An Unequal Cluster-based Routing Protocol Based on Data Controlling for Wireless Sensor Network

Slaheddine Chelbi[*], **Majed Abdouli**[***], **Mourad Kaddes**[***], **Claude Duvallet**[**], **and Rafik Bouaziz**[*]
[*]MIRACL Laboratory, University of Sfax, Tunisia
[**]LITIS, University of Le Havre, France
[***]FCIT, University of Jeddah, Saudi Arabia

Article Info

ABSTRACT

Wireless Sensor Networks (WSN) differ from traditional wireless communication networks in several characteristics. One of these characteristics is power awarness, due to the fact that the batteries of sensor nodes have a restricted lifetime and are difficult to be replaced. Therefore, all designed protocols must minimize the energy consumption and therefore preserve the longevity of the network. In this paper, we propose (i) to fairly balance the load among nodes. For this, we generate an unequal clusters size where the cluster heads (CH) election is based on energy availability, (ii) to reduce the energy consumption due to the transmission by using multiple metrics in the CH jointure process and taking into account the link cost, residual energy and number of cluster members to construct the routing tree and (iii) to minimize the number of transmissions by avoiding the unnecessary updates using sensitive data controller. Simulation results show that our Advanced Energy-Efficient Unequal Clustering (AEEUC) mechanism improves the fairness energy consumption among all sensor nodes and achieves an obvious improvement on the network lifetime.

Corresponding Author:
Slaheddine Chelbi
MIRACL Laboratory University of Sfax, Tunisia
slaheddine.chelbi@gmail.com

1. INTRODUCTION

In the last decade, with the development and advancement of sensor technologies and their relative cheapness, WSN have been widely deployed for both civil and military applications, e.g., harbor container monitoring system, marine monitoring for earthquake and tsunami, and military surveillance in battlefields [1][2]. A WSN consists of hundreds to thousands of sensor nodes, which have the ability to communicate among themselves using radio antenna. Since sensor nodes are battery powered and may be applied in dangerous or inaccessible environments, it is difficult and even impossible to replace or recharge the power supplies [3] [4]. We need energy-efficient mechanisms to reduce energy consumption of nodes and maximize network lifetime. Balancing the energy consumption in the network is an important issue for prolonging the network lifetime. Therefore, efficient routing techniques are highly required to balance the energy consumption among the network nodes and maximize the network lifetime [5][6].

Different routing protocols for WSN proposed in literature are categorized based on their computational complexity, network structure, energy efficiency and path establishment [7][8] [9]. One of the principal classes is hierarchical routing protocols. In this class, the main idea is that every sensor node within a WSN is grouped along with some other of its neighboring nodes in order to constitute a specific cluster. Clustering provides an effective method for prolonging the lifetime of a WSN. Data, collected by the sensor nodes belonging to a cluster, are not directly transmitted to the Base Station (BS). Instead, a node of the cluster, called CH, collects these data and forwards them to the BS after possibly having performed appropriate data aggregation. In this way, the number of transmitted messages to the BS is reduced and considerable power conservation is achieved.

However, routing protocols rarely consider the hot spot problem in multi-hop sensor networks. Indeed, when CH cooperate with each other to forward their data to the BS, the CH closer to the BS are burdened with heavier relay traffic and tend to die much faster, leaving the areas of the network uncovered and causing network partitions. To

mitigate the hot spot problem, an Unequal Cluster-based Routing (UCR) protocol is proposed in [10]. As shown in Figure 1, nodes are grouped into unequal sizes clusters: Clusters closer to the BS have smaller sizes than those farther away from it. Thus CH closer to the BS can preserve some energy for the purpose of inter-cluster data forwarding.
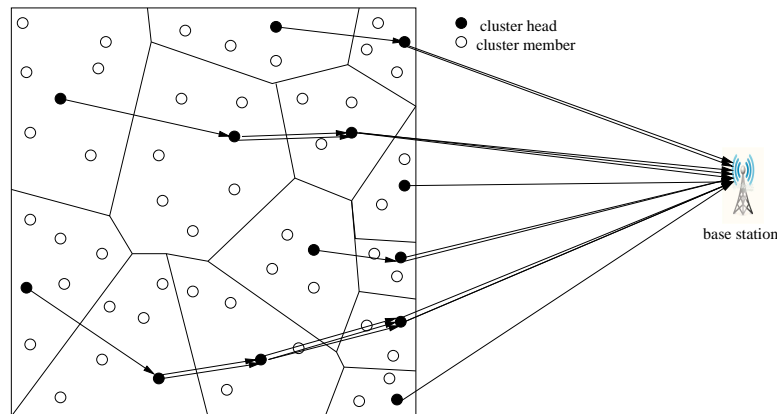

Figure 1. Unequal Cluster size with the UCR mechanism [10]

In this paper, we propose a new mechanism called AEEUC in order to enhance the WSN lifetime. AEEUC, as well as UCR [10], use an unequal clustering and multi-hop routing scheme to improve the network lifetime. However, the proposed mechanism to choose CH and inter-cluster communication in AEEUC is different from those of UCR. Our protocol aims to balance the amount of the energy consumption among CH within the network.
Furthermore, we propose to reduce the consumed energy by minimizing the unnecessary data transmissions and hence prolong the lifetime of the system. To achieve this goal, we propose to avoid the transmission of new value of data if it does not deviate from the current value more than Maximum Data Error (MDE). We remind that the MDE indicates the maximum deviation tolerated between the current value and the new one.

