EEBFTC: Extended Energy Balanced with Fault Tolerance Capability Protocol for WSN

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***Abstract*—This paper proposes a new framework for wireless sensor networks (WSN) by combining two routing protocol algorithms. In the proposed framework two algorithms are taking into consideration the energy balanced clustering (EBC) protocol in WSN with fault tolerance capabilities. The organizer is automatically selected by the base station (BS) and then it selects the cluster head (CH). The mechanism of selecting the organizer node and the cluster head (CH) is based on the power, efficacy and energy balance load. In addition, the organizer is responsible to select a new CH in case of failure and vice versa. So, the energy balanced clustering and fault tolerance operations will prolong the node life time and thus the network will be efficient in data transmission and more reliable. The new framework after implementation is named Extended Energy Balanced with Fault Tolerance Capability (EEBFTC) protocol.**

Keywords*—*wireless sensor network; clustering; EBC; energy; fault tolerant

I. Introduction

Recent technology improvements in micro-electro-mechanical systems (MEMS) technology, wireless communications, and digital electronics have made the attention from researchers to the wireless sensor network increased during the last years. The power of wireless sensor networks lies in the ability to deploy large numbers of tiny smart devices - such devices are called sensor nodes- that assemble and configure themselves. The most attractive feature of wireless sensor network is their autonomy. When deployed in the field, the microprocessor automatically initializes communication with every other node in range, creating an ad hoc mesh network for relaying information to and from the gateway node [10]. Moreover, these tiny sensor nodes consist of sensing, data processing, and communicating components, in which a large number of nodes collaborative their efforts together to do specific tasks [1, 2, 6, 7, 8, 24].

The application of WSNs are tremendous and is using for several purposes such as military monitoring, environmental observation, weather checking, traffic control application, detecting location of pollutants, home automation applications, security issues and it has been used in the healthcare to improve the quality of the provided care [2, 3, 4, 6, 12, 27] and is widely using in Internet of Things (IoT) [26].

Due to low bandwidth, limited energy sources, limited memory, limited processing power and low transmission range of nodes, deploying nodes inside the phenomenon or very close to it is required for more reliable data transmission [4, 7]. For efficient network operation, several battery driven energy preservation structures were proposed but due to its limited battery size, it diverts the research focus towards choosing the alternate closest sources of energy [25]. Besides, these constrains make the design issues of routing protocols is very challengeable. The designers look always for routing protocols that tend to good resource management for the sensor nodes. In this case, they consider the energy efficient and power aware capabilities in their designs to maximize the life of wireless sensor network and thus the life of entire application. Routing protocols proposed in the literature for WSNs used some routing strategies such as data aggregation, in-network processing, clustering, different node role assignment and data-centric methods, all these were employed to minimize energy consumption [1, 24, 27].

In WSN the data of individual node do not have significant importance. Sensor nodes are correlated with their neighbor nodes and the collected data aggregated before send it to the base station. This can increase reliability of the sensed parameter and decrease the overhead [3, 28]. Regarding that data gathering (routing) protocols should be utilized in an efficient way which takes into consideration the power consumption criteria. As mentioned in the literature, routing protocols in WSN can be divided into several categories: location-based protocols, data-centric protocols, hierarchal-based (cluster-based) protocols and QoS-based protocols [1, 9, 11, 24] and some have more categories. Research community classified the hierarchal-based (cluster-based) structure as an effective architecture for data gathering in WSN [4]. Moreover, [13, 21] ensures that clustering approach is energy-efficient protocol in which data transmission time is clearly reduced.

The concept of cluster-based protocol is to divide the region into zones (clusters), one high energy node called Cluster-Head (CH) will be chosen and will collect the data from all nodes in it’s own zone and make aggregation on the data before transmit it to the Base Station (BS) or to another CH which is closer to the BS [28, 29].

