Enhanced Location Based Energy-Efficient Reliable Routing Protocol for Wireless Sensor Networks

Ahmed Ali Saihood, Rakesh Kumar

Abstract— ***Designing energy efficient and reliable routing protocols for mobility centric applications of wireless sensor network (WSN) such as wildlife monitoring, battlefield surveillance and health monitoring is a great challenge since topology of the network changes frequently. Existing cluster-based mobile routing protocols such as LFCP-MWSN, LEACH-Mobile, LEACH-Mobile Enhanced and CBR-Mobile consider only the energy efficiency of the sensor nodes. However, reliability of routing protocols by incorporating fault tolerance scheme is significantly important to identify the failure of data link and sensor nodes and recover the transmission path. Most existing mobile routing protocols are not designed as fault tolerant. These protocols allocate extra timeslots using time division multiple access (TDMA) scheme to accommodate nodes that enter a cluster because of mobility and thus, increases end-to-end delay. Moreover, existing mobile routing protocols are not location aware and assume that sensor nodes know their coordinates. In this study the authors, enhanced the existing LFCP-MWSN to ELFCP-MWSN in which we reduce network energy consumptions and slightly less end-to-end data transmission delay than the existing LFCP-MWSN. ELFCP-MWSN also incorporates a simple range free approach to localise sensor nodes during cluster formation and every time a sensor moves into another cluster. Simulation results show that LFCP-MWSN protocol has about 25–30% less network energy consumptions and slightly less end-to-end data transmission delay than the existing LFCP-MWSN , in our study we try to decrease this percentage of energy consumption and more less end-to-end data transmission.***

Index Terms—WSN, CH, BS, ELFCP-MWSN.

I. INTRODUCTION

Wireless sensor network (WSN) is widely considered as one of the most important technologies for the twenty-first century [1]. In the past decades, it has received tremendous attention from both academia and industry all over the world. A WSN typically consists of a large number of low-cost, low-power, and multifunctional wireless sensor nodes, with sensing, wireless communications and computation capabilities [2,3]. These sensor nodes communicate over short distance via a wireless medium and collaborate to accomplish a common task, for example, environment monitoring, military surveillance, and industrial process control [4]. The basic philosophy behind WSNs is that, while the capability of each individual sensor node is limited, the aggregate power of the entire network is sufficient for the required mission. In many WSN applications, the deployment of sensor nodes is performed in an ad hoc fashion without careful planning and engineering. Once deployed, the sensor nodes must be able to autonomously organize themselves into a wireless communication network. Sensor nodes are battery-powered and are expected to operate without attendance for a relatively long period of time. In most cases it is very difficult and even impossible to change or recharge batteries for the sensor nodes. WSNs are characterized with denser levels of sensor node deployment, higher unreliability of sensor nodes, and sever power, computation, and memory constraints. Thus, the unique characteristics and constraints present many new challenges for the development and application of WSNs. Due to the severe energy constraints of large number of densely deployed sensor nodes, it requires a suite of network protocols to implement various network control and management functions such as synchronization, node localization, and network security. The traditional routing protocols have several shortcomings when applied to WSNs, which are mainly due to the energy-constrained nature of such networks [4]. For example, flooding is a technique in which a given node broadcasts data and control packets that it has received to the rest of the nodes in the network. This process repeats until the destination node is reached. Note that this technique does not take into account the energy constraint imposed by WSNs. As a result, when used for data routing in WSNs, it leads to the problems such as implosion and overlap [9,12]. Given that flooding is a blind technique, duplicated packets may keep circulate in the network, and hence sensors will receive those duplicated packets, causing an implosion problem. Also, when two sensors sense the same region and broadcast their sensed data at the same time, their neighbors will receive duplicated packets. To overcome the shortcomings of flooding, another technique known as gossiping can be applied [10]. In gossiping, upon receiving a packet, a sensor would select randomly one of its neighbors and send the packet to it. The same process repeats until all sensors receive this packet. Using gossiping, a given sensor would receive only one copy of a packet being sent. While gossiping tackles the implosion problem, there is a significant delay for a packet to reach all sensors in a network. Furthermore, these inconveniences are highlighted when the number of nodes in the network increases , figure 1 show the typical wireless sensor network.

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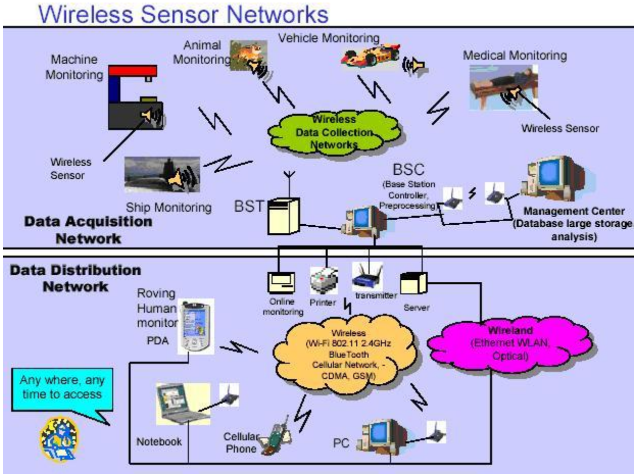

Figure 1: Wirless Sensor Networks[38]

Realization of these and other sensor network applications require wireless ad hoc networking techniques. Although many protocols and algorithms have been proposed for traditional wireless
ad hoc networks, they are not well suited for the unique features and application requirements of sensor networks. To illustrate this point, the differences between sensor networks and ad hoc
Networks [65] are outlined below:

•The number of sensor nodes in a sensor network can be several orders of magnitude higher than the nodes in an ad hoc network.
• Sensor nodes are densely deployed.
• Sensor nodes are prone to failures.
• The topology of a sensor network changes very frequently.
• Sensor nodes mainly use broadcast communication paradigm whereas most ad hoc networks are based on point-to-point communications.
• Sensor nodes are limited in power, computational capacities, and memory.
• Sensor nodes may not have global identification (ID) because of the large amount of overhead and large number of sensors.

