that the proposed technique achieves more energy savings than TBMS, PEGASIS, EAMMH based algorithms. The current protocol contributes that the total energy level performs better when the number of nodes and sensing area increase. This is because the proposed protocol takes smart decision to balance the traffic load. This means it shifts the traffic from the overloaded nodes to other nodes with less traffic and reduces the network congestion. This leads to increase the lifespan of the nodes. Hence, it minimizes the retransmission packets and thereby extend the network lifetime.

Fig. 16 reveals the number of alive nodes per rounds for four schemes. It is obvious from the figure that the proposed scheme achieves better performance than other methods. The proposed algorithm extends the network lifetime more than EAMMH, PEGASIS, and TBMS by (177%), (80%) and (42%) respectively. This improvement is due to the proposed algorithm has less energy consumption per round and less transmission distances than the other schemes.

End-to-end delay refers to the time required to transmit a packet across the network from the sender node to the ultimate receiver. During the multi-hop transmission process,

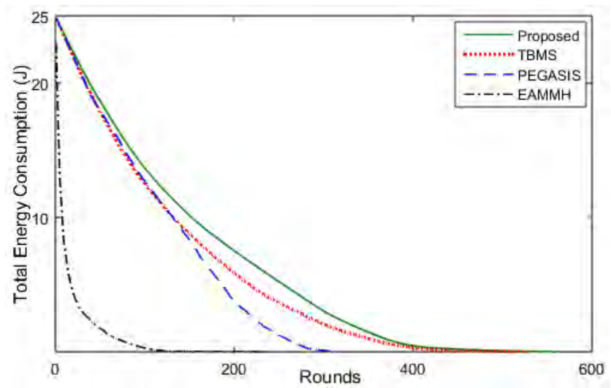

FIGURE 13. Total network energy (300m^2 sensing area and 100 nodes).

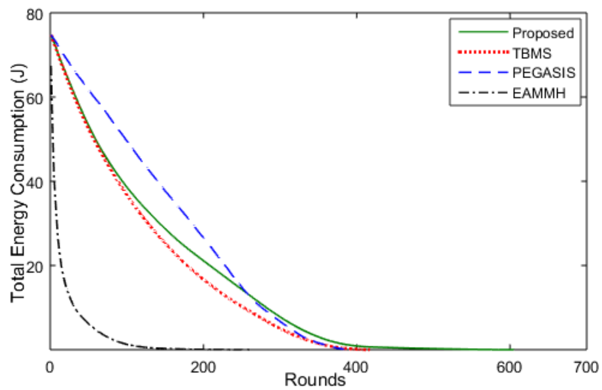

FIGURE 14. Total network energy (300m^2 sensing area and 300 nodes).

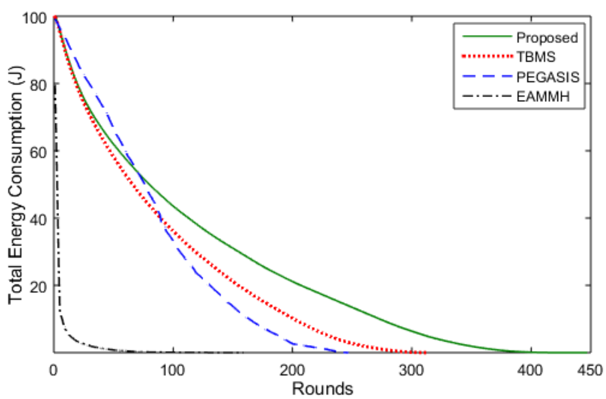

FIGURE 15. Total network energy (800m^2 sensing area and 400 nodes).

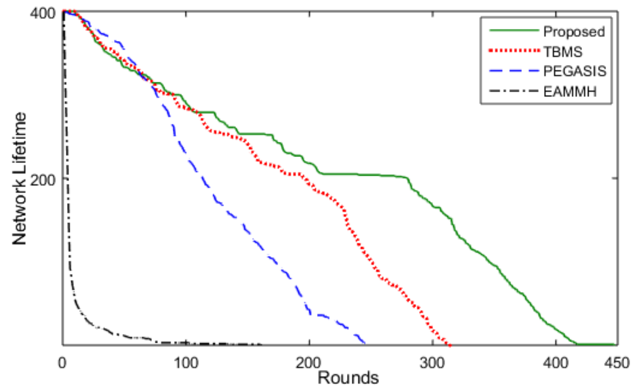

FIGURE 16. Node dying each round.

