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Optimal energy aware clustering in circular wireless sensor networks

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ABSTRACT

The lifetime of a wireless sensor node refers to the duration after which the node's energy has ended. Since battery replacement in most applications of wireless sensor networks is not possible, designing an energy-efficient communication protocol in these networks is very important. Therefore, many studies have been conducted to find a solution to increase the lifetime of these networks. Clustering is a useful technique for partitioning the network to areas, called clusters and entrusting energy-waste issues (e.g. data gathering, aggregating and routing to the sink) to some specific nodes, the cluster heads. In this paper, a new method for Optimal Clustering in Circular Networks (OCCN) is proposed which aims to mitigate energy consumption and increase the lifetime of wireless sensor networks. In this method, which is proposed for a circular area surrounding a sink, one hop communication between the cluster heads and the sink is replaced by an optimal multi-hop communications. Moreover, the optimal number of clusters is computed and the energy consumption is optimized by partitioning the network into nearly the same size clusters in a distributed manner. Simulation results indicate that the proposed method achieved more than 35% improvements in terms of energy consumption in comparison to other well-known clustering techniques.

1. Introduction

A wireless sensor network (WSN) consists of hundreds or even thousands of tiny and inexpensive electronic devices called sensor nodes. A sensor node usually includes different modules like communication, sensing, and processing module. The sensing module is in charge of measuring a parameter such as pressure, temperature, motion, etc. Then, the measured value is transmitted to a central point called sink using the communication module however, some initial processing over the measured value might be required before transmission [1].

WSNs have provided many benefits in various fields from healthcare systems, gaming and entertainments to even environmental and military applications. Like other types of wireless devices, the sensor nodes suffer from many limitations like unreliable communication links, limited frequency bands and security issues. Apart from these limitations, sensor nodes deal with many more challenges. Since the sensor nodes should be inexpensive, small and light, the memory capacity, CPU power and especially battery size is extremely limited. Moreover, in many scenarios like environment monitoring and military applications, the sensor nodes are not accessible for a long time. In such a situation, the battery replacement, if not impossible, is very difficult. Therefore, designing an energy efficient communication protocol for WSNs is inevitable.

In this regard, several protocols and communication methods with their cons and pros have been proposed to manage the energy consumption of communications in WSNs. Rault et al. [2] and Khan et al. [3] provide comprehensive studies on these protocols. Many of these protocols are designed based on the concept of clustering techniques [4–7], where the network area is divided into small areas, called clusters. In each cluster, a node is selected as the cluster head (CH) and is responsible for intra-cluster and inter-cluster communications. In communication protocols based on clustering concept, time is discrete and divided into time slots. During each time-slot, any non-cluster head node (non-CH) sends gathered data to its cluster head. After receiving the data from cluster members, the cluster head aggregates them and send the

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aggregation results for the next cluster head [5] or directly to the sink [4]. WSN's users have a high-level view of the environmental events and conditions. Hence, aggregation of low-level data (average, min, count, etc.) does not disturb the operation of the system [4]. If the cluster size is defined well, the correlation between data measured by sensors in a cluster is usually high. Hence, aggregation functions can significantly decrease the transmission power by reducing the size of the data sets have to be transmitted [4,8]. Additionally with this technique, issues related to non-cluster head nodes (e.g. scheduling and synchronization) remain in cluster level and are managed by the cluster head.

Since cluster heads are responsible for inter- and intra-cluster communications, they usually consume more energy compared to the non-cluster head nodes. Thus, many protocols have been proposed to balance the energy consumption in the network. LEACH [4] and HEED [7] are well-known clustering methods which try to balance the network energy consumption by periodically rotate cluster head role among all nodes. In LEACH the cluster heads are selected randomly. So, the energy dissipation in this step is low however, cluster heads may do not be distributed evenly in the network area which leads to high energy dissipation. In HEED the cluster heads are selected based on the residual energy and some intra-cluster communication cost. Therefore, the probability of selecting two neighbour nodes as cluster head is low. In [5] a clustering model for circular networks is proposed to reduce the energy consumption through optimal multi-hop communication. In a circular network the sink is placed in the middle of the network area and the clusters are formed in its surrounding. In this model, a cluster size and its region is determined offline using calculating the optimum one-hop distance, clustering angle and continuous working time of each cluster head.

In addition to clustering, other methods also have been investigated by many researchers. For instance, replacing one-hop links with multi-hop communications [5–7,9] and using a virtual backbone [10–12] are efficient solutions which are covered by a major part of the related researches. Furthermore, Karalis et al. [13] and Watfa et al. [14] have proposed a new method for energy transferring between high energy and low energy sensor nodes which its implementation will hopefully be a big step towards increasing the lifetime of sensor networks. Local computation in sensor nodes usually consumes less energy than communication [8]. Accordingly, many researches have focused on data aggregation techniques to reduce energy consumption by removing redundant data before transmitting to the sink [15–17].

