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NODIC: a novel distributed clustering routing protocol in WSNs by using a time-sharing approach for CH election

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Abstract Due to the battery limitations, energy-efficient routing is one of the most important issues in WSNs. In this paper, a novel distributed clustering routing protocol (NODIC) is proposed. The algorithm makes three main contributions to literature. Firstly, a time-sharing approach for CH election is suggested differently from the studies in literature. The most effective parameters are combined in a time-sharing approach on the purpose of gaining the highest performance. Secondly, easy implementation and self-reliant decision of probabilistic schemes and the guarantee that iterative schemes issue about selecting the desired CHs are pieced together without using any of them. Finally, since CH decision is performed locally and dynamically, the clusters can make their decisions independently from the others. NODIC is compared with three common corresponding approaches in literature for various values of the number of nodes and under different traffic distributions. The algorithms are evaluated by using the number of living nodes and total energy consumptions per round. The results show that NODIC performs considerably better than the other approaches for all number of nodes and under all distributions up to 79 %.

Keywords Wireless sensor networks · Routing · Distributed clustering · Cluster head

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1 Introduction

Wireless sensor network (WSN), which is widely considered as one of the most important technologies for the twenty-first century, typically consists of a large number of low-cost, low-power, and multifunctional wireless sensor nodes, with sensing, wireless communications and computation capabilities and one or more powerful sinks or base stations (BSs) collecting information from these sensor nodes. These sensor nodes communicate over short distance via a wireless medium and collaborate to accomplish a common task, including military surveillance, event detection, target tracking, environment and habitat monitoring, localization, safety navigation and industrial process control [1, 2].

Vast deployment of nodes on large-scale dimensions inclines deep investigation on routing protocols to ensure reliable and real-time data transmission, while considering the power constraints inherent in WSNs. A sensor node is generally powered by a battery and is unattended once deployed. Therefore, the proposed routing protocols for WSNs should not only address the challenges regarding the quality of service of the application such as real-time operation, fault tolerance, scalability and data reliability, but the limited capabilities of WSNs in energy storage, processing, memory and communication and topology changes due to nodes' mobility and demises should be addressed too [3, 4]. Owing to the fact that traditional routing protocols are not suitable for the unique characteristic of WSNs, a large number of research activities [5–22] have been carried out to explore and overcome the constraints of WSNs and solve design and application issues.

The routing protocols in WSNs can be divided into flat routing and hierarchical routing according to the network structure. All nodes perform the same tasks and have the same functionalities in the network in flat topology. Data transmission is performed hop by hop usually using the form of flooding. Although flat routing protocols are relatively effective in small-scale networks, it is out of favour in large-scale networks due to resource limitations for generating more data processing and using more bandwidth [23]. On the other hand, hierarchical routing algorithms are becoming an active part of routing technology in WSNs on account of a variety of advantages, such as greater scalability, less load, less energy consumption and more robustness [24].

The nodes in a hierarchical topology perform different tasks in WSNs and typically are organized into clusters according to specific requirements or metrics. Normally, each cluster comprises a leader referred to as cluster head (CH) and other member nodes (MNs) [23]. Coordination of a group of nodes located within the boundaries of the cluster, aggregating the sensed data by the cluster members and transmission of the aggregated data to the next hop or directly to BS are the main duties of a CH. Therefore, CH selection plays a significant role in the subsequent procedures of a clustering algorithm and thus performance, lifetime and energy-efficiency of the network. Due to this importance, many researchers have focused on optimizing the CH selection process [3]. Various factors, including location of the node with respect to the other nodes, mobility, energy level, trust and throughput of the node, can be considered for electing the best node as a CH [25]. However, using the parameters of the energy level and the location of the nodes for the CH election process are considerably popular in literature and these parameters can either be used singly [26–29] or together [30–33].

A significant issue apart from how to select CHs is where to operate this process. Clustering routing protocols in WSNs can be grouped into centralized routing, distributed routing and hybrid routing based on control manners of clustering. In centralized methods, a sink (or CH) requires global information of the network (or cluster) to control it. In distributed approaches, a sensor node is able to become a CH or to join a formed cluster on its own initiative without global information of the network or the cluster. Hybrid schemes are composed of centralized and distributed approaches [23]. Distributed clustering, which provides better collection of data and reliability than centralized methods, has a wide coverage in literature [34].

On the purpose of selecting CHs, the distributed clustering approaches in literature either use probabilistic schemes, including LEACH [26], WST-LEACH [31], CCRP [32], MELEACH-L [29], or iterative schemes, including HEED [30], DWEHC [33], CBHRP [35], HAUSDORFF [36]. The ease of implementation and self-reliant decision without any extra communication cost are the advantages of probabilistic schemes. Although the probability increases with using a threshold value in this approach, there is no guarantee to select the best candidate as CH according to the desired parameters. Therefore, some studies use a series of iterations to find the best CH. However, these iterations bring about extra communication cost due to the usage of control messages, which causes more energy usage, so adversely affect the network lifetime.

In this paper, a novel distributed clustering routing protocol (NODIC), which guarantees to elect the best candidate as CH without any iteration cost, is proposed. Besides, a comparison study between the most common CH election parameters, including the energy and the location of the nodes, is performed under the same circumstances (i.e. using a single cluster). The results show that if the CHs are selected according to their energy level, a productive usage of the network is achieved because the first node death is delayed. However, if the CHs are elected according to their inter-cluster and intra-cluster communication cost (i.e. optimum location) the network lifetime prolongs. According to the results, differently from the researches in literature, instead of combining these parameters in an equation by assigning a weight to each one, a time-sharing approach is proposed. The decision of using the energy level or the location of the node for CH election process is done in each cluster locally and dynamically according to the network situation. Thus, the best parameter can be used to elect the best CH in a cluster independently from the other clusters in network without an extra iteration cost.