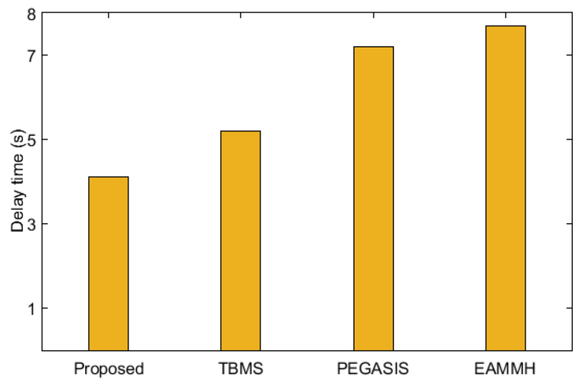

FIGURE 17. Delay time (s).

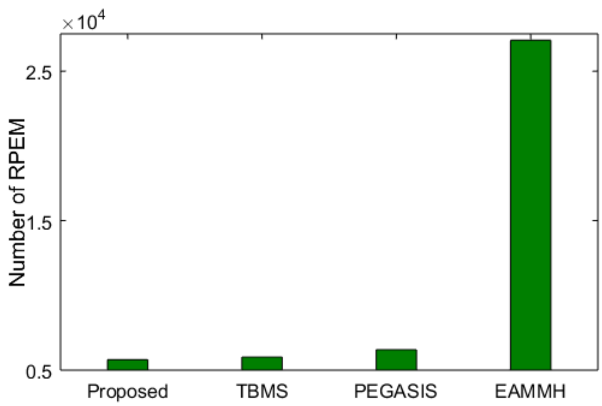

FIGURE 18. Number of RPEM.

each sensor requires the processing time to send and receive data. We adopt the simulation setting in [11], [21], which takes 2 ms for a sensor node to make a transmission. The propagation delay is calculated by (*transmission distance / speed of light*). Therefore, the total transmission time is measured by (*propagation delay + processing time for each transmission*). It appears from Fig. 17 that the average delay time for the proposed scheme is lower than TBMS, PEGASIS and EAMMH. This is a clear trend of decreasing transmission distances by the proposed algorithm.

When an intermediate node dies due to energy exhaustion, this leads to retransmit a packet from a sensor node that belongs to a hop node or CH node. We calculate the number of retransmission per each message (RPEM) for all the sensor nodes during the network lifetime. In view of Fig. 18, it shows the number of RPEM for four scenarios when the sensing area 800m^2. Obviously, the proposed scheme has a lower number of RPEM than others. This means that most of the messages of SNs can be delivered successfully per round. In other words, the throughput is higher than other schemes.

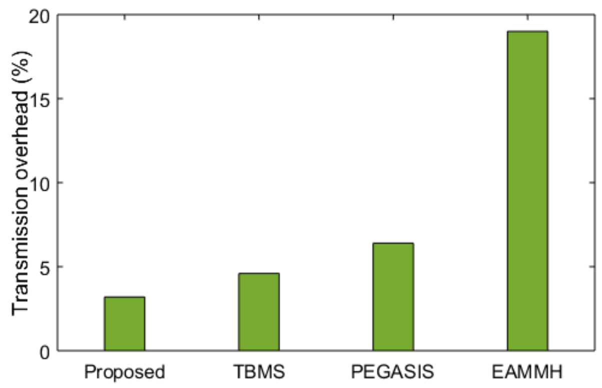

FIGURE 19. Transmission overhead (%).

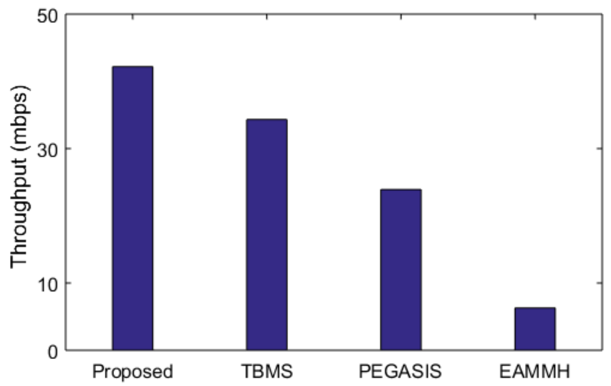

FIGURE 20. Throughput(%).

It reflects that the proposed algorithm brings a lower transmission overhead for each round as can be seen in Fig. 19.

Throughput is an important consideration in sensor networks. It is the summation of bits or packets successfully delivered to the ultimate receiver over total time divided by total time. As it can be seen in Fig. 20, our scheme performs much better than other scenarios in term of throughput. This is because the proposed algorithm balances the traffic load by selecting a node with fewer neighbor nodes and thus reduces the retransmission packets.

