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EECED: Energy Efficient Clustering Algorithm for Event-Driven Wireless Sensor Networks

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1. Introduction

In recent years, a new wave of networks labelled Wireless Sensor Networks (WSNs) has attracted a lot of attention from researchers in both academic and industrial communities. A WSN consists of a collection of sensor nodes and a base station connected through wireless channels, and can be used for many applications such as military application, building distributed systems, physical environment monitoring, and security surveillance among others. A big advantage of sensor networks is represented by ease of deployment, reducing installation cost, possibility to distribute the tiny sensors over a wide region, and larger fault tolerance (V. Loscri et al., 2005). However, despite the infinite scopes of wireless sensor networks applications, they are limited by the node battery lifetime. Such constraints combined with a typical deployment of large number of sensor nodes have posed many challenges to the design and management of sensor networks and necessitate energy-awareness at all layers of the networking protocol stack (Q. Xue & A. Ganz, 2004). Therefore, energy efficient algorithms have been one of the most challenging issues for WSNs.

Sensor nodes can be in one of four states, namely transmit, receive, idle and sleep. The largest part of a node's energy is consumed while transmitting and receiving. Minimizing the number of communications by eliminating or aggregating redundant sensed data saves much amount of energy (L. B. Ruiz et al., 2003). Among these clustering sensor networks are a very attractive approach because clustering allows for scalability, data aggregation, and energy efficiency. In a clustering network, nodes are grouped into clusters and there are special nodes called cluster head. They are responsible for an efficient way to lower energy consumption within a cluster by performing data aggregation. In a heterogeneous sensor network, two or more different types of nodes with different battery energy and functionality are used. On the other hand, in homogeneous networks all the sensor nodes are identical in terms of battery energy and hardware complexity. As a result, network performance decreases since the cluster head nodes goes down before other nodes do. Thus dynamic, energy efficient and adaptive cluster head selection algorithm is very important.

Sensor networks can be divided in two classes as event-driven and continuous dissemination networks according to the periodicity of communication (L. B. Ruiz et al.,

2004). In continuous dissemination networks, the sink is interested in the conditions of the environment at all times and every node periodically sends data to the sink. In event-driven sensor networks, the sink is only interested in hearing from the network when certain events occur. For example, if the application is temperature monitoring, it could be possible just to report data when the temperature of the area being monitored goes above or below certain thresholds. Configuring the network as event-driven is an attractive option for a large class of applications since it typically sends far fewer messages (C.Intanagonwiwat et al., 2000). This is translated into significant energy saving, since message transmissions are much more energy intensive when compared to sensing and (CPU) processing. Also some existing energy-saving solutions take that into consideration and switch some nodes off, leading the nodes to an inactive state, these are waken up only when interest matches the events "sensed" (J.N.Al-Karaki & A.E.Kamal, 2004). Therefore, event driven protocols are used to conserve the energy of the sensor nodes.

In general, routing in WSNs can be divided into flat-based routing, location-based routing, and hierarchical-based routing depending on the network structure. In flat-based routing, all nodes are typically assigned equal roles or functionality. In location-based routing, sensor nodes' positions are exploited to route data in the network. In hierarchical-based routing, however, nodes will play different roles in the network [8]. Many energy efficient hierarchical or cluster based routing protocols have been proposed in sensor networks for different scenarios and various applications (A. Abbasi & M. Younis, 2007). However, most protocols in the previous literatures have not been considering event driven WSNs and, their focus is on continuous networks. Therefore in this work we focus on energy efficient clustering algorithm for event-driven wireless sensor network. In order to extend the lifetime of the whole sensor network, energy load must be evenly distributed among all sensor nodes so that the energy at a single sensor node or a small set of sensor nodes will not be drained out very soon.

Low Energy Adaptive Clustering Hierarchy (LEACH) is one of the most popular clustering algorithms for WSNs (W. Heinzelman et al., 2000). LEACH guarantees that the energy load is well distributed by dynamically created clusters, using cluster heads elected dynamically according to predetermined optimal probability variable. The rotation is performed by getting each node to choose a random number between 0 and 1. A node becomes a CH for the current rotation round if the number is less than the following threshold:

$$T(n) = \begin{cases} \frac{p}{1 - p * (r \bmod \frac{1}{p})} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where p is desired percentage of cluster head nodes in the sensor network, r is current round number, and G is the set of nodes that have not been cluster heads in the last $1/p$ rounds. As long as optimal energy consumption is concerned, it is not desirable to select a cluster head node randomly and construct clusters. However, repeating round can improve total energy dissipation and performance in the sensor network. LEACH has some shortcomings: Firstly, remaining energy of sensor nodes is not considered to construct clusters. The choice of probability for becoming a cluster head is based on the assumption that all nodes start with an equal amount of energy, and that all nodes have data to send during each frame. Accordingly they are hardly applied to the real applications. In real environment, usually non-uniform energy drainage exists due to different distances

between sensor and sinks, different quantity of transmission messages and different transmission rate. If nodes have different amounts of energy, then the nodes with more energy should be cluster heads more often than the nodes with less energy, to ensure that all nodes die approximately at the same time. Some researches present a good solution to reduce energy dissipation using cluster head selection algorithm based on sensors' residual energy. But, in many cases, each node sends information about its current location and energy level to the BS. The BS needs to ensure that the energy load is evenly distributed among the all the nodes (Vinh Tran Quang & Takumi Miyoshi, 2008). Another approach is the BS selects cluster head nodes depending on the number of clusters alive in the network (Giljae Lee et al., 2008). Secondly, LEACH does not guarantee the number of cluster head nodes and their distribution because the cluster head nodes are selected stochastically by the value of probability. The different cluster numbers in WSNs will make the node numbers in every cluster different and uneven cluster numbers dissipate uneven energy in each round (Tung-Jung Chan, 2008). In this paper, by applying the optimal cluster numbers to the WSNs, the lifetime of WSNs can be extended very well.