The remainder of the paper is organized as follows. In Sect. 2, related work is briefly reviewed. Section 3 describes the simulation environment with the network model and explains the preparatory work including the comparison of the parameters used in CH election process. Section 4 presents the details of the proposed algorithm with its cost analysis and advantages. Finally, Sect. 5 shows the performance of the proposed algorithm by comparing it with its equivalent approaches.

2 Related work

2.1 CH election methodologies in distributed clustering approaches

In distributed clustering schemes, the CH selection decision is distributed within the network and each node. Either stochastically or involving some probabilistic parameters, nodes compete to be selected as CH [3].

The LEACH protocol, which was introduced by Heizelman et al. [26], is one of the most popular energy efficient distributed clustering routing protocols proposed for WSNs and has been utilized as the basis for many other subsequent protocols of such a kind [37]. The clusters are dynamically formed by neighbouring nodes in a distributed manner. Each CH that is a randomly chosen node in a cluster, forwards the aggregated data, which consists of the data collected from its cluster MNs, directly to the base station. The election of CH is based on the suggested percentage of CHs for the network and the number of times the node has been a CH so far.

Although some other proposed methods in literature still distribute CH election process among the sensor nodes, the procedure is not based on sheer probabilistic solutions, and rather node resources and other determinant factors are weighed up in selection of the optimum CHs. The energy level and the location of the nodes are commonly used parameters in CH election process. Some studies [27, 28] intend to select the nodes having the highest remaining energies as CH. The plenty of others [30–33] use an additional factor of inter-cluster and intra-cluster communication cost, which depend on the location of the node. When the remaining energy level of nodes are included in the decision of CH election process, the performance of the network increases up to 40 % [27], while the location of the nodes are also taken into consideration with the remaining energy parameter, the rate of the performance difference can achieve to 80 % [32].

2.2 Cluster formation methodologies in distributed clustering approach

In distributed clustering schemes, cluster formation is either performed by an equation used as a threshold value [27, 28, 31, 32] or a series of iterations [30, 33, 35, 36]. For selecting CHs, the threshold value, which is calculated from a predetermined equation, is compared with a random number generated on every round by all of the nodes. Various parameters, including the energy level and the location of the nodes, with various weights can be used for the constitution of the equation. In these approaches, the CH election decision is conducted in every node independently from the other nodes in the network. Therefore, an extra communication cost is not weighted upon the network. Besides, ease of implementation and scalability make this approach attractive.

Although using a threshold value increases the probability of a desired node to be selected as CH, it does not guarantee due to the factor of randomness. Therefore some other researches [30, 33, 35, 36] use a series of iterations instead of a threshold value for guarantying the best candidate nodes to be elected as CHs. In these approaches, since the desired nodes become CHs, more efficient usage of node batteries is provided. However, these iterations require additional control messages (i.e. broadcasts) to select the best CHs, which incline more energy usage of the nodes (i.e., the network lifetime is adversely effected).

3 Evaluation methodology

3.1 Simulation environment and network model

In this paper, the evaluation of both the preparatory work and the proposed algorithm with the compared algorithms in literature are conducted via simulation by using OMNeT++, which is an extensible, modular, component-based C++ simulation library and framework, primarily for building network simulators [38]. Since OMNeT++ has a generic architecture it can be used in various problem domains, such as modelling of wired and wireless communication networks, modelling of queueing networks and modelling of multiprocessors and other distributed hardware systems.

The cluster-based network model used in this paper, which has three basic components called BS, CH and MN, can be seen in Fig. 1. The BS or sink is responsible from evaluating the data, which is gathered from the CHs. The MNs transmit their data to its CH, while the CHs receive data from all of its cluster members, perform signal processing functions on the data, i.e. data aggregation, and transmit the aggregated data to the remote BS [39].

3.2 Preparatory work: energy VS location

In general, nodes with higher energies act as CH and perform the task of data processing and information transmission, while nodes with low energies act as MNs and perform the task of information sensing [23]. Therefore, most of the studies in literature are in tendency to elect the node with highest remaining energy as CH [27, 28]. Besides, with the purpose of minimizing the energy consumption of CH due to information transmissions, some studies in literature considers inter-cluster and intra-cluster

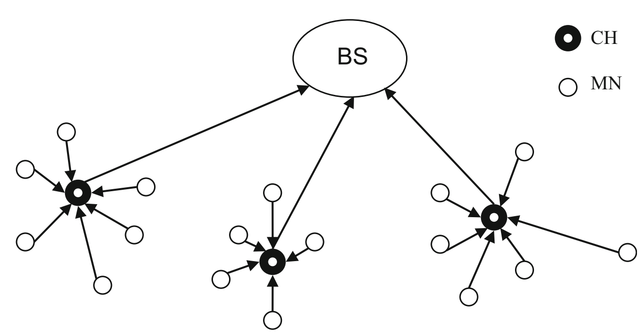

Fig. 1 A cluster-based network model

communication cost for CH election process [30–33]. In a clustered network, the communication is divided into intra-cluster, which refers to the communication from the member nodes of a cluster to their cluster head, and inter-cluster, which denotes the communication from CHs to a data center, i.e. sink or base station [33].

