Energy-Conserving Multi-Mode Clusters Maintenance For Hierarchical Wireless Sensor Networks

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Abstract— Since the beginning of the era of wireless sensor networks energy conservation has been a major concern because it is limited in nature. An energy-conserving multi-mode cluster maintenance method is proposed which works on event driven mechanism. This method is different form the conventional cluster maintenance model as it involves periodic re-clustering based on New Hierarchical Stable Election Protocol (NHSEP) algorithm among the whole network. The initiators of this method includes node's nodes residual energy being under threshold, joining or exiting from any cluster, and so on and so forth. Depending upon the damaged cluster, whether node is a member of different cluster or same cluster inter cluster maintenance or inner cluster maintenance can begin. The enhanced method can save a considerable amount of energy to maintain the damaged network thus prolonging the network life. Simulation is done using NS2 and performance parameters such as Energy Remaining, Bit error rate, Packet Delivery Ratio, Throughput and control overhead are compared.

Keywords— NHSEP, hierarchical, WSN, Lifetime

1. Introduction

Wireless sensor networks (WSNs) are battery powered ad hoc networks in which sensor nodes that are scattered over a region connect to each other and form multi-hop networks. Since these networks consist of a large number of micro sensor nodes that are battery operated and wireless communication, care has to be taken so that these sensors use energy efficiently. WSNs have been widely applied in many fields for their advantages of networking flexibility, scalability, etc [11, 12, 8]. The sensor nodes are generally battery powered and work in harsh environments, therefore, they have to energy-efficiently work to prolong lifetime of network as far as possible [4]. Hierarchical clustered topology of WSNs is the most popular networking mode, which has a great number of advantages, such as easy management, efficient energy utilization, simple data integration, etc [9]. WSNs have many sensor nodes with characteristics of strongly dynamics, which determines the maintenance tasks of cluster structure and can become very heavy, therefore, multi-mode clusters maintenance is necessary for the damaged clusters because they perhaps have many cases such as single damaged cluster, several damaged clusters which is whether adjacent or not, the damaged node is perhaps cluster head (CH) or ordinary node, the dimension of damaged cluster is too big or too small and so on. The conventional method of clusters maintenance is just periodically re-clustered, which does not distinguish the damaged state of network structure and the scope of changed clusters. This will result in many shortcomings, such as excessive maintenance, high maintenance costs, energy wastage, periodic service interruptions, tardy response and so on. To solve the above-mentioned problems, this paper proposes a new algorithm and its implementation mechanism called multi-mode clusters maintenance (M^2CM) for hierarchical WSNs. Adaptive local cluster maintenance is the main goal, the clustering operation among whole network only occurs when the system is established, and then the maintenance of cluster structure is triggered by an event and is only within the scope of the damaged clusters, that is to say, the cluster maintenance operation is based on events and local, therefore, it is non-periodic and instead of whole network. The local cluster maintenance operations will start when it is detected that the cluster head has failed, the residual energy of CH is below the set threshold, CH load is imbalanced or new nodes are added or the damaged cluster members (CM) to quit. In addition, according to the number of clusters and affected neighboring relations, this paper proposes two cluster maintenance programs: single cluster maintenance (inner-cluster) and multi-cluster maintenance (inter-cluster), which built up multi-mode clustering mechanisms to deal with different situations of damaged clusters. It's better to avoid energy wastage, service interruptions, and prolong the network lifetime as far as possible to protect the stability of the cluster structure.

2. Related Works

Battery powered ad hoc networks in which sensor nodes that are scattered over a region connect to each other and form multi-hop networks. Selvi et al. show that the average transmit distance of each hop is increased while the hop number is declined. The overall energy consumption is reduced and balanced among nodes, which extends the lifetime of the network[8] . Tripathi et al. shows that there is balanced energy consumption in the proposed non-uniform clustering as there are sufficient amounts of cluster heads are allocated depending on the number of nodes in the annular area compared to the uniform clustering where an equal number of cluster heads are allocated in each annular band[9]. Zheng et al. show that the proposed algorithm can ensure the reasonable distribution of the cluster heads, save node energy and ultimately prolong network lifetime[11].

