E²ACM: Energy Efficient Adaptive Cluster based Multilevel Routing Protocol for Wireless Sensor Networks

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ABSTRACT
It is a great challenge for designing a routing protocol that can maximize the network lifetime of Wireless Sensor Network (WSN), due to the limited energy of Sensor Node (SN). As a well-known hierarchical routing protocol in WSN, LEACH protocol could extend the WSN lifetime effectively. It assumes that all nodes can communicate with Base Station (BS) directly. With the expansion of WSN scale, the average distances between cluster head (CH) node and BS increase significantly, results in communication energy cost. For the large-scale WSN, this paper proposes a multimetric-based Energy Efficient Adaptive Cluster Based Multilevel (E²ACM) Routing Protocol. It regards the distance between CHs, nodes registered and residual energy of CH to construct a multihop path between CH and BS. Simulation results shows that proposed work significantly reduce the overall energy consumption of WSNs.

Keywords
WSN, LEACH, Cluster based routing, Energy Efficiency.

1. INTRODUCTION
A Wireless Sensor Networks (WSNs) is a group of homogeneous or heterogeneous SNs, which are independent and work in a collaborative manner. SNs compute, transmit, receive and forward the data to adjacent SNs, Cluster Head (CH) and further to the Base Station (BS). Sensor networks are limited in computations, node energy, buffer size and signal strength.The potential applications of WSNs are highly varied, such as environmental monitoring, target tracking and military surveillance [2]. Energy Conservation [1] methods such as LEACH help to reduce energy consumption to prolong the Network Lifetime of WSN. In case when network size increased, distance between CH and BS is also increased extremely. This large network is not suitable for LEACH, in which BS is assumed at single-hop to all CHs. In this case transmission energy cost of CHs is not affordable. To address this problem Multi-hop LEACH routing protocol as shown in Figure 1 is proposed. Furthermore, the routing protocols must be able to cope with the low capacity resources. For instance, it is possible that a route that was earlier found meet certain requirements no longer does so due to the dynamic nature of the topology. In such a case, it is important that the network intelligently adapt according to its changed conditions. In this paper, E²ACM routing protocol has been suggested which would allow CHs to maintain more reliable route to sink.

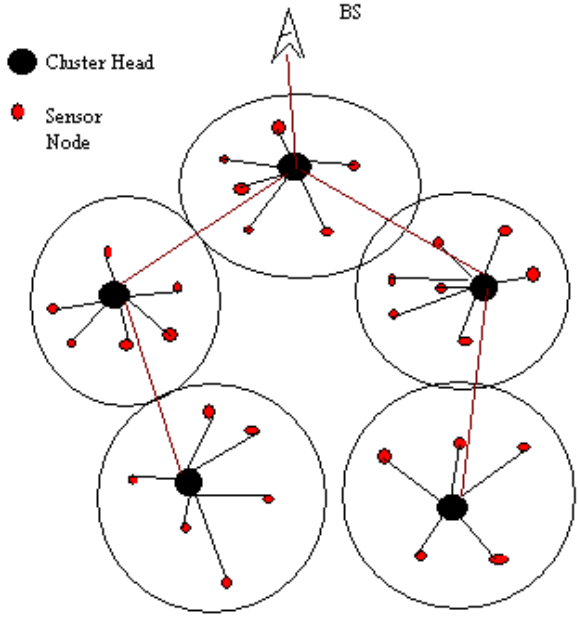

Fig 1: Multihop LEACH

The E²ACM routing protocol uses multi metrics based strength factor S_f of CHs to determine next CH to participate in routing. Although, there are several approaches that have been proposed which also includes multiple hops toward the sink.But the proposed E²ACM routing protocol is distinguished for following reasons: First, path selection is based on CH strength. Second, total number of nodes registered with CH takes into consideration in data forwarding. The contribution of the paper is as follows: In section 2, we briefly review the related work, section 3 discusses the system model, the proposed E²ACM routing protocol in section 4,simulation environment and its results are discuss in section 5, section 6 conclude the paper and future work is pointed out.

