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An improved energy aware distributed unequal clustering protocol for heterogeneous wireless sensor networks

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ABSTRACT

In this paper, an improved version of the energy aware distributed unequal clustering protocol (EADUC) is projected. The EADUC protocol is commonly used for solving energy hole problem in multi-hop wireless sensor networks. In the EADUC, location of base station and residual energy are given importance as clustering parameters. Based on these parameters, different competition radii are assigned to nodes. Herein, a new approach has been proposed to improve the working of EADUC, by electing cluster heads considering number of nodes in the neighborhood in addition to the above two parameters. The inclusion of the neighborhood information for computation of the competition radii provides better balancing of energy in comparison with the existing approach. Furthermore, for the selection of next hop node, the relay metric is defined directly in terms of energy expense instead of only the distance information used in the EADUC and the data transmission phase has been extended in every round by performing the data collection number of times through use of major slots and mini-slots. The methodology used is of retaining the same clusters for a few rounds and is effective in reducing the clustering overhead. The performance of the proposed protocol has been evaluated under three different scenarios and compared with existing protocols through simulations. The results show that the proposed scheme outperforms the existing protocols in terms of network lifetime in all the scenarios.
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1. Introduction

Wireless sensor networks (WSNs) are characterized by many resource constraints such as energy, processing power, storage and transmission range. Out of these factors, energy of deployed sensors has been the major resource constraint of the wireless sensor networks. Lot of research work has been carried out in the last decade to address this challenge [1–3]. WSNs are deployed densely for data gathering applications involving a large amount of area such as agriculture, forests, coal mines, monitoring of rail tunnels, monitoring of solar photovoltaic cell in a grid, etc., and WSNs require data from all locations [2,4–6]. The base station (BS) is placed far away from the sensing field in most of the cases. In such networks, data are gathered periodically by the BS. Clustering with hierarchical topology is found to be successful for realizing continuous monitoring networks [7–11]. It is exhibited that clustering the network offers greater lifespan than the network with direct data transmission. It is shown that the network lifespan gets improved by a factor of about 2 or 3 times with clustering [12].

There are many advantages of using clustering protocols in data-gathering networks. In dense network, normally there is large volume of traffic among the sensors, which leads to creation of interference and subsequently results into collisions. It is expected that grouping the sensors would minimize the number of long distance transmissions and thereby result into saving of the energy. In clustering, the normal sensor nodes (cluster members) sleep times are drawn out, while cluster heads coordinate the activities of its member nodes, again resulting into energy saving [13]. This activity scheduling is executed largely through TDMA based schedule [5,11,14,15]. Also clustering facilitates data aggregation at cluster head (CH) by decreasing the number of transmitted data packets, which helps in reduction of energy consumption of sensor nodes [13].

The communication in clustering protocols is executed in two steps, first is intra-cluster, i.e. within the clusters, and the second is inter-cluster, i.e. between the clusters and the BS. Furthermore, the communication in a wireless sensor network clustering protocol can be taken up either by employing single hop transmission, or multi-hop routing [16,17]. Most of the clustering protocols use single hop communication for communicating inside the cluster, as the distance between sensors within the cluster is relatively short, e.g. LEACH [11], LEACH-DT [15], HEED [18], etc. Researches proposed in literature report that multi-hop communication between

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the sensor nodes and the cluster head is more energy-efficient than single hop communication, when the propagation loss exponent is high. This is when sensor nodes are deployed in dense vegetation regions, or buildings, or factories [1,16]. In such cases, multi-hop communication is successful in overcoming signal propagation difficulties [1,7]. However, because the radio dissipates energy in not only transmission but also in reception, direct transmission is also useful. But there is a limitation in case of direct transmission also. It is good to use it up to a certain threshold distance only [19]. This is because in case of transmission distance beyond threshold distance, the energy expense increases according to the fourth power of the distance [15,20]. As the sensor nodes are energy constrained, they usually have a limited transmission range. Thus, in order to increase the network scalability also, multi-hop communication is preferable [21]. In case of communication from cluster head node to the BS, if BS being far away from sensor field, then, it is better to use multi-hop communication [19]. There are number of clustering protocols developed that use multi-hop communication for achieving more energy-efficient inter-cluster communication. Multi-hop LEACH [22], EADC [23], EDUC [24], etc. are some such protocols.

One of the primary concerns in wireless sensor networks is maximization of network lifetime because after the network becomes dysfunctional, significant amount of energy should not remain in the nodes, otherwise it is wastage. Many research works has defined the network lifetime to be when the first node is dead (FND). The idea behind this assumption is that it is important that all the nodes of the network die out approximately at the same time in order to avoid early loss of sensing coverage, and likely partitioning of the network [8,11,15,18]. But, as the lifetime requirement is application-specific, considering the first node dead as the lifetime definition is not a generic one [25]. There are different types of sensor network's applications [26] and therefore, to cater to different application requirements, lifetime of the network has also been evaluated at different stages, i.e. the time when first node dies, or certain percentage of nodes fail [27]. In any case, it is more important that network functions autonomously and guarantees its operation until its lifetime [28].

