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An Unequal Multi-hop Balanced Immune Clustering protocol for wireless sensor networks

Nabil Sabor[a,b,*], Mohammed Abo-Zahhad[a], Shigenobu Sasaki[b], Sabah M. Ahmed[a]

[a] Electrical and Electronics Engineering Department Faculty of Engineering, Assiut University, Assiut 71516, Egypt
[b] Department of Electrical and Electronic Engineering, Niigata University, Niigata 950-2181, Japan

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ABSTRACT

In multi-hop routing, cluster heads near the base station act as relays for far cluster heads and thus will deplete their energy very quickly. Thus, hot spots in the sensor field result. This paper introduces a new clustering algorithm named an Unequal Multi-hop Balanced Immune Clustering protocol (UMBIC) to solve the hot spot problem and improve the lifetime of small and large scale/homogeneous and heterogeneous wireless sensor networks with different densities. UMBIC protocol utilizes the Unequal Clustering Mechanism (UCM) and the Multi-Objective Immune Algorithm (MOIA) to adjust the intra-cluster and inter-cluster energy consumption. The UCM is used to partition the network into clusters of unequal size based on distance with reference to base station and residual energy. While the MOIA constructs an optimum clusters and a routing tree among them based on covering the entire sensor field, ensuring the connectivity among nodes and minimizing the communication cost of all nodes. The UMBIC protocol rotates the role of cluster heads among the nodes only if the residual energy of one of the current cluster heads less than the energy threshold, as a result the time computational and overheads are saved. Simulation results show that, compared with other protocols, the UMBIC protocol can effectively improve the network lifetime, solve the hot spot problem and balance the energy consumption among all nodes in the network. Moreover, it has less overheads and computational complexity.

1. Introduction

Wireless sensor network (WSN) is an emerging information acquisition technology. It has got a great scientific research development in recent years. Also, it has been used widely in many fields such as military, surveillance, medical aspects (e.g. monitoring patients) and environmental studies (e.g. flood, localization and tracking). A WSN typically consists of many small, low cost, low-power communication devices called sensor nodes. Each sensor node has limited on-board processing, limited storage and radio capabilities. Due to limited and non-rechargeable battery options, the energy resource of the node should be managed wisely. The energy-efficiency is the primary design issue, which greatly affect the WSN lifetime [1–3].

In the recent years, researchers developed many clustering protocols [1–5] to improve the lifetime, the bandwidth reusability and the scalability of WSNs. Clustering scheme divides the network into equal clusters, where each cluster consists of a Cluster Head (CH) node and many member nodes. Once the network has been divided into clusters, the communication between nodes can be intra-cluster or inter-cluster. Intra-cluster communication comprises the message exchanges between the member nodes and their respective CH, while inter-cluster communication includes transmission of CHs messages to base station (BS) via a single-hop or a multi-hop routing. In single-hop networks, the dissipated energy of CHs farther away from the BS is higher than that of the closest CHs to the BS due to a long distance. While in multi-hop networks, the closest CHs to the BS undertake data forwarding, which means that the energy consumption of these CHs is higher. This imbalance energy consumption leads to the death of a certain number of nodes prematurely, causing "hot spot" problem [6–12].

This paper proposes a new clustering protocol called an Unequal Multi-hop Balanced Immune Clustering protocol (UMBIC) to mitigate the hot spot problem and improve the lifetime of small and large scale/homogeneous and heterogeneous WSNs with different nodes' densities. In UMBIC, BS utilizes the Unequal Clustering Mechanism (UCM) [6,13] and the Multi-Objective Immune Algorithm (MOIA) [14–18] to partition the network into optimum unequal clusters on the basis of ensuring the connectivity among

* Corresponding author. Current address: Department of Electrical and Electronic Engineering, Niigata University, Niigata 950-2181, Japan. Tel.: +81 08092746344.
E-mail addresses: nabil_sabor@aun.edu.eg (N. Sabor), zahhad@yahoo.com (M. Abo-Zahhad), shinsasaki@ieee.org (S. Sasaki), sabahma@yahoo.com (S.M. Ahmed).

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nodes, balancing the consumption energy among nodes and minimizing the communication cost for data and overhead control packets. The MOIA algorithm is one of recently evolutionary algorithms. It has been considered here due to the following features [14,15]: (1) It has the global search performance; (2) It produces the solution sets that are highly competitive in terms of convergence, diversity and distribution; (3) It has elitism, which inherently embedded in the selection mechanism to preserve good solutions and not lose them during generations; (4) It adapts the population to a reasonable size for the specific problem and this reduces the number of objective function calls; and (5) It has much less computational cost.

The rest of the paper is organized as follows. Section 2 is a literature survey about various clustering protocols. The preliminaries and formulation of the clustering problem are explained in Section 3. Section 4 discusses the details of the proposed UMBIC protocol. The analysis of the UMBIC protocol is explained in Section 5. In Section 6, simulation results and discussion are given. Finally, Section 7 offers some conclusions.