A. WSN Network Characteristics

As compared to the traditional wireless communication networks such as mobile ad hoc network (MANET) and cellular systems, wireless sensor networks have the following unique characteristics and constraints:

Dense sensor node deployment: Sensor nodes are usually densely deployed and can be several orders of magnitude higher than that in a MANET.

Battery-powered sensor nodes: Sensor nodes are usually powered by battery and are deployed in a harsh environment where it is very difficult to change or recharge the batteries.

Severe energy, computation, and storage constraints: Sensors nodes are having highly limited energy, computation, and storage capabilities.

Self-configurable: Sensor nodes are usually randomly deployed and autonomously configure themselves into a communication network.

Unreliable sensor nodes: Since sensor nodes are prone to physical damages or failures due to its deployment in harsh or hostile environment.

Data redundancy: In most sensor network application, sensor nodes are densely deployed in a region of interest and collaborate to accomplish a common sensing task. Thus, the data sensed by multiple sensor nodes typically have a certain level of correlation or redundancy.

Application specific: A sensor network is usually designed and deployed for a specific application. The design requirements of a sensor network change with its application.

Many-to-one traffic pattern: In most sensor network applications, the data sensed by sensor nodes flow from multiple source sensor nodes to a particular sink, exhibiting a many-to-one
traffic pattern.

Frequent topology change: Network topology changes frequently due to the node failures, damage, addition, energy depletion, or channel fading.

B. WSN Architecture

Since wireless sensor networks (WSNs) consist of hundreds and thousands of unattended, resource-constraint and low–energy sensor nodes designing energy efficient routing protocols is significantly important. Clustering-based routing protocols are more useful in the context of energy efficiency where several sensor nodes in the communication range of one another form a cluster. Each cluster has a cluster head (CH), which coordinates all the nodes of a cluster Figure 2 show the clustering of the WSN. There may be a number of base stations (BS) also known as sink in a WSN that communicate with other networks. A CH aggregates data that are received from all member nodes of a cluster and sends to the BS. Besides CH, there exist gateway nodes in a cluster which are used for inter-cluster communications as shown in Figure 1.3. Hence, clustering protocols produce limited useful information from large amount of raw sensed data and transmitting this precise useful information to the BS of the network consume less energy [1, 2]. Most clustering protocols of WSN in the literature are designed for static sensor nodes. Thus, these protocols do not work for WSN applications that require mobile sensor nodes, such as habitat monitoring, wild life monitoring, target tracking and battlefield surveillance. Moreover, these protocols do not support localisation of sensor nodes but only assume that each node know their location, which make these protocols inefficient. For instance, low energy adaptive clustering hierarchy (LEACH) Protocol [3] is a standard static clustering protocol of WSN. LEACH is enhanced as LEACH-Mobile [4], LEACH-Mobile

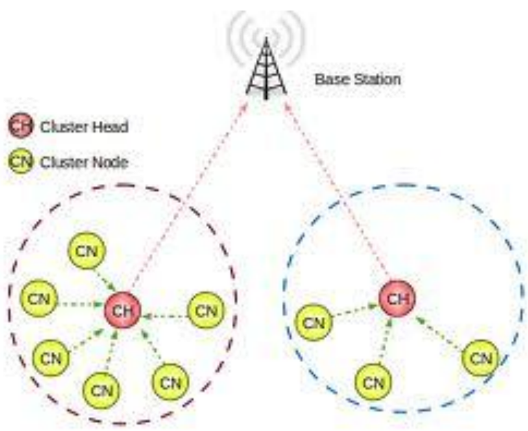

Figure 2 Wireless Sensor Network Clustering

Enhancement [5], and cluster based routing protocol for mobile nodes in wireless sensor network (CBR Mobile-WSN) [1] to support mobility of sensor nodes. In these protocols, if a non-CH sensor node A does not receive Data Request packets from CH or CH does not receive data from node A after sending the data request packet, the node A is assumed to be moved from its previous location. Then the CH discards the timeslot of node A and allocates this free timeslot to a new mobile member node of this cluster. Node A also tries to find a new CH node of a cluster. However, this same condition may also arise for the failure of CH and non-CH cluster members. Thus, these protocols cannot detect the failure of sensor nodes. Moreover, these protocols work in rounds and initiate a new cluster formation phase at every round, where each round comprises cluster formation, CH selection and data transmission phases. This is also not considered energy efficient since a large number of messages are transmitted to form a cluster. To alleviate this problem we propose a location aware fault tolerant clustering protocol for mobile WSN (ELFCP-MWSN). In this protocol, a special packet is sent by a non-CH node A if A has no sensed data to send to the CH at its allocated timeslot and thus, saves energy by not sending data at every timeslot. At the end of a round a node with the least mobility is selected as a new CH, which is calculated as the ratio of the number movements of a node inside and outside of its cluster. Moreover, CH does not receive data or special packet from a node A at its allocated timeslot if (i) data or special packet transmission fails (ii) node A moves out of the cluster or (iii) node A dies. In such case, CH waits until the next timeslot for node A to confirm the transmission failure. If CH does not receive data or special packet from node A in the next timeslot CH deletes node A from its member list, discards the timeslot of node A and also notifies BS the ID of node A. In each frame, a timeslot is kept free for allowing the moving nodes to notify the CH of a new cluster. Thus, if node A moves into a new cluster it sends a JOIN REQUEST message to the CH of new cluster at the free timeslot. CH of this new cluster accepts the JOIN REQUEST of node A only when a timeslot becomes free because of the moving of another node out this cluster. Then the CH of this cluster sends the ID of node A to BS. Thus, if BS receives ID of the node A from two different CH as a leaving node from a cluster at frame x and a new node into a cluster at frame x + t, then node A is considered to be moved from a cluster. Otherwise, node A is considered as a failed node. In addition to this, ELFCP-MWSN supports sensors localisation in the cluster formation phase and every time a node moves to a new location since without location information sensors data are meaningless for most of the applications.