In this paper, a new method for Optimal Clustering in Circular Networks (OCCN) is proposed. OCCN mitigates the energy consumption and increases the network lifetime. In OCCN, the optimal number of clusters is calculated based on the optimal one-hop inter-cluster communication distance. Then, the network area is divided into a few rings surrounding the sink. The distance between the borders of two consequent rings is equal to the optimal distance between two consequent nodes in optimal multi-hop communication. Each ring, based on its area, includes some clusters in which, optimality of clustering around the network is provided. Since the optimal clustering method is done off-line, a distributed clustering method is proposed to provide almost similar performance compared to the optimal clustering method. One of the striking features of OCCN is its scalability which is achieved by implementing the multi-hop communication. Compared to other well know methods, the simulation analysis shows that our proposed OCCN improves the network lifetime more than 35%. The outline of the paper is as follows. Section 2 provides the network model on WSNs. Optimal number of clusters is calculated in Section 3. Section 4 describes proposed clustering method. Analysis and simulation results are shown in Section 5 and finally, Section 6 concludes the paper.

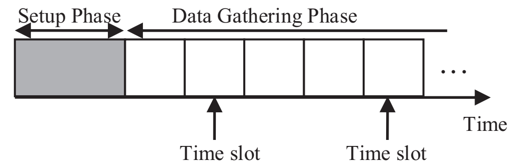

Fig. 1. OCCN timeline with Setup Phase and Data Gathering Phase.

2. Model and assumptions

In this section, the network model, energy usage model and other assumptions are considered. We have tried to develop our proposed clustering method on a realistic scenario.

2.1. Network model

In this paper, similar to [5,6,18–20] the network is considered as a circular area in which, the sink is placed in the centre and nodes are evenly distributed around it. The timeline of our proposed communication protocol is depicted in Fig. 1. The communication protocol starts with setup phase. In this phase, each node participates in a self-organizing process to identify its role (either CH or non-CH) in the next phase and receives its time schedule. In data gathering phase, network operation is divided into many time slots and each time slot includes time frames. In each time slot, non-cluster head nodes act only in their scheduled time frame and are inactive in the rest of it to save energy. At the end of each time slot, cluster head nodes perform perfect aggregation on received data and send it to the sink hop by hop. We assume that packet generation rates and initial energy (E_0) of all sensor nodes are identical. They are synchronized by the sink and receive initial parameters from it.

2.2. Energy model

A sensor node is always in either the active or the passive mode. An active node is a node which participates in the network's operation or sensing the environment or sending data to the other nodes or sink. A passive node is a node which is temporarily abandoned sensing or participating in running a protocol or has run out of energy and has died. The energy consumption of an active node is comprised of three parts (the energy consumption of sending (E_{Tx}), receiving (E_{Rx}), and data processing (E_{DP}) [4,5]. The simplified energy consumption model for each of these parts in a free space environment is presented in (1):

$$\begin{cases} E_{Tx}(l) = l \times \left(E_{elec} + E_{amp} \times d^{\Upsilon}\right) \\ E_{Rx}(l) = l \times E_{elec} \\ E_{DA}(l) = l \times E_{cpu} \end{cases} \tag{1}$$

where l is packet length (bit), d is transmission distance (m), E_{elec} (nJ/bit) is the electronic energy to run the radio circuitry, E_{amp} (nJ/bit/m2) is the amplifier energy needed by the transmitter for an acceptable Signal to Noise Ratio (SNR) at the receiver demodulator and γ is the path loss exponent which is 2 in the free space environment. E_{DA} (nJ/bit) is the energy dissipation for data aggregation and E_{CPU} (nJ/bit) is the energy dissipation for processing per bit [4,5]. As we can see in (1), the distance between the sender and the receiver (d) has a significant impact on the energy consumption. In a multi-hop communication, the sender transmits its data through an intermediate node Fig. 2). Therefore, a transmission with distance d is transformed into several shorter consecutive transmissions with the distance of d_x. The optimal distance between intermediate nodes (d_{opt}) in a multi-hop communication (to minimize the network energy consumption) is fully investigated in

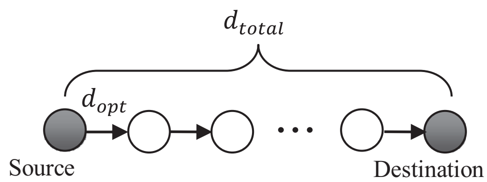

Fig. 2. Linear model for multi-hop communication.