For the purpose of observing the effect of these parameters on CH election process, a preparatory work is carried out in this paper. The first parameter is the remaining energy of the nodes, while the second parameter is the optimum location of the nodes, which refers to the location that minimizes inter-cluster and intra-cluster communication cost. For accomplishing an accurate evaluation, the performance of these parameters should be observed under equal circumstances. Therefore, the simulations are performed on a single cluster having twenty nodes by using OMNeT++. The number of the nodes used in this single cluster refers to average number of nodes in a cluster of a 100 node system [26], which specifies the expected probability of CHs as 0.05. The energy model of designed system is the same as LEACH_C [27]. The simulation parameters used in this preparatory work can be seen in Table 1.

Figure 2 shows the number of living nodes in each round when the highest remaining energy and the optimum location of the nodes are taken into consideration on CH election process. As is seen in Fig. 2, if the nodes with the highest remaining energies are selected as CHs, although the death of the first node (round no: 1475) is postponed, the number of living nodes inclines a sharp downfall. This situation signifies that the data can be collected from the network with the highest rate for a certain time, but after a node dies, the network lifetime has discontinued in a short time (i.e. the last nodes dies at the round of 1951). If the nodes having the optimum locations are selected as CHs, although the death time of the first node is earlier (at the round of 687), the death of the resting nodes shows almost a linear tendency, so the death time of the last node is prolonged (round no: 2342), which brings about longer network lifetime. Some applications may demand longer network lifetime, while others can desire higher data rates, i.e. more yielding detection statistics from sensed area. In

Table 1 The simulation parameters used in preparatory work

Parameter	Value
Network area	20 m × 20 m
Number of nodes	20
Number of clusters	1
Position of sink	(0, −50)
Initial energy	0.5 J

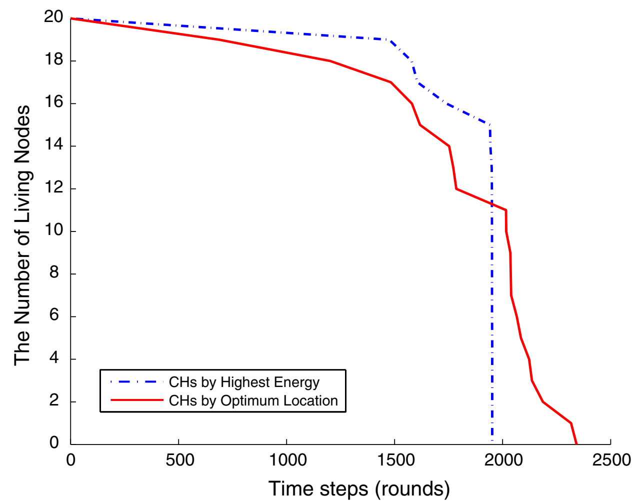

Fig. 2 The number of living nodes in each round when the remaining energy and the optimum location of the nodes are taken into account on CH election process

this case, the applications can choose the appropriate parameter between energy and location according to their unique requests. However, independently from the application, these parameters should be implemented together for keeping the network alive longer with higher data rates. In this paper, differently from the researches in literature, instead of assigning weights to these parameters and combine them in a single equation, a time-sharing approach is proposed.

In proposed work, due to the delayed death of the first node, CHs are elected according to their energy level for a certain time. After a while, the system switches the CH election parameter from residual energy to optimum location for prolonging the network lifetime. In order to determine the optimum switching time, a series of simulations are conducted. Figure 3 shows the number of living nodes on each round under different switching rates ranging from 50 to 80 %. As long as average energy of the nodes in a cluster in any round is higher than x % (i.e. switching rate) of their total initial energies, the nodes sustain electing themselves as CHs according to the highest residual energy. Otherwise, the CH election is based on optimum location of the nodes. Therefore, the switching rate of 100 % signifies that the CH election process only depends on the highest residual energy, while the switching rate of 0 % implies that the CHs are solely elected according to their optimum location.

As is seen in Fig. 3, the performance of the switching approach ranges between the individual performances of energy and location, independently from the switching rate. Bu using this switching method, both the death round of the first node is postponed in comparison with the corresponding round under location parameter and the death of

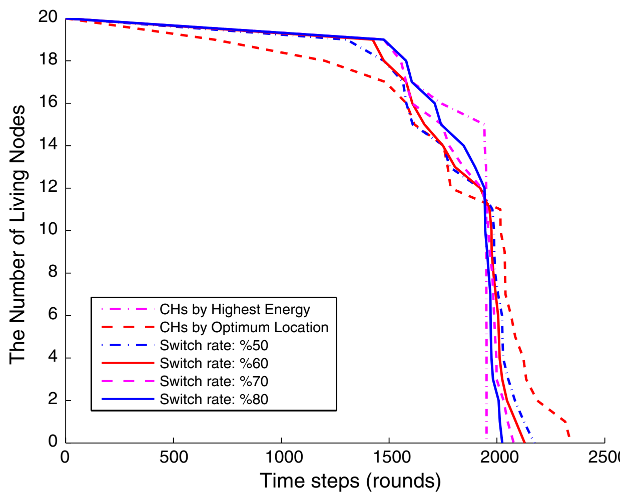

Fig. 3 The number of living nodes on each round under switching rates of 0 % (i.e. highest energy), 50, 60, 70, 80 and 100 % (i.e. optimum location)

the last node (i.e. network lifetime) is prolonged with respect to the related round under energy parameter. For instance, the first node dies at the round of 1303, 1423, 1475 and 1476, while the last node dies at the round of 2173, 2128, 2077 and 2024 under the switching rates of 50, 60, 70 and 80 %, respectively. Therefore, switching methodology combines the advantages of both approaches by maintaining a longer network lifetime with higher sensed data rates. Besides, not only the performance of the switching approach lies within the boundaries designated by the performances of energy and location, but also it gradually neighbours to energy (location) as the switching rate increases (decreases).