C. Objectives

The objectives of this paper is summarized as follow

- To study WSN and all the present protocols already implemented for it.
- To propose a new protocol named Enhanced LFCP-MWSN.
- To improve Packet Deliver Ratio as the time slot will be allocated according to node requirement.
- Reduce the energy consumption of networks.

Analyze the simulated results and compare it with the existing protocol.

II. RELATED WORKS

Low energy adaptive clustering Protocol (LEACH) [21] works well for homogeneous networks, where every node has the same initial energy. This protocol works in rounds and each round is divided into cluster formation and steady phases. In the cluster formation phase, a cluster is formed and p.n sensor nodes are selected as cluster heads (CH) for the proper utilisation of energy, where n is the number of sensor nodes and p is the desired percentage of CH. Otherwise, if only one node is selected as CH it will fail because of the shortage of energy. If a random number (between 0 and 1) chosen by a node A is less than a threshold value, A is selected as a CH in the current round. The steady state is divided into many frames where CH assigns time slots to each non-CH node using TDMA scheme. At the end of each round, the CH collects and aggregates data and sends to the BS. In LEACH, a new cluster formation is initiated in every round, which is not energy efficient. Moreover, occasionally all CHs exist in a close area (since CH rotates in a cluster) and require more energy for non-CH nodes to communicate CHs. LEACH also does not support mobility of sensors.

In [26], Bajaber and Awan propose dynamic static clustering protocol (DSC) for (WSN) and find the DSC has better performance than LEACH in terms of energy efficiency, network lifetime and communication overhead. DSC protocol has dynamic and static cases. Dynamic case is divided into two phases: setup and steady phase. In the setup phase, the base station (BS) forms clusters and selects CH for each cluster based on the energy levels and positions of the sensor nodes. Then, the BS broadcasts CH ID to all nodes. A sensor node will be a CH if its ID matches with the CH ID. In the steady phase, CH uses TDMA scheme by dividing each frame into x number of timeslots, where x is the total number of non-CH nodes in that cluster. A non-CH node transmits data to the CH only in the allocated timeslots and saves energy by turning its radio off (sleep mode) in all other timeslots. When a round is completed, data transmitted by all non-CH nodes are aggregated and sent by the CHs to the BS. In the next round, the current CH of a cluster selects a node as a new CH, which has the most remaining energy.

Static case has only the steady phase, which is similar to that of dynamic case except for after a certain number of rounds (i.e. 10) a new cluster formation/setup phase is initiated. However, the static case has less number of cluster formation phases as compared to the dynamic case and so, has less transmission overhead. However, DSC also does not provide mobility of sensor nodes and cannot be used in applications that require mobile sensor nodes such as habitat monitoring, target tracking.

To provide mobility of sensor nodes, Kim and Chung [24] propose LEACH-Mobile (LEACH-M) routing protocol where cluster formation and CH selection mechanism is same as LEACH. LEACH-M ensures the communication of a node with a CH even if node is in motion by transmitting data request packet from CH to the sensor node in its allocated timeslot using TDMA scheme. For this purpose, a member node A of a cluster with CH B waits two timeslots of two consecutive frames to decide whether A has moved. The node A does not send any data at its allocated timeslot to B until it receives data-request from B and if the node A does not receive any Data Request at the beginning of a timeslot (when it is awake) from B then A goes to the sleeping mode and waits for the Data-Request from B until the next frame. If

A does not any receive the Data Request in the next frame as well it requests for a JOIN-ACK message to join in a new cluster. Then A joins to a new CH which is in the vicinity of A and from which A receives the advertisement message for the first time by sending a registration message. The CH then sends A a TDMA schedule, which contains timeslots that are assigned to all members including new mobile node A. Similarly if a CH does not receive data from A in two consecutive rounds (after sending the Data- Request packet) CH discards A from its membership and removes A from its TDMA slot considering that A has moved. However, LEACH-M handles node mobility by assuming that the CHs are stationary. Hence, LEACH-M is not considered efficient in terms of energy consumptions and data delivery rate because a large number of packets are lost if the CH keeps moving before selecting a new CH for the next round. To alleviate this problem of LEACH-M, Kumar et al. propose LEACH-Mobile-Enhanced (LEACH-ME) [27, 28], where a node with the minimal mobility factor is selected as a CH, if the residual energy of the node is not below a threshold value. They calculate mobility factor based on the number of times a node moves from a cluster to another cluster. Since mobility factor (or remoteness) is a function of distance among nodes it is calculated by multiplying node's velocity with the time required to move a node from a position to another. For this purpose, an extra timeslot known as ACTIVE slot is assigned during TDMA scheduling, where all member nodes wake up simultaneously, broadcast their IDs with timestamp information and receive their neighbouring nodes IDs by setting a time out. For example, node i can make use of IDs of all other nodes it hears and calculate dij(t) as dij(t) =RadioVelocity∗|t2 - t1|, where at time t1 node I broadcast its ID and at time t2 it receives the ID of node j.

