

Cluster-based Novel Routing Protocol to Improve QoS in Wireless Sensor Networks

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Abstract

In this paper, we propose a cluster-based novel routing protocol to achieve uniform energy depletion among all the nodes in order to achieve longer network life time. In this approach, the Region of Interest is divided into virtual zones with each zone having a designated cluster head node. Any node can be a part of a cluster or it may remain as an independent entity. IRP - Intelligent Routing Process enables a non-cluster member to transmit its data to next hop node. If any cluster member node is elected as a next hop on the transmission path, it rejects IRP and forwards the packets to cluster head, which later forwards them to sink. As the clusters aid the overall routing process, this protocol is called as Cluster Aided Multipath Routing (CAMP). The performance of the proposed protocol is compared with LEACH, PEGASIS, DIRECT TRANSMISSION, CEED, and CBMR.

Keywords: Cluster-based, Region of Interest, Intelligent Routing Process, LEACH.

1. Introduction

A wireless sensor network (WSN) consists of tiny, low powered sensors communicating with each other possibly through multi-hop wireless links and collaborating to accomplish a common task [1]. They have naturally emerged as enabling infrastructures for cyber-physical applications that closely interact with external stimulus. Homeland security, physical infrastructures monitoring, health care, building or factory automation are just a few elucidative examples of how these emerging technologies will impact our daily life and society at large [2, 3]. Sensor nodes are small micro-electromechanical systems (MEMS) devices [4, 5], which operate on limited power supplies for pervasive computing [6] and Internet of Things [7] which globally interconnect smart devices and sensor networks.

Thus, it becomes essential to keep them functional as long as possible [8]. Conventional, single shortest path routing algorithms like Bellmanford [9] are not well suited in this context as they will cause significant energy depletion of nodes constituting a single shortest path, leading to shorter network lifetime [10]. Moreover, they will cause either significant degradation in the perceived quality at the sink nodes or large queuing delays due to insufficient bandwidth [12]. Traditional routing protocols of computer networks are not apt for energy constrained wireless sensor networks. All these protocols do not consider the limited memory and energy capacity of the sensor nodes. Thus, many routing protocols [11] have been proposed and specifically tailored to minimize the energy consumption of sensor nodes. They can be broadly classified into flat and hierarchical algorithms [13].

The former approach includes DD [14], SPIN [15] etc. and latter includes LEACH [16], PEGASIS [17], TEEN [18], HEED [19] etc. In flat routing, a node generally transmits its packets to neighboring nodes within its transmission range. Whereas in hierarchical routing a node transmits its data to its nearest cluster head (CH) which in turn sends it to the sink. Both the approaches have their own advantages and drawbacks. The founding principle of flat routing is cooperative multi-hop forwarding, but in doing so, a large volume of traffic is generated [in simplistic case a packet from each node is generated and forwarded to the Base Station (BS) or sink¹] and it results in energy depletion of many nodes. Whereas, in hierarchical routing scheme, there are some designated cluster head nodes which are responsible for data aggregation from their cluster members and finally sending the aggregated information to the sink themselves. This conserves the energy of cluster members but puts a heavy toll on CHs [20, 21]. Also, since all the sensor nodes are bound to latch themselves

to some CH, they may do so by communicating out of normal radio range. This further results in poor QoS [22] and degraded performance.

CAMP attempt to provide a solution to the aforementioned problems by incorporating both hierarchical and flat routing strategies. It primarily divides the ROI into equal sized zones, each having a unique CH. In CAMP, only those nodes which lie in the communication range of CHs become the part of the cluster, and adopts hierarchical routing. Remaining nodes act as independent entities, and adopts multi-hop routing for communication with BS.

2. System model

Network model

A wireless sensor network can be represented as an undirected graph $G = (V, E)$, where V is the set of sensor nodes and E describe the adjacency relation (set of links) between the nodes. E is dependent upon transmission range of a sensor. In our model, we have assumed that N number of nodes are randomly deployed in the terrain, and each node has an ID (unique identity) associated with it. A node is represented as i (its ID), and $N(i)$ is a set of alive neighbors of node i .

