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ANALYSIS OF ENERGY AWARE CLUSTER APPROACHES FOR IMPROVEMENT OF LIFETIME IN WIRELESS SENSOR NETWORKS

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ABSTRACT

This research work proposes four energy-aware clusteringapproaches to improve the lifetime of wireless sensor networks. Juxtaposingand assimilating the merits of existing solutions, the proposed clusteringapproaches attempt to improve the energy characteristics and lifetime of awireless sensor network. The second proposed clustering approach, namely, Zonal Clustering Algorithm (ZCA), focuses to improve the lifetime of a sensornetwork by eliminating the impact of hot-spot issues in clustering. Clusterheads functioning nearer to the sink tend to deplete their energy in a rapidmanner and experience hot-spot issue in the conventional clustering process.The third proposed clustering approach, namely, Centralizeddata Aggregation Supported Transmission Scheme Selection (CAS-TSS)focuses on selecting an efficient transmission scheme between Multiple InputMultiple Output (MIMO) and Single Input Single Output (SISO).The fourth proposed approach of the research workconcentrates on providing efficient energy harvesting resources to wirelesssensor networks since the techniques employed on tiny, limited and nonrechargeableenergy resources are always constrained in their lifetimeguarantees.The performance of the proposed energy-aware clusteringapproaches has been compared against the conventional and modernclustering approaches using the simulation done in MATLAB. Simulationresults exhibit that the proposed clustering approaches achieve energyefficiency in comparison with the existing clustering approaches. Hence thelifetime of wireless sensor network has been improved in all these proposedapproaches against the benchmarked and contemporary clusteringapproaches.The first proposed approach of this research work presents aclustering algorithm for wireless sensor networks, namely, Energy AwareFuzzy Clustering Algorithm (EAFCA). This approach employs fuzzy logic toelect cluster heads for clusters in a wireless sensor network. The cluster headsare elected based on three parameters: residual energy, mean distance to 1-hop neighbors and 2-hop coverage of the competing sensor nodes.

1. INTRODUCTION

1.1 WIRELESS SENSOR NETWORKS

In the recent years, wireless sensor networks have attainedsignificant progressive steps in various applications. They have attracted theattention of researchers due to their complex, multifaceted requirements whichoften divulge inherent tradeoffs. A Wireless Sensor Network (WSN) refers toa group of spatially dispersed, autonomous and dedicated sensors formonitoring and recording the physical conditions of the environment and organizing the collected data at a central location. Here, the environmental parameters include

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temperature, humidity, sound, light, wind velocity, etc.A typical wireless sensor network contains sensory devicesnamed sensors, communication units named transceivers, microcontrollers andpower units. The generic architecture of a WSN is presented in Figure 1.1.

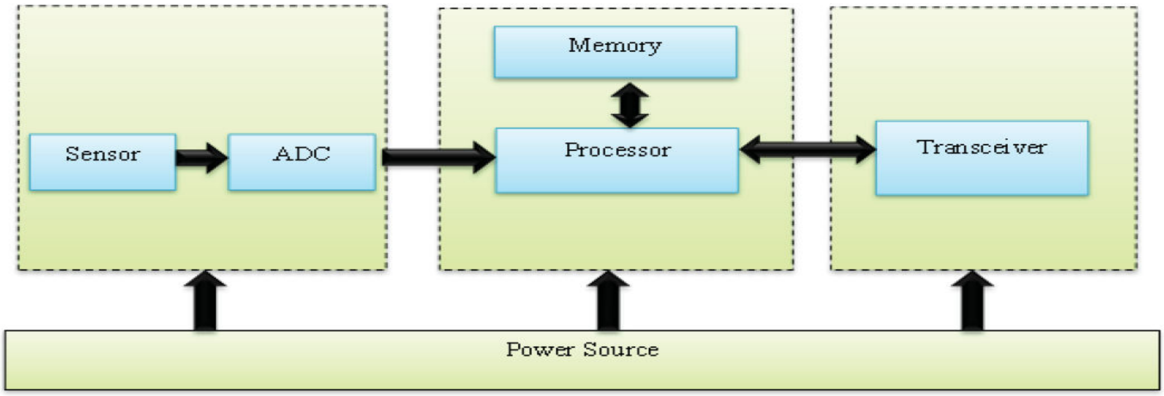

Figure 1.1 Architecture of Wireless Sensor Network

A wireless sensor network is basically an ad hoc network. Likeany ad hoc network, sensor nodes are equipped with self-organizationcapabilities. Cooperation of these sensor nodes is required to accomplish theoperations. The survey done by Akyildi