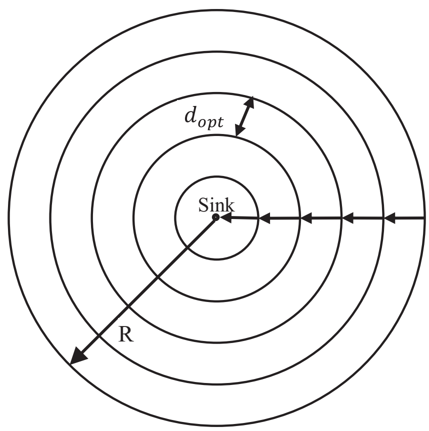

Fig. 3. Multi-hop communication between cluster heads.

[5] and is computed by (2):

$$d_{opt} = \sqrt{\frac{2\ E_{elec} + E_{cpu}}{E_{amp}}} \tag{2}$$

In [5], a novel clustering method for circular networks has been proposed. In this method, each cluster head sends its data to the sink using the upper cluster heads and through multi-hop communication. In order to reduce the energy consumption, it is preferred to organize clusters in a way that the distances of a cluster head from its upper cluster head in the way to the sink is d_{opt}. Thus, the network is divided into concentric rings whose radius is an integer multiple of d_{opt} (Fig. 3). Accordingly, the network is divided into m rings, and it is expected that the average distance of each cluster head from its upper and lower cluster head is d_{opt}. The area of ith ring is computed as follow:

$$m = \frac{R}{d_{opt}} \tag{3}$$

$$S_{ring\_i} = \pi\,(i \times d_{opt})^2 - \pi\,((i-1) \times d_{opt})^2 \tag{4}$$

3. Optimal parameters

The energy consumption of a network in a cluster based model is directly related to the number of its cluster [4]. Hence, the optimal number of clusters to minimize the energy consumption is calculated. Assume the network is divided into k clusters, such that the average cluster size (number of nodes in the cluster) is N/k where N is the total number of nodes in the network. The energy consumption of a cluster head is mainly comprised of three parts: the energy consumption for receiving data from the cluster members, aggregating the received data, and sending the aggregated data to the upper cluster head or the sink [5,6]. The averaged total energy consumption of a cluster head per each time slot is computed by (5):

$$E_{CH} = l \times \left(E_{elec} \times \left(\frac{N}{k} - 1\right) + E_{DA} \times \frac{N}{k} + E_{elec} + E_{amp} \times d^2_{to-next-CH}\right) \tag{5}$$

where $d_{to\text{-}next\text{-}CH}$, is the distance between cluster head and its upper cluster head or the sink. In each time slot, a non-cluster head node is only responsible for sending the measured value to its cluster head. Therefore, the average energy consumption of a non-cluster head in each time slot is:

$$E_{non-CH} = l \times (E_{elec} + E_{amp} \times\ d^2_{to\ CH}) \tag{6}$$

where $d_{to\text{-}CH}$ is the average distance between a non-cluster head node and its cluster head. Assume that the cluster head is at the centre of a circle (cluster). The average distance of the points in the circle from the centre is calculated as follow:

$$E\left[d^2_{toCH}\right] = \iint \left(x^2 + y^2\right)\rho(x, y)dxdy \tag{7}$$

By transforming the Cartesian coordinates into polar coordinates, we have:

$$E\left[d^2_{toCH}\right] = \iint r^2 \rho(r, \theta) r\ drd\theta \tag{8}$$

In this equation, ρ is the density of nodes distribution in the network which is computed by (9).

$$\rho = \frac{N}{\pi R^2} \tag{9}$$

On the other hand, we know that the area of the network is πR^2. Thus, if there are k clusters in the network, the average area of the cluster is:

$$S_{cluster} = \frac{\pi R^2}{k} \tag{10}$$

If the cluster is considered as a circle with radius of r and a cluster head at its centre, the area of the cluster is calculated as follow:

$$S_{cluster} = \pi r^2 \tag{11}$$

From (10) and (11), it can be concluded that the radius of the cluster is:

$$r = \frac{R}{\sqrt{k}} \tag{12}$$

Therefore, Eq. (8) is redefined as below:

$$E\left[d^2_{toCH}\right] = \rho \int_{\theta=0}^{2\pi} \int_{r=0}^{\frac{R}{\sqrt{k}}} r^3 drd\theta \tag{13}$$

By replacing (9) in (13), we have:

$$E\left[d^2_{toCH}\right] = \frac{R^2}{2k} \tag{14}$$

Therefore, Eq. (6) is redefined as follow:

$$E_{non-CH} = lE_{elec} + lE_{amp}\frac{R^2}{2k} \tag{15}$$

The total energy consumption of a cluster in each time slot is equal to the sum of cluster head energy consumption and the energy consumption of non-cluster head nodes inside that cluster. Since the average number of cluster member nodes is N/k we have:

$$E_{cluster} \cong E_{CH} + \left(\frac{N}{k} - 1\right) \times E_{non-CH} \tag{16}$$