The rest of this paper is structured as follows: section 2 presents a brief related work. Section 3 outlines the design of our proposed routing protocols AEEUC. Section 4 presents simulations and results. Finally, section 5 draws the conclusion and some future work.

2. RELATED WORK

In the few recent years, a WSN have gained the attention of researchers in many challenging aspects. The most important challenge in these networks is energy conservation. Particulary, two major issues are explored to optimize energy consumption: routing techniques and data aggregation.

- The routing techniques are classified into three categories depending on the network structure: flat, hierarchical, and location-based routing [11]. Hierarchical clustering techniques can help to reduce useful energy consumption. Hierarchical or cluster-based routing are well-known techniques with special advantages related to scalability and efficient communication [2] [12] [13].

- Data aggregation in WSN is a data transfer technique by which several packets from sensor nodes are combined into one [14] [15]. This technique is essential because the reduction of data packets reduces energy consumption, increases network lifetime, and therefore improves successful data transmission ratio.

LEACH (Low Energy Adaptive Clustering Hierarchy) is one of the first hierarchical routing protocol proposed for WSN [3]. It is also the first clustering protocol that was proposed for reducing power consumption. LEACH randomly selects a few sensor nodes as CH and rotates this role to evenly distribute the energy load among the sensors in the network. The idea is to form clusters of the sensor nodes based on the received signal strength and use local CH as routers to the BS. The operations of LEACH are done into two phases, the *setup phase* and the *steady state phase*. In setup phase, the clusters are organized and CH are selected. CH change randomly over time in order to balance the energy dissipation of nodes. In the steady state phase, the current data is transferred to the BS.

Although LEACH is able to increase the network lifetime, it suffers from a few limits: (1) routing in LEACH protocol is based on the assumption that each node can transmit directly to both its CH and the BS. However, such a single hop routing is impractical in networks having their sensors deployed over wide regions. It is not always a realistic assumption for single-hop inter-cluster routing with long communication range. Besides, long-range communications directly from CH to the BS can lead to high energy consumption. (2) Despite the fact that CH rotation is

performed at each round to achieve load balancing, LEACH cannot ensure real load balancing because CH are elected in terms of probabilities without energy considerations. (3) LEACH randomly selects a list of CH and it has not a constraint on their distribution. Hence, probably all CH will be concentrated in the same area. Therefore, some nodes will not have CH in their neighborhoods. To overcome these drawbacks, many extension of LEACH are proposed in literature [16]. In [17], the authors propose a central control algorithms named C-LEACH. The latter propose to construct the clusters in such a way that CH are scattered throughout the network. In [18], the authors propose MODLEACH protocol. In this protocol, the CH is changed until and unless it has more energy than the certain required threshold, unlike LEACH where the CH is changed after every round. Furthermore, MODLEACH categorised communication into different categories in order to optimize energy spend for communication. In [19], a multi-hop protocol entitled MH-LEACH is proposed. This protocol increases network life time by using neighbour nodes for data transmission which results in lesser energy consumption.

Hybrid Energy Efficient Distributed (HEED) is a distributed clustering algorithm in which two parameters are used to determine the eligibility of a node to become a CH [20]. Since prolonging the network lifetime is the main goal, residual energy is used as the first parameter, which allows nodes with higher residual energy to become CH, thus balancing the overall energy of the network. The second factor intra communication cost, which can be cluster density, allows a node to join a CH with the least number of nodes so as to reduce the load of the intra-cluster traffic on the CH. However, HEED does not make any assumption about the network such as density or size. HEED introduces extra communication overhead because it needs to exchange a large number of messages in order to compute the communication cost with its neighbors.

In [21], Yu et al. proposed a cluster-based routing protocol for WSN with non-uniform node distribution (EADC), whose cores are an energy-aware clustering algorithm and a cluster-based routing algorithm. EADC is a competition based algorithm, where CH is selected on the basis of the ratio between its residual energy to the average residual energy of its neighbors. To form clusters, each node chooses the nearest CH without taken into account its residual energy. Each CH chooses a next hop CH with higher residual energy and fewer cluster members as its next hop.