1.2 WIRELESS SENSOR APPLICATIONS

Depending upon the nature of applications, various categories ofsensor nodes are provided for monitoring issues such as temperature, moisture,sound, motion of objects, etc. In essence, sensor networks compensate humanworks in inaccessible terrains and present more comfortable, smart snapshotsof life style. In the recent future, sensor networks would conquer an integralpart of human life and make existing personal computers, mobilecommunication devices and other computing devices less popular.A sensor network may be composed of homogenous orheterogeneous sensor nodes. They may monitor either space or objects orinteractions of these two. Today, sensor networks are employed in diversifiedfields such as battle field surveillance, medical diagnostics, precisionagriculture, weather monitoring and home appliances. Every sensorapplication demands its own set of requirements and characteristics. Somesensor applications employ reactors in the place of ordinary sensors to react tothe events in an appropriate manner.

Design of WSNs exhibits challenges due to the limited resourcesin terms of storage, processing and communication of messages. In most of thesensor applications, these resources become non-renewable also. Theoreticalestimation could not be accurate enough in many scenarios to predict andprevent failure of sensor networks. The design complexity of WSNs increaseswith emerging applications and their requirements. Conventional algorithmsdesigned for ad hoc networks miscarry to reflect the requirements of thesesensor applications and new definition of policies and boundaries are requiredhere.

Wireless sensor networks can be classified in to pre-deterministicand unattended networks based on the type of applications. Former category ofnetworks gains the advantages of Quality of Service (QoS), fault tolerance,robustness and scalability. In many pragmatic scenarios, human supervisionfor sensor networks is limited or prohibited since the nodes are dispersed incritical environments such as deeper part of jungles and underwaterenvironments. These networks are called as unattended networks.An inherent tradeoff is observed amidst the parameters used todetermine the performance of a WSN. The applications seldom reconcile withidentical set of parameters. Juxtaposing the requirements, they resistgeneralized solutions owing to their nature of self-contradiction andapplication-specific precincts. As the autonomy of nodes increase, scalabilityof the solutions is challenged. Research efforts made to improve throughputoften result in increased overhead. There is a combined need for fastconvergence time and minimum energy consumption of sensor nodes. Whenthe solutions are inclined towards one or a set of parameters, they habituallycompromise the rest of the performance factors. This intricacy leads to manyinteresting queries and solutions in describing the efficiency of a WSN.Slicing over the temporal and spatial domains, the process becomes morecomplex, multifaceted and highly specialized.

1.3 ENERGY REQUIRMENTS IN WIRELESS SENSORNETWORKS

Existence of several performance factors complicates themeasures on efficiency. However, the lifetime of a WSN becomes aninevitable and crucial requirement, especially in the case of unattendednetworks. Handy et al. (2002) employs three metrics to measure the lifetime ofa sensor network: First Node Dies (FND), Half of the Nodes Alive (HNA) andLast Node Dies (LND). The first definition among them estimates the lifetimeof a WSN till the first node dies in the network. This definition emerges fromthe point that the death of the first node in the network indicates the end of theentire network lifetime. The second definition extends the lifetime of a WSNtill half of the population drains off the energy. This metric certifies thefunctioning of the network beyond the death of certain number of sensor nodesand advocates that half of the population is sufficient to perform the assignedresponsibilities of a WSN. The final metric extends the lifetime of a WSN tillthe last node in the network dies. This definition is a traditional interpretationof lifetime but it cannot guarantee the functional requirements of a WSN whenthe population of alive nodes is below some required threshold. The definitionchosen for a WSN should be justified against the application-specificrequirements and pragmatic constraints.