Aggregation model

In CAMP, each node is capable of doing data aggregation, as it significantly decreases the energy consumption of the network. Figure 1 depicts the simplistic scenario, where nodes are placed in linear order. Each node has data packets to be transmitted to the sink. In the first case, since each node transmits (without data aggregation), a total of $N(N + 1)/2$ data packets are observed in the network. While for the other case (using data aggregation), a total of N data packets are observed in the network (each node aggregate its sensed data with the data received from the preceding node). Hence using data aggregation, $(N + 1)/2$ data packets would be reduced in the network.

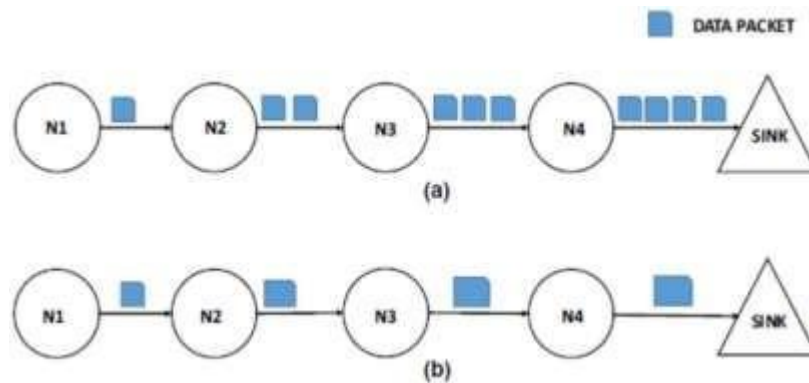


Fig. 1 Data transmission with a) no data aggregation b) data aggregation

Energy model

In wireless sensor networks, energy scavenging is of utmost importance as each sensor node has a limited battery supply. WSN once deployed is left undisturbed with an intention of periodic (or event driven) data collection. A sensor node consists of many functional units constituting sensor, processor, memory, battery and transceiver unit. It is an established fact that among all, transmitter consumes maximum energy [26]. The first order radio model suggests that if a node i has to transmit k bit data to node j , which are d distance apart, then energy consumed by node i is given as

$$E_{Tx}(k, d) = \begin{cases} E_{elec} * k + E_{fs} * k * d^2 & \text{if } (d < d_0) \\ E_{elec} * k + E_{mp} * k * d^4 & \text{if } (d \leq d_0) \end{cases} \quad (1)$$

And energy consumed by node j is given as

$$E_{Rx}(k, d) = E_{elec} * k \quad (2)$$

In the above equations, E_{elec} represents the energy that is consumed by transmitter or receiver circuitry. E_{fs} and E_{mp} indicate the energy consumed by the transmitter amplifier for free space and multipath model respectively. And d_0 is the threshold value equals to $\sqrt{\frac{E_{fs}}{E_{mp}}}$.

Network life time

In this work, we adopt *First Node Dead Statistics (FND_Stats)* as a metric for network lifetime. It is defined as the interval between the rounds where the first node start transmitting data and the round where the first node gets dead [25, 27].

3. CAMP algorithm

CAMP is a self-sustained pro-active routing protocol in which at any instance of time, each node stores the information about its neighbors only, thereby reducing the memory requirements. The neighbor table (*Nbr_Table*) of each node has only three fields:

1. Neighbor ID (*Nbr_ID*).
2. Location of neighbor (*Nbr_Loc*).
3. Residual energy of the neighbor (*Nbr_Residual_Energy*).