2. RELATED WORK

The main goal of cluster-based routing protocol is to utilize the energy consumption of SNs through multihop communication. Hasan Farooq et al. [3] use energy level, traffic load, and link quality of the nodes to establish appropriate route from CH to the sink. Deng Zhixiang and Qi Bensheng [4] propose Three Layered LEACH (TL-LEACH) which divides clusters into levels. Each CH is elected during set up phase of LEACH. They don't communicate directly to BS. Another set of CHs is selected to send data to the BS which is second level. Zuo Chen et al. [5] propose LEACH-MM which selects the CH node whose residual energy is greater than the average residual energy of adjacent cluster node to become the minsuper cluster head node. Cluster member node send data packet to the CH node, then CH node fuses data and sends the data packet to the ms-clusterhead node. Ms-cluster head node fuses data and forwards the data packet to the SINK node via the selected super cluster head node. Jiguo Yu et al. propose the EADC algorithm [6] in which CH chooses the neighbor CH with higher residual energy and fewer cluster members to construct the multihop path

3. SYSTEM MODEL

3.1 Network Model

To simplify the network model, we adopt following assumptions:

1. N sensors are randomly dispersed within a square field.

2. The BS is located at centre of sensing area.

3. All sensors and the BS are stationary after deployment.

4. SNs are location-aware. The location of the BS is known by each node.

5. All SNs are homogeneous, i.e., they have the same energy.

3.2 Energy Model

E^2ACM routing protocol uses energy model discussed in [15].To transmit an L-bit data to a distance d, the radio expands energy.

$$E_{TX}(L,d) = L * E_{elec} + L * \epsilon_{fs} * d^2 \quad if\ d \le d_0 \qquad (1)$$

$$L * E_{elec} + L * \epsilon_{fs} * d^4 \quad if\ d \ge d_0 \qquad (2)$$

where $E_{TX}(L,d)$ is energy consumed by a node to transmit L bit packet at distance D, E_{elec} is the electronic energy that depends on factors such as the digital coding, coding, modulation or, is the amplifier energy that depends on the transmission distance and the acceptable bit-error rate.

While receiving, the radio expands energy:

$$E_{RX}(L) = L * E_{elec} \qquad (3)$$

$E_{RX}(L)$ is energy dissipated by a node to received L bit packet .

3.3 Routing Metrices

E^2ACM consider energy level, total number of the nodes registered with CH and distance metrics during route selection to improve the performance.

3.3.1 *Energy Level*

Energy is valuable resource for battery powered SNs since their life directly depends upon how much energy is available to them [7]. The energy level of the nodes involved in most of multihop transmission will be depleted quickly, and so the protocol should consider energy states of the nodes during route formation with highest energy nodes. E^2ACM protocol keeps track of the energy state of the CH on the basis of residual energy of the node.

3.3.2 *Link Quality*

SNs communicate in outdoor environment, and active route breaks occur even on stationary nodes due to the effect of shadowing and consequently cause the network degradation [3]. Shortest available path is not always the best path available since routing over short path with weak RF link quality leads to increased packet loss and retransmissions. Consequently, E^2ACM protocol use multi metrics based S_f of the CHs while choosing candidates for route formation.

3.3.3 *Multimetric Combination*

Routing based on multiple criteria is a classification problem, and we can combine multiple criteria (energy level, total number of nodes registered with CH and distance) into a single criterion to prolong network lifetime. Most of the multimetric routing protocols use the weighted sum approach to combine multimetric over an available path.

