An Overview of Energy Efficient Hierarchical Cluster Based Routing Protocols in Wireless Sensor Networks

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Abstract:- *With recent technologies in wireless communication and computation, wireless sensor networks have transitioned into one of the most important technologies in the twenty-first century, enabling development of low cost, low power sensor nodes. Increasing life span of sensor nodes within a network has become one of the major areas of research in wireless sensor network, with a view of addressing the inherent limited battery power present. Much research has been undergone towards developing low power protocols, in which optimal routing can be achieved, in context of energy. In this paper, an overview of routing protocols is present, with a view towards discussing popular energy efficient hierarchical cluster-based routing protocols available for wireless senor networks.*

Keywords- Wireless senor networks, Routing protocols, Hierarchical routing, Energy efficient routing.

INTRODUCTION:

Wireless sensor networks (WSN), in general, are defined as a group of spatially dispersed sensors, used for monitoring and recording physical conditions, with the collected data being organised and stored at a central location [1]. Each sensor node can independently perform their sensing and processing tasks, in addition to communicating with other nodes, thereby allowing organised data to be redirect to a central unit. With the recent technological advancements, various aspects of wireless communications have progressed on to become integral part in relation to operation of wireless sensor networks. Wireless sensor networks have, in recent times, become the standard services employed in industrial and commercial applications, due to processor development, as well as communication and low-power usage of embedded computing devices. Due to the sensing and actuation faculties present in the sensor nodes encompassing a wireless sensor network, in additional to the computation and communication abilities, wireless sensor network find implementation in various scenarios, from disaster relief operations, biodiversity mappings, machine surveillance, to medicine and healthcare. In all of these applications, there is a clear distinction between sources of data and sinks, including where data is delivered. Event detection, periodic measurements and other fields more often implement the use of the interactive patterns that appear between sources and sinks in WSNs [2].

ROUTING PROTOCOLS IN WSN:

Wireless sensor networks are inherently different in characteristics from other wireless networks like mobile ad hoc networks or cellular networks. This leads to routing becoming a challenging task in relation to wireless sensor networks. To begin with, it is not possible to develop a global addressing scheme for the deployment of sensor nodes, due to the presence of large number sensor nodes and the overhead of ID maintenance being relatively high. Furthermore, wireless sensor networks are in general stationary after deployment, in contrast to other traditional networks, which leads to unpredictable and consistent topological changes. The sensor nodes present in wireless sensor networks are also limited and constrained, in terms of energy, processing and storage capacity. Some of the routing and design challenges are described below [3].

I. **Node deployment**: Manual node deployment can satisfactorily provide coverage of area through precise selection of node density. However, this acts as a disadvantage, particularly in harsh environment, due to higher node costs. In random node deployment, the nodes are arbitrarily scattered, which is advantageous in relation to applications in event detection.
II. **Fault Tolerance:** For wireless sensor networks as a whole, it is imperative that they are able to tolerate faults, particularly because of the possibility of nodes being drained of energy and damaged, or communication between nodes permanently interrupted.
III. **Nature of node:** The nodes present in wireless sensor networks can be wither homogenous or heterogeneous, depending on range of transmission, battery life and processing life. While majority of the network architecture assumes stationary sensor nodes, several applications require the mobility of base station, as well as nodes.
IV. **Quality of service**: Routing protocols should be able to provide for a sustained level of quality of service, which comprises of various parameters such as bandwidth, delivery delay, throughput and others. Multimedia networks, for example, require higher throughput as compared time sensitive data, where target detection and tracking application require a lower level of transmission delay [4].

With the energy restrictions present in wireless sensor networks, in addition to unpredictable topological changes, finding and maintaining routes have become inconsequential. Being inherently data centric networks, various routing mechanisms have been developed to address the routing problems present, which also account for the inherent features present in WSNs. Routing in WSNs, in general can be classified into five ways, as shown in the figure below:

The network structure based routing protocols can be categorised as flat based, hierarchial based (cluster based) and location based routing protocols [5].While flat routing protocols are effective for small networks, they proved to be of disadvantage when scaling to large and dense networks, since all nodes are alive and generate more processing and bandwidth usage. Hierarchial or cluster based protocols allow for an energy efficient alternative, being more scalable and energy aware. In hierarchical based routing, nodes play different roles in the network and typically are organised into clusters. Clustering is the method in which nodes those having high energies are arbitrarily selected for processing and sending data while nodes those having low energies are used for sensing and sending information to cluster heads (CHs). This property of cluster based routing contributes to the scalability, lifetime maximization, and energy minimization. Clustering also allows for intra-cluster and inter-cluster routing which reduces the number of nodes taking part in a long distance communication, thus allowing significant energy saving in addition to smaller dissemination latency. Hierarchical or cluster based routing are generally classified into three broad categories: block cluster based, grid cluster based and chain cluster based routing protocols. The classification is as shown below. Here, we discuss some of the popular energy efficient cluster based routing protocols implemented in wireless sensor networks [6].