On the other hand, the total energy consumption of the network (including k clusters) per each time slot is:

$$E_{total} \cong k \times E_{cluster} \cong l \times \Big((2N-k) \times E_{elec} + N \times E_{DA} + k \times E_{amp} \times d^2_{opt} + (N-k) \times E_{amp} \times \frac{R^2}{2k}\Big) \tag{17}$$

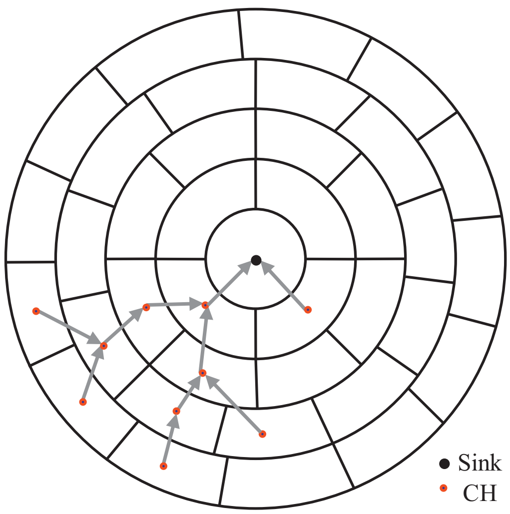

Fig. 4. Clustering and communication between cluster heads.

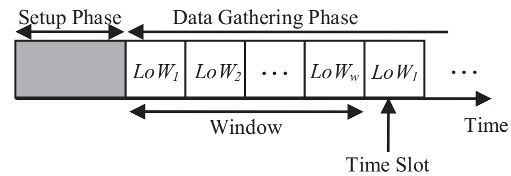

Fig. 5. Setup phase of the time line is divided to three steps and Data gathering phase is divided to some windows with length *w*.

To minimize the network energy consumption, the optimal value of k should be found. To this end, the Eq. (17) is differentiated with respect to k. Then, the absolute minimum value of E_{total} is found as below:

$$\frac{dE_{total}}{dk} \cong l \times \left(-E_{elec} + E_{amp} d_{opt}^2 - \left(\frac{NR^2}{4k^2} \right) E_{amp} \right) \tag{18}$$

$$k_{opt} \cong \sqrt{\frac{N \times R^2 \times E_{amp}}{2 \times (E_{amp \times} d_{opt}^2 - E_{elec})}} = \sqrt{\frac{N \times R^2 \times E_{amp}}{2 \times (E_{elec} + E_{cpu})}} \tag{19}$$

Fig. 4 presents an example of network partitioning into the static clusters using the proposed OCCN. As it can be seen, each ring is assigned to some clusters in proportion to its area. In other words, a ring with larger area includes more clusters proportional to its size.

4. Proposed reservation based clustering method

As it explained, clustering, data aggregation and, multi-hop communication are three major techniques to reduce network energy consumption. On the other hand, load balancing among all nodes helps to avoid premature death of nodes. Hence, we proposed an optimal scalable clustering method which provides fair traffic forwarding using optimal sized clusters and optimal multi-hop packet relaying. Since the energy consumption of CH nodes is much higher than that of non-CH nodes, all nodes change their role intermittently. To apply the proposed clustering method, a manual node placement procedure has to be done. In case the sensor nodes should be distributed randomly, their location information is needed at the sink. Assuming the nodes are equipped with GPS, each node sends its location information to the sink. Then, the sink would be capable of clustering the network optimally as described before. Although manual node placement or equipping sensor nodes with GPS is not very far from some real world scenarios, we present a feasible version of OCCN, a distributed sub-optimal clustering algorithm which benefits from the optimal parameters explained before. Data gathering phase in distributed OCCN is similar to the optimal version, though the setup phase includes two different steps: reservation phase and upper cluster head selection phase. In the rest of this section, the setup phase is described step by step.

4.1. Setup phase

As explained before, the cluster head role in each cluster is assigned to all of the cluster members regularly. Although it helps to balance the energy consumption, cluster head selection is an energy and time consuming procedure. Hence, we propose a reservation based cluster head selection mechanism in which, each node reserves special sets of time slots for being cluster head, once at the setup phase. Then, sensor nodes broadcast their decisions to aware other nodes in the network. Since cluster head selection procedure is done once, it considerably reduces the message passing overhead and consequently energy consumption at the cost of some more memory usage. To this end, data collection phase is divided into a number of time frames or windows as depicted in Fig. 5. Each window includes w time slots. Each sensor node has to act as cluster head once during each window. Hence, w is expected to be equal to the cluster size ($w = N/k_{opt}$). Accordingly, if a sensor node acts as cluster head, it does not need to operate as cluster head again until all other cluster members (other $N/k_{opt} - 1$ sensor nodes) act as cluster head. Each time slot j in a window is called Leaf-of-Window (*LoW*) and is labelled with a number x ranging from 1 to w which is calculated using (20) where *mod* is a function that finds the remainder after division of j by w.