3.4 CH Strength Factor (S_f) Calculation

Considering a WSN, where there are multiple CHs. The S_f of CH is function of $S_f = f(b,n,d)$ where b is battery life of CH, n is the number of nodes registered with the CH and d is distance between neighbour CHs which is calculated as Eq.(4).

$$S_f = \frac{w_1 * b}{w_2 * n * w_3 * d} \qquad (4)$$

Where w_1, w_2 and w_3 are the respective weights to be assigned to the corresponding parameters. Here all the weights are assumed to be 1. The following values as shown in Table 1 are used to determine S_f of a CH. To avoid registration with a node which has a remaining battery life of less than 10%, the value of *b* and the function S_f have been chosen in such a way that it should lead to a zero value.

Table 1. For determining the remaining battery life 'b'

Value	Battery life 'b' %tage
3	If b >80%
2	If b is within 50–79%
1	If b is within 10–49%
0	If b <10%

4. E²ACM: PROPOSED PROTOCOL

In this section, we describe E²ACM routing protocol which is aware of residual energy, link quality, and distance between the CH to overcome the fore mentioned issues. In this protocol the route formation improved in such a way that CH embed their residual energy, number of nodes, and distance information in the route request packets, and CH is able to select the best reliable path to the sink.

4.1 The protocol phases

The functionality of the E²ACM protocol is divided into two phases: Set-up and Route Formation Phase:

4.1.1 *Set-up Phase*

The main objective of this phase is election of CH among the SNs which are randomly deployed in sensing area and calculating S_f of each CH according to Eq. (4). LEACH [8] forms clusters by using a distributed algorithm, where nodes make autonomous decisions without any centralized control. Initially a node decides to be a CH with a probability (p) and broadcasts its decision. Each non-CH node determines its cluster by choosing the CH that can be reached using the least communication energy. The role of being a CH is rotated periodically among the nodes of the cluster in order to balance the load. The rotation is performed by getting each node to choose a random number ‘‘T’’ between 0 and 1. A node becomes a CH for the current rotation round if the number is less than the threshold.

4.1.2 *Route Formation*

In this phase, E²ACM construct a multihop based routing path on the elected CH set. CH C_i chooses the nearest neighbor CH with higher S_f. From Eq. (4), it can be analyzed that the CH with shortest distance, higher residual energy and fewer cluster members will have a larger “strength”. This multihop route process continues until data reaches to the sink as shown in Figure 2.The pseudo-code in Figure 4 illustrate the E²ACM routing algorithm.

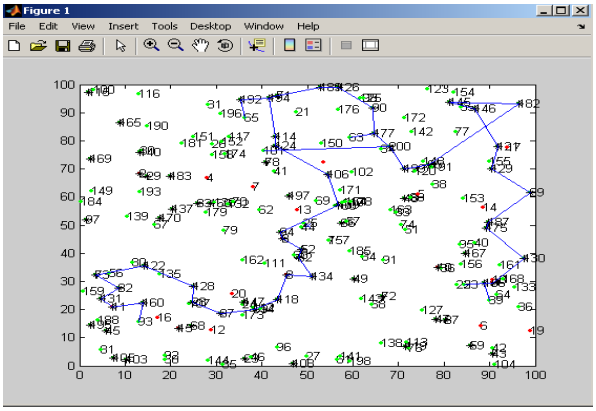

Fig 2: Route Formation with E²ACM Routing Protocol (When Rounds=5, Initial Energy=0.5J p=0.4)

4.1.3 *Route Maintenance Phase*

In WSNs, few SNs or CH may fail or be blocked due to lack of power, physical damage, or environmental interference. The failure of SNs should not affect the overall task of the sensor network. If many nodes fail, medium access control (MAC) and routing protocols must accommodate formation of new routes to the sink. In E²ACM routing protocol, CH can die after certain round that cause unexpected failures. Once the CH dies or is blocked, leading a certain area to be unreachable. However, re-clustering a whole network only to solve one failure may result in significant waste of resources. To guarantee the delivery, each CH, which forwarded a data, is responsible for ensuring that alternate successor of maximum S_f has successfully received the packet. Seeking an alternative successor CH starts by the immediate downstream node of the broken link to find alternate CH having maximum S_f.