Wireless sensor networks usually encounter node failure due to the limited power sources which may lead to split the network into multiple isolated parts, prevent transmitting data therefore data loss and even worse lead to whole network failure since faulty nodes can’t be repaired or exchanged [12]. Recently, a popular and important issue is fault tolerant ability when the CH has experienced some faults a backup node should be available to maintain the cluster works and avoid isolating their cluster nodes, shutting down or re-clustering the network [23].

Nowadays, several WSN proposed protocols are paying attention to save the energy of the nodes with a fault tolerant mechanism to improve the reliability of data transmission and extend the application life to reasonable times.

The paper enhanced an energy balanced routing protocols by adding the fault tolerant mechanism, this done by combining two publish protocols which are: Energy Balanced Clustering EBC [4] and the Fault Tolerance Power Aware protocol with Static Clustering FTPASC [3]. Combining may produce a better protocol that maximizes the network life.

II. Literature Review

As mentioned in the previous section routing protocols in WSN can be divided into several categories, we will concentrate in our related work on the hierarchal-based routing that conserve energy and provide the fault tolerant capabilities.

Over the recent few years, most of the routing approaches that designed for WSNs focused on the energy aware to extend the node lifetime and thus the entire network [9]. A failed CH caused limited accessibility to the cluster nodes and may degrade the performance of the network [16]. Therefore, a multi objective routing approach that meet different application requirements is needed to support the failure of CH beside the energy efficiency.

Low-Energy Adaptive Clustering Hierarchy (LEACH) which is the first and most popular hierarchal-based routing protocol for WSN proposed specifically to reduce power consumption [9, 11, 21]. It combines the ideas of energy-efficient cluster-based routing and media access together with application-specific data aggregation to provide a good performance in system lifetime, latency, and application-perceived quality. LEACH provides self-organization of large numbers of nodes using high distributed cluster formation technique, algorithms for adapting clusters and rotating cluster head positions using probability formula, and techniques to enable distributed signal processing to save communication resources [14]. The main drawback of LEACH that it doesn't guarantee good CH distribution [11], also doesn't guarantee a good CH selection depends on the residual energy [17].

An improvement protocol that considered as an extension of the LEACH is PEGASIS (Power-Efficient GAthering in Sensor Information Systems). PEGASIS is a near optimal chain-based protocol for data-gathering problem in WSN. PEGASIS avoids cluster formation, each node transmits to its local neighbors instead to CH and one node in a chain chosen to transmit the aggregated data to the BS each round, thus the total energy spent per round reduced. Simulation shows the performance of PEGASIS is better than the LEACH [15].

Hybrid Energy-Efficient Distributed Clustering (HEED) overcomes the LEACH drawbacks by using a new CH selection methodology depends on two parameters which are residual energy of the node and node degree (i.e. number of neighbors). HEED ensures a well distributed CHs across the network and minimizes the communication cost [18].

Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN) is a data-centric mechanism that passes data to the BS through multi-hierarchical levels [19]. The Adaptive Periodic Threshold Sensitive Energy Efficient Sensor Network Protocol (APTEEN) is an extension of TEEN that has the same architecture. Considering energy dissipation and network life time APTEEN's performance is between LEACH and TEEN [20].

An EPMPAC (Efficient Power Management Protocol with Adaptive Clustering) is a cluster-based protocol partitions the network into adaptive local clusters each has its own organizer. The protocol distributes the loads among organizers and cluster-heads. The ease of deployment, energy conservation, mobility management, and extension of network lifetime make EPMPAC reliable and robust protocol for wireless sensor networks and give better performance than conventional protocols [22].

A distributed clustering protocol for robust ad-hoc sensor networks called REED (Robust, Energy Efficient, Distributed clustering) build a k-multiple independent cluster head overlays on top of the physical network. When a cluster head failure detected, every node automatically switch to another cluster heads and should be able to communicate with at least one of the k-cluster head directly using the intra-cluster communication. REED prolonged the network lifetime and periodically re-clustering the network to fairly distribute energy consumption among sensor nodes [23].