$$x = \mod(j, w) + 1 \tag{20}$$

Reservation phase starts with competition among nodes in which, each node tries to reserve a fixed LoW_x by the end. Once each node reserves a *LoW*, it broadcasts its ID and the index of its reserved *LoW* within the distance of d_{opt}. For the sake of better understanding, an example is considered. Assume a sensor node N_a reserves LoW_x which means it has been decided to act as a cluster head in the xth time slot of each window, regularly. Hence, N_a broadcasts a control packet (reservation packet) including its ID and the index of the reserved time slot, x, within the distance of d_{opt}. On the other hand, each node N_b may receive a couple of such a reservation packets for LoW_i. Thus, it selects the closest node as its cluster head in all of the windows. If a sensor node does not receive any reservation packet corresponding to LoW_i, it acts as cluster head within LoW_i however, our simulation results reveals that it is a rare case, especially when the network is dense.

In the rest of this section, we focus on the way the sensor nodes compete to reserve a LoW_x. As it mentioned, reservation phase starts with competition among nodes in which, each node tries to reserve a fixed LoW_x by the end. The competition is done through an iterative closed loop including several rounds. Each round of competition (represented by r), includes w sub-rounds in which, in sub-round x, sensor nodes competes to reserve LoW_x. The maximum number of rounds is shown by r_{max} which is discussed later this section. Fig. 6 shows the procedure how a sensor node competes to reserve a *LoW*. Each sensor node sets a probability vector P so that the vector has w elements corresponding to w sub-rounds. Each element P_x represents the probability that the sensor node competes at the sub-round x (to reserve LoW_x). Since each node wants to reserve only one *LoW*, it competes in only one sub-round of each round and stays silent in other sub-rounds. At

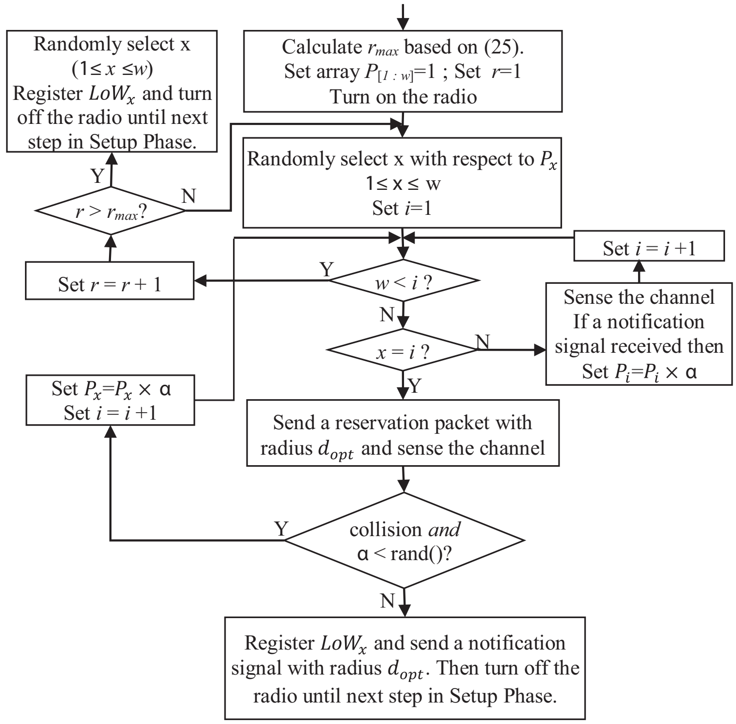

Fig. 6. The reservation process.

the beginning of the first round of competitions ($r=1$), $P_x = 1/w$ ($1 \le x \le w$). Hence, each sensor node randomly (according to the P vector) selects a sub-round x to compete. Then, it waits until the competition at sub-round x is begun. When the competition at sub-round x is started, each sensor node which is decided to compete for reserving LoW_x, broadcasts a reservation packet within the range of d_{opt} and measures the energy over the channel at the same time to find if collision is happened. If collision is not detected, the sensor node wins the competition. Therefore, turns off its radio until the end of reservation phase. The probability that a sensor node successfully reserves a LoW without any collision by the end of round r is presented by equation below:

$$p_{s1} = 1 - \frac{q}{n-1} \tag{21}$$

where n is the number of nodes which are going to compete in round r and q is the average number of neighbours in radius d_{opt}. Obviously, $n = N$ at first round of competition ($r = 1$). Otherwise, if collision occurs, the sensor node finds that some other nodes in its neighbourhood are competing for the same LoW_x. In this case, the sensor node either reserves LoW_x with the probability of α or ignores it with the probability of 1- α.