In BCEE [22], CH is selected by using K-means algorithm. To form clusters, BCEE does not require position of each node but uses the idea of receive signal strength indicator (RSSI). To route the data to the sink, the techniques of ant colony optimization is used to establish an optimal multi-hop route from CH to the sink using rational and hop-selecting technique. However, BCEE introduces extra communication overhead and delay of data transmission to the sink node.

In [23], the authors have used the advantages of two approaches i.e. fuzzy c-means (FCM) clustering and neural network to make an energy efficient network by prolonging the lifetime of network. The cluster formation is done using FCM to form equally sized clusters in network and the decision of choosing CH is done using neural network having input distance from BS, heterogeneity and energy of the node.

The main focuses of these algorithms are to reduce and balance the energy consumption of nodes by using clustering algorithms. In fact, clustering (1) enables data aggregation at CH, hence reduces the number of unnecessary data transmissions, and saves energy of the sensor nodes, (2) simplify routing management because only CH need to maintain the local route setup of other CH and thus require small routing information, (3) conserves communication bandwidth [24] . However, CH bear some extra work load contributed by their member sensor nodes. In the other hand, when the multi-hop inter-cluster communication model is adopted, the CH closer to the BS are burdened with heavier relay traffic and will depletes energy much faster, leaving areas of the network uncovered. To mitigate the hot spot problem, Chen *etal*. [10] have proposed UCR protocol.

In UCR, CH is selected based on local information *i.e.*, the residual energy of neighboring nodes. The node's competition range decreases as its distance to the BS decreases. The result is that clusters closer to the BS are expected to have smaller cluster sizes, thus the CH will consume lower energy during the intra-cluster data processing, and can preserve more energy for the inter-cluster relay traffic.

The UCR protocol produces a distribution of CH through an election process using a competition radius. The remaining sensor nodes receive the broadcast from one or more CH and make their association decision based on minimum communication cost. The inter-cluster multi-hop routing protocol considers the tradeoff between the energy cost of relay links and the energy of relay nodes. UCR extends LEACH and HEED by choosing CH with more residual energy.

In UCR protocol, clusters closer to the BS are expected to have smaller cluster sizes. Thus they will consume lower energy during the intra-cluster data processing, and can preserve more energy for the inter-cluster relay traffic. But, in networks with non-uniform node distribution, this mechanism is not always effective. Consequently, the higher energy consumption still exists among CH closer to BS due to the non-uniform node distribution. Moreover, in UCR several tentative CH are randomly selected to compete for final CH. Hence, the participation of some tentative CH

may be at the expense of other nodes having higher residual energy.

3.   THE AEEUC MECHANISM

In this section, we present the relevant details of Advanced Energy Efficient Unequal Clustering mechanism in WSN. We suppose that the WSN is composed by a BS and a set of homogeneous sensor nodes which are randomly distributed over a bounded area of interest. The sensors nodes and BS are stationary after deployment. The BS is a node with high capabilities and unlimited power but the sensor nodes are energy constrained.

The main idea of AEEUC is based on the creation of energy-efficient clusters for a given number of transmissions. The task of being a CH is rotated among sensors in each round (a set of transmissions) to distribute the energy consumption across the network. AEEUC is a distributed CH competitive algorithm where nodes with higher energy will be elected as CH.

To mitigate the hot spot problem, we use in the AEEUC protocol unequal sizes clusters. Thus, clusters closer to the BS have smaller cluster sizes, and, consequently, they will consume less energy during the intra-cluster data processing, and can conserve some more energy for the inter-cluster relay traffic.

By producing cluster with unequal sizes, UCR succeeds in making the energy consumption of CH balanced. However, in some cases and due to non-uniform distribution of nodes, it may happen that CH with a small competition range will have more members' nodes. In this case, they have high intra-cluster energy consumption [21] . For this, in our work, each CH will select the neighbor CH with higher residual energy, minimum link cost and a smaller number of cluster members as the next hop to balance the energy consumption among CH.

To avoid the unnecessary updates and subsequently optimize the use of resources, in [25] data is allowed to deviate, with a certain degree, from their corresponding values in the external environment. They introduce the notion of data error, denoted DE, which gives an indication of how much the value of stored data deviates from the corresponding real-world value. This deviation has a threshold named MDE (Maximum Data Error). The transmission of data is discarded if the deviation between the current data value and the stored value is less or equal to MDE (if $DE \leq MDE$). In the same way to reduce the number of transmission, we allow data error in AEEUC.

The whole process is divided into three phases: CH competition phase; cluster formation phase and data transmission phase.

3.1.   CH competition phase

AEEUC is a distributed CH competitive algorithm, where the CH selection is primarily based on the residual energy of tentative CH and rotating CH periodically to distribute the energy consumption among nodes in each cluster. Only nodes which have not been CH in N late rounds are eligible to be a tentative CH for the current round to ensure that only nodes with sufficient energy are selected as CH.