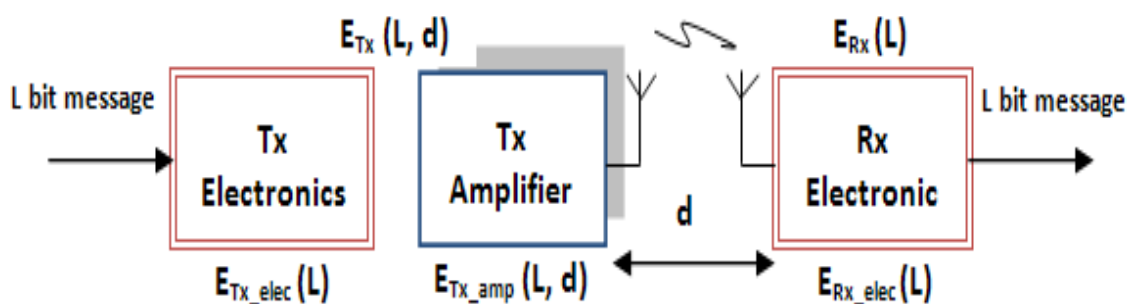


Fig. 1. Radio energy dissipation model

2. Sensor network models

2.1 Network Model

In this work we assume a sensor network model with following properties:

- The sink locates at the centre of sensor nodes and has enough memory and computing capability.
- Sink node is assumed to know all the node locations.
- All sensor nodes are immobile and have a limited energy.
- All nodes are equipped with power control capabilities to vary their transmitting power.
- Also we assume event-driven protocol architecture.

2.2 Radio Model

For the purpose of this study, we use the same condition in LEACH with the simple model for the radio hardware energy dissipation, as a shown Fig.1. L is the number of bits per packet transmission and d is distance between the sender and the receiver. Electronics energy consumption is same for transmitting and receiving the data, is given by,

$$E_{Tx-elec}(L) = E_{Rx-elec}(L) = E_{elec} * L \quad (2)$$

E_{elec} is the energy dissipated per bit to run the transmitter or the receiver circuit. Transmission cost to transmit L -bit message between any two nodes over distance d is given by the following equation:

$$E_{Tx}(L, d) = E_{Tx-elec}(L) + E_{Tx-amp}(L, d) \quad (3)$$

$E_{Tx-amp}(L, d)$ is the amplifier energy consumption and it can be further expressed in terms of ϵ_{fs} or ϵ_{mp} , depending on the transmitter amplifier mode that applied. They are power loss factors for free space (d^2 loss) when $d < d_0$; and multipath fading (d^4 loss) when $d \geq d_0$, respectively. The threshold d_0 can be determined by equating the two expressions, resulting:

$$d_0 = \sqrt{\epsilon_{fs}/\epsilon_{mp}} = 87.7m \quad (4)$$

Thus, to transmit L -bit message within d distance, a node expends:

$$\begin{aligned} E_{Tx}(L, d) &= L*(E_{elec} + \epsilon_{fs}*d^2) & \text{if } d < d_0 \text{ or} \\ E_{Tx}(L, d) &= L*(E_{elec} + \epsilon_{mp}*d^4) & \text{if } d \geq d_0 \end{aligned} \quad (5)$$

To receive L -bit message within d distance, a node expends:

$$E_{Rx}(L) = E_{Rx-elec}(L) = E_{elec} * L \quad (6)$$

2.3 Optimal Fixed Number of Cluster

Suppose that there are N sensor nodes randomly deployed into an $M \times M$ region. In the k clusters WSN, the squared distance from the nodes to the cluster head is given by (W. Heinzelman et al., 2000):

$$E[d_{toCH}^2] = \frac{M^2}{2\pi k} \quad (7)$$

If assumed that $M=100$ and the base station locates centre of sensing area, then maximum distance of any nodes from the base station is approximately 70m. Thus, from (4), every time d_{toBS} and d_{toCH} are less than d_0 .

Hence, using (5) and (6) the energy consumption for each cluster head, E_{CH} , and energy consumption for non cluster head, E_{nonCH} , can be obtained by:

$$E_{CH} = L\left(\frac{N}{k} - 1\right)E_{elec} + L\frac{N}{k}E_{DA} + LE_{elec} + L\epsilon_{fs}d_{toBS}^2 \quad (8)$$

$$E_{nonCH} = LE_{elec} + L\epsilon_{fs}d_{toCH}^2 \quad (9)$$

respectively, and E_{DA} represents the processing (data aggregation) cost of a bit per signal and L is length of data message. Also we assumed that clusters are equally sized, thus there are average N/k nodes per clusters and $(N/k) - 1$ non cluster head nodes.

The energy dissipated in a cluster per round, E_{cluster} , is expressed by:

$$E_{\text{cluster}} = E_{\text{CH}} + \left(\frac{N}{k} - 1\right) E_{\text{nonCH}} \quad (10)$$

Therefore, the total energy dissipated in the network per round, E_{rnd} , is expressed by:

$$E_{\text{rnd}} = k * E_{\text{cluster}} = L \left(2NE_{\text{elec}} + \varepsilon_{\text{fs}}(kd_{\text{toBS}}^2 + Nd_{\text{toCH}}^2) \right) \quad (11)$$

By (7) and (11), we can find the optimal cluster number k given by (Tung-Jung Chan, 2008):

$$\frac{\partial E_{\text{rnd}}}{\partial k} = 0$$

$$k_{\text{opt}} = \sqrt{\frac{N}{2\pi} \frac{M}{d_{\text{toBS}}^2}} = \sqrt{\frac{N}{2\pi}} M = \sqrt{N} \quad (12)$$

3. Energy Efficient Clustering for Event-Driven (EECED) Protocol Architecture

Our modified protocol called “Energy Efficient Clustering Algorithm for Event-Driven Wireless Sensor Networks (EECED)” is aimed at prolonging the lifetime of a sensor network by balancing energy usage of the nodes. EECED makes the nodes with more residual energy have more chances to be selected as cluster head. Also, we use elector nodes which take the responsibility of collecting energy information of the nearest sensor nodes and selecting the cluster head. We compared the performance of our EECED algorithm with the LEACH protocol using simulations.