This modified CHs election process of LEACH-ME provides a minimal data loss in case of node's mobility. In steady phase, a non-CH node A might not receive Data Request that is sent by the CH because of mobility and since the new location of node A is out of the range of CH.

In this case if CH does not receive any acknowledgement from A in two timeslots in consecutive frames, then A is declared as mobile and its allocated timeslot will be deleted and A joins in a new cluster. The performance of LEACHME is better than LEACH-M in successful data transmissions in different mobility factors. However, LEACH-M is not energy efficient since it consumes energy for determining mobility factor in active slots.

Awwad et al. propose [21] cluster based routing protocol for mobile nodes in WSN (CBR Mobile-WSN) to reduce energy consumption and the number of packets loss of LEACH-M. CBR-M is an adaptive protocol that avoids wastage of timeslots and hence, ensures efficient bandwidth utilisation. Each CH keeps some free timeslots to enable other incoming mobile nodes from other clusters to join its cluster. A CH sends data request message to the non-CH nodes and if the CH does not receive data from a member, the packet is considered to be lost and the CH discards the nodes membership, at the end of the frame. Consequently, if a sensor node A does not receive data request message from its CH then A tries to join in a new cluster to avoid loss of packets. If the sensor node A receives Data Request message from CH but A has no data to send, A will not hold any time slot and this timeslot can be assigned to another node that has data to send. In another scenario, if a sensor node A moves and hence, does not receive data request message from its CH at its allocated timeslot A sends its data to the free CH to avoid the loss of data. Then A sends a registration message to join the cluster of a nearby CH. When a CH finishes receiving data messages from all sensor nodes in a round, the CH checks whether it receives data messages from all members, and then removes the sensor nodes from which the CH did not receive any data. Each sensor node A wakes up one timeslot before its scheduled timeslot to check whether it has really been assigned that timeslot. If A has not been assigned any timeslot it goes back to sleep mode and its timeslot might be used by a mobile sensor node that enters the cluster. This phenomenon reduces energy consumptions. However, CBR-mobile has more average delay as compared to LEACH-M since the moved sensor nodes send data to the free CH whenever that sensor node did not receive any data request from its CH which adds delay to the network whereas in LEACH-mobile assume packets are lost when sensor nodes do not receive any data request from CH, L. Karim proposed LFCP-MWSN protocol for mobile WSN in which incorporates a simple range free approach to localise sensor nodes during cluster formation and every time a sensor moves into another cluster, He proposed LFCP-MWSN in several phases. The proposed algorithm works with the following assumptions.

- All sensors are mobile.
- Once a node is selected as a CH, it remains in the same

cluster.

- Initially, all sensors have the same energy.
- A node in each cluster is equipped with GPS and work only for localisation. This node is known as an anchors node.
- Sensors are heterogeneous in terms of their roles since they work as anchor nodes, cluster heads, and cluster members. There are many other clustering protocols, which considering both stationary and mobile sensor nodes, such as LESCS [28], ECR [27], SP [29], CBR-MWSN [21], GBEER [30], are not discussed here. Although they are considered as energy efficient most of them are not fault tolerant.

III. Proposed Mobile Routing Protocol

We present the working principle of our proposed ELFCP-MWSN in several phases. The proposed algorithm works with the following assumptions.

- All sensors are mobile.
- Once a node is selected as a CH, it remains in the same cluster.
- Initially, all sensors have the same energy.
- A node in each cluster is equipped with GPS and work only for localisation. This node is known as an anchors node.
- Sensors are heterogeneous in terms of their roles since they work as anchor nodes, cluster heads, and cluster members.

A. Setup phase:cluster formation, nodes localization, and cluster head selection

Initially, (BS) divides the network into a number of clusters based on the geographical locations of sensors, assigns ID to clusters and sensors. Then sensors are localised using the technique that is presented in the Section 3.1.4. Then BS selects CHs based on the initial node energy and position of the sensors. Since initially all nodes have the same energy, CH is randomly selected based on a random number between 0 and 1 and CH probability, which is similar to the method used in the LEACH protocol [22, 26]. Then CHs broadcast their positions and IDs. A node A is assigned to a cluster whose CH is at the minimum distance with A. The node A then sends a registration message to the CH with its ID and current location. All clusters' information is then sent to BS for centralized control and operations. Once a CH is selected at the beginning of a round it is considered to be static until a new CH is selected in the next round based on the mobility factor of sensor nodes. After a number of rounds a new cluster formation and CH selection phase (based on nodes mobility) is initiated to balance the energy consumptions. Once the network operation starts and nodes move at a fixed and low velocity, each node keeps track of the number of movements inside and outside of its current cluster based on which nodes mobility is calculated at each round.

B. Steady phase: data/special packet transmission, new CH selection, fault tolerance

In the steady phase, CHs assign timeslots to the member nodes using TDMA scheme. Member nodes of a cluster transmit data, receive acknowledgement from CH and count their movement inside and outside of the cluster at the allocated timeslot. Thus, no extra timeslot is required to calculate nodes mobility. However, one extra timeslot is assigned in each frame to allow a mobile node to send JOIN REQUEST message to the CH of a new cluster when that node moves out of a cluster. Existing mobile routing protocols mention that mobile nodes join in a new CH by sending a join request packet but do not mention how this join request message is transmitted in the TDMA scheme since timeslots are all allocated only to the cluster member nodes. We will give priority of mobility to each cluster ,we will account the mobility ratio to each cluster according to the number of nodes entering to the cluster and going out the cluster , if the number of mobility is high then the priority of mobility will be high and we shall give four extra time slots to that cluster and if it is middle priority of mobility we shall give two extra time slots and if it is low priority of mobility we shall give only one extra time slot . However, if a node moves into a new cluster and sends JOIN-REQUEST message to CH using the free timeslot, the CH does not allocate the node a timeslot until any timeslot becomes free for moving a node out of this cluster.