Ordinary nodes which have not been CH in N late round become tentative CH with the same probability T which is a predefined threshold.

It should be noted that T is used to reduce the message overhead on the dense network.

$$State(s_i) = \begin{cases} "Tentative" & if\ s_i \in G\ and\ \mu < T \\ "Member" & Otherwise \end{cases} \quad (1)$$

Where μ is the probability of being selected as tentative CH and G is the group of the nodes which have not been CH in N late rounds.

Each tentative CH s_i has a competition range R_i. Different competition ranges are used to produce clusters of unequal sizes. Only one final CH is allowed in each competition range. If s_i becomes a CH at the end of the competition, there will not be another CH s_j in s_i's competition range.

The task of being a CH is rotated among sensors in each round to distribute the energy consumption across the network. Similar to UCR, CH closer to the BS should support smaller cluster sizes. Thus, more clusters need to be produced closer to the BS. That is to say, the tentative CH's competition range should decrease as its distance to the BS decreases. We need to select a proper scope of competition ranges in the network. R is the maximum competition range and the minimum competition range is set to $(1 - c)R$ correspondingly, where c is a constant coefficient between 0 and 1. Thus the tentative CH s_i's competition range R_i can be expressed as a linear function of its distance to the BS (cf. Formula 2):

$$R_i = (1 - c\frac{d_{max} - d(s_i, BS)}{d_{max} - d_{min}})R \quad (2)$$

Where d_{max} and d_{min} denote respectively the maximum and minimum distance between sensor nodes in the network and the BS and $d(s_i, BS)$ denotes the distance between s_i and the BS.

Each tentative CH maintains a set S_{CH} of its adjacent tentative CH. Tentative CH s_j is an adjacent node of s_i if s_j is in s_i's competition diameter or s_i is in s_j's competition diameter.

In the CH competition phase, the broadcast radius of every control message is R. Each tentative CH broadcasts a $CompeteHeadMsg$ which contains its competition radius and residual energy. After the construction of S_{CH} has finished, each tentative CH checks its S_{CH} and makes a decision as to whether it can act as a CH.

If the node s_i has the largest residual energy among all tentative CH in its S_{CH}, it is elected as CH and broadcasts a $FinalHeadMsg$ message. Otherwise, it gives up the competition. The following pseudo-code gives the details of this phase.

Algorithm 1 CH competition algorithm

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  if $s_i \in G$ **then**
    $\mu \leftarrow RAND(0, 1)$
  else
    $\mu \leftarrow 1$
  end if
  if $\mu < T$ **then**
    $beTentative = True$
  end if
  for each tentative s_i **do**
    $CompeteHeadMsg(id; R_{comp}; E_{res})$
  end for
  On receiving a $COMPETEHEADMSG$ form node s_j
  if $d(s_i, s_j) < s_j.R_{comp}$ or $d(s_i, s_j) < s_i.R_{comp}$ **then**
    Add s_j to $s_i.S_{CH}$
  end if
  while $State == Tentative$ **do**
    if $s_i.E_{res} > s_j.E_{res}; \forall s_j \in s_i.S_{CH}$ **then**
      State = *Head*
      $FinalHeadMsg(id, E_{res})$
      Exit
    end if
    On receiving a $FINALHEADMSG$ form node s_j
    if $s_j \in s_i.S_{CH}$ **then**
      State = *Member*
      $QuitElectionMsg(id)$
      Exit
    end if
    On receiving a $QUITELECTIONMSG$ form node s_j
    if $s_j \in s_i.S_{CH}$ **then**
      Remove s_j from $s_i.S_{CH}$
    end if
  end while

After the CH has been selected, sleeping nodes now wake up and each CH broadcasts a $CHADVMSG$ across the network field which contains its id and its residual energy.

3.2. Cluster formation phase

In UCR, each ordinary node chooses its closest CH. If node i was to make a decision based on a single parameter it could result in a bad choice over all. For example, selecting the closest CH will lead to choosing a CH which is at a smaller residual energy, thus resulting in more CH load. Hence, when a node makes a decision about associating with the CH, it is necessary that many parameters should be considered.

In the proposed technique, the first focus is optimizing the energy usage in cluster formation; i.e. the decision process

used by an ordinary sensor node to associate itself with a CH is based on minimum overall communication cost. For the node j, the cost of joining the CH k is computed by equation (3):

$$Cost_j^k = \alpha \times \frac{d(j,k)}{d_{max}} + (1-\alpha) \times \frac{E_{max} - E_{Res}^k}{E_{max}} \tag{3}$$

$$d_{max} = max\{d(j,k)\}, K \in S \tag{4}$$

$$E_{max} = max\{E_{Res}\}, K \in S \tag{5}$$

Where α is the weighted factor for the trade-off between the distance to the CH and the residual energy of the CH, and S is a candidate CH set of the node j.