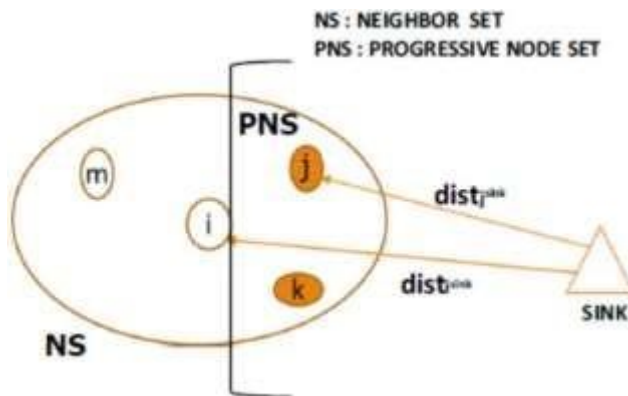


Fig. 2: Progressive node set

The fundamental idea of CAMP is to have balanced *CH* density in ROI. Thus, it divides the ROI into n equal sized zones, such that each zone is assigned at least one *CH* (or multiple *CHs* depending on the node density of the zone), which makes *CH* density uniform across the field. Also, in existing clustering algorithms each node is bound to latch to some *CH*, whereas in CAMP nodes are not forced to join any *CH*. If *CH* and sensor node both are in communication range, then only, peering will occur else sensor node performs multihop (or flat) routing. In CAMP, network management task (such as *CH* selection) has been taken away from nodes and are given to BS, to reduce the overall complexity of the network. This algorithm is generic in nature and has not been designed to meet the specific requirements of any application. It also performs well with BS located at different locations. We placed BS at three locations (i) center of the field (ii) corner of the field (iii) far away from the field, and found that, in all scenarios, it outperformed other protocols such as DIRECT TRANS-MISSION, LEACH [16], PEGASIS [17], CEED [23], and CBMR [24] with respect to various network parameters.

CAMP works in two phases: Setup Phase and Routing Phase (divided into rounds). In Setup Phase, each node exchanges its information with their neighbors and update their *Nbr_Table*. Those nodes for which BS is a direct neighbor constitutes *Direct_Set* and throughout their life time, they transmit their data directly to BS only. Later, BS virtually divides the ROI into equal sized zones and designates a *CH* to each zone. In each zone, all those nodes which are one hop away with *CH* (in communication range) constitute the cluster and are

termed as cluster members (*CM*). Rest of the nodes are designated as non-cluster-member (*NCM*). *Direct_Set* nodes are excluded from this grouping process. If total cluster heads are more than number of regions, then those regions which have maximum remaining *NCMs* are assigned additional *CHs*. Formally, it can be represented as,

$$\sum_{\forall \text{zones}} |NCM| + |CM| + |Direct_Set| = N \quad (3)$$

In Routing Phase, a node after sensing the environment, transmit its packets towards BS either in multihop or in a hierarchical manner. If a node is not a part of any cluster, the former approach is used otherwise latter approach is adopted. To adopt multihop communication, a node undergoes *IRP*. For this, it constructs a *Progressive Node Set (PNS)* depicted in Figure 2. Nodes *m*, *j*, and *k* constitute the Neighbor Set (*NS*) of node *i*. Any node which belongs to *NS*, and is also present in between Node *i* and sink, constitutes the *PNS* (nodes *j* and *k*). For instance, node *j* must satisfy the following two conditions, to become the member of *PNS* of node *i*,

1. Node $j \in NS$.
2. $dist_i^{sink} - dist_j^{sink} > 0$.

Energy consumption in a virtual zone

Let us assume there are total N_{zone} nodes in the zone. Since a zone has cluster members (*CM*), non-cluster members (*NCM*) and direct set nodes (*Direct_Set*)

$$N_{zone} = P + Q + R$$

where

$$P = |CM|_{zone}; Q = |Direct_Set|_{zone}; R = |NCM|_{zone}$$

where *CM* includes cluster head (*CH*) and non cluster head (*NCH*).

$$P = S + T$$

where

$$S = |CH|; T = |NCH|$$

Energy consumed in a round,

$$E_{Round} = E_{DT} + E_{NCM} + E_{CM}$$

Energy consumed by the nodes constituting the *Direct_Set* (*Q*)

$$E_{DT}(ID, k, d) = \begin{cases} E_{elec} * k + E_{fs} * k * d^2 & \text{if } ID \notin D_{agg} \\ E_{elec} * k + E_{mp} * k * R \\ + E_{D_{agg}} * k * (R - 1) + E_{fs} * k * d^2 & \text{if } ID \in D_{agg} \end{cases} \quad (4)$$