EECED involves three main steps; the initial phase, the clustering phase and the data transmission phase. The initial phase is performed only once at the beginning of network operation. Similar with LEACH, the operation of EECED is divided into round, where each round consists of the clustering phase and the data transmission phase. Each round begins with clustering phase when the clusters are organized, followed by a data transmission phase when data are transferred from the nodes to cluster head and on to the base station (BS). In the following sub-sections we discuss each of these phases in details.

3.1 Initial Phase

The sink selects k_{opt} number of elector nodes using (12), then the sink broadcasts an elector advertisement message (ELEC_ADV) in initial phase, as shown in Fig. 2.

3.2 Clustering Phase

The clustering phase is similar with LEACH protocol, involving cluster head selection part and cluster construction part. During the cluster selection phase, elector node determines CH based on the residual energy of the node. Those with higher residual energy have the advantage during the CH competition. Clusters are created by non-CH nodes choosing to

join a CH based on the signal strength of advertisements received from CHs. It has been shown that our protocol reduces energy consumption and improves network lifetime compared to probability schemes.

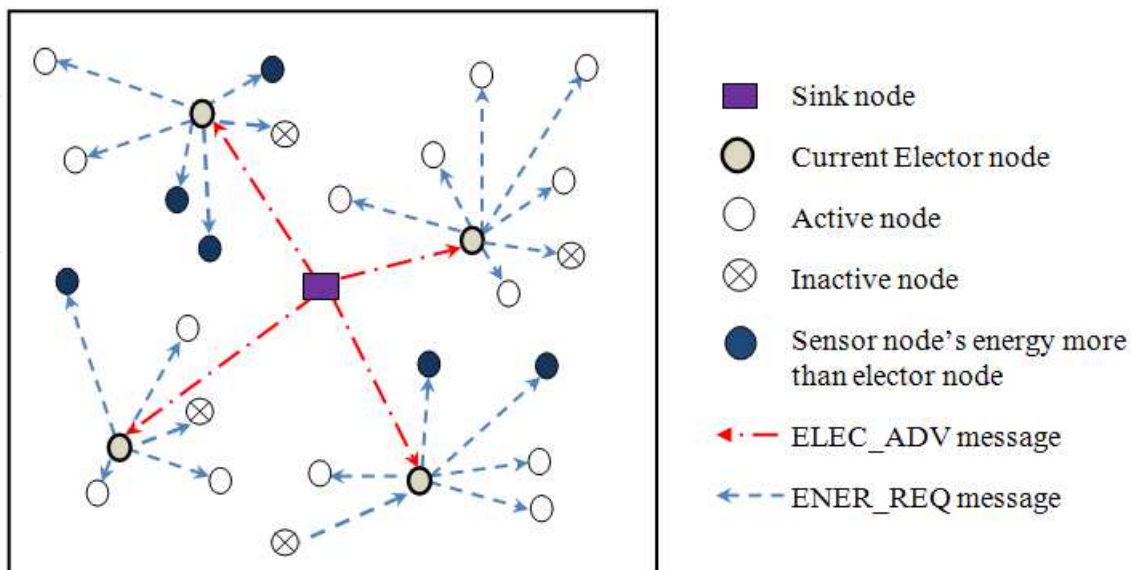


Fig. 2. Initial phase and Energy Request message transmission

3.2.1 Cluster Head Selection

To reduce global communication, a cluster-head may implement one or more optimization functions such as data fusion and transmits to more distant cluster-heads. In a homogeneous network, cluster head uses more energy than non cluster head nodes. As a result, network performance decreases since the cluster head nodes goes down before other nodes do. Clustering schemes have to ensure that energy dissipation across the network should be balanced and the cluster head should be rotated in order to balance the network energy consumption.

Our protocol uses dynamic CH selection algorithm based on higher residual energy. In this part, elector nodes take responsibility for collecting nearest sensors' energy information and selecting cluster head.

- When normal node knows that it has become elector node, then it broadcasts energy request message (ENER_REQ) with its own energy level information to its surrounding nodes, as shown in Fig. 2.
- The normal nodes first compare its own energy level with energy level of most nearest elector node.
- If normal node's energy level is greater than elector node, it sends energy reply (ENER_REP) message, otherwise it waits for cluster head advertisement (CH_ADV) message, as a shown Fig. 3.
- Elector node selects cluster head with maximum residual energy and next elector node with second maximum residual energy.
- Elector node becomes available to become cluster head if its energy is greater than others.

