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A Load-Balanced Clustering Protocol for Hierarchical Wireless Sensor Networks

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Abstract—**The energy limitations and associated problems are main challenging issues for designing and employing battery powered wireless sensor networks (WSNs). This paper proposes a novel energy-efficient clustering protocol. The protocol uses a new algorithm for distributing cluster heads (CHs) in network. The cluster formation structure is used for load balancing among far and near cluster heads to the base station (BS). The paper focuses on intra-cluster communication and CHs use single hop scheme to communicate with BS. The protocol works well in small size networks. Simulation results verify that proposed protocol outperform over LEACH and TCAC protocols for 29% and 10% in term of functional network lifetime respectively.**

Keywords— wireless sensor networks, hierarchical clustering, energy efficiency, load balancing.

I. Introduction

The wireless sensor networks are mainly considered as potential solution to monitor physical and harsh environments with limited access and collecting data from them [1]. The limitations on battery and power systems of nodes, illustrate that energy is a critical issue for employing WSNs for different applications [2]. In recent years much research has been conducted to mitigate the critical challenges of energy constraints. In periodical data collecting application a common technique is used to cluster the nodes. In this approach, a leader node named cluster head (CH) node in each cluster is selected and all common nodes send their sensed data to corresponding CH node. The CH nodes aggregate the data and send them to the BS directly or via other nodes using multi-hop communication scheme. The main idea behind this technique is to decrease the number of messages that should be sent to the BS through local aggregation as well as decrease long-distance communication both for energy saving [3].

In fair management schemes of large scale WSNs the decentralized approaches are considered where nodes use local information to make decision about their tasks such as sensing, communicating and processing tasks using controlling packets. In this scheme one challenge is the CH count variation.

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In fact large cluster count has high inter cluster communication cost and small cluster count increases intra cluster energy consumption. The energy unbalancing among all nodes especially in CH nodes cause quickly draining energy of some nodes making network un-functional.

This may be due to CH nodes distribution, differences in nodes distances to the BS or special structure of used protocol. For example in case of communication approaches between CHs and the BS, in single hop scheme, the CHs that are farther to the BS have more energy consumption in contrast to multi hop communication scheme impose larger traffic burden on near BS nodes[4].

In proposed protocol in this paper, in order to mitigate CH count variation first some nodes are selected as CH candidates so that candidate number is larger than desired CH number and ,therefore, protocol knows how many candidates should be eliminated. On other hand for fair CH distribution, the protocol uses a distance based algorithm which in a repetitive manner delete some candidate. In this way the algorithm deletes some candidates, so a fixed CH count and a good possible CHs distribution could be achieved depending on candidate's distribution. In clustering scheme CH nodes have more energy consumption. In proposed protocol to protect low level energy nodes, these nodes have no chance to become CH node and CH nodes uses single hop approach to communicate with the BS. For balancing energy consumption in CHs, the clusters farther to the BS are smaller than close ones. This is deferent from common multilayer technique in WSNs that both CH node density and cluster size vary with distance to the BS.

In remaining of the paper, section II overview energy efficient hierarchical protocols, section III describes proposed protocol in detail, then in section IV proposed protocol is evaluated in term of energy efficiency and finally section V concludes the paper.

II. Related Works

This section provides a quick review on some related works on clustering protocols in WSNS. In [5], an adaptive distributed architecture named LEACH protocol was introduced. The protocol uses two star topology layers in network. In first layer, CH nodes are centers and in second layer the BS. The protocol assumes that all CHs or member nodes have the same energy consumption. Totally in LEACH all nodes have the same chance to become CH node.

In each round each node calculate its chance to become CH node as follows:

$$T(n)=\begin{cases}\dfrac{P}{1-P\left(r \bmod \dfrac{1}{P}\right)} & if \quad n\in G\\ 0 & otherwise\end{cases} \quad (1)$$

Where P is total cluster head probability, r is current round number and G is nodes that in *1/P* have not been selected as cluster head. The LEACH protocol cannot control the CH nodes distribution across the network and CH nodes count may be completely deferent from desired CH number.

In [6] an energy-aware protocol named TCAC is proposed. The TCAC protocol uses a powerful algorithm to have good CHs distribution in each round. This protocol tries to balance energy consumption in CH nodes and prolongs network lifetime.

III. The Proposed Protocol

This section first make all assumptions and network model, then give proposed protocol in details.

A. *Network Model*

- N nodes are dispersed in a M×M area and are fixed after deployment
- The base station (BS) is stationary and far from network area.
- Nodes don't have any information about their location and aren't equipped with global positioning system.
- Network application is periodic data collection and in each cycle called round sensed data are gathered and send to the BS after local aggregation.
- Each node can estimate its distance to another node or the BS based on strength of receiving signal from the node.
- The BS has not such limitation as processing, storing, energy.