Energy consumed by the nodes constituting the *NCM* set (*R*)

$$E_{Tx}(k, d) = \begin{cases} E_{elec} * k + E_{fs} * k * d^2_{neighbour} & \text{if } ID \notin D_{agg} \text{ and } d < d_0 \\ E_{elec} * k + E_{mp} * k * d^4_{neighbour} & \text{if } ID \in D_{agg} \text{ and } d \leq d_0 \end{cases} \quad (5)$$

$$E_{DT}(ID, k, d) = \begin{cases} E_{elec} * k + E_{fs} * k * (R - 1) \\ + E_{elec} * k * (R) + E_{fs} * k * d^2_{neighbour} & \text{if } ID \in D_{agg} \text{ and } d < d_0 \\ E_{elec} * k + E_{elec} * k * (R - 1) \\ + E_{D_{agg}} * k * (R) + E_{fs} * k * d^4_{neighbour} & \text{if } ID \in D_{agg} \text{ and } d \geq d_0 \end{cases} \quad (6)$$

Cluster member nodes (P) consist of two types of nodes CH and NCH

$$E_{CM} = E_{CH} + E_{NCH} \quad (7)$$

$$E_{CH}(ID, k, d) = \begin{cases} E_{elec} * k + E_{elec} * k * ((\frac{P}{S}) - 1) \\ + E_{elec} * k * (\frac{P}{S}) + E_{fs} * k * d^2_{sink} \end{cases} \quad \text{if } d < d_0 \quad (8)$$

$$E_{NCH}(ID, k, d) = \begin{cases} E_{elec} * k + E_{elec} * k * ((\frac{P}{S}) - 1) \\ + E_{D_{agg}} * k * (P/S) + E_{mp} * k * d^4_{sink} \end{cases} \quad \text{if } d \geq d_0$$

$$E_{NCH}(ID, k, d) = \begin{cases} E_{elec} * k + E_{fs} * k * d^2_{CH} & \text{if } ID \notin D_{agg} \\ E_{elec} * k + E_{elec} * k * R \\ + E_{D_{agg}} * k * (R + 1) + E_{CH} * k * d^2_{sink} & \text{if } ID \in D_{agg} \end{cases} \quad (9)$$

Each zone consists of three mutually disjoint set of sensor nodes, CM , NCM and $Direct_Set$. Energy consumption of each type of node can be estimated using the first order radio energy model.

Table 1: $|NCM|$ of each zone after assigning single CH to each of the four zones respectively.

Zone	No. of NCM
NW	40
NE	30
SW	20
SE	10

Equation (4), calculates energy consumed by $Direct_Set$ nodes. Some of those nodes may perform data aggregation (if received packets from neighbors) and some may not. Since, CM will transmit their packets to CHs , only NCM can transmit their data to $Direct_Set$ nodes for further transmission towards the sink. Thus, $Direct_Set$ nodes can receive packets from the maximum of R sensor nodes.

Equation (5), represents the scenario for those NCM nodes which have not received data packets from other neighboring nodes and does not incur data aggregation cost. Whereas, Eq. 6, represents the case, where an NCM node has received data from other NCM nodes (maximum $R - 1$; excluding itself) and performs data aggregation.

For CM (divided into CH and NCH), Eq. (8), represents the energy consumed by a CH . Initially, it receives packets from its $P/S - 1$ (average number of cluster members assigned to each CH , excluding itself) cluster members, and later it performs data aggregation on the received data packets. Equation (9), represents the case, where an NCH (member of NCM) receives data packets from NCM nodes (maximum of R nodes) and then performs data aggregation.

Setup phase

In the beginning, the network is in the gestation period. Each node sends *hello_packet* to all other nodes (in its communication range) and complete the entries in their *Nbr_Table*. BS, after obtaining this information from all the nodes divides the field (and nodes) into n equal sized zones. For e.g., with $n = 4$, we divide the field into 4 zones namely North West (NW), North East (NE), South West (SW) and South East (SE). To each of these zones, a unique CH is assigned. For this, BS calculates a parameter, *chance of election* (CE) for each of the node based on three factors:

1. *Node degree* and its tuning factor alpha (α): the number of direct neighbors of the node.
2. *Residual Energy* and its tuning factor beta (β): the total remaining energy of the node.
3. *Dist_to_Sink* and its tuning factor gamma (γ): the euclidean distance of the node from the sink.