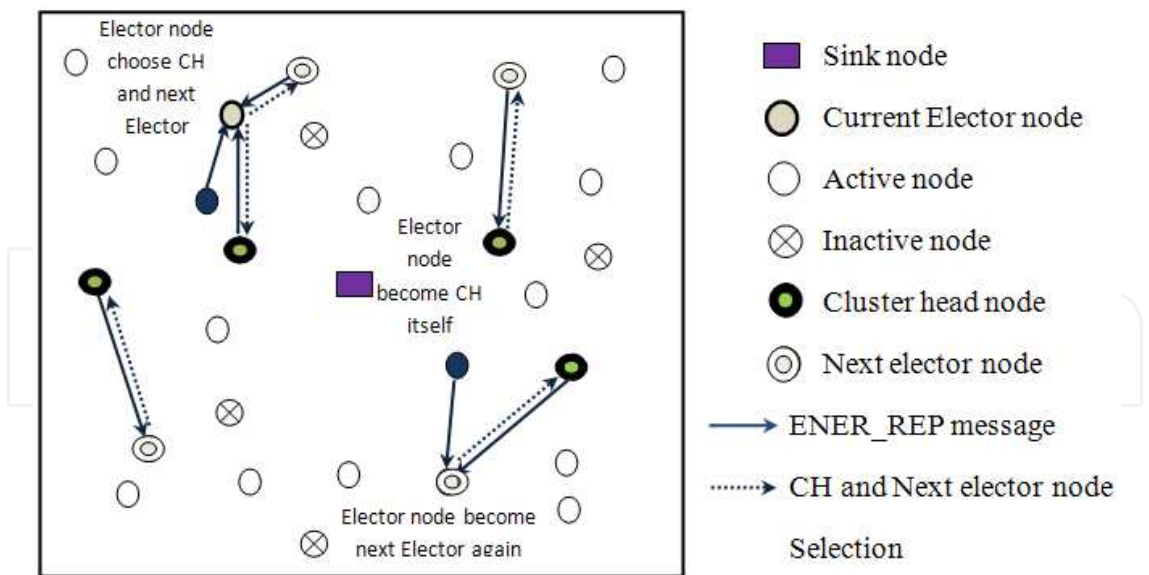


Fig. 3. Cluster head and next elector node selection

3.2.2 Cluster Construction

- After cluster head is selected by elector node, the cluster head node broadcasts a cluster head advertisement message (CH_ADV) containing cluster head ID.
- Non-cluster head sensor nodes then select the most relevant cluster head node according to the signal strength of the advertisement message from the cluster head nodes. Each member node transmits a join request message (JOIN_REQ), as shown in Fig. 4.

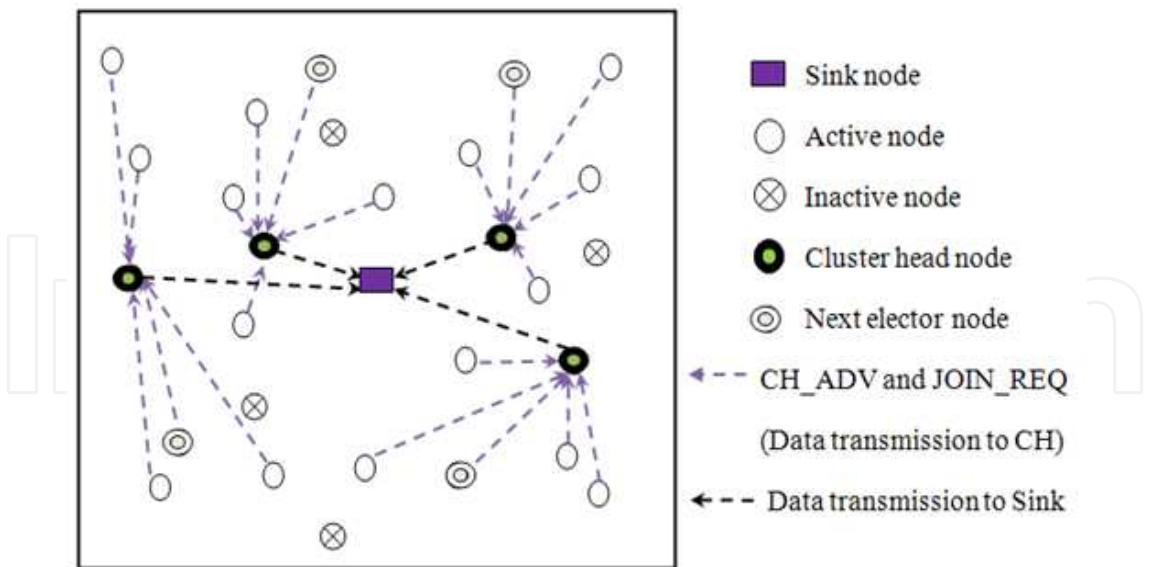


Fig. 4. Cluster construction and Data transmission

Our proposed protocol has some overhead of control message exchanges. To ensure minimizing energy consumption of broadcast messages, we use optimal transmission radius, minimum message length and minimum number of control messages. Elector nodes

take responsibility of collecting nearest sensors’ energy information, so transmission range is minimized. Also control message size is small containing a header that distinguishes this message type. Some nodes which have energy greater than energy level of elector node ensure minimization of ENER_REP message transmission. Control messages use a non persistent CSMA MAC protocol to avoid collision. Message types and message field size are shown in Table1 and Table2 respectively. Also power consumption can be reduced by assigning the lowest necessary transmission power to the nodes in networks where the nodes exchange control message and are able to adjust their transmission power.

Source ID	Dest ID	Seq ID	Flag	RSSI value	Energy level	Spec info
2 byte	2 byte	2 byte	1 byte	2 byte	2 byte	Variable

Table 1. Control message field size

Flag	Control Message type
1	ENER_REQ (Energy Request)
2	ENER_REP (Energy Reply)
3	CH_ADV (Cluster Advertisement)
4	JOIN_REQ (Join Request)

Table 2. Control and data message type

3.3 Data transmission Phase

In data transmission phase, the cluster head nodes act as local control centers to coordinate data transmission in their cluster, as shown in Fig.4.

Once the selected cluster head node receives the JOIN_REQ message from member nodes, the cluster head set up a TDMA schedule according to their active member nodes. The function of the schedule is to avoid the collision on data transmission and to keep the synchronization among all the nodes within the cluster. Active member nodes wait for receiving the TDMA schedule from the cluster head. Meanwhile, they can turn their radio components off except for their own transmission period. Active sensor nodes exchange their matching data without collision. Inactive nodes go to sleep mode until next round. When cluster heads have aggregated data from their active nodes, they send it to BS directly, because we assume all the nodes are equipped with power control capabilities to vary their transmitted power.