The lifetime of a sensor network is highly influenced by theenergy conservation of the entire network. To achieve an optimal lifetime of aWSN, energy consumption should be minimized as well as balanced amongthe nodes. As observed in the survey done by Al-karaki & Kamal (2004),replenishment of power resources is not supported in many sensor applicationsdue to the unmanned environments and hence the need arises for energysaving in the networks through all possible means.When the energy consumption is not equally distributed acrossthe nodes in an effective manner, sensor network lifetime will get reduced asper the metrics aforementioned. For an instance, sensor nodes near to the sinkare heavily engaged with data relay operations and this leads to their energygetting depleted sooner to the rest of the nodes. Thus the energy equilibrium ofthe WSN is disturbed. As the time goes on, only a few sensor nodes are aliveand active in a network and many existing routes become unavailable.

2. LITERATURE REVIEW

Analyzing the research efforts on achieving energy efficiency, aninherent tradeoff is experienced amidst the performance requirements of aWSN. A typical tradeoff scenario among the goals of the data aggregationprocess such as energy, latency and accuracy of data is indicated in the workdone by Boulis et al. (2003).

The survey done by Abbasi & Younis (2007) explores the meritsand demerits of various clustering approaches for WSNs. One of the mostprimitive and earliest clustering work, named, Low Energy AdaptiveClustering Hierarchy (LEACH) proposed by Heinzelman et al. (2000) electscluster heads based on local decisions. The state of permanently being in therole of cluster head leads them to heavily dissipate their energy and they diesooner than the rest of the sensor nodes. To prevent this, LEACH rotates therole of cluster head for every round randomly among the sensor nodes in acluster and attempts to achieve uniform distribution of energy dissipation overthe cluster members.

The limitations of LEACH motivate the researchers to revisit andimprove the LEACH protocol to adopt QoS requirements of WSNs.Heinzelmen et al. (2002) present LEACH-C, (LEACH-Centralized) a variantof LEACH which depends upon the sink to collect location and energy levelinformation of sensor nodes, selects the cluster heads and broadcasts thisinformation. This centralized architecture fails to support the scalability of theWSNs. Manjeshwar & Agrawal (2001, 2002) propose two event-driven,hierarchical approaches on LEACH namely, Threshold sensitive EnergyEfficient sensor Network protocol (TEEN) and Adaptive Threshold sensitiveEnergy Efficient sensor Network protocol (APTEEN).

Eventhough it effectively administers network scales ina typical multi-hop environment, it demands all the nodes to acquire the globalknowledge of the entire network which is practically infeasible in many sensorapplications. Also, this protocol imposes threats on network reliability. Asobserved by the work done by Vidacs & Vida (2014), LEACH and its variantssuffer from scalability and load balancing despite their simplicity.Researchers have shown their interest in the process of efficientcluster head selection in a sensor network and they consider additionalparameters to make the process more efficient. Particle

Swarm Optimizationtechnique (PSO) is used in some research works from this perspective. Sert etal. (2015) have proposed a Multi-objective Particle Swarm Optimization(MOPSO) algorithm which considers the node degree, transmission power andenergy consumption of mobile nodes to regulate and reduce intra-cluster andinter-cluster traffic. The performance of this approach can be tuned byconsidering more optimization parameter from the total energy consumptionof the WSN. Elhabyan & Yagoub (2015) employ a PSO-based clustering androuting phenomenon in which optimal number of cluster heads is chosen toensure clustering stability and energy efficiency.

3. ENERGY AWARE FUZZY CLUSTERING ALGORITHM(EAFCA)

3.1 OVERVIEW

Wireless Sensor Networks (WSNs) exert a pull on the modernresearch community towards many design challenges, especially, constraintson their lifetimes. Solutions proposed to save energy in WSNs possess theirown merits and limitations. The trends evolved from the perspective ofimproving performance and scalability of conventional clustering approaches.They emerge by adopting cognitive techniques to handle uncertainty andinstability present in the application environment. A wireless sensor networkconsists of homogenous/ heterogeneous sensor nodes which work together toaccomplish a common set of objectives. These nodes are typically equippedwith limited, non-rechargeable power resources which are seldom underhuman monitoring. The lifetime of a WSN is defined with respect to theapplication-specific requirements of sensor networks. Invariably, energypreservation in the sensor nodes becomes the dominant and monolithicconstraint on achieving lifetime efficiency under all these scenarios.