For a node to be elected as *CH*, all the aforementioned parameters must be high and $\alpha + \beta + \gamma = 1$ must hold good. In this algorithm, biasing can be done for any parameter by increasing the weight of its tuning factor. For e.g., $\alpha = 0.6$, $\beta = 0.2$, and $\gamma = 0.2$ will favor that node which has the highest node degree.

If total cluster heads are more than four, then those zones which have maximum remaining *NCMs*, are assigned additional *CHs*. For instance, in the scenario depicted in Table 1, zone NW will be allocated the fifth *CH*. This process is repeated till the ROI has *CHs* equal to *Total_CH*.

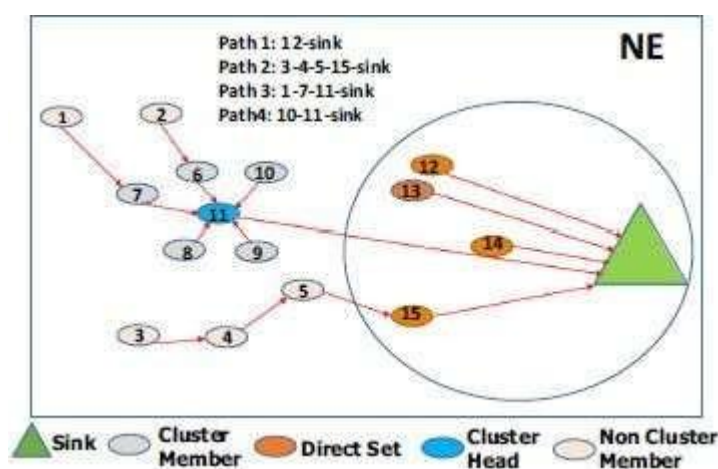


Fig. 3 Camp routing process in zone NE

Routing phase

At this stage, ROI has been divided into n equal sized virtual zones and each node uniquely belong to a particular zone. Before the commencement of routing operation, each node is expected to have its *Nbr_Table* instantiated (viz., it is aware of all its neighbors *Nbr_ID*, *Nbr_Loc* and *Nbr_Residual_Energy*). Also, each node knows whether it is *NCM*, *CM* or member of *Direct_Set* as shown in Fig. 3. In each zone, a node can opt following routing policies,

Case 1 Node is a member of *Direct_Set*.

The node for which BS is in communication range, transmit messages directly to BS. In Fig. 3, node 12 sends data to BS using *Path1*.

Case 2 Node is *CM*.

If the node belongs to some cluster, it send packets to its *CH*, which aggregate it with its own sensed data packet and packets received from other *CMs*. Finally, *CH* sends the data to sink (shown as *Path4*, Fig. 3).

Case 3 Node is *NCM*.

If the node is not a part of any cluster, it will opt for multi-hop communication [using intelligent routing process as explained in procedure IRP(n)]. IRP is a greedy selection approach which selects the next hop node based on the trade-off between the remaining energy of itself (and its corresponding forwarding neighbor) to the energy required to transmit packets to its neighbor. The aim is to maximize the residual energies of the nodes and minimize the transmission energy for communication. The neighbor which has the maximum value, is chosen as next hop. If the next hop node is also *NCM*, the same process is repeated (shown as *Path2*, Fig. 3). On the contrary, if the next node is a *CM*, it aggregates its data with received data and transmits it to *CH*.

CH, later transmits this data to BS (shown as *Path3*, Fig. 3). When node 7 (*CM*) receives packets from node 1, it performs data aggregation and sends it to node 11 (*CH*), which eventually transmit the packets to the sink.

This represents the possibility that a *CH* can also directly transmit data to BS (contrary to normal control flow of CAMP, where *CH* communicates with sink using other *CH*'s as intermediate hops). Any node

which calls *IRP* (only *CH* and *NCM* can adopt *IRP*), obtains the flexibility to choose between direct or multihop communication towards the sink. Node calculates a local selection parameter for all its neighbors and sink. The node corresponding to the highest parameter value is selected as next hop. If the sink has the highest parameter value, direct transmission is adopted else multihop communication takes place.