2. Related works

Many clustering protocols have been developed in the past few years to maximize the lifetime of WSNs [1–3]. Low Energy Adaptive Clustering Hierarchy (LEACH) [1] is the most popular single-hop based clustering scheme, which plays a great role in reducing energy consumption of the sensor nodes and enhancing the network lifetime. In order to balance the energy depletion, the role of CH is periodically rotated among the nodes. LEACH has been widely served as a benchmark, so that a lot of improvement schemes based on this algorithm have been developed such as LEACH-Centralized (LEACH-C) [1], LEACH-based Energy (LEACH-E) [2] and a centralized Genetic Algorithm-based Energy-Efficient adaptive clustering hierarchy Protocol (GAEEP) [3]. Due to the limited transmission range of sensor nodes and large scale of WSNs, the previous literature [4–12] have shown that the single-hop routing is obviously a waste of energy. Therefore for energy-saving purposes, many multi-hop equal clustering protocols [4,5] have been developed. In [4] a cluster-based routing protocol for WSNs with non-uniform nodes distribution was presented. It includes an Energy-Aware Distributed Clustering Algorithm (EADC) and a cluster-based routing algorithm to construct clusters of even sizes. The imbalanced energy consumption caused by non-uniform nodes distribution is solved by increasing forwarding task of CHs in sparse areas. Decentralized energy-efficient Hierarchical Cluster-based Routing protocol (DHCR) was suggested in [5] to reduce the energy consumption caused by extra control message transmissions. Therefore, concurrently with the CHs selection, a routing tree is constructed among CHs and BS is located at the root. DHCR balances a load distribution between CHs by selecting a next hop relay node with more residual energy. Moreover, it prevents premature death of relay CHs close to BS by making common nodes associate with high-energy CHs, in a low-density area which are not close to BS.

Although the equal clustering schemes balance the average energy consumption among different intra-cluster communications well, they ignore the energy balancing problem among CHs in the inter-cluster communication. The nearest CHs to the BS take a heavier energy burden to relay data of the farthest CHs via multi-hop routing, so that they deplete energy more rapidly which cause a hot spot problem [12]. Thus, several distributed and centralized unequal clustering protocols [6–11] have been developed to solve this problem. Distributed clustering protocols depend on the local information and are executed on each node. Authors in [6] suggested an Energy-Efficient Unequal Clustering protocol (EEUC) to mitigate the hot spot problem of homogeneous WSNs. EEUC wisely organizes the network via unequal clustering and multi-hop routing. It is a distributed competitive algorithm, where CHs are elected by localized competition, and the node's competition range decreases as its distance to BS decreases to balance the load of CHs. But in CHs election process of EEUC, the residual energy of nodes is not considered and the iterative phenomenon can be raised easily in the clustering process. In [7] an Unequal Cluster-based Routing (UCR) distributed protocol was presented to solve the hot spot problem of homogeneous WSNs based on an unequal clustering mechanism. UCR consists of two parts; the first one is an Energy-Efficient Unequal Clustering (EEUC) algorithm for topology management. While the other part is a greedy geographic and energy-aware routing protocol for inter-cluster communication, which considers the trade-off between the energy cost of relay paths and the residual energy of relay nodes. However, the close CHs to BS are burdened with heavy relay traffic and tend to die early, leaving areas within the network uncovered and causing network partition. A distributed Unequally Clustered Multi-hop Routing (UCMR) protocol was developed in [8] to improve the energy consumption of homogeneous WSNs. UCMR calculates the cluster size based on its distance with reference to BS. It uses the multi-hop routing with Dijkstra's shortest path algorithm for intra-cluster and inter-cluster transmission. In [9] a Distributed Energy-efficient Unequal clustering routing protocol (DEU) was designed based on combining uneven clustering and multi-hop mechanism to prolong the lifetime of WSNs. DEU balances energy consumption among CHs by varying the competing radius of CH according to its distance to BS and energy. In constructing routing tree, CHs calculate optimal forwarding hops, and then they select the relay nodes with considering candidate-nodes' optimal forwarding hops, residual energy and communication cost.

On the other hand, centralized clustering protocols rely on the information of all nodes in the network and are executed at the BS. A centralized Improved Fuzzy Unequal Clustering scheme (IFUC) has been adopted in [10] to balance the energy consumption and prolong the lifetime of large-scale homogenous WSNs. Based on gathering the information of nodes such as energy level, distance to BS and local density, IFUC uses a fuzzy logic system to estimate each node's chance of becoming CH and the CH competition radius. Moreover, it uses Ant colony optimization method to construct the energy-aware routing between CHs and BS. The tentative CHs in IFUC are selected randomly, which then run fuzzy logic for final CHs selection. Thus, there are chances that nodes with less residual energy, ones which are far from BS or having fewer neighboring nodes might become final CHs. In [11] a centralized Energy-Balanced Unequal Clustering routing protocol (EBUC) was presented to improve the lifetime of homogenous WSNs. By utilizing the particle swarm optimization (PSO) algorithm, EBUC partitions all nodes into clusters of unequal size, in which the close clusters to the BS have smaller size. CHs of these clusters can preserve some more energy for the inter-cluster relay traffic and the hot spot problem could be avoided.

Even though the existing unequal cluster-based protocols can effectively mitigate the hot spot problem, they have some shortages. The shortages of the distributed protocols are: (1) they do not guarantee that the elected CHs cover the whole sensing field; as a result the CHs are randomly dispersed and do not guarantee fully connected network; (2) they have no control on the percentage of CHs they create, so the number of CHs selected varies rapidly from round to round; (3) they suffer from an imbalanced energy dissipation among sensor nodes due to irregular CHs formation; and (4) they require processing power from the sensor nodes which have limited processing and power capabilities, as a result the battery level of the sensor nodes may run low quickly. While the shortages of the centralized protocols are: (1) they bring a high