This work proposes Energy Aware Fuzzy Clustering Algorithmfor WSNs which addresses the issues raised above. It combines the advantagesof many research works and contributes a hybrid model which benefits from
the multifaceted analysis on WSN performance factors. This work contributesa cluster head election process with respect to three constraints: the residualenergy, node centrality and 2-hop node coverage. The cluster heads transmitthe data to the sink based on the probabilistic based multi-hop relay model.The lifetime of a sensor network is defined on various degreesdepending upon the nature of the application, traffic pattern and theavailability of resources. A sensor node conserves energy during transmission,reception and idle states. When a sensor node drains off its total energy, it isconsidered to be a 'dead' node.

3.2 PROPOSED SYSTEM

The proposed system has been designed from the perspective ofachieving lifetime enhancement through energy reduction in WSNs. Thefollowing set of assumptions is made about the characteristics of energy modeland network model for the proposed algorithm.

3.2.1 Energy Model

The energy consumption model for this work is adopted from thework done by Kang and Nguyen (2012). Equation (3.1) represents the amountof energy required to transmit 'L' bits of data to a distance of 'd'. The energy components of Equation (3.1) are calculated at transmitter circuitry and RFamplifier.

$$E_{txr}(L,d)= \begin{cases} L\,E_{elec} + L\,\varepsilon_{fs}\,d^2 & d < d_0 \\ LE_{elec} + L\varepsilon_{mpf}\,d^4 & d \geq d_0 \end{cases} \quad (3.1)$$

where 'd' is the transmission distance, εfs and εmpf are the amplifier energyfactors for free space and multi-path fading channel models, respectively. 'd0'represents the threshold distance that differentiates these two fading models.Equation (3.2) calculates the amount of energy dissipated inreceiving 'L' bits of data in the receiver side.

$$E_{rxr}(L) = LE_{elec} \quad (3.2)$$

3.2.2 Network Model

The WSN environment is modelled with the following set ofassumptions:

_ Sensor nodes are randomly deployed and unattended afterdeployment.

_ All sensor nodes and the sink are stationary.

_ All sensor nodes are equipped with same amount of energy at theinitial deployment.

_ Every sensor node is assigned with a unique identifier.

_ The distance between any two nodes can be computed from thereceived signal strength and the links are symmetric.Consider the distributed unconnected graph, G as

$$G= \{V(G), E(G)\} \quad (3.3)$$

3.3 FUZZY BASED CLUSTERING ALGORITHM

3.3.1 Cluster Formation

During the sensor network deployment phase, the sink broadcastsa beacon signal to all the sensor nodes. The sensor nodes compute the distanceto the sink by received signal strength. According to the node density, the sinkdetermines a fraction of 'f' nodes as temporary cluster heads from thenetwork. A threshold 'T' is calculated and communicated to all the sensornodes for every round to determine the eligibility of a tentative cluster headaccording to LEACH. Each sensor node computes a random number in theinterval (0,1) and compares the same against then threshold 'T'. If thecomputed value is more than the threshold, it declares itself as a cluster headand broadcasts the same to other nodes. Otherwise, it considers itself to be anordinary cluster member. A wireless sensor network with 2-hop intra-clustercoverage is shown in Figure 3.1.