4. Comparative analysis and simulation results

In this section, we validate our claims by extensive MATLAB simulations and compared CAMP's performance with other established routing protocols in the existing literature. Figure 4, represents the different communication paths adopted by data packets under CAMP routing protocol. Pink path denotes the communication links, which consist of *NCM* and *CM* together. Communication starts at *NCM* node 80 and when the *CM* node 68 is reached, *IRP* is rejected, and hierarchical communication takes place. *CH* node 56 directly transmits to the sink. Yellow path denotes communication links consisting of *NCM* nodes only, thus adopting *IRP* throughout. Green link denotes direct transmission by the *Direct_Set* node to the sink. For our experiments, performance is measured by quantitative metrics like network lifetime, total energy consumption and network coverage.

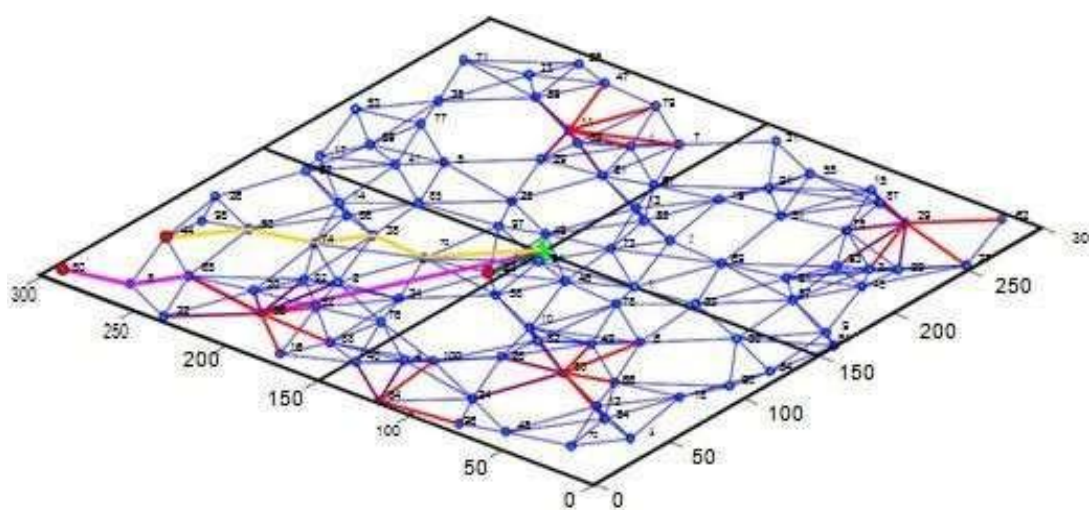


Fig. 4 MATLAB simulation of CAMP routing process

Network life time

In this work, we adopt *First Node Dead Statistics (FND_Statistics)* as a metric for network lifetime. It is defined as the interval between the rounds where the first node start transmitting data and the round where the first node gets dead [25,27]. Here, network was created, by randomly deploying 150 nodes in the terrain size of 200x200 m², under the following scenarios:

1. Scenario 1: sink at center
2. Scenario 2: sink at far
3. Scenario 3: sink at corner

Analysis of the three aforementioned scenarios are described in Figs. 5, 6, and 7. Figures plot the *FND_Statistics* for different routing protocols including CAMP. It can be observed from the figures, that CAMP very well outperformed other protocols (for *FND_Statistics*), for all the three simulated scenarios. Figure 10 establishes the robustness and completeness of CAMP. It can be visualized, that for any network lifetime definition (*FND*, 10, 25, 50, 75% of node dead and *LND* statistics), CAMP performs better than others.

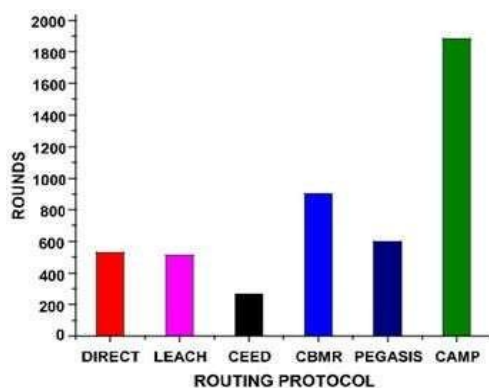


Fig. 5 FND_Stats (sink at center)