B. *Energy Consumption Model*

In this paper a node consumes energy for transmitting, receiving and processing data as follows:

1) Transmitting mode

To transmit a L bit message to distance d required energy is:

$$E_{tx\,(d)}=\begin{cases}(E_{cx}+\in_m d^4).\mathrm{L} & \mathrm{d}\ge\delta\\ (E_{cx}+\in_f d^2).\mathrm{L} & \mathrm{d}<\delta\end{cases} \quad (2)$$

Where E_{cx} is radio circuit energy consumption, $\in_m$ and $\in_f$ are multipath fading channel and free space model factors.

2) Receiving mode

In this mode energy consumption is:

$$E_r = E_{cx}.L \quad (3)$$

3) Processing mode

It is assumed that the microcontroller consumes energy only for aggregating sensed data as follows:

$$E_{pr}=E_{DA}.n.L \quad (4)$$

Where n is number of data messages and E_{DA} is data aggregation energy.

C. *Protocol Description*

In this protocol each round is composed of two time duration called set up phase and steady state phase. In first phase, the cluster and cluster heads are selected then in second phase, the data gathering is performed depending on topology formed in previous set up phase so that member node send their data to assigned cluster head directly and cluster heads after aggregating gathered data send them to the BS directly. In following we explain how the protocol selects cluster heads and form clusters.

In an initial phase, before first round all nodes estimate their distance to the BS.

1) Cluster head selection

To select cluster heads proposed protocol first select some candidate from high level energy nodes depending on energy information provided by cluster heads in provirus round. In this way to protect low energy nodes, the nodes that their energy is less than a threshold (E_{th}) essentially are not the candidate. This threshold is different for different nodes but during network operation is fixed for each node:

$$E_{th_i}=((\frac{N}{K}).\mathrm{E}_{cx}.(1+\lambda)+\mathrm{E}_{t\,(\mathrm{d(i,BS)})}).L_{data} \quad (5)$$

where i is node ID, K is desired cluster head count, λ is protocol parameter between zero and one, L_{data} is data packet size and $d\,(\mathrm{i,BS})$ is distance between node i and the BS.

So in set up phase, all nodes with energy level more than corresponding E_{th} calculate a threshold number T as follows:

$$T_i=\frac{E_{res_i}}{Z} \quad (6)$$

where E_{res_i} is residual energy of node i and Z is:

$$Z=\frac{E_{Tot-Th}}{k_c} \quad (7)$$

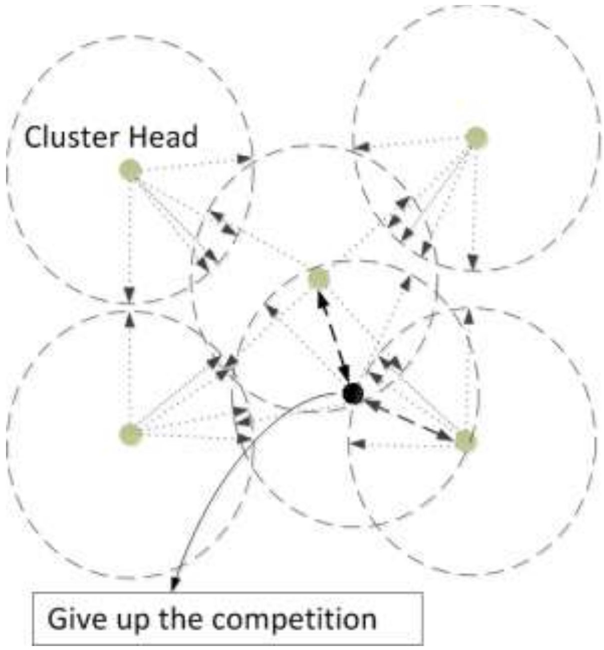

Figure. 1. The candidate eleminating approach

where K_c is expected candidates and E_{Tot-Th} is total energy of nodes that their energy is more than corresponding E_{Th} . Now each node produces a random number in $(0,1)$ and compares that with its T and if this value is less then T consider itself as a candidate otherwise in current round will be a member node. These elementary candidates introduces themselves by broadcast across the network using a *candidate-msg* including its ID and normalized distances to other introduced candidates in Rad radiance. As soon as number of introduced candidates satisfies k_c , remaining un-introduced candidates doesn't continue this procedure and will consider themselves as member nodes.

At first every candidate calculates its *pnt* value that is multiplying distances to other candidates (Rad is used instead of distances larger than Rad). Each candidate with respect to other *candidate-msg* calculates other candidates *pnt* values. The candidate with least *pnt* gives up the competition. The *pnt* values are recalculated but distances to eliminated candidate no longer aren't taken into account. A candidate with least *pnt* gives up the competition again. This procedure is followed till number of remaining candidates be equal to *K*. Fig. 1 shows an example of this procedure.

In some latest cycle of network operation nodes residual energy may be very low, such that the number of nodes with energy level higher than E_{th} is not bigger than k_c and these rounds are called *ltst* rounds. In these rounds nodes don't take E_{th} into consideration to become cluster head candidates and in relation (7), E_{Tot} (total remaining energy) is used instead of E_{Tot-th} .