Once the data transmission phase ends, network reforms the cluster head selection procedure in a new round, as shown in Fig.5. For distributed energy dissipation next elector nodes will become elector nodes since the elector nodes dissipate little more energy than normal nodes. Here, we assumed no emergency information occurs in this application.

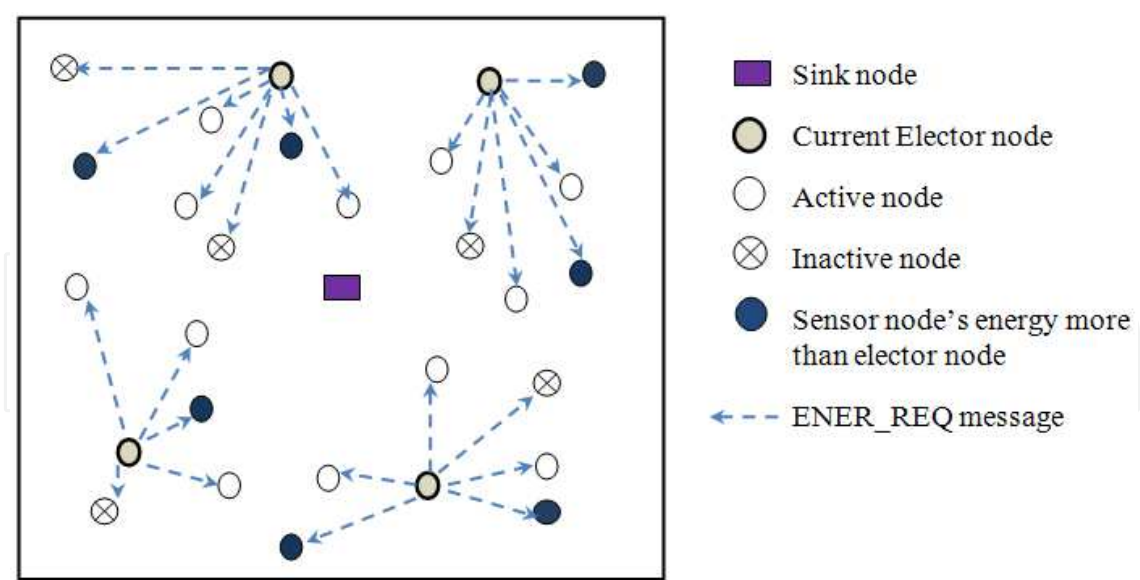


Fig. 5. Condition of next new round

4. Performance evaluation

4.1 Energy Consumption and Simulation Parameters

In this simulation, energy is decreased whenever a node transmits or receives data and whenever it performs data aggregation. We don't decrease energy during carrier-sense operations. For simplicity, we assume that the maximum distance of any node to the cluster head is $\leq d$. From (9), we calculated energy dissipation in normal node during a round is given by the following formula:

$$E_{normal} = L_{data} (E_{elec} + \epsilon_{fs} d_{toCH}^2)$$

(13)

According to (5) and (8), the energy used in each cluster head node is equal to:

$$E_{CH} = L_{data} (N_{normal} (E_{elec} + E_{DA}) + \epsilon_{fs} d_{toBS}^2)$$

or

$$E_{CH} = L_{data} (N_{normal} (E_{elec} + E_{DA}) + \epsilon_{mp} d_{toBS}^4)$$

(14)

where N_{normal} is the number of member nodes in the cluster, E_{DA} is the processing (data aggregation) cost of a bit per signal and L_{data} is length of data message. We do not assume any static energy dissipation, but we calculated energy dissipation of some control messages containing energy level. The energy consumed in each elector node is equal to:

$$E_{elector} = L_{broad} (E_{elec} + \epsilon_{fs} d_{toCH}^2 + E_{elec} N_{res})$$

(15)

where L_{broad} is constant and small size of control message and N_{res} is the number of response nodes whose energy level is greater than energy level of elector node. Table 3 shows simulation parameters.

Notation	Description	Value
$M \times M$	Area	100x100
N	Number of the sensors	100 and 300
sinkX, sinkY	Sink node location	50x50
E_0	Initial energy	0.2 J and 0.1J -0.3J
E_{elec}	Electronics energy	50nJ/bit
E_{DA}	Energy of data aggregation	5nJ/bit
d_0	The threshold distance	87m
ϵ_{fs}	Amplified transmitting energy using free space	10pJ/bit/ m ²
ϵ_{mp}	Amplified transmitting energy using multipath	0.0013pJ/bit/ m ⁴
L_{data}	Data packet size	500bytes
L_{broad}	Broadcast packet size	25 bytes
p	Probability	0.1

Table 3. Simulation parameter

4.2 Result analysis

We simulated the performance of our EECED algorithm compared to LEACH protocol. We considered both equal initial energy (0.2J) and different initial energy (0.1-0.3J) in each node. Our performance was measured by total residual energy per round, total number of received packet at the BS, network lifetime, total number of nodes alive in the network, and round of first died node. In this simulation, network lifetime is defined as the round interval from the start of operation until death of the last alive node, and the first node died round is defined as the round interval from the start of the network operation until the death of the first sensor node.

Fig. 6 shows the total number of nodes alive per round when total number of sensors in the network varies from 100 to 300, and initial energy is different from each other. From Fig.6, it can be seen that network lifetime and round of the first died node of our algorithm are longer than LEACH. Also EECED shows that the round of the first died node and network lifetime staysare the same regardless of the increase in network size. In case of LEACH protocol, round of the first died node is very fast and linearly decreases until last round. Simulation proves that our algorithm can balance the energy consumption of the entire network compared to LEACH protocol.