V. CONCLUSION

In order to minimize energy consumption and enhance the network lifetime of wireless sensors, a new routing strategy and a distributed clustering formation are presented. The proposed protocol has shown that the overhead of measuring interference effects in relating to the number of neighbor nodes such as energy consumption and communication traffic. In this investigation, we found that the transmission overhead and energy consumption increase when the number of neighbor nodes increases. The clustering-based algorithm also balances the traffic load by selecting the best node to become a cluster head periodically. The performance of the proposed algorithm has been evaluated in terms of power consumption, end-to-end delay, transmission distances, and compared with the state-of-the-art algorithms. The simulation results introduce significant improvements in energy saving and thus prolong the network lifetime for the overall system when interference based routing and clustering technique is adopted. Detailed analysis shows that the proposed scheme achieves (19%), (62.9%), and (86.3%) in energy conservation as compared to TBMS, PEGASIS, and EAMMH protocols respectively. Moreover, the proposed algorithm extends the network lifetime more than EAMMH, PEGASIS, and TBMS by (177%), (80%), and (42%) respectively.

REFERENCES

[1] A. Kamilaris and A. Pitsillides, "Mobile phone computing and the Internet of Things: A survey," *IEEE Internet Things J.*, vol. 3, no. 6, pp. 885–898, Dec. 2016.

[2] Z. Wang, Y. Liu, Y. Sun, Y. Li, D. Zhang, and H. Yang, "An energy-efficient heterogeneous dual-core processor for Internet of Things," in *Proc. IEEE Int. Symp. Circuits Syst. (ISCAS)*, Lisbon, Portugal, May 2015, pp. 2301–2304.

[3] L. Farhan and R. Kharel, "Internet of Things: Vision, future directions and opportunities," in *Modern Sensing Technologies*, S. C. Mukhopadhyay, K. P. Jayasundera, and O. A. Postolache, Eds. Cham, Switzerland: Springer, 2019, pp. 331–347.

[4] J. So and H. Byun, "Load-balanced opportunistic routing for duty-cycled wireless sensor networks," *IEEE Trans. Mobile Comput.*, vol. 16, no. 7, pp. 1940–1955, Jul. 2017.

[5] L. Davoli, L. Belli, A. Cilfone, and G. Ferrari, "From micro to macro IoT: Challenges and solutions in the integration of IEEE 802.15.4/802.11 and sub-GHz technologies," *IEEE Internet Things J.*, vol. 5, no. 2, pp. 784–793, Apr. 2018.

[6] T. A. Al-Janabi and H. S. Al-Raweshidy, "A centralized routing protocol with a scheduled mobile sink-based ai for large scale I-IoT," *IEEE Sensors J.*, vol. 18, no. 24, pp. 10248–10261, Dec. 2018.

[7] D. Goyal and M. R. Tripathy, "Routing protocols in wireless sensor networks: A survey," in *Proc. 2nd Int. Conf. Adv. Comput. Commun. Technol.*, Jan. 2012, pp. 474–480.

[8] C.-W. Ang, "Multihop interference and multihop propagation of control signaling in IEEE 802.16d mesh networks," in *Proc. 3rd Int. Conf. Adv. Mesh Netw.*, Jul. 2010, pp. 41–47.

[9] L. Farhan, R. Kharel, O. Kaiwartya, M. Hammoudeh, and B. Adebisi, "Towards green computing for Internet of things: Energy oriented path and message scheduling approach," *Sustain. Cities Soc.*, vol. 38, pp. 195–204, Apr. 2018.

[10] M. I. Khan, W. N. Gansterer, and G. Haring, "Static vs. mobile sink: The influence of basic parameters on energy efficiency in wireless sensor networks," *Comput. Commun.*, vol. 36, no. 9, pp. 965–978, May 2013.

[11] I. H. Hou, "Packet scheduling for real-time surveillance in multihop wireless sensor networks with lossy channels," *IEEE Trans. Wireless Commun.*, vol. 14, no. 2, pp. 1071–1079, Feb. 2015.

[12] L. Farhan, R. Kharel, O. Kaiwartya, M. Quiroz-Castellanos, U. Raza, and S. H. Teay, "LQOR: Link quality-oriented route selection on Internet of Things networks for green computing," in *Proc. 11th Int. Symp. Commun. Syst., Netw. Digit. Signal Process. (CSNDSP)*, Budapest, Hungary, 2018, pp. 1–6.