4 The proposed algorithm: NODIC

In a traditional distributed clustering routing algorithm just as LEACH [26], the CH selection decision is distributed within the network and each node. If a node elects itself as a CH in any round, it broadcasts an ADVERTISEMENT message to the network including its coordinates and then starts pending for JOIN messages. In the meantime, MNs receive ADVERTISEMENT messages from all CHs and then they select its closest CH to connect. After the determination of CHs, each MN sends JOIN message to its CH on the purpose of informing its membership. When CHs get all JOIN messages, they constitute their clusters and create TDMA schedules for their MNs. Thereafter, CHs send ACK messages to their MNs for reporting their transmission time slot according to TDMA schedule. After these stages, data forwarding stage can begin. Before CHs send their data to BS, they collect the data from its MNs and perform aggregation process on it. After the data is sent to BS from CHs, the round ends and each node decides if it can participate in the next round by checking its energy level.

The proposed algorithm, NODIC, adds a number of modifications, which can be seen in Fig. 4, to the traditional approaches explained above. As is seen in Fig. 4, although these re-formations implemented by NODIC seems to be simple, they pretty redirect the process of the algorithm with keeping its ease of implementation. These modifications are as follows:

- Adding Residual Energy to JOIN Message: Although the decision of CHs is based on an absolute stochastic selection at the beginning of the round, NODIC elects CHs according to their location or remaining energy level as explained in Sect. 4. This determination process is locally performed by randomly selected CHs (i.e. temporary CH), who need the remaining energy levels and the locations of their MNs. Even though the location of the MNs is provided in JOIN Messages by traditional approaches, the residual energy is not supplied to CH. Therefore, NODIC requires each MN to put their residual energy into JOIN Message.
- Determination of new CH: After temporary CHs get all JOIN Messages from their MNs, they calculate average remaining energy of their cluster in order to choose the best parameter between the highest energy and the optimum location for new CH selection. If average remaining energy of a cluster is less than a threshold value, the new CH of this cluster is the one who has the highest remaining energy. Otherwise, the node having the optimum location is selected as the new CH. Thereafter this stage, temporary CH creates a TDMA schedule before declaring the new CH to the other cluster nodes. If the new CH is the same with the temporary one, then there is no need to update the TDMA schedule. However, if not, temporary CH is levelled down to MN and the time slot of the new CH with reference to the TDMA schedule is assigned to it.
- Declaration of new CH in ACK Message: In traditional approaches, the time slot of MNs, which are identified in TDMA schedule, is declared to them with ACK Messages by CHs. NODIC injects the coordinates of the new CH into this message. Thus, the MNs can directly communicate with the new CH during their dedicated time slot. Besides, the new CH is ready for the following stages without making any extra effort.

4.1 The contributions and cost analysis of NODIC

The contributions of NODIC are as follows:

- Easy implementation and self-reliant decision of probabilistic schemes and the guarantee that iterative