[17] proposed Fault tolerant, Energy Efficient, Distributed clustering (FEED) for WSN which uses energy, density, centrality and distance between nodes as factors to provide a new routing technique that gives better network lifetime than in LEACH and HEED. The property provided by FEED for replacing the failure CH with a supervisor node will help the network to be fault tolerant.

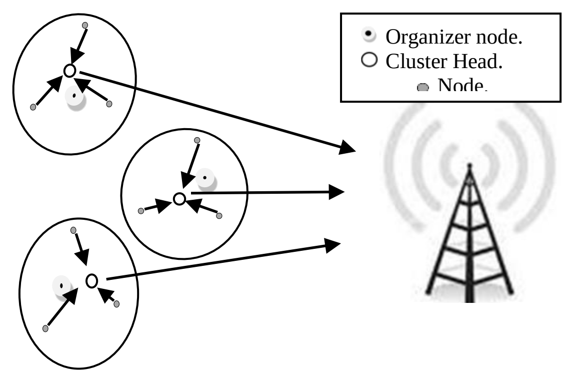

Fig. 1. WSN organized in clusters

III. Proposed Framework

In the proposed protocol, the fault tolerance and energy efficiency will be taken into consideration as a major design issues. The new protocol is derived by combining between two routing protocols which are: the Energy Balanced Clustering EBC and the Fault Tolerance Power Aware protocol with Static Clustering FTPASC. Hence the basic structure and entities of the new protocol is similar to the EBC.

EBC is for energy balances cluster formation, cluster head selection, intra cluster and inter cluster communications in wireless sensor network. EBC ensures energy balance that prolongs the sensor nodes life and thus increase the overall life time of the wireless sensor network [4].

FTPASC is a fault tolerance routing algorithm that maximizes the life time of sensor network and increase the reliability of the network through electing two nodes with good properties, one act as an organizer node and the other as a cluster-head [3], the role of the organizer and cluster-head will be described briefly in the new proposed algorithm.

A. Proposed algorithm assumptions

Before describing the basic steps in the proposed protocol, we can assume the following: (1) The BS has an unlimited power source, processing power, and storage capacity and able to compute the residual energy of all sensors in each round according to their location and the amount of transmission data. (2) The sensed data transmitted to the BS via radio communication where it can be processed by the user. (3) The communication process consumes more energy than processing data in a sensor node. (4) The protocol will use the first order radio model [21] to calculate the energy dissipation in transmit and receive modes. The Eelec = 50 nJ/bit and ∊amp = 100 pJ/bit/m2, where Eelec the energy dissipates to run the transmitter or receiver circuitry and ∊amp is the transmit amplifier. Thus to transmit a k bit-message a distance d, the energy dissipates equal to

$$ETx\ (k,d) = Eelec * k + \epsilon\ amp * k * d2 \qquad (1)$$

respectively, the energy dissipates to receive a k bit-message

$$ERx\ (k) = Eelec * k \qquad (2)$$

(5) After deployment, each node is able to determine its location and battery power. These information is very useful in CH selection, TDMA scheduling, intra and inter clustering communication.

B. Setup phase: initialization and organizer selection

In the setup phase, the BS broadcasts a setup-start message determining the geographical location of the organizer nodes. The chosen of these locations should take into consideration the following criteria: (1) in different clusters, the average number of sensor nodes is the same, (2) in each cluster, the average distance between sensor nodes minimized. Such criteria guarantee reduction in the power and distributed load among the nodes in overall whole network. After organizer nodes determined, each one sets up it’s own cluster by sending an invitation message to their neighbors. The sensor node which hears the invitation message will choose their organizer based on the strength of power of the received signals and will send (joint-REQ) message to the organizer to be registered in the cluster. The organizer sends an ACK to each node confirming their registration in the cluster. The power level of the sensor node will be attached with the (joint-REQ), so the organizer will have the essential information about its nodes which is enough to elect the cluster-head for this cluster. After receiving all (joint-REQ) messages, each sensor node in the network is attached only to one cluster that has one organizer node and thus the clusters are defined like in figure 1. The previous process will be formed before the network start to work. The organizer now elects a node to be a cluster-head of the cluster.