Each ordinary node chooses its CH and then informs the CH by sending a $JOINCLUSTERMSG$ which contains the id and residual energy of this node. The CH sets up a time division multiple access (TDMA) schedule and transmits it to the nodes in its cluster. Each CH collects the messages from its cluster members and save them.

3.3. Data transmission

The data transmission is divided in two phases. The first one is intra-cluster where each non CH nodes send data to CH and the second is inter-cluster where the CH transmits aggregated data to BS.

3.3.1. Intra-cluster communication

In our protocol, the task of being a CH is rotated among sensors in each round to balance the energy consumption across the network. Each round is composed of a predefined number of iterations in which each cluster will keep its structure. But, a new clustering will be triggered only when one CH is dead or the end of a round is reached. This mechanism reduces the overhead traffic through reducing control messages. Thus, the energy will be saved. At the beginning of each round (first iteration), every non-CH node waits for their TMDA slot to transmit data. When the time slot arrives, the node transmits the data to CH. From the second iteration, each node, during its allocated transmission time, sends to the CH quantitative data concerning the sensed events. Data are transmitted by a node to its CH only when this value changes by an amount equal to or greater than the MDE (if $DE \geq MDE$). Hence, only parts of nodes passing data verification need to transmit data to CH. This reduces the transmission energy consumption.

In the second phase, each CH receives the data from its cluster nodes. When, all the data are received, each CH aggregate the data it has received along with its own data into a single composite message. When CH receives a packet of any type, it updates, in its table of cluster member, the residual energy field and the data value of the sender node to be aware of the death of a node.

When the time slot of one node arrives and this node doesn't transmit the data to CH, this later will use the value of data stored and the deviation is allowed.

3.3.2. Inter-cluster communication

After receiving and aggregating data from different cluster members, the CH begin, in this phase, the routing of data to the next hop nodes.

As the energy dissipation is directly proportional to transmission distance and due to their energy constraint, WSN usually have a limited transmission range making multi-hop data routing toward the BS more energy-efficient than one-hop transmissions.

The CH sent all collected data of the cluster members to BS by multi-hop manner, which saves the energy consumption of CH when BS is very far in WSN. Each CH s_i selects the next CH s_j.

If a s_i's distance to the BS is smaller than *TD-MAX*, it transmits its data to the BS directly; otherwise it should find a relay node which can forward its data to the BS.

Before selecting the next hop node, each CH broadcasts a beacon message across the network at a fixed power which consists of its node id, residual energy, number of cluster member and distance to the BS.

The multi-hop forwarding algorithm considers nodes on the CH backbone in the forward direction (i.e., closer to the BS) only. The neighboring node set R_{CH} of CH s_i is defined by equation 6 where x is the minimum integer that lets $s_i.R_{CH}$ contain at least one item.

$$s_i.R_{CH} = \{s_j / d(s_i, s_j) \leq xR_i, d(s_j, BS) < d(s_i, BS)\} \tag{6}$$

In UCR, in order to reduce inefficiencies of energy consumption, a tradeoff is made between the two criteria of residual energy and link cost E_{relay}.

$$E_{relay}(s_i, s_j) = d^2(s_i, s_j) + d^2(s_j, BS) \tag{7}$$

s_i first chooses k eligible neighbor nodes from $s_i.R_{CH}$, denoted as the set $S_{eligible}$:

$$s_i.S_{eligible} = \{s_j / s_j \in s_i.R_{CH}, E_{relay} \text{ is the } k \text{ smallest}\} \tag{8}$$

In this mechanism, s_i chooses as its relay node the neighbor in $s_i.S_{eligible}$ that has the biggest residual energy.

This method has some drawbacks: In UCR, it is going to choose k nodes with the smallest E_{relay} ($k = 2$). Then, it chooses the one with the highest residual energy. Practically, in some cases, the choice based on residual energy will be at the expense of distance. In fact, the choice of the second node is not always valid mainly when the gap between the first E_{relay} and the second one is large. Thus, it can results in more energy expenditure.

In UCR, if CH s_j's distance to the BS is smaller than *TD-MAX*, and CH s_i selects s_j as its relay node according to the approach described before and if the residual energy of s_j is smaller than that of s_i it let s_i communicate with the BS directly rather than aggravating the load of s_j: this hypothesis, in some cases, is not the best choice when the difference between $s_i.E_{res}$ and $s_j.E_{res}$ is too small and at the same time the distance between s_i and BS is too long. In our solution, if a node's distance to the BS is smaller than *TD-MAX*, it transmits its data to the BS directly; otherwise it's better to find a relay node which can forward its data to the BS. Therefore, a tradeoff is made between the three criteria of residual energy, number of cluster members and link cost E_{relay}. CH selects the neighbor CH with higher residual energy and a smaller number of cluster members and minimum link cost E_{relay} as the next hop in order to balance the energy consumption among CH and reduce the energy cost of the link in the relay process.