Fig. 7 shows the number of nodes alive per round in case of initial energy being same. The Fig. explains that in case of initial energy being the same with all of sensors, EECED performance of round first node is similar with LEACH, but network lifetime is greater than LEACH in case of large network.

Fig. 8 shows number of packets received at the BS per round in the case of total number of nodes being 100 and initial energy being different from each other. From Fig. 8, our targeted algorithm has better performance of data transmission.

The total residual energy per round in case of having total number of nodes as 300 and in case of different initial energy can be seen from the Fig. 9, whereas if initial energy is different, EECED performs better than LEACH.

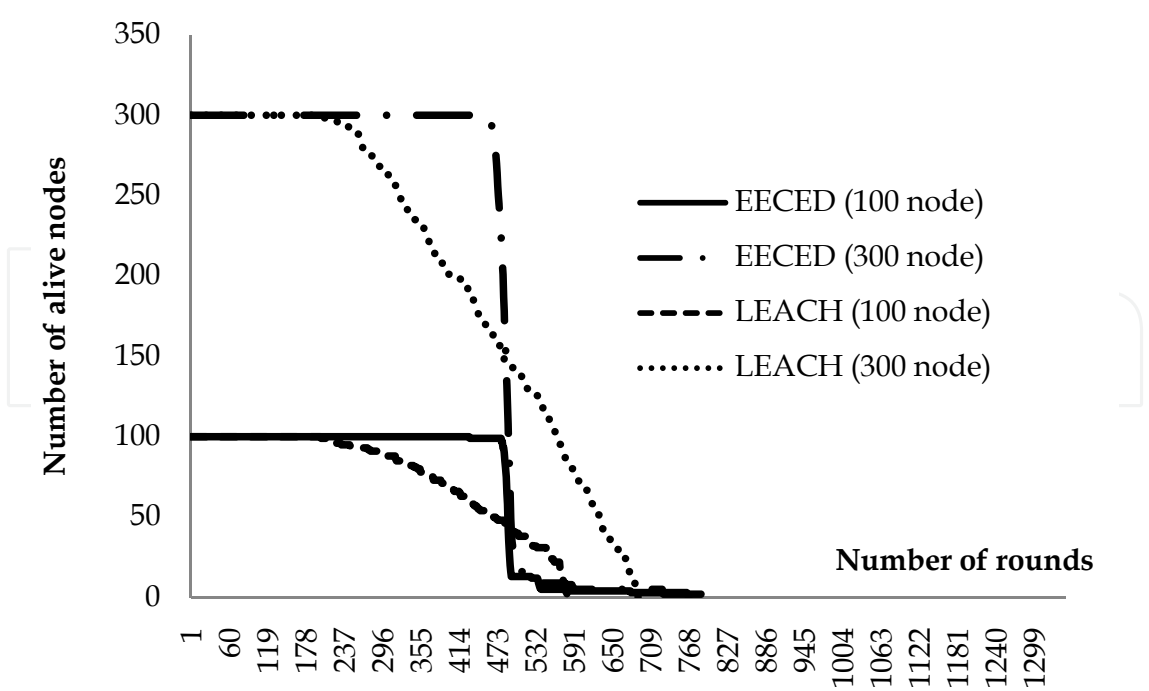


Fig. 6. Number of living nodes in each round with different initial energy is used and total number of nodes 100 and 300

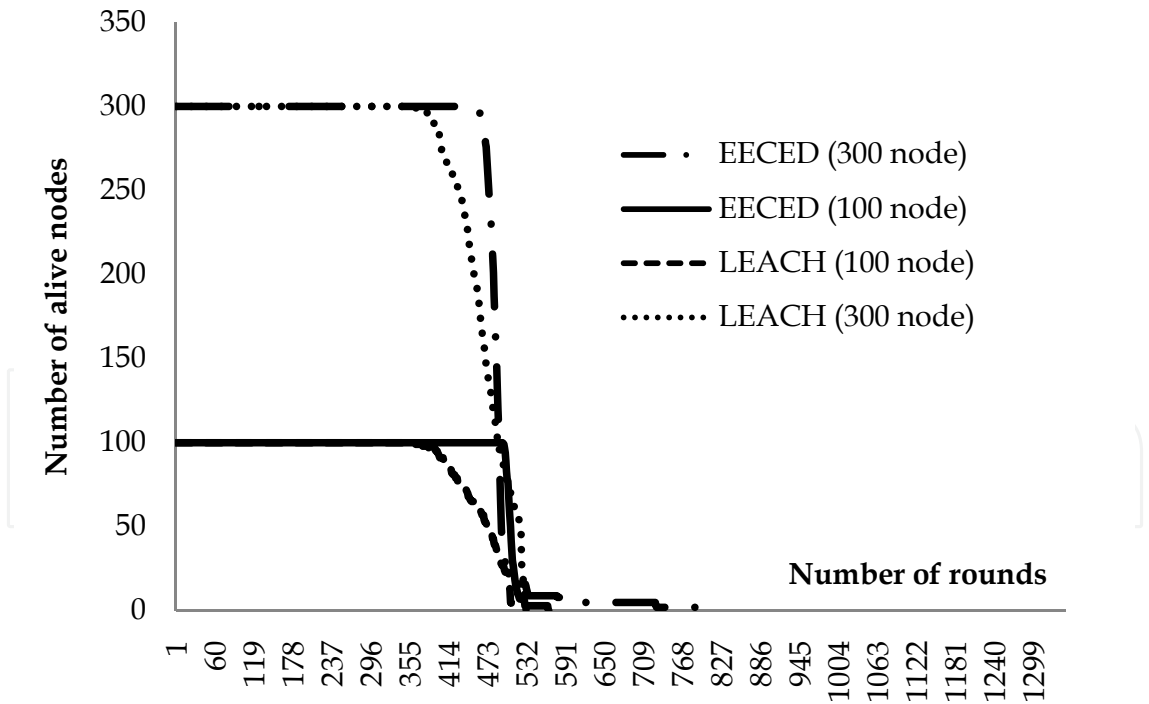


Fig. 7. Number of living nodes in each round with same initial energy is used and total number of nodes 100 and 300