LEACH is the most representative of the clustering routing algorithm for WSNs [5], it is able to achieve good scalability of cluster structure from which some clustering routing algorithms draw their ideas. For example, a hybrid network topology is given by introducing node residual energy during the formation of the cluster head [14], which is a two-wheeled clustering protocol based on LEACH. Heinzelman proposed two centralized cluster head generation algorithm [5]: LEACH-C algorithm completes the work of cluster heads selection at the base station, and only the node with higher residual energy than the average energy is likely to become cluster head. In LEACH-F algorithm, the structure of cluster is no longer changed once formed, cluster nodes are constructed around clusters without circulating around to reduce the cost of constructing clusters. Pothalaiah et al. shows that NHSEP protocol has better performance in the parameters Energy Consumed, Energy Remaining, Packet Delivery Fraction, End to End Delay and Dead Nodes comparison with LEACH and SEP protocol [2].

With further research, traditional method uses periodic re-clustering mechanism to fit and maintain the network, but "re-clustering" leads to larger maintenance energy consumption and is not targeted, is "periodic" and difficult to determine, some algorithms have improved this. Yan and Li mention the centralized algorithm [10], which is similar to LEACH-C. It introduces cluster similarity in the cluster head rotation; when the similarity is less, the cluster head rotates in the cluster, otherwise the whole network is re-clustered. Enam et al. uses the energy threshold mode, where, the whole network re-clustering will trigger when the remaining energy of a cluster head is below the threshold or a cluster head is detected dead [4]. Gao et al. proposed the cluster head to rotate in the cluster when the residual energy is below the threshold, and the whole network to be re-clustered when more than half of the clusters have been cluster head rotated [7]. El- said, Shaimaa Ahmed et al. planned an optimized hierarchical routing technique that aims to cut back the energy consumption and prolong network time period. In this technique, the selection of optimal cluster head (CHs) locations is based on artificial fish swarm algorithm that applies various behaviors such as preying, swarming, and following to the formulated clusters and then uses a fitness function to compare the outputs of these behaviors to select the best CHs locations [3].

In summary, the existing cluster maintenance methods research is mostly focused on the generation and optimization of cluster head exclusively and balancing the energy dissipation among the sensor nodes, and a small amount of algorithms are developed for the problems of "periodical re-clustering". However, the work done has been simple, one-sided, and has not developed cluster maintenance solutions such as event-driven and local clustering algorithms which are important to the WSNs.

3. Proposed Methodology

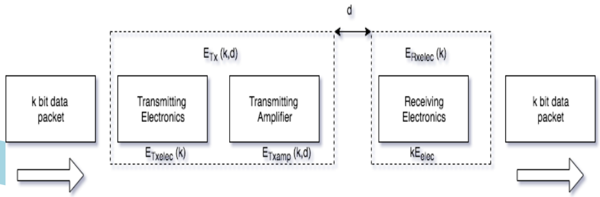

Fig. 1 Radio communication energy model

Assuming that the channel is symmetric, when *k* bit information transmitted through the process of distance *d*, the energy consumption for the transmission can be given by:

$$E_{TX}(k,d) = E_{TXelec}(k) + E_{TXamp}(k,d)$$
$$= k\,E_{elec} + k\,\varepsilon_{fs}\,d^{r}$$

Where E_{elec} is the energy consumption of the wireless transceiver circuit, ε_{fs} and ε_{mp} are the energy consumption of the power amplifier in the free-space model and the multipath fading model respectively, *r* is a constant of wireless channel decided by the transmission distance of signal *d* (r = 2 if $d < d_0$, otherwise, r = 4), and is the transmission distance threshold which is defined as:

$$do = \sqrt{\frac{\varepsilon fs}{\varepsilon mp}}$$

The energy consumption of the receiving side can be calculated as follows:

$$E_{RX}(k) = E_{RXelec}(k) = kE_{elec}$$

Definition : - Maximum cluster or Minimum cluster: the number of CH exceeds the upper limit $N_{max} = \theta.N/K_{opt}$ Which is the maximum cluster, the CH number below the lower limit $N_{min} = \beta.N/K_{opt}$ which is the minimal cluster. Where *N* is the total number of active nodes in the monitoring area, K_{opt} is the optimal number of CH , θ and β are the adjustable parameters and $\theta > 1$, $0 < \beta < 1$.

(i) Algorithm

Step 1 Clusters generating phase. Clustering is a well-known approach to cope with large nodes density and efficiently conserving energy in wireless sensor networks, therefore, the first step of M^2CM algorithm is still generation of clusters based on the well-known LEACH algorithm.

Step 2 Clusters communication phase. Secondly, on completing clusters establishment, the network enters into the normal communication phase. CM sends its residual energy the collected data packets information to CH in a scheduled TDMA time slot, and then CH makes the received information fusion and transmits them to BS.