C. Set up phase: cluster-head (CH) selection

After a cluster is established, the organizer chooses the most powerful node in the cluster to be the cluster-head. There is other metrics can be considered in choosing CH as stated in literature as number of linked nodes, distance from BS…etc. The CH will collect the sensed data from sensor nodes of it’s cluster, perform data aggregation, and send the aggregated data to the BS. After a round (specific time interval) a CH selection process is performed in each cluster to select new CH to guarantee the energy balance between sensor nodes. New CH may not require for a specific round when CH is idle and forward very little traffic i.e. there is no significant change in the residual energy of the CH as it was at the start of the round, so the probability to choose the same CH for the next round is very high. The CH residual energy will be compared to a specific threshold to decide implementing the CH selection process. The issue of electing new CH when needed will save a lot of the energy. The re-clustering process will be done only in case of organizer failure. The node that will take place of the organizer and selected by the CH will do the re-clustering process and elect new CH for the new clusters.

D. Set up phase: TDMA schedule

After organizer selected the CH, it will assigns a fixed time slots for the first round to all the sensor nodes in the cluster using TDMA technique, so the sensed data by each sensor can be send to the CH. For the subsequent round, TDMA can be adaptive and arranged based on the traffic load of the node. The idea is to give the nodes with more traffic longer time slots, and give minimum time slot for idle nodes. The sensor node will request the organizer to increase or decrease its own time slot depends on the data to be sent. That will conserve the energy as time slot of idle node is decreased, and improve the delay as time slot of overloaded node is increased, hence sensed data can be forwarded to CH very fast.

E. Steady phase: forwarding sensed data

At every round the organizer sends a frame-start packet including the CH of the current round. The sensor node starts to send the sensed data to the CH using a single-hop (Intra cluster communication), each in it’s time slot assigned by the organizer. The sensor nodes sent also their residual power with the packet in a piggy back form that reduces the overheads in the network and save some energy. At the end of the round the CH send the aggregated data to the BS (Inter cluster communications) or to other CH who is nearer to BS. The CH uses CSMA when transmitting data to the BS to avoid collisions, it sense the channel and transmits when free, or waits when busy [13]. The CH also recognizes the most powerful nodes and sends this information to the organizer to be used in CH selection of the next round.

F. Steady phase: In the presence of faulty CH or organizer

The organizer monitors the functionality of the CH and responsible for selecting new CH in case of failure. If CH fails to work, then the organizer will continue CH role for the remaining time of the round. The organizer will choose the new CH basis on the power levels information of the current nodes.

On the other hand, the CH checks and monitors the organizer operations and chooses alternative one in case of failure. If organizer fails to work, then CH will play itself the role of the organizer for the remaining time of the round then the BS will select a new organizer and a re-clustering process will take place.

Periodically organizer and CH should exchange their status so they remain updated in case one takes place of the other.

Figure 2 shows the flowchart of the following algorithm which summaries the whole process briefly.

Algorithm

1. For first round:
   - The BS determines the organizers location.
   - The organizers form the clusters.
   - The organizer elects the most powerful node to be CH of the cluster.
2. For subsequent rounds:
   - CH receives data from the sensor nodes in it's cluster, with the residual energy for each node.
   - Aggregate the data.
   - If CH_{re} < Th.

     Do new CH selection.

   Else

     No new CH selection required.

   , where CH_{re} = CH residual energy and Th. = specific threshold.
3. When new CH selection, the organizer recognizes the most powerful nodes and selects the new CH.
4. In each cluster, the organizer and CH will check the status of each other, in case one of them fail the other will take place.