$$\alpha = \frac{d}{d_{opt}},\ \ 0 < d \le d_{opt} \tag{22}$$

α is proportional to the average distance (d) between nodes which are in collision or hearing each other divided by d_{opt}. Notice that d is calculated through measuring the energy on the channel during competition. In case a collision is detected, the equation below represents the average probability that a sensor node can reserve a LoW at the end of each round:

$$p_{s2} = \frac{q}{n-1} \times \left(\frac{w-1}{w} + \frac{\alpha}{w}\right) \tag{23}$$

As it shown in Fig. 6 if the sensor node ignores LoW_x when multiple sensor nodes compete at the same time and collision is detected, it reduces P_x proportional to α in order to decrease the probability of competing for LoW_x in the next rounds of competition. For the same reason if in a sub-round i, any other sensor node N_b, receives a notification signal from a sensor node N_a which means N_a has succeeded to reserve a LoW, then, N_b reduces its P_i proportional to α.

$$P_i = P_i \times \alpha,\ \ 0 \le \alpha \le 1 \tag{24}$$

When P_i is decreased, the probability of other P_j ($1 \le j \le w$, $j \neq i$) should be increased. Hence, the sensor node normalizes the P vector so that $\sum_{i=1}^{w} P_i$ always remains 1. For the next round of the competition, those sensor nodes which have not reserved a LoW, select a sub-round according to their P vector and follow the same procedure explained above. By the end of each round, the number of sensor nodes that can reserve a LoW is:

$$f(n) = n(p_{s1} + p_{s2})^{n-1} \tag{25}$$

According to (25), the total number of rounds of competition (r_{max}) is proportional to the network area and the number of nodes. As it can be seen in Fig. 7, for a circular network area with the radius of 60 m and including 300 nodes, more than 98% of the nodes have been succeeded to reserve a LoW by the end of 7th round. Notice that almost 50% of the sensors have reserved a LoW at the first round ($r = 1$). It means, the reservation phase is not going to be an energy consuming however, it is just run once during the network lifetime.

Once the cluster heads per each LoW are determined, the sensor nodes run a procedure to find the cluster heads toward the sink. This step is divided into w time slots. During time slot i, those sensor nodes which reserved LoW_i broadcast their ID and their distance to the sink within the range of d_{opt}. If a sensor node is not going to act as cluster head in LoW_i, can easily select the nearest cluster head. Otherwise, if the sensor node is going to act as cluster head in LoW_i, it can find its upper cluster head toward the sink.

5. Simulation and evaluation

In this section, we evaluate the performance of proposed clustering method in terms of energy consumption. To this end, a fair amount of simulations using MATLAB have been carried out. In the

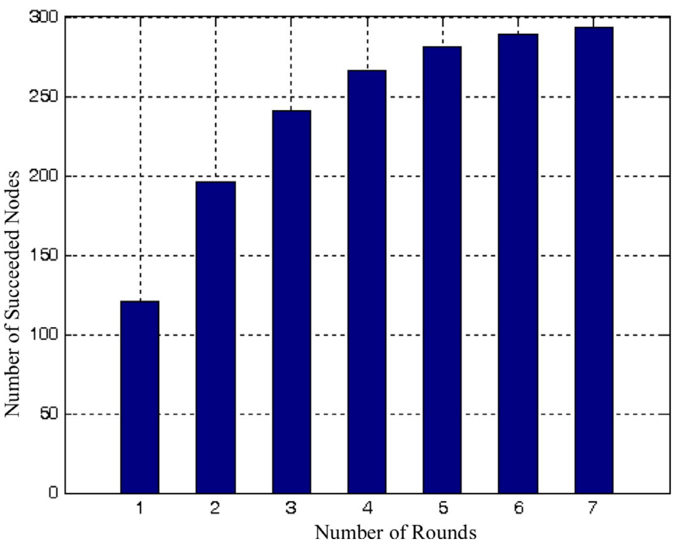

Fig. 7. Cumulative number of nodes which have reserved a *LoW* vs. the number of rounds.