Step 3 Clusters maintenance phase. After a period of data communication, the cluster will start single cluster maintenance program in the cluster when the following events occur: CH failures or residual energy below the set threshold, new nodes join the cluster or CM fails to exit. If multiple adjacent clusters achieve the conditions which start single cluster maintenance simultaneously, start multi-cluster maintenance program to jointly safeguard these multiple clusters.

Step 4 Clusters re-communication-maintenance loop phase. After the clusters maintenance, restore the cluster back to the cluster communication phase, begin to enter the cluster communication once again i.e. cluster maintenance cycle until energy depletion, or if too many nodes die or unable to form a complete cluster structure, the network is no longer able to communicate properly. It means that the lifetime of whole network is over. The flowchart of energy-efficient multimode clusters maintenance mechanism is shown in figure 2

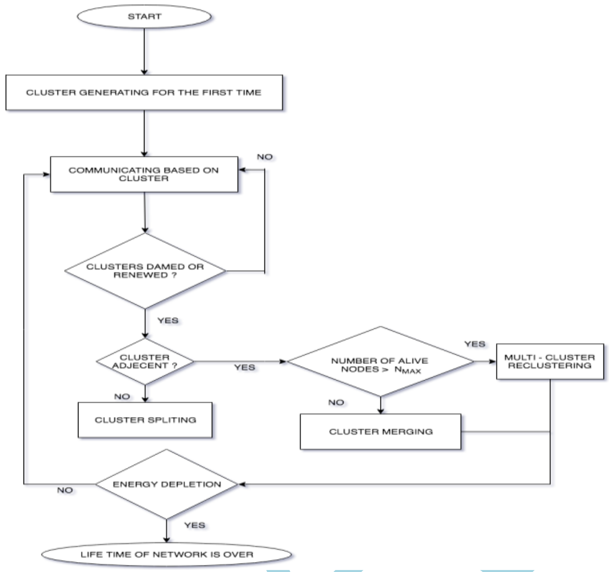

Fig. 2 Flowchart of energy-efficient multi-mode clusters maintenance

(ii) Single cluster maintenance

Single cluster maintenance program is the cluster maintenance performed only within a single cluster, which does not involve other clusters, mainly in the following situations.

Mode 1 (Cluster splitting) When the number of CM within a cluster is larger than N_{max} and the number of CM in the adjacent clusters is between N_{min} and N_{max}, starts cluster split maintenance strategy. The CH determines the number *n* of clusters that will be split according to avg = mem / n , where *mem* is the number of CMs, *n* is the number of CHs in the current cluster, with the initial value of 1, the algorithm makes avg < N_{max} through *n* plus 1 to determine *n*. Then the cluster splitting algorithm is performed, CH specifies the former *n* nodes have the maximum energy in the cluster to the new CHs. The new CHs broadcast the CH message ADV_CH, CMs decided to join the strongest signals corresponding to the cluster where the CH located. In order to avoid the number of nodes in new cluster being greater than N_{max}, the new CH will no longer accept JOIN_REQ from the CMs when the number of JOIN_REQ messages equals to N_{max}.

(iii) Multi-cluster maintenance

When the damaged area of clusters within network is larger, and the damaged clusters (at least two) are adjacent, in order to conduct a comprehensive assessment and overall coordination, to achieve load balancing between clusters, a more rational use of network resources, setting the multi-cluster maintenance mode

Mode 2 (Cluster merging) When multiple adjacent clusters are damaged, and the number of nodes does not exceed after the merging of these clusters within a cluster, then start the cluster merge maintenance strategy. In the clusters merge process, setting the CH which first sends the merge message as the associated CH generally, responsible for inter-cluster notice. Other CHs of the adjacent clusters broadcast merge message in its respective cluster, and join the cluster where the associated CH located. Meanwhile the associated CH chooses the node of the largest energy as the new CH in the correlation clusters.

Mode 3 (Multi-cluster re-clustering) When multiple adjacent clusters are damaged, and the number of nodes exceeds N_{max} after the merging of these adjacent clusters within a cluster, then start multi-cluster re-clustering strategy in the multiple adjacent clusters within the scope of the damage.

Suppose there are n clusters damaged, set the CH which first sends the merge message as the associated CH generally, responsible for inter-cluster notice. Other CH of the adjacent clusters broadcasts in its respective cluster, and sends the number of CM to the associated with the CH. Then the associated CH determines the number of nodes in the consolidated clusters according to the received information, then calculates the average number of all the damaged adjacent clusters (including this cluster), denoted by avg as follows:

$$avg = \frac{\sum_{i=1}^{n} mem_i}{n}$$

Where mem_i is the number of nodes within the i -th adjacent cluster. By adjusting the value of n making avg not greater than N_{max} and not less than N_{min}, writes down the number of new CHs n at this time. Then the adjacent CH broadcasts the re-clustering message, starts the re-clustering based on LEACH algorithm within the scope of the damaged adjacent clusters to ensure the number of CHs is n.