$$Route_{Formation(s,C,LCH)}$$
$$C \leftarrow Set\ of\ all\ CHs$$
$$C_{i=}Local\ CH$$
$$while(C_i \neq CH_{near_{BS}})$$
$$foreach(C_j \in Adj(C_i)$$
$$S_f(C_j) = \frac{b(C_j)}{n(C_j) * d(C_i * C_j)}$$
$$end\ for$$
$$Select\ C_j\ from\ Adj(C_i) having\ maximum\ S_f$$
$$C_i = C_j$$
$$end\ while$$

Fig 3: E²ACM Routing pseudo code

This process repeats until route formation/reconfiguration from source to sink. This route maintenance phase depicted in Figure 4 improves the reliability and network lifetime of E²ACM routing protocol.

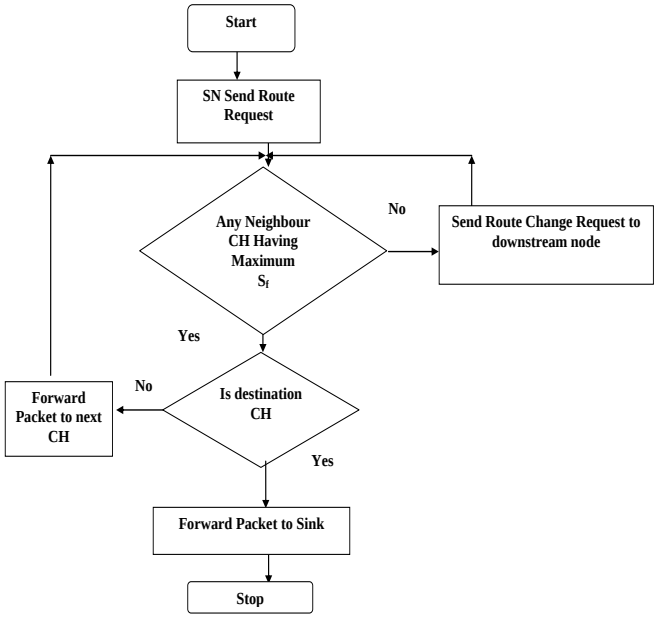

Fig 4: Flowchart for Link Failure Maintenance

5. SIMULATIONS

A set of simulations are performed to analyze the E^2ACM routing protocol in MATLAB 7. For simulation environment the following parameters are given in Table 2.

Table2: Simulation Parameters

Simulation parameter	Value
Topology size	100*100m^2
Number of Nodes(n)	200
Initial Energy	0.1-0.5J
Transmission Range	50-90m
Probability (p)	0.1-0.5

5.1 Average Remaining Energy

Energy Constrained SNs require energy efficient protocol for prolonging the network lifetime.The comparative analysis of E^2ACM protocol and randomly CH selection based approach is performed on basis of average remaining energy.Figure 5 shows the average remaining energy during different rounds. When compared to random CH selection protocol, the total remained energy of E^2ACM protocol increase up to 36%.

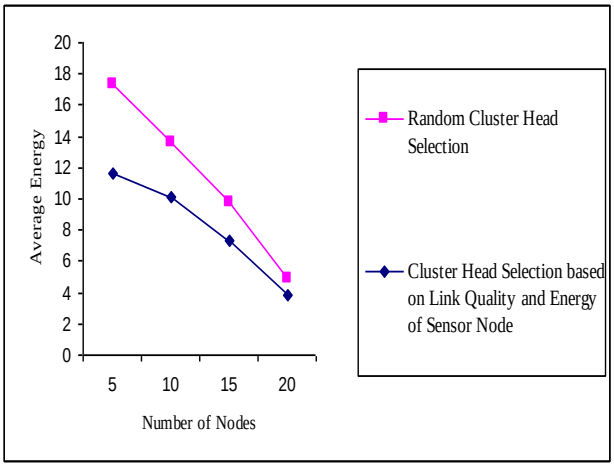

Fig 5: Remaining Average Energy Vs No. of Nodes

In Figure 6 we analyse that the overall energy consumption of the network reduces as the probability of CH selection increases. This is because when more CHs are elected, each CH has more candidate CHs to get selected in route formation.