Initially, CH subscribes to each node A for some events of interest such as 'notify if the temperature exceeds 708'. Whenever the subscribed events occur at the allocated timeslot to A, the node A sends the event's data packet to CH. If the events do not occur at the allocated timeslot to A, the node A sends a small sized special packet to notify CH that it is still alive or within the communication range of CH (i.e. it has not moved). After receiving the data or special packet CH replies to A with an ACK packet.

If a CH does not receive any data or special packet from node A at its allocated timeslot the CH assumes that (i) data or special packet transmission has failed or (ii) the node A has moved out of its cluster or (iii) node A has failed. To confirm about the transmission failure CH waits until the next timeslot of node A. If CH does not receive any data or special packet in the next timeslot CH deletes node A from its members list and also the timeslot allocated to that node. CH also notifies BS the ID of A that it has either moved or died. On the other hand, whenever A does not receive any ACK packet from CH, since it has moved out of the communication range of CH after sending the data/special packet, A assumes that it is no longer attached to its CH because of mobility. Then A sends a JOIN-REQUEST packet at the free timeslot of a frame to the CH of a new cluster whose CH is at the shortest distance to node A. However, CH of this new cluster accepts the join request by replying with an ACK-JOIN packet only when a timeslot becomes free owing the moving of a member node out of that cluster. This new CH of node A thus allocates a timeslot to A and notifies BS the ID of A. If BS receives ID of the node A from two different CH as a leaving node from a cluster at frame x and a new node into a cluster at frame x + t, then node A is considered to be moved from a cluster. Otherwise, node A is considered as a failed node because if it is not failed node it would send JOINREQUEST and later BS would know the ID of this node. Thus, ELFCP-MWSN provides ACK-based fault tolerance mechanism using special packets that detects the failure of member nodes of a cluster.

C. Nodes mobility determination

Mobility factor is the most important criterion in MWSN to determine a new CH and also the cluster to which a node belongs to. The node with the lowest mobility factor in a cluster is selected as a CH if its remaining power is above a threshold value. If there is a tie with the lowest mobility factor the node with the most residual energy is selected as a CH. However, once a node is selected as a CH it is assumed to be static or remained in the same cluster. The mobility factor that determines the frequency of a node to move into a different cluster during the steady phase is calculated as the ratio of the number of times a node enters different clusters to the number of times a node changes positions within a cluster. Hence, the least number of times a node enters other clusters the least mobility factor it will have and the more probability that this node becomes a CH since node with the least mobility factor will have high probability to remain in the same cluster until the new CH selection. Each node keeps track of the current time at the beginning of its allocated timeslot in two consecutive frames. Let the current time at the beginning of a timeslot is t1. Since the node can move, it measures the distance d it has travelled at the beginning of timeslot t2 in the next frame as

$$d = |t_2 - t_1| \times velocity \qquad \text{---(1)}$$

If d > 0 and the node does not receive any ACK from its CH then the node assumes that it has moved to a new cluster and joins that cluster sending a JOIN-REQUEST message (as is presented above). Otherwise, the movement of the node will be counted as the position change within its own cluster. Then each node A measures its mobility as

$$Mobilty_A = \frac{Count\ move\ out\ of\ cluster}{Count\ move\ inside\ the\ cluster} \ldots\ldots\ldots(2)$$

D. Nodes localization

Sensors localisation is very important since without location information sensors data are meaningless for many WSNapplications such as wild fire detection. However, localizing mobile sensors nodes and keeping the updated location information of mobile nodes is a great challenge. In the proposed ELFCP-MWSN protocol sensors are localised at the cluster formation phase and whenever a node moves out of a cluster to join a new cluster. Although moving sensors inside a cluster change their location their initial location in the cluster can still allow the applications to predict the location of the event of interest.

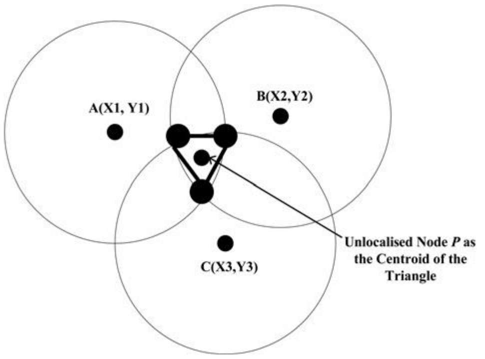

Figure 3: Localisation of a sensor node P

A simple, light-weight and range-free localisation approach is used in ELFCP-MWSN protocol. This localisation approach uses sensing range to communicate with nodes, where a pair of nodes communicates each other only when their sensing circles intersect each other. The relationship between communication and sensing range is given in [31] by Rc = n × Rs, n ≥ 2. In this localisation approach, only one or two mobile anchor nodes are used that are equipped with GPS. The main objective of using these anchor nodes in the network is to localise the other sensor nodes. Anchor node moves and broadcasts its current position. An un-localised node P that is within the sensing range of the anchor node receives the anchor position and assumes that an anchor node exists at that position. In such way, whenever P(XP, YP) receives three positional information of anchor nodes or positions A(X1, Y1), B(X2, Y2) and C(X3, Y3), P estimates it position using the centroid of a triangle that is formed by connecting the intersected position of sensing circles of three anchor nodes. Equation (3) shows the coordinate of node P.

$$X_P = \frac{1}{3}\sum_{i=1}^{3} X_i \ , \quad Y_P = \frac{1}{3}\sum_{i=1}^{3} Y_i \dots \dots (3)$$

Figure 3 illustrates the working principle. In [32], proposed and showed that this localisation approach is very efficient in terms of energy consumptions since it uses sensing range instead of larger communication range and hence, has a very low localisation error.