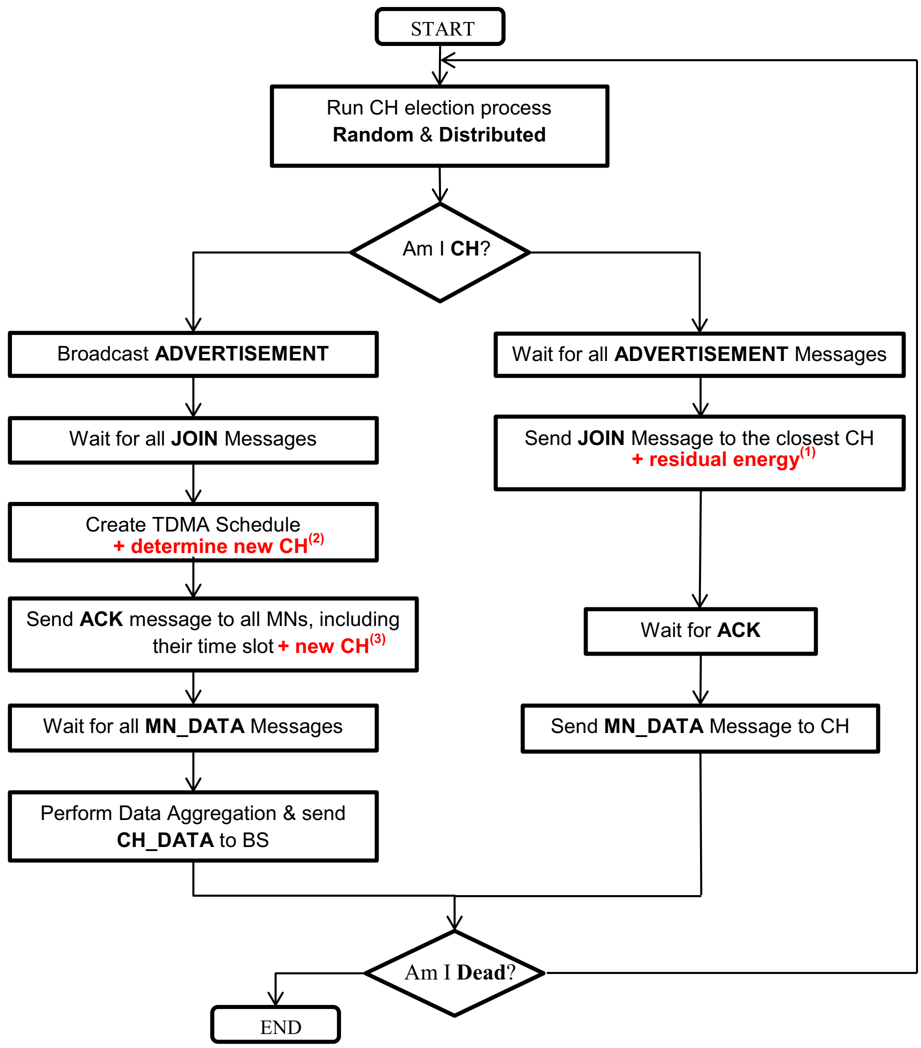

Fig. 4 The flowchart of a traditional distributed clustering routing algorithm with briefly explained modifications implemented by NODIC, including (1)—adding residual energy to JOIN Message, (2)—decision of new CH and (3)—reporting new CH to MNs

schemes issue about selecting the desired CHs are pieced together by NODIC. Neither a single equation nor a series of iterations are conducted with the purpose of electing CHs. Thus, both the decision of CHs does not give up to randomness as in probabilistic schemes and the communication cost does not dramatically increase due to the control messages as in iterative schemes.

- During the formation of the clusters, although a probabilistic approach is used due to its easy implementation, more beneficial parameters are considered for CH election process.
- Energy and location, which are two of the most efficient parameters on CH election process, are pieced together using a time-sharing approach in an effort to gain maximum profit from both of them.
- The decision of CH election is performed locally and dynamically on every cluster. So each cluster can choose the appropriate parameter due to its situation independently from the other clusters in network.

One of the most important advantages of NODIC is that no new control message is added to the system. Therefore, the batteries of the nodes are utilized efficiently. The necessary modifications are carried out by updating the existing messages in a cost-effective way. Accordingly, the remaining energies of the nodes are included in JOIN Messages, while the identifications of the new CHs are attached to ACK Messages. Thus, the proposed algorithm can productively be performed with an insignificant increase in the size of the messages.

5 Performance evaluation of NODIC

NODIC, which is the proposed distributed cluster-based routing algorithm in this paper, is evaluated by OMNeT++ under various values of different network parameters and elaborately compared with a number of distributed clustering approaches in literature, including LEACH [26], CCRP [32] and WST-LEACH [31].

LEACH [26] uses a fixed probabilistic method for CH election as is seen in Eq. 1. In LEACH, each node creates a random number between [0, 1] and compares it with a threshold value T(n), to determine whether it is chosen as CH in current round or not. Although the selection of the CH in CCRP [32] and WST-LEACH [31] is still distributed among the sensor nodes, the procedure is not based on sheer probabilistic solutions anymore, and rather node resources and other determinant factors, including the energy and the location of the nodes, are weighed up in selection of the optimum CHs [3]. On the purpose of reducing inter-cluster communication between CH and MNs, the nodes having larger number of neighbours have more chance to be CHs in CCRP [32], as is seen in Eq. 2. WST-LEACH [31] uses a weighted function of the remaining energy of the nodes, the distribution of the nodes and the distance of the nodes to the BS, as is seen in Eq. 3, for the election of CHs.

In the equations, p_{CH} is desired percentage of CHs; r_c is the current round; E_c is the current energy of the node; E_i is the initial energy of the node; N is the total number of the nodes; N_b is the neighbour numbers of the node within a radius R; d_{BS} is the distance between the node and the BS; and w_1, w_2, w_3 are coefficients.

$$T(n) = \begin{cases} \dfrac{p_{CH}}{1 - p_{CH} * \left(r_c \bmod \left(\dfrac{1}{p_{CH}}\right)\right)}, & \text{if } n \in G \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

$$T(n) = \begin{cases} \dfrac{p_{CH}}{1 - p_{CH} * \left(r_c \bmod \left(\dfrac{1}{p_{CH}}\right)\right)} \left[\dfrac{E_c}{E_i} + \left(1 - \dfrac{E_c}{E_i}\right) \dfrac{N_b}{1/p_{CH} - 1}\right], & \text{if } n \in G \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

$$T(n) = \frac{p_{CH}}{1 - p_{CH} * \left(r_c \bmod \left(\frac{1}{p_{CH}}\right)\right)} * \left\{0.2 * \frac{E_c}{E_i} + 0.3 * \frac{N_b}{p_{CH} * N} + 0.5 * \frac{1}{d_{BS}}\right\} \tag{3}$$

Apart from modifying CH election equation, CCRP and WST-LEACH use multi-hop communication between CHs and BS on the purpose of decreasing the battery usage of the nodes. CCRP constructs a chain [32], while WST-LEACH uses a weighted spanning tree [31].

5.1 Simulation and evaluation parameters

The simulation parameters can be seen in Table 2. For the evaluation of the algorithms, a 100, 200 and 400 of nodes are uniformly distributed on a 200 m × 200 m network. The network consists of homogeneous nodes, which have the initial energy of 0.5 J. The base station is located outside the network at the position of (250, 100). The desired percentage of the cluster heads is 5 %, while the energy model is the same with LEACH_C [27]. The switching rate, which is used to exchange the dominant parameter from energy to location on CH election process, is set to 70 % according to the preparatory work.