In a clustering protocol, a CH is heavily burdened as it has to perform various tasks such as cluster formation, data aggregation, data transmission and relaying. Cluster heads therefore consume more energy as compared to non-CH nodes. In inter-cluster transmission for both the modes of communication, single hop and multi-hop, there is inevitable problem of energy imbalance among sensor nodes [24]. For single hop communication, cluster heads which are far away from BS drain out their energy primarily because of the long distance transmission. But when using multi-hop communication in clustering protocols, then, the cluster heads near the base station deplete their energy quickly because of the extra burden of traffic relaying. This unbalanced communication load results in energy hole or hot spot area. Due to this, loss of sensing coverage and partitioning of the network occur and ultimately affect the network performance. Previous research [29] has demonstrated that if sensors are distributed uniformly in the area of interest, 90 percent of the total energy of the sensors is left unused when network lifetime ends, i.e. the time when first node is dead. It is proved in reference 30 that unbalanced energy depletion among all the sensors is unavoidable because of many-to-one communication paradigm in WSNs. For maximizing the network lifetime, energy consumption among all the network nodes must be balanced. Recently, much research has been carried out to address energy imbalance and mitigate energy hole problem for clustered WSNs. A number of strategies such as using node mobility [31,32], mobile sink [33–36], hierarchical deployment [37], non-uniform clustering [8,24,38], data compression and traffic aggregation [36,39], node distribution [2,29,30,40], etc. have been proposed for solving energy hole problem.

In this paper, an attempt has been made to improve network lifespan of an EADUC protocol used in continuous monitoring applications [38]. The EADUC employs non-uniform clustering algorithm to mitigate the energy hole problem. The core idea in our proposed scheme is that during the cluster head selection sub-phase, nodes competition radius assignment would be based on not only the distance factor and node's residual energy as is used in EADUC, but also a tertiary factor, number of neighbor nodes. This neighborhood information is considered as the clustering parameter to extend network lifespan. Another key idea used in our improved EADUC protocol is during selection procedure of traffic relaying. The cost involved in relaying, in terms of energy, is incorporated as the metrics for selecting one of the feasible nodes as a relay node instead of only the distance information used in EADUC. The proposed scheme poises the energy consumption of the nodes in the network for uniform distribution as well as for non-uniform distribution. Further to enhance the network lifetime, the idea of extending the data transmission phase by dividing into major slots and mini-slots is effectively combined with the proposed clustering and relaying technique as used in reference 41. The data collection occurs in each mini-slot using the same clusters once formed and the number of mini-slots comprises a major slot. After each major slot, cluster head rotation within the current cluster boundary and handover of the cluster members takes place. The proposed approach reduces the clustering overhead and thereby prolongs the network lifetime. The performance of our proposed protocol is compared with the existing protocols using network lifetime as the performance metric.

The remainder of this paper is organized as follows: Section 2 reviews the related work and Section 3 presents the system model. Section 4 describes the proposed protocol operation in detail and Section 5 analyzes the protocol characteristics. Section 6 gives the simulation results of our sensor deployment schemes and compares it with existing protocols. Section 7 concludes the paper.

2. Related work

Earlier research work undertaken in the area of clustering algorithms has been primarily based on the rotation of role of cluster heads in every round, and selecting cluster heads with more residual energy in order to enhance the lifespan of the network. A pioneer protocol available in this category is low-energy adaptive clustering hierarchy (LEACH) protocol [20]. The LEACH protocol assumes one-hop communication between the nodes and to the base station. This makes it unsuitable for large-scale networks. Many LEACH based protocols have been developed in the past which are improvements over the LEACH protocol, such as LEACH-DT [15] or a multi-hop variant of LEACH, called as M-LEACH [1]. A hybrid energy-efficient distributed (HEED) clustering algorithm is proposed in reference 18, which select cluster head according to not only the node residual energy but also intra-cluster communication costs. It uses multi-hop communication among the cluster heads for inter-cluster communication. It is successful in prolonging the network lifetime but not so effective in balancing the communication load as node's closer to BS still die faster. Another protocol, the distributed energy efficient clustering algorithm (DEEC), is available [42]. In DEEC, cluster heads are chosen by a probability that is based on the ratio of residual energy of a node and the average energy of the network. In all these energy-efficient clustering schemes, although periodic rotation of cluster head function sees that nodes run through energy more evenly, but it is not effective in avoiding the energy hole problem of many-to-one data gathering wireless sensor networks.

Many methods have been proposed in literature for mitigating the energy hole problem, and thereby maximizing the network

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