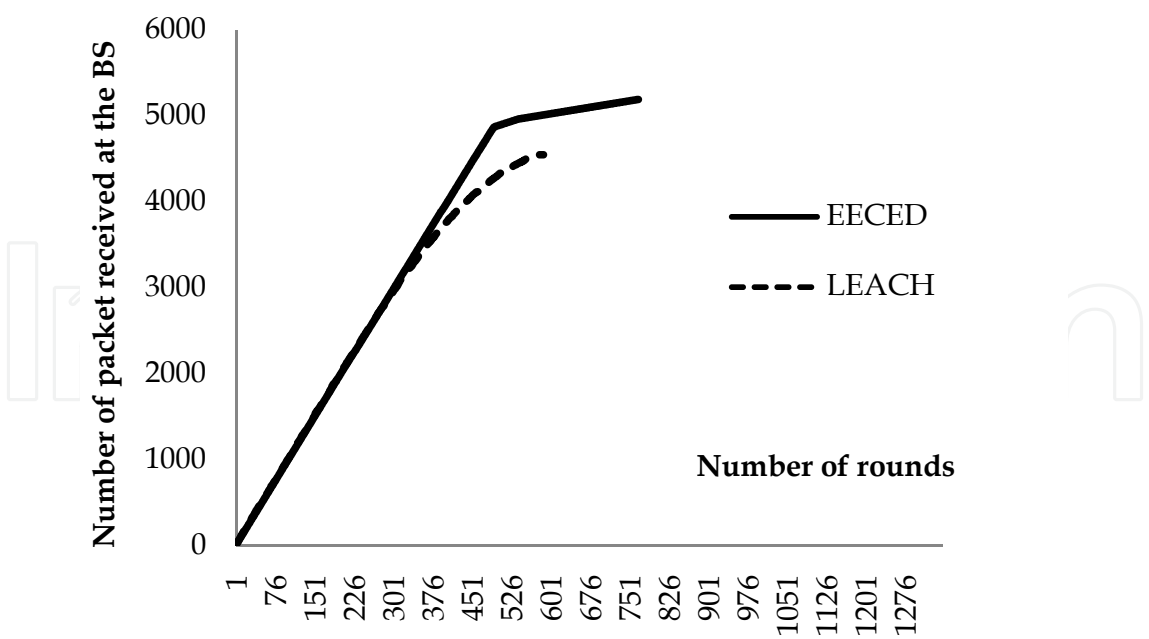


Fig. 8. Number of packet received at the BS (different initial energy and total number of nodes 100)

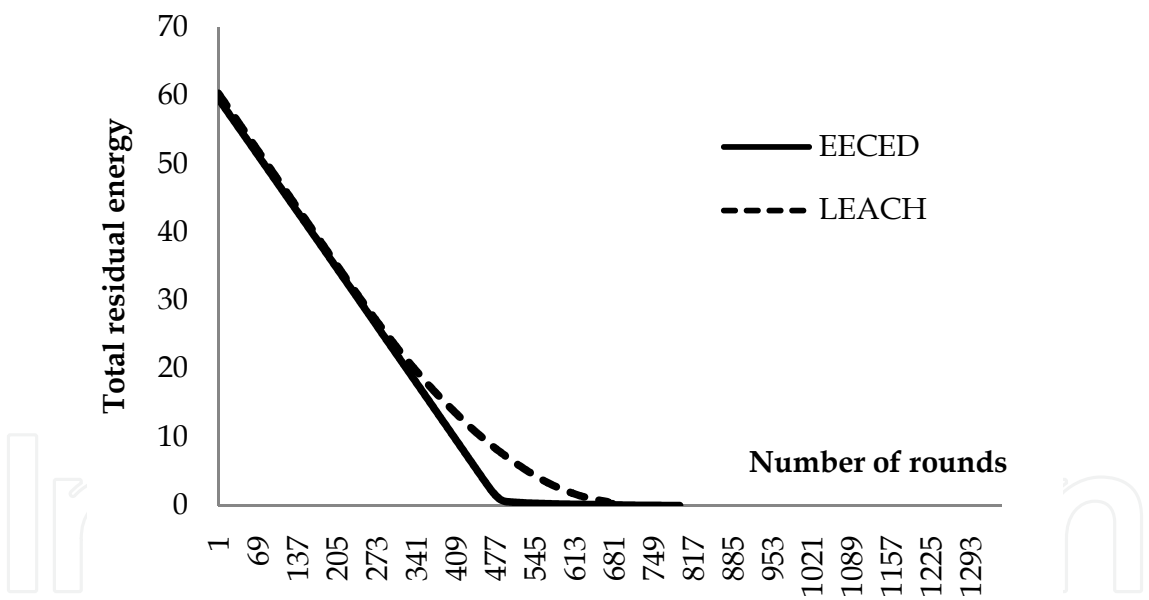


Fig. 9. Total residual energy per round (different initial energy and total number of nodes 300)

Also we simulated the performance changes in large network. The simulation result shows, that the network lifetime decrease rapidly in large area network and the period that the first dead node appears is earlier than those of previous cases. The phenomenon is caused by the fact that the cluster heads waste the considerable amount of energy for transmitting their data to the far away base station. Because in these scheme, all cluster heads transmits aggregated data to the BS directly. In direct transmission, nodes far away from the BS dissipate their energy much faster than those close to the BS, therefore some nodes drained

out very soon. We simulated the performance changes of EECED as the size of sensing field increases. The network lifetime when total number of nodes is 100 is shown in Fig. 10. It shows, if size of sensing field increases, the network lifetime of EECED decreases rapidly.