After a detailed benchmark under these network parameters between NODIC and the studies in literature, which use the equations above for electing CHs, the algorithms are also run under hot region distribution of the nodes. The hot regions on the network are created in two different ways. In both ways, 50 % of the nodes are uniformly distributed on the quarter of the network area, while the other 50 % are interspersed throughout the remaining area. The difference between the hot regions is their locations. As is seen in Fig. 5, the first hot region is resided close by the BS, while the other is populated on a far-off locale (Fig. 6).

The results are evaluated under two performance parameters, including the number of living nodes and total energy consumption per round. When the battery of a node goes down below 95 % of its full battery, the node is supposed to be dead. The nodes with sufficient energies can participate in following rounds. At the end of each round, the number of living nodes is calculated and the energy consumption of every node is totalized in order to develop a point of view about the network condition and lifetime.

5.2 Results and discussion

5.2.1 *Evaluation under various numbers of nodes*

The number of living nodes and total energy consumption in each round on a uniformly distributed 100, 200 and 400 node network with using the NODIC, LEACH, CCRP and WST-LEACH, can be seen from Fig. 7 through Fig. 12, respectively.

As is seen in Figs. 7, 9 and 11, the NODIC yields better performance (i.e. having higher number of living nodes on most of the rounds) than the other approaches independently

Table 2 The simulation parameters

Parameter	Value
Network area	200 m × 200 m
Number of nodes	100, 200 and 400
Desired percentage of clusters	5 %
Position of BS	250, 100
Initial energy	0.5 J
Node distribution	Uniform, hot region
Switching rate	70 %
Broadcast/control packet size	500 bit
Data packet size	2000 bit
E_{elec}	50 e^{-12}
E_{fs}	10 e^{-12}
E_{mp}	0.0013 e^{-12}
Threshold distance (d_0)	87 m

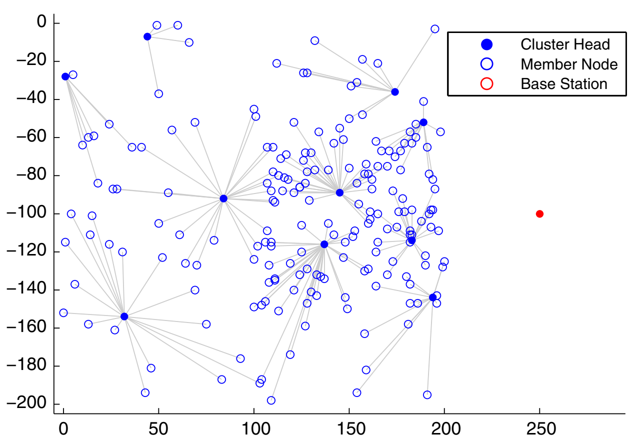

Fig. 5 Hot region area close by BS

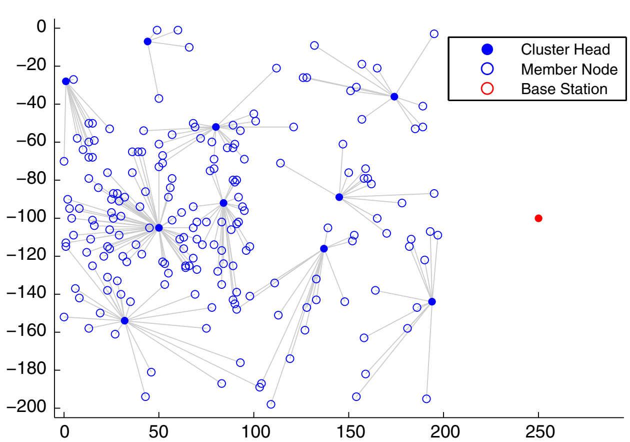

Fig. 6 Hot region area far from BS

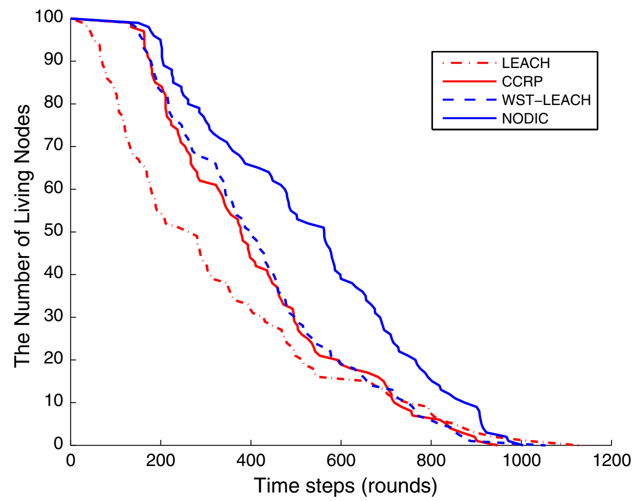

Fig. 7 The number of living nodes in each round on a uniformly distributed 100 node network with using the NODIC, LEACH, CCRP and WST-LEACH