E. Time Slots Allocation to Clusters

Existing mobile routing protocols mention that mobile nodes join in a new CH by sending a join request packet but do not mention how this join request message is transmitted in the TDMA scheme since timeslots are all allocated only to the cluster member nodes, LFCP-MWSN assume that all nodes are homogeneous in terms of mobility and so, while a node moves out of a cluster there is a high probability of another node entering into that cluster.

In ELFCP-MWSN we shall consider there are variable number of time slots allocated to each cluster according to the number of moving of nodes inside and outside the cluster, the BS allocate IDs to each cluster and two more variables for the number of nodes entering the cluster and the number of nodes going out of the cluster, the selected CH in each cluster will observe the moving nodes outside or inside the cluster , the BS will increase the number of moving in or out according to CH notifications .

The cluster mobility will estimate as shown in Equation 4

$$Cluster\ mobility = \frac{No.of\ nodes\ moving\ inside\ cluster}{No.of\ nodes\ moving\ outside\ cluster} \dots\dots (4)$$

In each round for each cluster we do

- Estimate the maximum Cluster mobility(MCM).
- If the Cluster Mobility (CM) less than MCM and more than (MCM/2) then it will be high priority of mobility and then three extra time slots will allocate to that cluster .
- If the Cluster Mobility (CM) less than MCM/2 and more than (MCM/3) then it will be middle priority of mobility and then two extra time slots will allocate to that cluster .
- If the CM less than MCM/3 then it will be low priority of mobility and one extra time slot is allocate.

IV. Performance Analysis

A. Energy consumption models[39]

We are going to establish energy consumption models based on [39] network model and assumptions as shown in figure 4.1. Let n denote the total number of nodes in the network and $A = \pi r^2$ the area of the network field (i.e., the area of Cq). We have

$$n = \rho A = \rho \pi R^2 \dots\dots (6)$$

The expected number ni of nodes in Ai (1 > i < q) is

$$ni = \rho A_i = \rho \pi {R_i}^2 - R_{i-1} \dots\dots (7)$$

For uniform distribution of sources, the expected number Ti of sources in Ai is

$$T_i = T\frac{Ai}{A} = T\frac{{R_i}^2 - R_{i-1}}{R^2} \dots\dots (8)$$

Because source-to-sink paths associated with sources in annuli Aj (j > i) all have the sink as destination, sensors in Ai collectively participate in all these paths as message forwarders. The expected number m_{fw}(i) of such paths per node in Ai is

$$m_{fw}(i) = \frac{1}{n_i}\sum_{i<j\leq q} T_j = \frac{T}{n_i}\sum_{i<j\leq q}\frac{{R_j}^2 - R_{j-1}}{R^2} = \frac{T}{n_i}\frac{R^2 - R^2{}_i}{R^2} \dots (9)$$

The expected number m_{og}(i) of paths originated per node in Ai is

$$m_{og}(i) = \frac{T_i}{n_i} \dots\dots (10)$$

Hence, the energy consumption E(i) of each sensor in Ai is

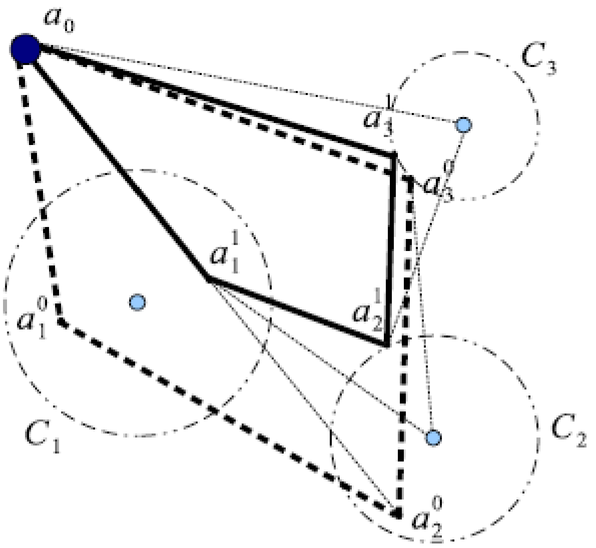

Figure 4.1 Point set computation

$$E(i) = \left(m_{fw}(i) + m_{og}(i)\right)E_c(w_i) \ldots\ldots\ldots.(11)$$

Then we get

$$E(i) = \frac{\lambda T}{\rho\pi R^2}\frac{w_i^{\alpha} + c}{R_i^2 - R_{i-1}^2}(R^2 - R_{i-1}^2) \ldots\ldots\ldots(12)$$

Equation 11 is a general formula describing sensor energy consumption behavior. From this equation, it is not difficult to find that E(i) is proportional to ρ and T and reverse proportional to β and R2. When every sensor is a source, i.e., when T = n = $\rho\pi R_i^{\ 2}$, E(i) becomes independent from T and ρ. When fixed parameters ρ, T, R, and λ are ignored, the equation will be

$$E(i) = \frac{w_i^{\alpha} + c}{R_i^2 - R_{i-1}^2}(R^2 - R_{i-1}^2) \ldots\ldots\ldots(13)$$