i. Low Energy Adaptive Clustering Hierarchy (LEACH): Low-Energy Adaptive clustering Hierarchy (LEACH) is one of the most popular hierarchical routing algorithms for sensor networks. LEACH is a cluster-based protocol with distributed cluster formation with random clusterhead election. A sensor node chooses a random number between 0 and 1. If this random number is less than a threshold value, *T (n)*, the node becomes a clusterhead for the current round. This threshold value is calculated using:

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

Where P is the desired fraction of nodes to be clusterheads, r is the current round and G is the set of nodes that have not been clusterheads in the last $\frac{1}{P}$ round.

ii. LEACH-C: LEACH-C is a centralised version of LEACH where only the advertisement phase differs. At this phase, each node sends information about its current location and residual energy level to the sink. Based on the node's location, the sink builds clusters using the simulated annealing algorithm so that the energy required by member nodes to transmit their data to their respective clusterheads is minimised.

iii. E-LEACH: E-LEACH proposes a cluster head selection algorithm for sensor networks that have non-uniform starting energy level among the sensors. However, this algorithm assumes that sensors have global information about other sensor's remaining energy. E-LEACH also determines that, under certain assumptions, the required number of cluster heads has to scale as the square root of the total number of sensor nodes to minimise the total energy consumption.

iv. LEACH-F: LEACH-F is the further development of LEACH, which is based on clusters that are formed once and then fixed. Then, the cluster head position rotates among the nodes within the cluster. The advantage is that, once the clusters are formed, there is no set-up overhead at the beginning of each round. To decide cluster, LEACH-F uses the same centralised cluster formation as LEACH-C.

v. Energy Efficient Hierarchical Clustering (EEHC): Energy Efficient Hierarchical Clustering as be seen as an extension of LEACH with multi-hop intra cluster and a hierarchy of clusterheads to route data to the sink.

vi. Hybrid Energy-Efficient Distributed Clustering (HEED): HEED provides an extra step towards energy efficient cluster based routing with explicit consideration of energy. Selected clusterheads in HEED have relatively high average residual energy compared to member nodes. In HEED, the distribution of energy consumption extends the lifetime of all the nodes in the network, thus sustaining stability of the neighbour set.

vii. Clustering Method for Energy Efficient Routing (CMEER): CMEER is another attempt to achieve well distributed cluster heads. In CMEER, a node declares itself as a candidate to be clusterhead using equation 1 where P is chosen higher than adopted values in LEACH. Each candidate advertises its intention to be a clusterhead within its radio range. Each node decides to join a given clusterhead based on the received signal strength of the advertisement message. The simulation results show that CMEER outperforms LEACH in terms of energy consumption and network lifetime.

vii. TEEN: Threshold sensitive Energy Efficient Sensor Network Protocol is one of the cluster-based routing protocols which aim to achieve QoS requirements such as end-to-end delay and available bandwidth when building paths in a sensor network. TEEN is a clustering communication protocol that targets a reactive network and enables CHs to impose a constraint on when the sensor should report their sensed data. TEEN builds a 2-tier clustering topology and relies on broadcasting hard and soft thresholds by each clusterhead to its member nodes. Important features of TEEN include its suitability for time critical sensing applications. Energy consumption is lower than proactive networks, since message transmission consumes more energy than data sensing. TEEN is however quite limited in applications where periodic reports are needed. The Adaptive Threshold Energy Efficient sensor network protocol (APTEEN) is an extension to TEEN, which aims to provide application with periodic data collection, while being sufficiently reactive to time critical event [7].

Challenges to Routing:

Applications of routing protocols have greatly improved over recent years, yet there remain several drawbacks to ensuring for efficient use of these routing techniques [8]. The performance and availability of adjacent clusterhead, including their role in rotation of adjacent clusters must be considered as an important factor in the calculation as well as selection of clusterheads. Also, the adaptability and scalability of clustering techniques must be carefully considered while enlarging the monitoring area in the presence of additional nodes, particularly for large scale deployments. The strength of clustering methods is also pivotal, due to periodic topological changes of wireless sensor networks, owing to territorial circumstances. Redundancy management, specifically in relation to minimising the use of redundant nodes in order to build proficient relay backbone is also an important area for further research in cluster based routing protocols. Furthermore, transient fault management, due to temporal link failures in communication between sensor nodes in wireless sensor networks also needs attention.

Conclusion:

Energy efficiency present as one of the major challenges in the design and development of routing protocols for WSNs. With a view towards extending the network lifetime by keeping the sensors operating for as long as possible, this paper presents an overview of the various routing techniques employed in wireless sensor networks, while focusing on the popular energy efficient hierarchial cluster based protocols present. Even though the performance of the protocols discussed is promising, in relation to energy efficiency, further research would be need to address the factors affecting cluster formation and clusterhead communications, including Quality of service and real time applications.

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