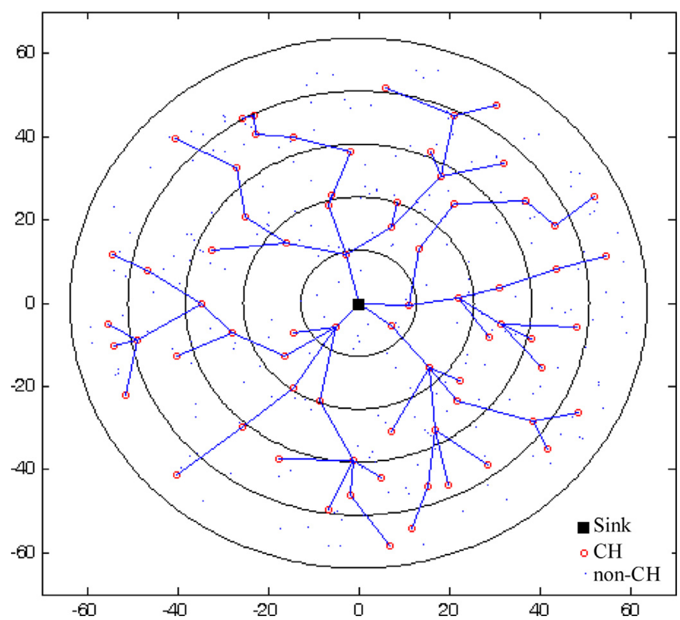

Fig. 8. Node distribution and routes to the sink in a random topology.

Table 1
Simulation parameters.

Parameters	Value
E_{elec}	50×10^{-9} J/bit
E_{amp}	0.659×10^{-9} J/bit/m^2
E_{cpu}	7×10^{-9} J/bit
E_0	0.5 J
Y	2 (free space model)
N	300
R	60 m
Data packet length	1000 bit
Control packet length	200 bit

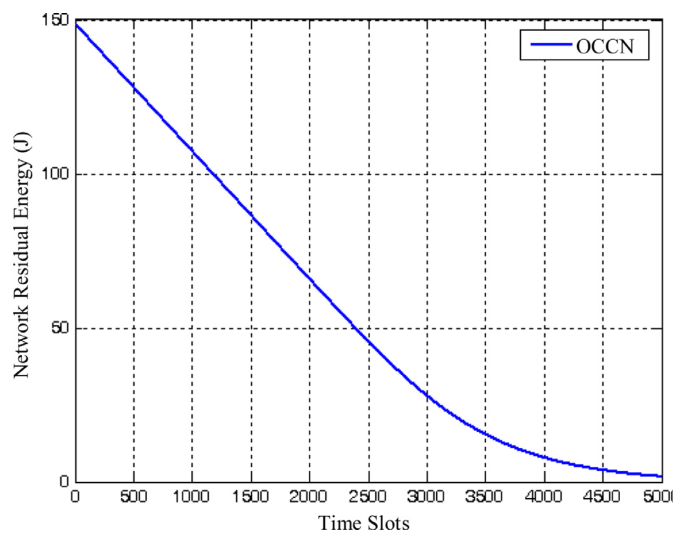

Fig. 9. Energy consumption of OCCN over time.

simulation setup, it is assumed that the sensor nodes periodically generate packets at a constant rate. Then, the generated packets are transmitted to a central point (sink) which is in charge of collecting and analysing the measured values. The proposed reservation based OCCN is compared with three other well-known methods, LEACH, HEED and the proposed method in [5]. The energy model, including energy consumption in transmitting mode, receiving mode and processing mode is discussed in Section 2. The transmission power is assumed to be continuous which means, a sensor node is capable of adjusting its transmission power level according to the distance to the receiver. Moreover, it is assumed that the antenna is ideal, an isotropic antenna which radiates its signal uniformly in all directions. In other words, antenna disseminations are concentric. Although there are different definitions for network lifetime depending on the network application, we depict the average number of alive nodes during the time the simulation is running.

Referred to [5], simulation parameters are presented in Table 1. As it can be seen, the data packet and control packet length are set to 1000 bits and 200 bits, respectively. The network field is considered as a wide circle, where the radius is 60 m. Since such a scenario looks suitable for agricultural, environmental or military applications, we assume the network area is open space. Hence, path loss exponent is assumed to be 2.

Assuming the sink knows the parameters presented in Table 1, it needs to calculate the optimal parameters. According to (2) and (19), the optimal one-hop distance and the optimal number of clusters are calculated as below:

$$d_{opt} = \sqrt[\gamma]{\frac{(2E_{elec}+E_{cpu})}{E_{amp}(\gamma-1)}} = \sqrt[2]{\frac{(2 \times 50 \times 10^{-9}+7 \times 10^{-9})}{0.659 \times 10^{-9}}} = 12.7423\ m$$

$$k_{opt} = \sqrt{\frac{300*60^2*0.659*10^{-9}}{2*(50*10^{-9}+7*10^{-9})}} \cong 79$$

Once k_{opt} are calculated, the window length is computed as below:

$$w = \frac{300}{79} \cong 4$$

According to (25), the competition between nodes in reservation phase lasts at least for 7 rounds. Fig. 7 illustrates the cumulative number of nodes which have reserved a *LoW* after each round. Fig. 8 shows an example of random topology in a WSN in which, cluster head nodes and non-cluster head nodes are shown by red circles and blue dots, respectively. Besides, the blue links represent the routes from cluster heads to the Sink constructed by proposed clustering algorithm.