We assumed all the nodes are mobile so the radiuses of the circles are variable so we obtain the normalized energy consumption per route for a node in Ai as follows:

$$E_{out}(i) = \frac{R_1^{\propto} + c}{2i - 1}(q^2 - (i-1)^2) \ldots\ldots\ldots.(14)$$

Similarly, energy consumption of a node for sending a special packet to the CH.Special packet is a small sized packet containing only header information with a packet type that is sent by a member node of a cluster when the node does not have any subscribed data event to send to CH. This is used to achieve fault tolerance as presented in chapter 3. In equation (5) represents the energy consumptions of radio for driving the transmitter (50 nJ/bit) .

Special packet only contains header information with a packet type field that identifies itself as a special packet whereas data packet contains both header and data information. Thus the size of the special packet is much smaller than that of the data packet.

The energy consumption for the existing ELFCP-MWSN is estimated from the equation 11.

B. Simulation setup

We simulate the proposed ELFCP-MWSN protocol using MATLAB simulator. A simulation model is implemented with a network of size 100 × 100 m. BS is place at the coordinate (90, 170). Table 4.1 shows the network parameters and their respective values that are used in the simulation.

Table 1 Simulation parameters and their values

Parameter	Value
network size	100 × 100 m
number of nodes	maximum 200
number of clusters	maximum 16
base station position	(90, 170)
data packet size	256 bits
special packet size	16 bits
transmitting energy consumption	50 nJ/bit
energy consumptions in free space	0.01 nJ/bit/m^2
initial node energy	2 J
cluster head probability	0.03
sensor nodes velocity	0.01 m/s

C. Simulation results

We measure the performance of the ELFCP-MWSN protocol and compare it with the existing ELFCP-MWSN mobile clustering protocol in terms of network energy consumptions, packet delivery ratio, and end-to-end delay.

Network energy consumption is defined as the total energy consumed by all the sensors nodes for routing data over a certain period of time. Network energy consumptions also reflect the lifetime of the network, that is, the remaining network energy since network energy consumptions is inversely proportional to the network lifetime.

We measure the end-to-end delay as the time that is required to transmit data from any source sensor node to the BS based on the traversed Euclidean distances.

We measure the packet delivery ratio which is defined as the total number of packets received at the BS to the total number of packets transmitted by the senders, Another important parameter to measure the performance of a mobile routing protocol in term of packet delivery ratio.

We run the simulation over a number of rounds, where a round consists of a number of frames. Each nonCH node has a timeslot allocated to it in a frame. The number of frames in a frame is dynamically adjusted based on the residual energy of networks at the end of each round.

1) Comparison with existing LFCPMWSN protocol in term of Network Energy Consumption:

Figure 4 illustrate the performance of ELFCPMWSN protocol in terms of network energy consumptions, over a number of rounds. Figure 4 shows that the network energy consumptions for ELFCP-MWSN protocol are much less than that of LFCP-MWSN protocols. Hence, the network lifetime of ELFCP-MWSN is more than that of LFCP-MWSN protocols. That because the distribution of sources (nodes) divided into annuli by *q* concentric circles centered at the sink.

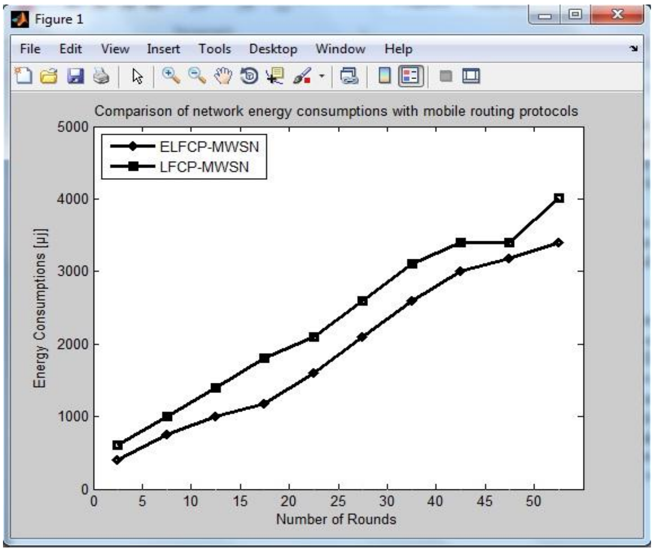

Figure 4: comparison of network energy consumptions with ELFCP-MWSN

2) Comparison with existing LFCPMWSN protocol in term of Network end-to-end Delay:

Figure 5 shows that the end-to-end delay of ELFCP-MWSN is slightly lower than ELFCP-MWSN protocol, statistical analysis (student's t-test at 95% confidence interval) reveals that all these three protocols are same in terms of end-to-end delay. One of the possible explanations is that although we are expecting that mobility of each node are equally likely (if a node A enters a new cluster, another node exits that cluster so that x has no delay to be allocated a timeslot), in reality this is not the case.