2) Cluster formation

After determining cluster heads, they broadcast a message named *ch-msg* containing their ID, distance to the BS and spreading code. Now each member node hearing some or all of *ch-msg* messages select its cluster head to send sensed data to that, as follows:

If there is at least two CHs in R_{mem} (a parameter of protocol) radiance, the member node select one that is closer to ehe BS, otherwise select nearest cluster head.

Then each member node sends a *join-msg* message including its ID, cluster head ID and residual energy to inform its cluster head. Each cluster head identify its members and all cluster heads calculate E_{Tot-th} or E_{Tot} cooperatively to use in following round and inform all nodes about this value. After this procedure, like LEACH protocol, each cluster head sends a *schedule-msg* message to inform all members about time slot numbers that they should send their data and the medium access is based on TDMA protocol.

Now set up phase is ended and steady state phase get started.

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IV. Simulation Results

To evaluate proposed protocol in term of energy efficiency the proposed protocol is simulated and compared with two energy efficient protocol named LEACH and TCAC protocols. In this paper MATLAB tool is used to simulate all protocols. In literature there are deferent lifetime definitions. Totally, this depends on network application though some works define lifetime with respect to simplicity of protocol analysis [7]. In this paper the time to first node dead in round is considered as network lifetime. Therefore to increase lifetime a protocol should consider both energy consumption and load balancing especially among nodes in deferent region of network area. All parameters used in this paper is summarized in Table 1. The high R_{mem} values increase intra cluster communication distances and small values makes unbalancing in cluster head loads, so that farther to the BS cluster heads have more energy consumption. Also high cluster heads number increase data packets that should be sent to the BS consequently increase energy consumption especially in far BS cases. In small cases intra cluster energy consumption throughout the network is increased.

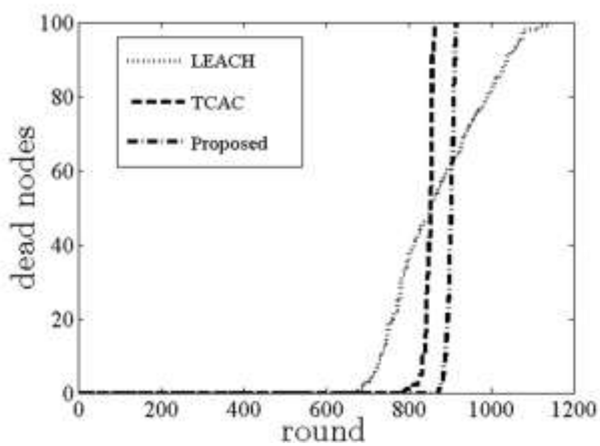

Fig. 2. The dead nodes in each round

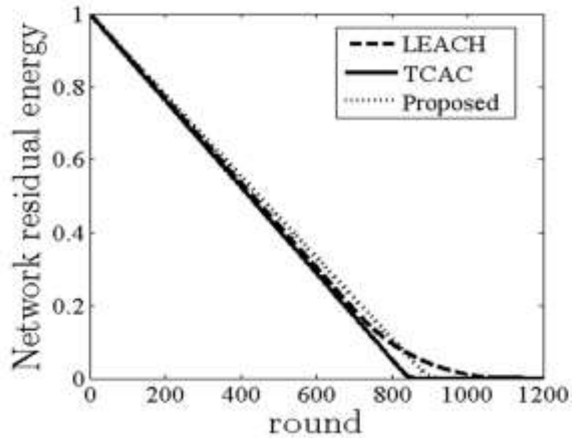

Fig. 3. The network residual energy

The simulation parameters are considered as; $k=5$, $k_c=8$, $\lambda=.5$ $Rad=55$ and $R_{mem}=25$ for simulation conducted in this paper. In the proposed protocol, the variation

of cluster head number is small. This is reasonable as expected cluster head number (k) is smaller than desired cluster head candidates (k_c). For LEACH protocol $k_{opt}=5$ is used and in TCAC protocol $K_{initial}$ and $Range$ is set to 30 and 32 respectively. Fig. 2 shows that proposed protocol decrease energy consumption and Fig. 3 shows the dead node number in each round considering after first node death.

As shown, the proposed protocol mitigates energy unbalancing among nodes and increase network lifetime. The proposed protocol can work with both heterogynous and homogenous networks as uses residual energy of nodes to select cluster heads.

V. Conclusion

This paper proposed a distributed energy-aware protocol that considers CH node count variation and CHs distribution across the network. Simulation results verified that proposed decreases total energy consumption along with improving load balancing. Also proposed protocol increased functional network lifetime 29% and 10% over LEACH and TCAC protocols respectively.

TABLE I. THE USED PARAMETERS AND NOTATIONS

Parameter	value
Area	(0,0)~(100,100)
Location of BS	(50,175)
N	100
$E_{initial}$	.5J
E_{cx}	50 nJ/bit
$\in_m$	10 pJ/bit/m^2
$\in_f$	.0013 pJ/bit/m^4
δ	87
E_{DA}	5 nJ/bit/signal
Data Packet size	4000 bits
Control Packet Size	200 bits

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