4. Simulation and Results

Simulation involves scenarios, where 51 nodes randomly distributed in 975 m×578 m area. All sensor nodes have the same initial energy 20J, data packet size is 500 Bytes, head size of packet is 25 Bytes, and Base Station is located. Typically, the power consumption of receiving and transmitting circuit to deal with 1bit data is E_{elec} =50 nJ/bit, the power consumption of amplifier to deal with each bit data transmission is ε_{fs} =10 pJ/bit/m^2. Here the chosen simulation parameters are typical and same as papers of kind in order to conveniently compare each other in performances. Here the values of θ = 1.5 and β = 0.5. In the below figures red lines represents mode 2 whereas green line represents mode 3.

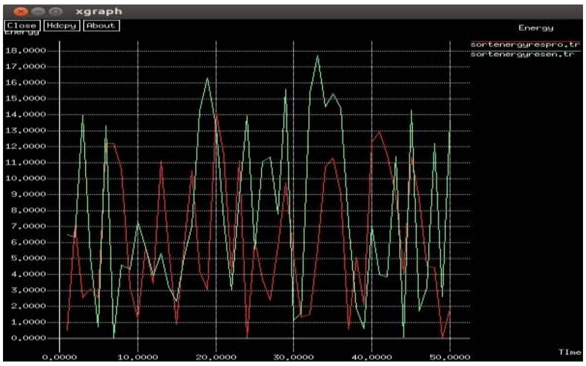

Fig-3 Showing energy remaining in mode 3 and mode 2. The energy remaining in mode 3 is more than in mode 2.

Fig-4 Showing control overhead in mode 3 and mode 2. The control overhead in mode 3 is more than in mode 2.

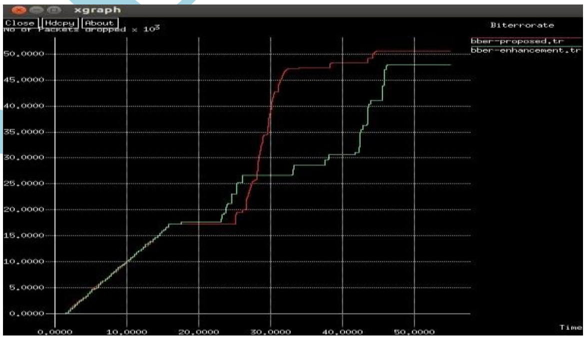

Fig-5 Showing Bit error rate in mode 3 and mode 2. The Bit error rate in mode 3 is less than in mode 2.

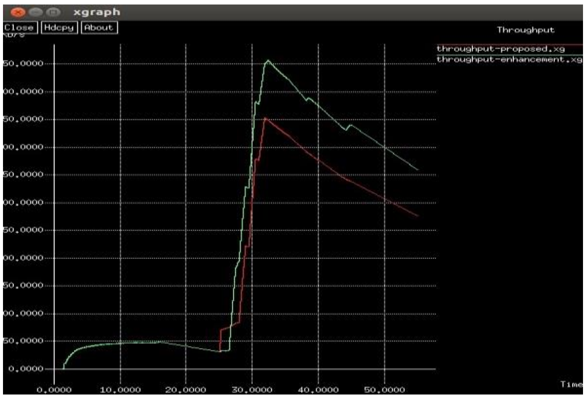

Fig-6 Showing Throughput in mode 3 and mode 2. The Throughput in mode 3 is more than in mode 2.

Fig-7 Showing Packet delivery ratio in mode 3 and mode 2. The Packet delivery ratio in mode 3 is more than in mode 2.

5. Conclusion

In this paper an energy-conserving multi-mode cluster maintenance method is proposed which works on event driven mechanism which improves energy utilization rate and the network service performance. It involves periodic re-clustering based on [2] New Hierarchical Stable Election Protocol (NHSEP) algorithm which gives better performance when compared with LEACH and SEP protocol. It does targeted maintenance and local cluster structural adjustment. Simulation is done using NS2 and performance parameters such as Energy Remaining, Bit error rate, Packet Delivery Ratio, Throughput and control overhead are compared. Based on results it is found that enhanced method saves a considerable amount of energy to maintain the damaged network thus prolonging the network life.

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