In this case, the CH s_i calculates the cost function to choose the best relay node among all candidates S. The node that has the minimum value of $Cost_j$ will be selected as the next relay. The cost function is defined by equation 9:

$$Cost_j = \alpha \times \frac{E_{relay}(s_i, s_j)}{Relay_{max}} + \beta \times \frac{E_{cons}(s_j)}{E_{max}} + \gamma \times \frac{s_j.d}{N} \tag{9}$$

$$Relay_{max} = max\{E_{relay}(s_i, s_j)\}, s_j \in S \tag{10}$$

Where N is the number of alive node and $s_j.d$ is the number of cluster member of s_j. $E_{cons}(s_j)$ represents the energy consumed by the node j.

We can see from formula 9, the CH with minimum consumed energy (i.e., higher residual energy), minimum link cost and fewer cluster members will have smaller $Cost$. CH s_i chooses the neighbor CH with the smallest $Cost$ as its next hop.

4. SIMULATIONS AND RESULTS

In order to evaluate the proposed mechanism, we use our simulator and we have compare results to the UCR mechanism [10]. Our simulations involve two parts. In the first part, data is sent to CH without controls. In the second part, we control data before sending it to CH.

4.1. Experiment settings and metrics

Our paper adopts the same radio energy model with [17]. The energy consumed in the transmitter node (E_{tx}) and in the receiver node (E_{rx}) with distance d for transmitting a b-bit data packet can be calculated as follows:

$$E_{tx}(b, d) = \begin{cases} b \times E_e + b \times E_f \times d^2 & if \ d \leq d_c \\ b \times E_e + b \times E_{tr} \times d^4 & if \ d > d_c \end{cases} \tag{11}$$

The parameters E_f and E_{tr} are the amount of energy dissipates per bit in the radio frequency amplifier according to the distance d_c. d_c is the threshold distance that depends on the environment. In our work we consider, both the free space (d^2 power loss) and multi-path fading (d^4 power loss) channel models depending on the distance between the transmitter and the receiver. We assume free space model if ($d < d_c$), otherwise multi-path fading model is intended. The energy for receiving a b-bit message is calculated as follows:

$$E^{rx}(b) = b \times E_e \tag{12}$$

Where E_e represents the electronics energy. It depends on such electronic factors as digital coding, modulation, filtering, and spreading of the signal. Simulation parameters are given in Table 1.

For simplicity, we assume:

Table 1. Simulation parameters.

Parameters	Values
Network field	400 x 200
BS location	(500, 100)
E_e	50 nJ/bit
$E_{friss-amp}$	$10pJ/bit/m^2$
$E_{two-ray-amp}$	$0,0013pJ/bit/m^4$
d_C	87
Data packet size b	500 bytes
Initial Energy of sensor E_0	1 J
Number of sensors	600
TD-MAX	150

- An ideal MAC layer and error-free communication links.

- Nodes are GPS-enabled and each node is aware of its geographic location.

- Each node is assigned a unique id to help us identifying one node from other neighboring nodes.

- Sensors can use power control to modify the amount of transmission power according to the distance to the desired recipient.

- Each node can communicate directly with any other node on the network.

- Sensors are capable of operating in an active mode or a low-power sleeping mode.

In this paper, the performance will be evaluated via simulations with respect to the following metrics: First Node Dies (FND) and Half of the Nodes Alive (HNA). We note that a node is considered "dead" if its remaining energy is less than the value for the transmission task.

4.2. AEEUC without data controlling

Figure 2 shows that, under AEEUC, the level of residual energy of CH is larger than under UCR. In fact, in UCR protocol, CH are randomly selected to compete for final CH. Yet, in AEEUC protocol, only nodes which have not been CH in N late round are eligible to be a tentative CH for the current round. Thus, only nodes with sufficient energy are selected as CH. This explains which leads to avoiding the premature death of CH.
Our protocol tends to minimize the unbalanced communication cost which is evaluated for each CH as follows:
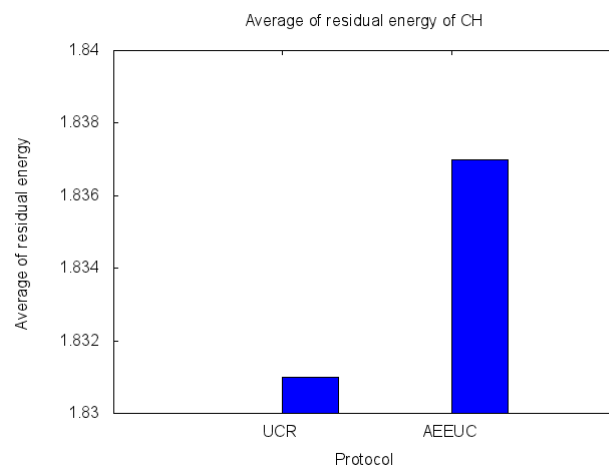