[13] B. Ahlgren, M. Hidell, and E. C.-H. Ngai, "Internet of Things for smart cities: Interoperability and open data," *IEEE Internet Comput.*, vol. 20, no. 6, pp. 52–56, Nov. 2016.

[14] O. B. Sezer, E. Dogdu, and A. M. Ozbayoglu, "Context-aware computing, learning, and big data in Internet of Things: A survey," *IEEE Internet Things J.*, vol. 5, no. 1, pp. 1–27, Feb. 2018.

[15] S. Diaz, D. Mendez, and R. Kraemer, "ICI—Interference characterization and identification for WSN," in *Proc. Wireless Telecommun. Symp. (WTS)*, Chicago, IL, USA, Apr. 2017, pp. 1–7.

[16] Q. Chen, B. Zhou, and Z. Zhao, "A minimum route-interference routing metric for multi-radio wireless mesh networks," in *Proc. 4th Int. Conf. Commun. Netw. China*, Aug. 2009, pp. 1–4.

[17] J. V. Vadavi and A. G. Sugavi, "Detection of black hole attack in enhanced AODV protocol," in *Proc. Int. Conf. Comput. Commun. Technol. Smart Nation (IC3TSN)*, Oct. 2017, pp. 118–123.

[18] Y. Meraihi, D. Acheli, and A. Ramdane-Cherif, "QoS performance evaluation of AODV and DSR routing protocols in city VANET scenarios," in *Proc. 5th Int. Conf. Electr. Eng. Boumerdes (ICEE-B)*, Oct. 2017, pp. 1–6.

[19] S. Lindsey and C. S. Raghavendra, "PEGASIS: Power-efficient gathering in sensor information systems," in *Proc. IEEE Aerosp. Conf.*, Mar. 2002, p. 3.
[20] M. R. Mundada, V. CyrilRaj, and T. Bhuvaneswari, "Energy aware multi-hop multi-path hierarchical (EAMMH) routing protocol for wireless sensor networks," *Eur. J. Sci. Res.*, vol. 88, no. 7, pp. 520–530, 2012.
[21] J.-Y. Chang and T.-H. Shen, "An efficient tree-based power saving scheme for wireless sensor networks with mobile sink," *IEEE Sensors J.*, vol. 16, no. 20, pp. 7545–7557, Oct. 2016.
[22] W. B. Heinzelman, A. P. Chandrakasan, and H. Balakrishnan, "An application-specific protocol architecture for wireless microsensor networks," *IEEE Trans. Wireless Commun.*, vol. 1, no. 4, pp. 660–670, Oct. 2002.
[23] K. Singh, "WSN LEACH based protocols: A structural analysis," in *Proc. Int. Conf. Workshop Comput. Commun. (IEMCON)*, 2015, pp. 1–7.
[24] C. Fu, Z. Jiang, W. Wei, and A. Wei, "An energy balanced algorithm of LEACH protocol in WSN," *Int. J. Comput. Sci. Issues*, vol. 10, no. 1, pp. 354–359, 2013.
[25] Y. Noh, S. Lee, and K. Kim, "Basestation-aided coverage-aware energy-efficient routing protocol for wireless sensor networks," in *Proc. IEEE Wireless Commun. Netw. Conf.*, Mar./Apr. 2008, pp. 2486–2491.
[26] A. Yektaparast, F.-H. Nabavi, and A. Sarmast, "An improvement on LEACH protocol (Cell-LEACH)," in *Proc. 14th Int. Conf. Adv. Commun. Technol. (ICACT)*, 2012, pp. 992–996.
[27] R. Kaur, D. Sharma, and N. Kaur, "Comparative analysis of leach and its descendant protocols in wireless sensor network," *Int. J. P2P Netw. Trends Technol.*, vol. 3, no. 1, pp. 22–27, Jan. 2013.
[28] L. Iannone and S. Fdida, "MRS: A simple cross-layer heuristic to improve throughput capacity in wireless mesh networks," in *Proc. CoNEXT ACM Conf. Emerg. Netw. Exp. Technol.*. Toulouse, France, Oct. 2005, pp. 21–30.
[29] T. Matsui and H. Nishi, "ECORS: Energy consumption-oriented route selection for wireless sensor network," in *Proc. IEEE 14th Int. Conf. Ind. Inform. (INDIN)*, Jul. 2016, pp. 1044–1049.
[30] V. Preetha and K. Chitra, "Clustering & cluster head selection techniques in mobile adhoc networks," *Int. J. Innov. Res. Comput. Commun. Eng.*, vol. 2, no. 7, pp. 5151–5157, 2014.

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