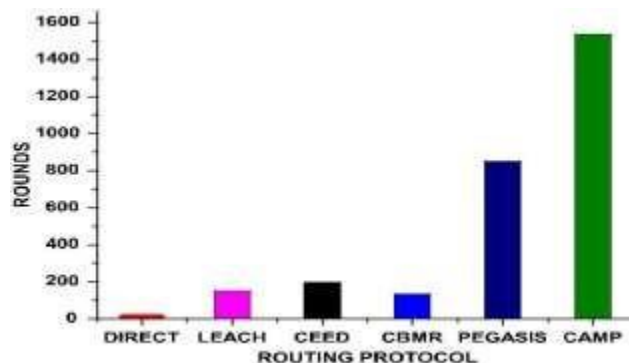


Fig. 6 FND_Stats (sink at far)

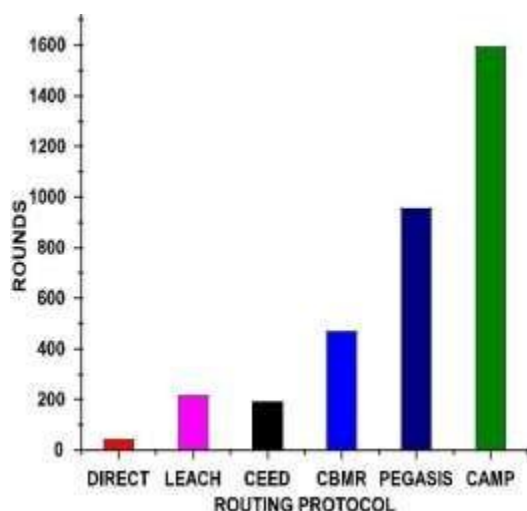


Fig. 7 FND_Stats (sink at corner)

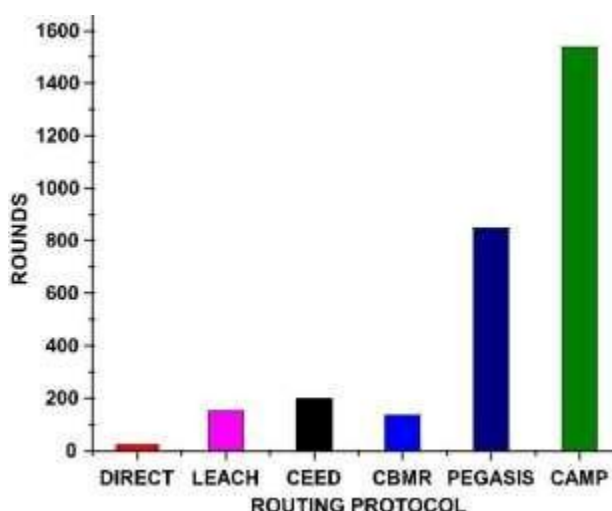


Fig. 8 Alive node statistics (sink at far)

For different set of experiments (placing sink at different locations), with different routing protocols, CAMP remarkably outperformed all its existing counterparts. For PEGASIS, it achieves a minimum of 86% improvement, whereas for LEACH it achieves a maximum of 910% improvement.

Total energy consumption

It is defined as the sum of energy consumed by all nodes in each rounds. Total Energy consumption (TEC) is expressed as:

$$TEC = \sum Rounds \sum Nodes (E_{Tx(Nodes)} + E_{Rx(Nodes)}) \quad (10)$$

Figure 9 shows the total **energy consumption** of the protocols against number of rounds. The plot depicts that CAMP has a desirable energy expenditure curve against other existing protocols. The total energy exhaustion occurs at 4500 rounds for CAMP, whereas for others, it is as low as 1500 rounds.