Figure 2. Average of residual energy of elected CH.

$$C_{unbalanced} = Max(C_i) - Min(C_i) \qquad (13)$$

Where C_i is the communication cost of CH i and is calculated as follows:

$$C_i = \frac{E_{cons}}{E_{res}} \tag{14}$$

Where E_{cons} and E_{res} represent the consumed energy and the residual energy respectively.
The higher value of $C_{unbalanced}$ means the more unbalanced communication cost. Figure 3 plots the level of the unbalanced communication cost over time for different algorithms.
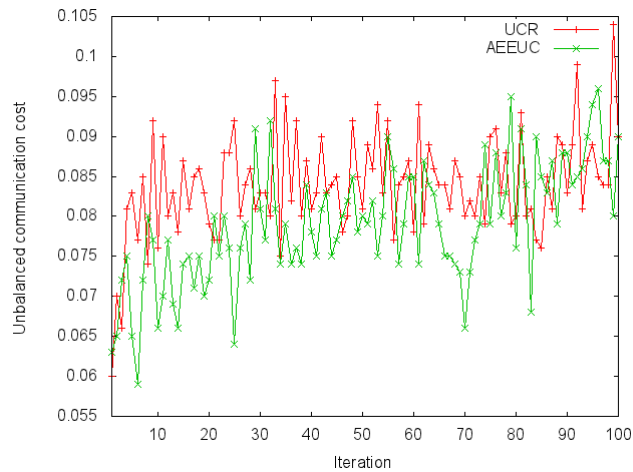Figure 4 shows the average of the unbalanced communication cost.

Figure 3. Unbalanced communication cost

As shown in Figure 3 and 4, we find that the unbalanced communication cost in the proposed algorithm is lower than
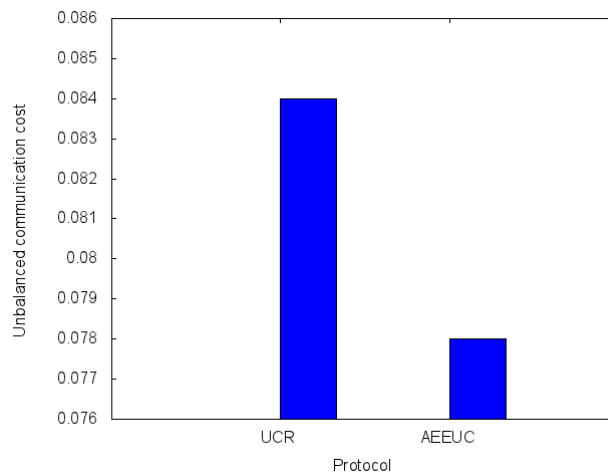

Figure 4. Average of Unbalanced communication cost

the other algorithm. Our protocol minimize the unbalanced energy consumption among CH within the network.
Figure 5 shows the comparison between UCR and AEEUC in term of network lifetime. Under AEEUC, the first node of the network is died after 425 rounds while under UCR the first node die much before, i.e. 380 rounds. Moreover, HND is reached later under AEEUC (480 rounds) than under UCR (465 rounds). AEEUC gives better performances than UCR in prolonging network lifetime. This can be explained firstly by the fact that the CH elected is the node with higher energy. Second, when nodes join clusters, they consider both the distance to CH and the residual energy of CH. Third, CH choose those nodes as relay node, which have minimum energy consumption for forwarding, fewer number of cluster member and maximum residual energy to avoid early death.
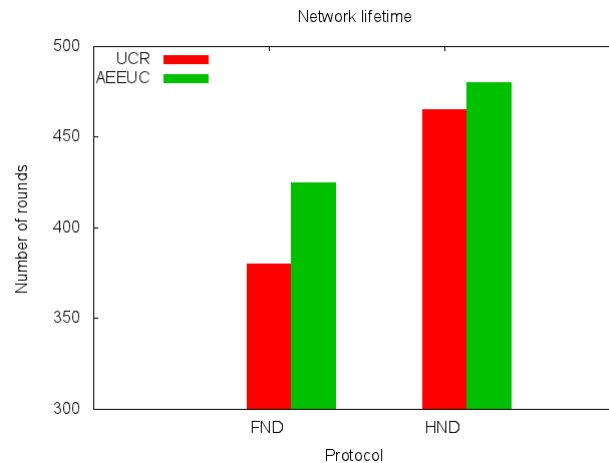
Figure 5. Network lifetime

4.3. AEEUC with data controlling

Our work aims to reduce the number of unnecessary data transmissions. To achieve this goal, a Maximum Data Error (MDE) technique is used to reduce the number of transmissions and thus considerable energy conservation is achieved.