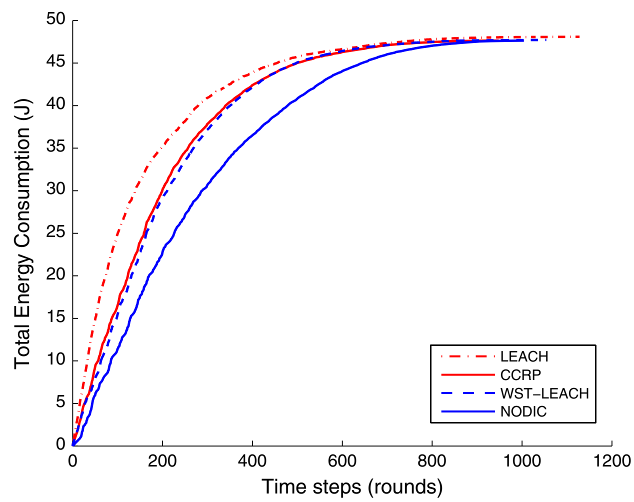

Fig. 8 Total energy consumption in each round on a uniformly distributed 100 node network with using the NODIC, LEACH, CCRP and WST-LEACH

from the number of nodes. The reason is that total energy consumption per round under NODIC is lower than that of under other algorithms for all numbers of nodes (Figs. 8, 10, 12), which shows that NODIC consumes the battery of the nodes efficiently and hence increase the lifetime of the nodes. Furthermore, the performance difference between NODIC and the other approaches increases as the number of nodes increases in the system. For instance, NODIC performs better than the other algorithms according to the parameter of the number of living nodes up to 68 % on average under a 100 node network. This increasing rate arrives at 77 and 78 % for a 200 node and a 400 node network, respectively. Accordingly, the decreasing rate of total energy consumption under NODIC with regards to the other approaches reaches up to 44 %.

The death of the first node is postponed under NODIC compared to the other approaches regardless from the number of nodes. For instance, on a 200 node network (Fig. 9), the first node dies at the round of 337 under NODIC, while the round of the death of the first node ranges between 16 and 55 under other algorithms. This result implies that NODIC obtains higher data rates (i.e. significant sensing data) than the corresponding approaches by keeping the nodes alive together for a longer time.

Although the difference is quite insignificant, the death of the last node is prolonged under the other approaches than that of under NODIC. For instance, the last node on a 100 node network dies at the round of 1003 under NODIC, while this round number is 1127 and 1053 under LEACH and WST-LEACH, respectively (Fig. 7). This result seems like the corresponding algorithms has a higher network lifetime than NODIC, at first glance. However, only a few nodes, which are closed by the BS live a longer time under

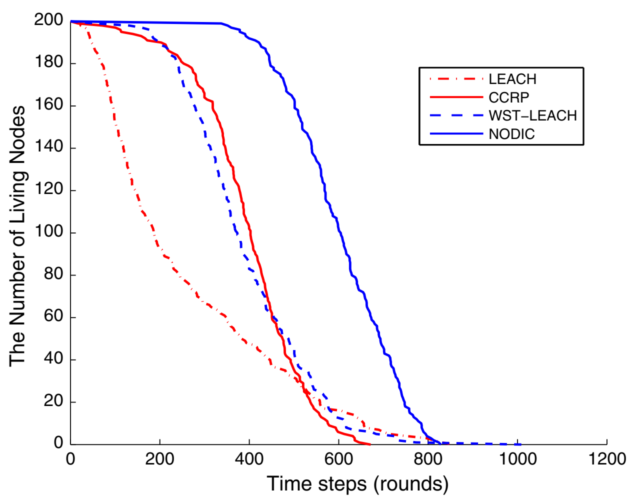

Fig. 9 The number of living nodes in each round on a uniformly distributed 200 node network with using the NODIC, LEACH, CCRP and WST-LEACH

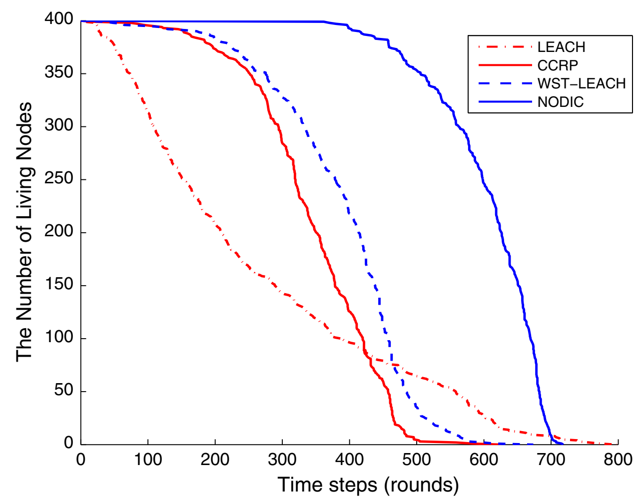

Fig. 11 The number of living nodes in each round on a uniformly distributed 400 node network with using the NODIC, LEACH, CCRP and WST-LEACH

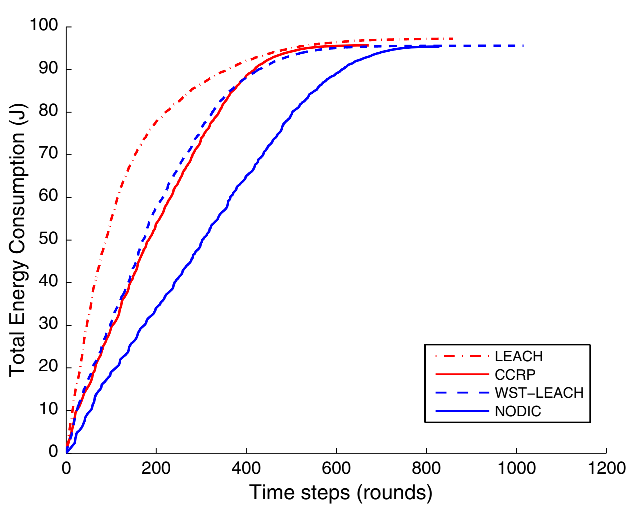

Fig. 10 Total energy consumption in each round on a uniformly distributed 200 node network with using the NODIC, LEACH, CCRP and WST-LEACH