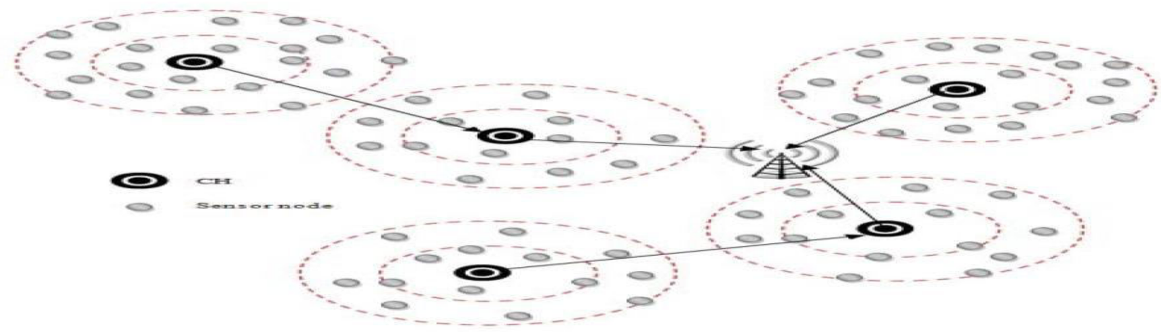

Figure 3.1 A 2-hop Coverage Clustered Wireless Sensor Network

The fuzzy logic is introduced to elect eligible cluster heads fromthe set of tentative cluster heads. It is proposed to form the clusters in theWSN in such a way that any node can reach the cluster head with a maximumof 2-hop distance. For every tentative cluster head, the following set ofparameters is computed.

_ **Remaining Residual Energy (represented as 'Energy'):**

This parameter is expected to be higher for an eligible clusterhead in a competition phase since it is heavily engaged to intra-cluster andinter-cluster data traffic.

EAFCA algorithm

The list of steps involved in the proposed Energy Aware Fuzzybased Clustering Algorithm (EAFCA) are summarized as follows:

Algorithm: Energy Aware Fuzzy Clustering Algorithm (EAFCA)

Input: A randomly deployed WSN with N sensor nodes

Output: Clusters with Cluster Heads (CHs)

1. **Begin**
2. S ← Set of Sensor Nodes, |S|= N
3. Status (S[i]) ← M, i=1,2,…N
4. T ← Number of Tentative CHs
5. CH ← Set of Temporary Cluster Heads | CH[i], i=1,2,…T selected from S
6. S ← S - CH
7. Chance[j]← Probability of CH[j] to become a Cluster Head, j=1,2,…..,T
8. **For** every Tentative Cluster Head CH[j], j=1,2…T
9. Calculate Chance[j] using fuzzy if-then mapping rules
10. Broadcast Advertisement (Chance[j]) to all its 1-hop and 2-hop neighbours
11. **While** (timer)
12. **If** (Advertisement from any CH[x] & (Chance[j] < Chance[x]))
13. Add CH[j] to S
14. CH← CH- {CH[j]}
15. **End if**
16. **Else**
17. Status (CH[j]) ← H
18. Broadcast Advertisement (Status (CH[j])) to all its 1-hop and 2-hop neighbours
19. **End else**
20. **End While**
21. **End For**
22. **For** every sensor node S[i]
23. **If** Advertisement(Status(CH[k])) received form exactly one Cluster Head CH[k]
24. Add S[i] to CH[k]
25. **End if**

// To avoid overlapping of clusters

26. **Else If** (CHAdvertisement() message received from N number ofCluster Heads)

CONCLUSION

The current research work focuses on prolonging the lifetime ofsensor networks, especially in the case of unattended sensor networks.Irrespective of the techniques employed on current research works, theyemphasize on reducing energy consumption in a WSN.This research work proposes four clustering approaches to reduceenergy consumption in WSNs and to improve lifetime of these networks. Theproposed clustering approaches, namely, Energy Aware Fuzzy ClusteringAlgorithm (EAFCA), Zonal Clustering Algorithm (ZCA), Centralized data-Aggregation supported Transmission Scheme Selection (CAS-TSS) algorithmand Efficient Energy Harvesting

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assisted Clustering (EEHC) algorithmpossess the common objective aforementioned and contribute the lifetimeimprovement of a WSN in credible manner. Sensor nodes in the experimentalenvironment are assumed to be static and unattended.Conventional and model clustering algorithms have been taken asbenchmarked algorithms and the performance of the proposed clusteringalgorithms have been tested.

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