Figure 6 shows the change in the number of messages transmitted by the nodes to CH in a given period. In the UCR
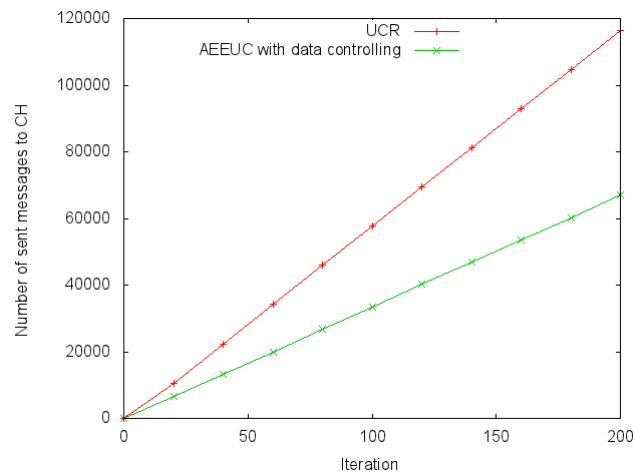

Figure 6. Variance of number of sent messages to CH

protocol, every non-CH node must transmit its sensed data to CH at every iteration. In AEEUC protocol, before each transmission, all the nodes are entitled to verify their data, but only parts of them will transmit their data to CH. This obviously reduces the transmission energy consumption.

As shown in Figure 7, the energy consumption of our protocol is less than that of UCR. Less energy consumption means longer lifetime for the network. Figure 8 shows the variation in the number of all alive nodes based on the number of messages received by the BS. As shown in the figure, the number of dead nodes in the proposed protocol is always less than that of UCR protocol.

AEEUC clearly improves the network lifetime over UCR. Simulations showed that AEEUC reduces the energy dissipation and thus extending the overall network lifetime.
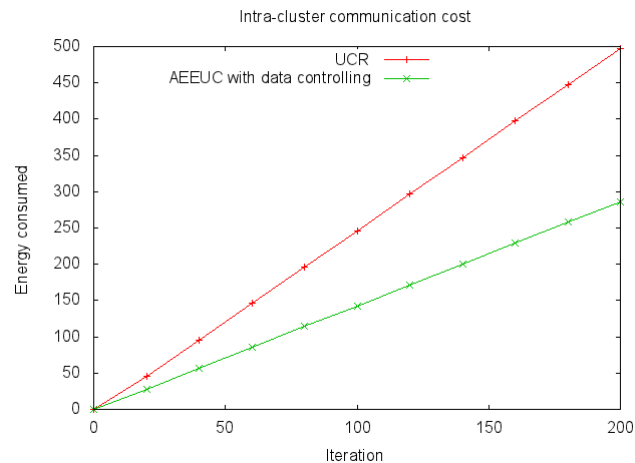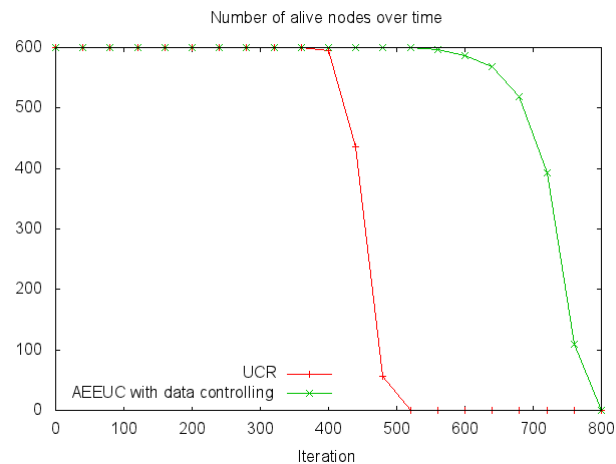
Figure 7. Variance of energy consumption (J)

Figure 8. Number of alive nodes.

5. CONCLUSION

We have presented in this paper a new hierarchical routing in WSN called AEEUC. Based on unequal cluster, AEEUC improves energy efficiency. Indeed, it improves the distribution of CH node across the network. Moreover, AEEUC use a multi-criterion cluster formation in order to distribute and balance efficiently the energy consumption among the CH. In addition, AEEUC takes into account the sensitive data controlling to reduce the number of transmission . Furthermore, for the inter-cluster communication, AEEUC use an energy efficient multi-hop routing policies. Simulations conducted throughout the paper show that AEEUC outperforms the EEUC protocol and enhance the life-time of network.

For future work, we will consider new QoS requirements such as real-time and reliable communication.

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