Fig. 9 represents the trend of energy consumption in the network where 300 nodes communicate using proposed OCCN. As it

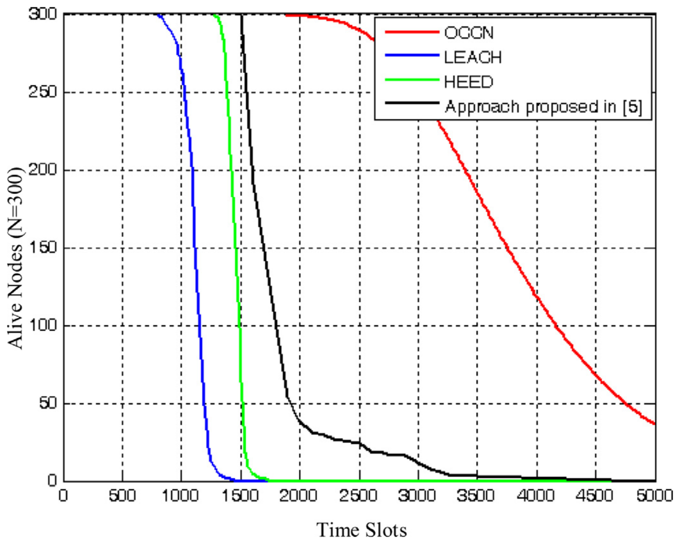

Fig. 10. The number of alive nodes as a function of time.

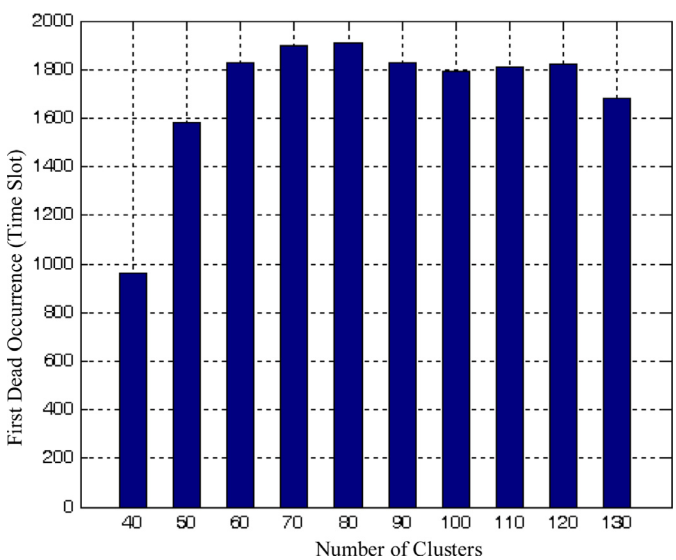

Fig. 11. Time of the first dead under different number of clusters.

can be seen, there is no any fluctuation in energy consumption trend which means the network behaviour in terms of energy consumption is predictable. The idea of predicting energy consumption under using OCCN can be discussed in the future works. In order to evaluate and compare the performance of OCCN with other well-known approaches, the lifetime of a WSN with parameters presented in Table 1 is averaged among 20,000 different random topologies and presented in Fig 10. In this figure, the horizontal axis represents time slots and the vertical axis shows the number of alive nodes in each time slot. As it can be seen, OCCN presents a considerable improvement in comparison to LEACH, HEED and the approach proposed in [5] so that, the first dead happens after 1900 time-slots.

Hence, it can be concluded that OCCN is better than other three methods under all definition of network lifetime. To evaluate the performance of OCCN in terms of first dead, a set of simulations over 20,000 different topologies have been run. Each round of simulations has been done under a specific number of clusters to find the effect of the optimal number of clusters (presented in (19)) on the first dead. As Fig. 11 shows, the first dead lasts more than 1900 time-slots when the number of clusters is set to 79 which is the optimal number of clusters in the network with characteristics displayed in table 1. In other scenarios with more or fewer number of cluster heads, there is no any improvement in the first dead time.

6. Conclusion

Tiny wireless sensor nodes suffer from different constraints such as small battery capacity. Hence, in this paper, a multi-hop communication protocol is proposed which benefits from optimal parameters. The optimal parameters including optimal one-hop communication, the optimal number of cluster size and the optimal number of clusters are considered for a circular network in which, the sink is located in the centre of the network. Moreover, a distributed reservation based cluster head selection is proposed to reduce the energy consumption due to a large number of message passing during iterative cluster head selection. Compared to the existing method, the proposed OCCN improves the network lifetime considerably. Apart from network lifetime, the energy reduction trend is almost linearly, at least until 50% of the nodes are alive. It means the energy consumption trend of the network is predictable. Additionally, OCCN perfectly postpones the time that the first node is dead when the network is divided into the optimal number of clusters.

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