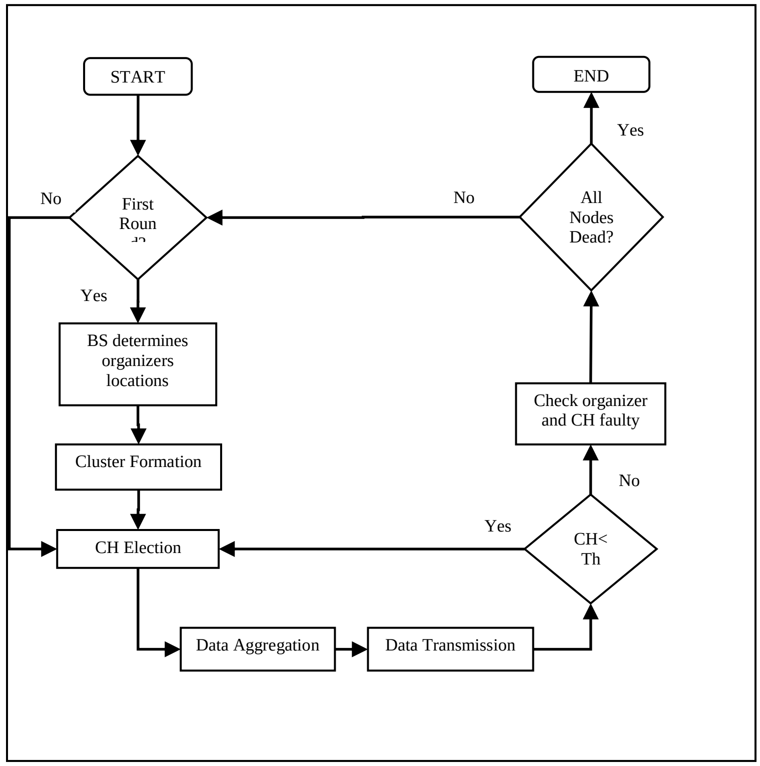

Fig. 2. The flowchart for EEBFTC protocol

IV. Discussion/ Results Analysis

The proposed approach expected to give the following enhancements:

Reduction in power consumption: several factors contribute to work on that such as the criteria of organizer selection will preserve the energy consumption and grantee balanced load between all the nodes in the network, the amount of data to be sent to BS can be reduced due to aggregation, re-clustering formation mechanism that tend to re-clustering only when organizer failed, using dynamic TDMA scheduling so the node with lots of traffics to send will continuous transmitting for longer time slots, sending the node residual energy using piggy back form and average energy spent in forwarding a packet is reduced because of reliability and minimum data loss that provided through the fault tolerant capability.

Network lifetime extended: as a result of energy saved and the fault tolerance ability the node life will extended and thus the entire network.

Throughput: the amount of data transmission received successfully per second at the BS will increase as a balanced load distributed among nodes increase the node life.

Delay time improved: through using dynamic TDMA scheduling to allow overloaded node to have more time slots comparing to the idle one.

Furthermore, we expect the EEBFTC to give better performance when compared to EBC and FTPASC individually. The distributed load over the nodes and conserved energy will prolong node life that affect directly the throughput of the whole network.

In addition, one of the good features of this approach the awareness of battery level for each node. Each node will send it's residual energy after each round to help the organizer selecting the candidate node to be CH for the next round. The node sends this information using a piggy back form to reduce the overheads inside the network.

Summarizing our predications to which the power consumption minimized, throughput increased, overheads decreased and delay time improved leading the network to be highly reliable. The efficiency and reliability of the proposed protocol intends to have a robust protocol for wireless network.

V. Conclusion

In this paper, we proposed the framework of EEBFTC protocol which is a new routing protocol for wireless sensor networks. The EEBFTC is an enhancement of EBC protocol for low energy consumption. As new contribution in this paper, we proposed a fault tolerant ability in order to achieve further improvement in network life time.

EEBFTC utilizes several mechanisms that enhance the data transmission, delay and throughput. Moreover, the cluster formation, CH selection, re-clustering, intra cluster communications, and inter cluster communications, as well as the ability in which CH will be substituted by the organizer in case of failure and vice versa will increase the reliability of transmission and prolong network life through balanced power distribution.

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