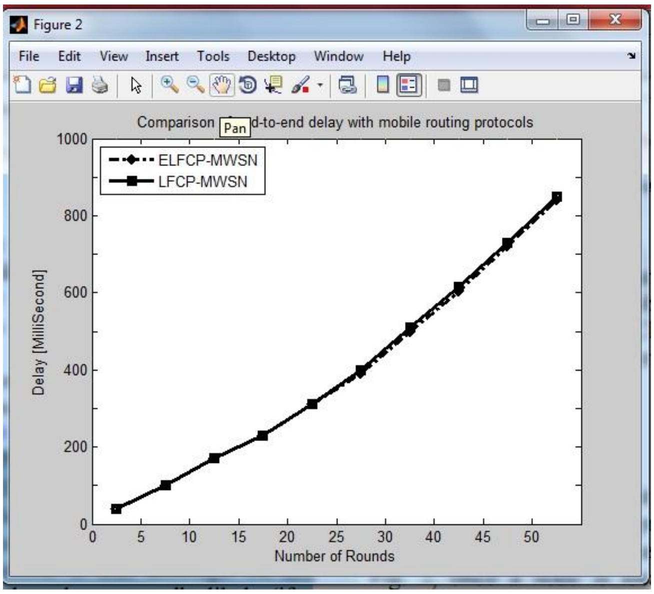

Figure 5: comparison of end-to-end Delay with LFCP-MWSN

3) Comparison with existing LFCPMWSN protocol in term of Network Packet Delivery Ratio:

Figure 6 show that the Packet Delivery Ratio is higher than the existing LFCP-MWSN, packet delivery ratio which is defined as the total number of packets received at the BS to the total number of packets transmitted by the senders, Another important parameter to measure the performance of a mobile routing protocol in term of packet delivery ratio.

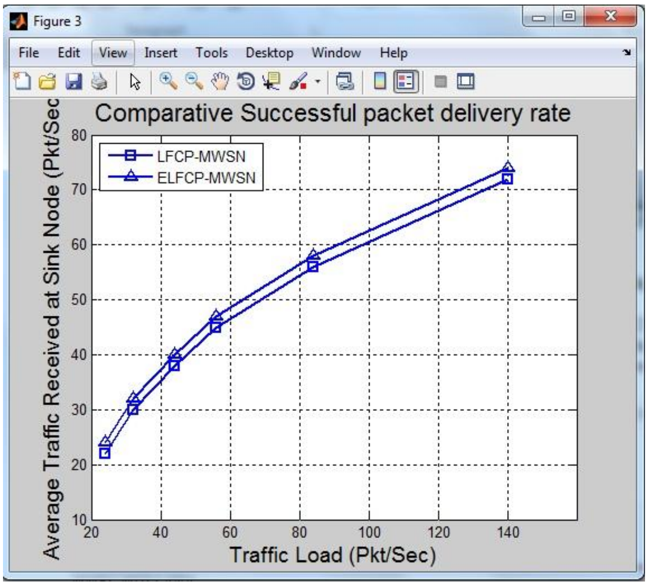

Figure 6: Comparison of Packet Delivery Ratio with LFCP-MWSN

D. Discussion

Setup phase is initiated after a certain number of rounds in ELFCP-MWSN protocol, Since setup phase consumes much energy for transmitting a large number of control messages, the proposed ELFCP-MWSN protocol is expected to be more energy efficient, This is because we used another technique for transmitting control messages ELFCP-MWSN protocol as compared to the exiting LFCP-MWSN protocol.

In ELFCP-MWSN protocol, events of interest are subscribed to sensors and when these events occur sensor nodes send data packets; otherwise, sensors send small sized special packets, which consume much less energy as compared to larger data packets. Thus, ELFCPMWSN is considered to be more energy efficient. In each round of setup phase, member nodes of a cluster send either sensed event or special packet to BS. Thus, the complexity of Algorithm in each round will be O(n). Similarly, the complexity of localization will be O(an) if the number of anchor positions is an out of which at least three anchor nodes or positions are within the sensing range of an un-localised node.

To achieve reliability or detect the failure of nodes, CH sends the ID of the sensor node to BS, for which CH assumes that it has been moved out of the cluster and also the ID of the node which sends JOIN-REQUEST message, ELFCP-MWSN achieves reliability at the cost of these extra messages transmissions.

In the proposed ELFCP-MWSN, no extra timeslot is needed to calculate the nodes mobility. Moreover, in ELFCP-MWSN the number of frames that constitutes a round is not fixed. CH determines the number of frames at the beginning of each round based on the residual energy of the network that balances energy consumptions of the network. In LFCPMWSN, a node can localise itself, which is very important for a routing protocol since without location information sensor data are useless and cannot be used in most popular sensor network applications. The localisation approach used in ELFCP-MWSN is a very lightweight in terms of energy consumptions and simulation results show that localization does not increase the overall network energy consumptions as compared to existing approaches.

E. Conclusion and future work

In this paper, we propose a ELFCP-MWSN that supports mobility of sensor nodes and sensors localization. Sensors localization is considered one of the most important features for WSN applications, ELFCP-MWSN uses special packets, which are sent by member nodes of a cluster to CH when member nodes have no sensed event to send to CH but these special packets allow the ELFCP-MWSN protocol to detect the mobility and failure of member nodes of a cluster. Simulation results show that ELFCP-MWSN protocol is more efficient in terms of energy consumptions than those of the existing LFCP-MWSN protocol. Moreover, ELFCP-MWSN detects the failure of sensor nodes. Although the analysis shows that ELFCP-MWSN protocol should have less end-to-end network delay than LFCP-MWSN simulations results show that they are almost identical in terms of end-to-end delay, the simulation results show that Packet Delivery Ratio in ELFCP-MWSN is higher than the existing LFCP-MWSN. Moreover, in ELFCP-MWSN protocol, we consider that once a node with the least mobility factor is selected as a CH, then the CH will not move out of the cluster in the current round. In future, we will also allow the mobility of a CH out of cluster in the current round.

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