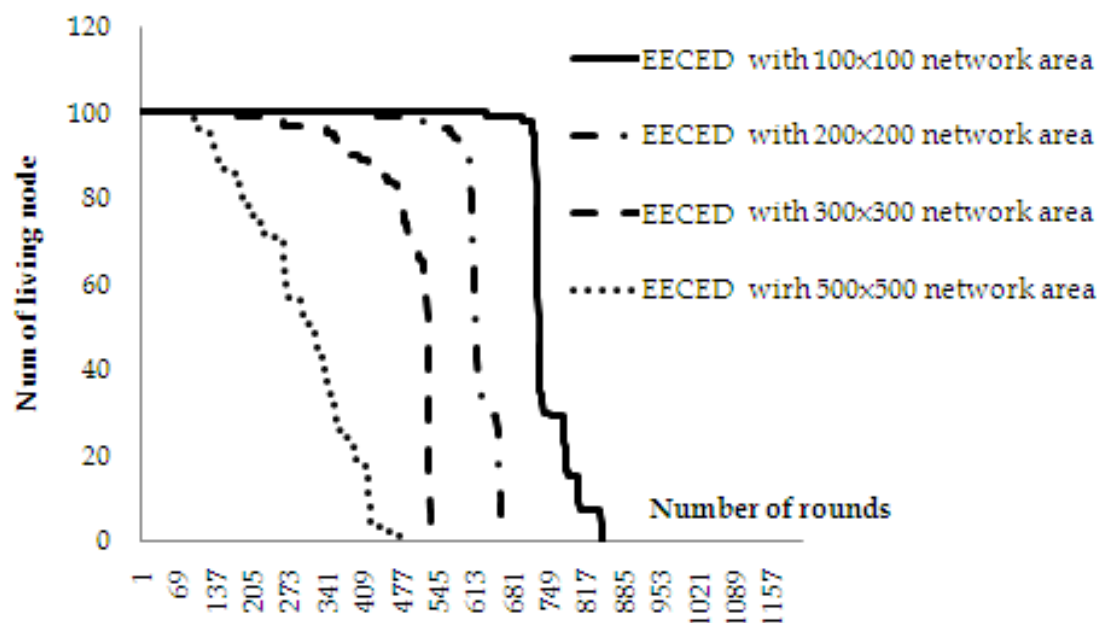


Fig. 10. Number of living nodes in each round with the increase in network

5. Conclusion

Routing in sensor networks is very challenging due to several characteristics that distinguish them from traditional communications and wireless ad-hoc networks since several restrictions, e.g., limited energy supply, computing power, and bandwidth of the wireless links connecting sensor nodes. The major difference between the WSN and the traditional wireless network is that sensors are very sensitive to energy consumption. Introducing clustering into the networks’ topology has the goal of reducing the number of message that need to be delivered to the sink in large-scale WSNs.

We proposed an “Energy Efficient Clustering Algorithm for Event-Driven Wireless Sensor Networks (EECED)” to extend the network lifetime of a sensor network by balancing energy usage of the nodes. AEEC improved the energy efficiency of WSNs:

- CHs have higher burdens than member nodes; therefore, rotating the role of the CH shares the burden and thus extending the useful lifetime of those clusters.
- If nodes have different amounts of energy, then the nodes with more energy should be cluster heads more often than the nodes with less energy.

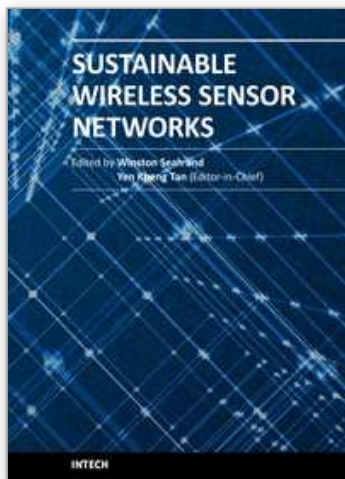
We showed that in many cases our algorithm is more energy efficient than LEACH. The results show that the proposed algorithms can maintain a balanced energy consumption distribution among nodes in a sensor network and thus prolong the network lifetime.

WSNs are increasingly being used for event-driven communications ranging from health care, transportation, manufacturing, and much more. In these kinds of applications, the energy usage is different on all sensors. Cluster-based routing protocols are used in the event driven model, considerable energy can be saved. Our approach is well suitable for the

event-driven application in WSNs, because in event-driven sensor network applications, events occur randomly and transiently, and accompanied by the bursts of large numbers of data, therefore, network energy consumption is uneven.

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Sustainable Wireless Sensor Networks

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Wireless Sensor Networks came into prominence around the start of this millennium motivated by the omnipresent scenario of small-sized sensors with limited power deployed in large numbers over an area to monitor different phenomenon. The sole motivation of a large portion of research efforts has been to maximize the lifetime of the network, where network lifetime is typically measured from the instant of deployment to the point when one of the nodes has expended its limited power source and becomes in-operational “ commonly referred as first node failure. Over the years, research has increasingly adopted ideas from wireless communications as well as embedded systems development in order to move this technology closer to realistic deployment scenarios. In such a rich research area as wireless sensor networks, it is difficult if not impossible to provide a comprehensive coverage of all relevant aspects. In this book, we hope to give the reader with a snapshot of some aspects of wireless sensor networks research that provides both a high level overview as well as detailed discussion on specific areas.

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