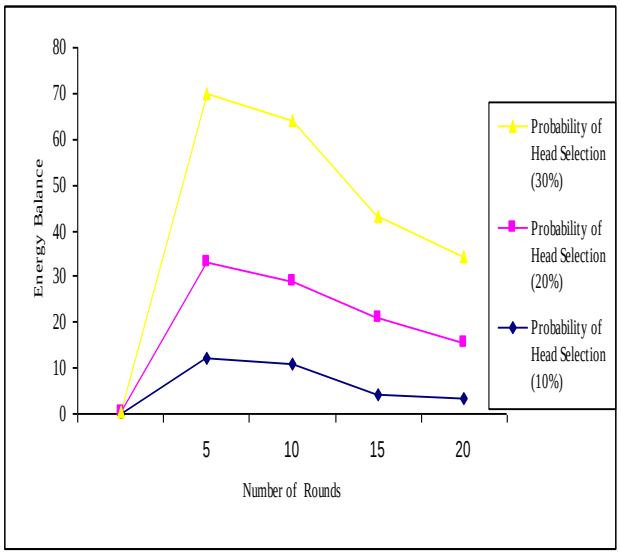

Fig 6: Energy Balance after 5-20 Rounds with Different Probabilities (p) on E^2ACM

5.2 Network Lifetime

Performance metric to estimate when studying the energy consumption in a WSN is the lifetime of the WSN, e.g. the time until the first sensor dies [10]. In Figure 7, Network Lifetime is plotted on y-axis with varying number of initial energy on x-axis. It can be observed that the network lifetime increase as the initial energy of node and probability of CH selection increases. The reason for increasing network lifetime in proposed E^2ACM routing protocol is that the next node in route is selected having maximum energy and reliable link based on S_f.

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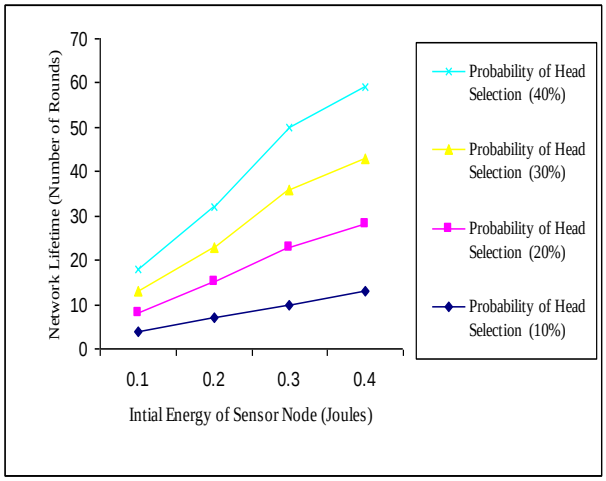

Fig 7: Network Lifetime for different level of Energy of SNs on E^2ACM protocol

6. CONCLUSION AND FUTURE WORK

The WSNs have been envisioned to help in numerous monitoring applications. Energy efficient cluster based routing is paramount to extend the lifetime of the system. LEACH assume that all the nodes communicate with BS directly.With the expansion of WSN the average distance between node and BS increase that results in much energy consumption.For this reason E^2ACM protocol establish

multihop path between CHs toward sink.The E^2ACM protocol enable the nodes to graceful handle the link failure, as topology dynamically changes to improve network lifetime in terms of number of rounds. Simulations are carried out to evaluate the performance which shows that the use of aforementioned parameters for route selection in E^2ACM protocol significantly reduces the overall energy consumption of whole network. Further direction of this work will deal with utilising the same for the data aggregation or duty cycling to improve the overall network performance.

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