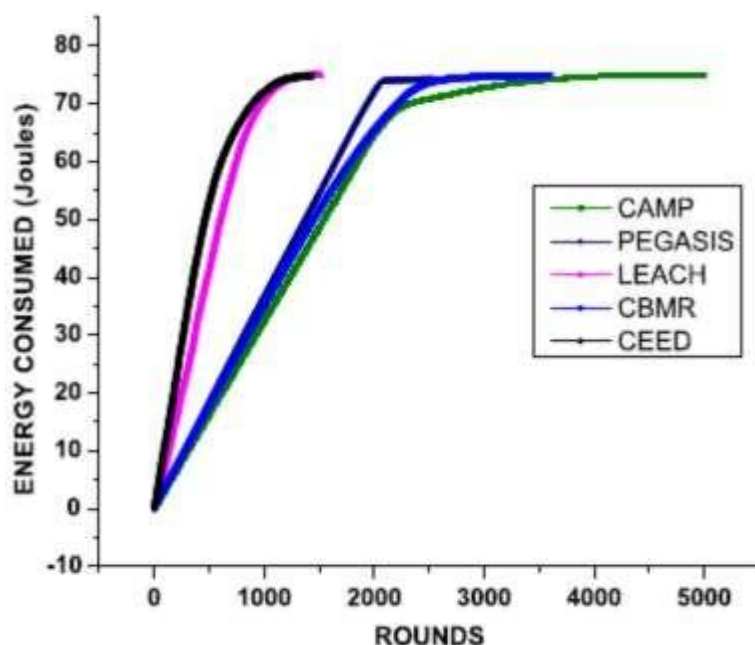


Fig. 9 Total energy consumption of network

Impact of network area variation

In order to test the suitability of CAMP for large network areas, we evaluate the performance of CAMP by increasing the ROI. We tested the performance of CAMP by varying the terrain size. For these experiments, we fixed the number of nodes to 300 and increased the terrain size from 100 to 1000 m². The simulation was carried out for 100 rounds. Figures 10 and 11, represents the variation of the number of alive nodes and energy consumed (by all the nodes) with increasing area. Again, CAMP outperformed other protocols, with remarkable improvements.

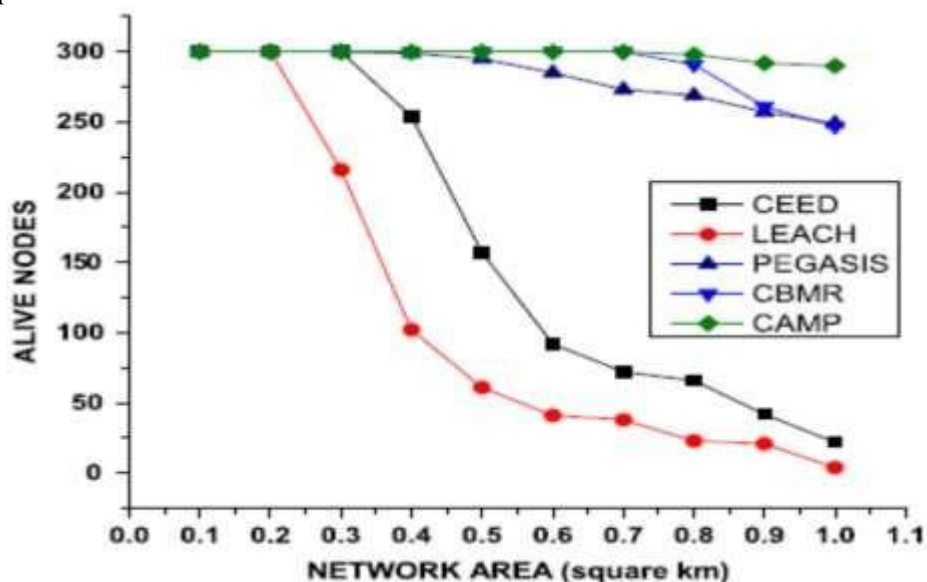


Fig. 10 Number of nodes alive as a function of network area

Fig. 11 Total energy consumption over varying network areas

5. Conclusion

A novel energy conservation protocol CAMP, which can adopt itself, is presented for the Wireless Sensor Networks. This protocol has two phases: clustering and routing phases. The CAMP ensures that no node transmits greater than d_0 distance as opposed to existing hierarchical approaches like LEACH which consumes more energy due to the large distance between cluster nodes and cluster head. Simulations are conducted with different parameters and settings. Results indicate that CAMP improves the network life time and reduced energy consumption compared to existing protocols.

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