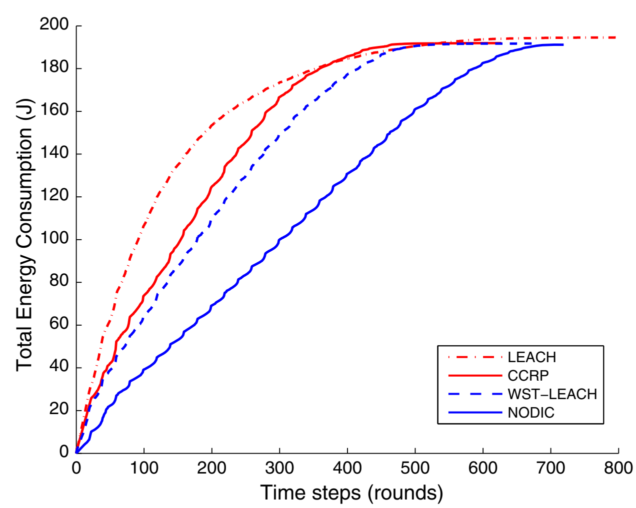

Fig. 12 Total energy consumption in each round on a uniformly distributed 400 node network with using the NODIC, LEACH, CCRP and WST-LEACH

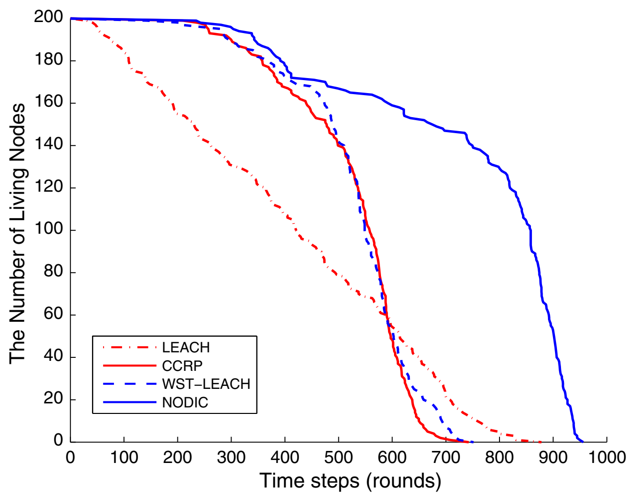

Fig. 13 The number of living nodes in each round on a 200 node network under a hot region distribution created close by BS with using the NODIC, LEACH, CCRP and WST-LEACH

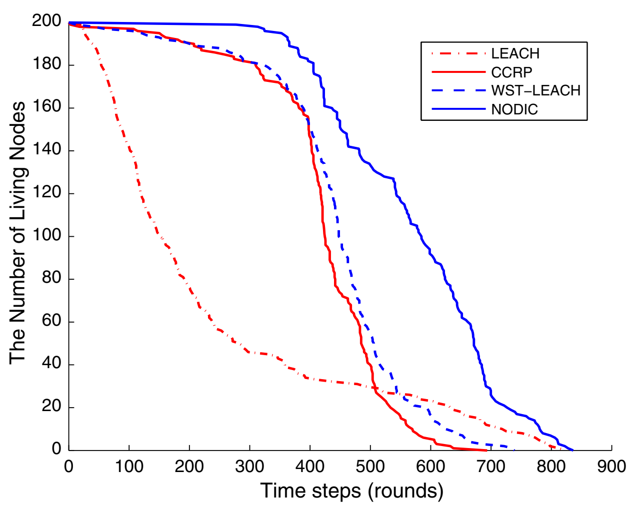

Fig. 14 The number of living nodes in each round on a 200 node network under a hot region distribution created far from BS with using the NODIC, LEACH, CCRP and WST-LEACH

these approaches. Since their sensed area is quite limited, their data is insufficient. On the other hand, the NODIC benefits from these closer nodes through the simulation time and utilize them to increase the lifetime of the other nodes. Therefore, a functional sensing is accomplished due to the distribution of the load among all nodes.

5.2.2 Evaluation under various distributions of nodes

The number of living nodes in each round on a 200 node network under a hot region distribution created close by and far from BS with using the NODIC, LEACH, CCRP and WST-LEACH, can be seen in Figs. 13 and 14, respectively. As is seen in figures, the NODIC yields better performance than the other approaches regardless of the formation of hot region. The difference of the performance between NODIC and the other algorithms runs up to 77 % on average under uniform distribution, while this rate increases to 80 % under hot region created far from BS and decreases to 69 % under hot region formed nearby BS. Since the compared approaches economize the BS-adjacent nodes and do not benefit from them to increase the life of the other nodes, these nodes have a longer life and as the nodes get closer to BS, they draw on this advantage further. Therefore, the performance of the NODIC draws away under the hot region distribution created away from BS.

The results show that although CCRP and WST-LEACH take the advantage of multi-hop inter-cluster communication, the performance of NODIC is higher than that of them under all numbers and distributions of nodes. Therefore, the future work of this work includes increasing the lifetime of the network by adding multi-hop intercluster communication to NODIC.

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