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A Survey on Energy Efficient Routing in Wireless Sensor Networks

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Abstract— An energy efficient routing is a significant issue in the designing of Wireless Sensor Network (WSN) protocols. This paper presents a comprehensive survey on energy efficient routing protocols in WSNs.

Keywords— Energy Efficiency, Network Lifetime, Routing Protocols, Wireless Sensor Network (WSN), Ant Colony Optimization (ACO)

I. INTRODUCTION

A wireless sensor network is an ad-hoc infrastructure of sensing, communicating elements that gives the ability of observing, reacting in specific environment. The environment can be an information technology framework, the physical world or a biological system. This paper describes the study of various energy efficient routing protocols in WSNs which are important for their designing purpose so as to meet the various resource constraints. The paper is organized as follows: Routing factors and designing of WSN is described in the Section II. Section III reviews previous survey articles on WSN routing. And finally Section IV concludes the paper with proposed future directions.

II. ROUTING FACTORS AND WSN DESIGN

Routing design is closely related to the network system architecture mode and the design of routing protocols in WSNs is influenced by many challenging factors to be addressed which are outlined and discussed as in [29]:

A. Sensor Location

The sensor nodes are either equipped with global positioning system (GPS) or other form of sensing the sink to learn about their locations, another challenge which has to be managed is the location of the sensors.

B. End-to-End Delay

It is time taken for a one node to send packet to a sink or vice-versa. It can be either one way or round trip (packet sent from source to sink and from sink to source)

C. Node Deployment

Sensor nodes are deployed on the basis of application and affect the performance of routing protocol. The nodes if randomly deployed organized themselves to establish path so as to acquire energy efficient and reliable connectivity network operation.

D. Fault Tolerance

In case of failures (like environmental interference, physical damage, power etc), routing protocols generate new routes to the data collection point or the destination as in [30]

E. Scalability

The number of sensor nodes deployed in the sensing area may be in the order of hundreds or thousands depending upon the routing algorithms as they should be scalable enough to respond to the events.

Due to the factors mentioned above, researchers have designed various routing protocols especially for WSNs due to the differences between routing in WSNs and other wireless networks. Almost all applications of sensor networks require the flow of sensed data from multiple regions (source nodes) to a particular sink. Generated data traffic has significant redundancy in it since multiple sensors may generate the same data within the near-by region. Such redundancy needs to be exploited by the routing protocols to improve energy and bandwidth utilization.

III. LITERATURE SURVEY

Routing is very important factor in the design of WSNs. The work done by several researchers till date is described in this section.

LEACH (Low-energy adaptive clustering hierarchy) proposed in [2] which is adaptive clustering protocol for distributing energy load among the sensor nodes in the network. LEACH uses randomized rotation of the cluster base stations or cluster-heads and the corresponding clusters and is able to distribute energy dissipation evenly throughout the sensors, doubling the lifetime. The clusters are used for transmitting data to the base station provides the advantages of smaller transmitting distances for most of the nodes, requiring only a few nodes for transmitting the data far distances to the base

station. It increases the performance of classical clustering algorithms by using adaptive clusters and rotating cluster-heads, allowing the energy requirements of the system. In addition, this protocol is able to perform local computation in each cluster to reduce the amount of data that must be transmitted to the base station. This achieves a large reduction in the energy dissipation. [14] proposed another protocol named M-LEACH which is an energy efficient routing protocol for mobile wireless sensor networks. This protocol has some features of LEACH, the location of cluster heads are chosen to reduce the total power attenuation. In this protocol, during the Setup phase, each node sends information including locations, energy level to the base station and during the transmission phase, each node sends data during it allocated transmission time.[15] proposed Cluster-tree LEACH which supports single or multi-cluster networks. Each single cluster in multi-cluster network acts as a cluster head and these cluster-heads are fixed in each cluster during the lifetime of the network. This protocol has increased the lifetime of the network by nearly 50% of the original lifetime of the network.

[3] proposed PEGASIS (Power efficient gathering in sensor information systems), a greedy chain protocol which resolves the data-gathering problem of the wireless sensor networks. The main thing is for each node to receive from and transmit to close neighbours and take turns being the leader for transmission to the base station. This approach will distribute the energy load evenly among the sensor nodes in the network. Initially the nodes are placed randomly in the field, and the sensor nodes are arranged to form a chain, which can either be accomplished by the sensor nodes themselves using a greedy algorithm starting from some node. Alternatively, the base station can compute this chain and broadcast it to all the other sensor nodes. For constructing the chain, all nodes have global knowledge of the network and then employ the greedy algorithm. A loop will be constructed to ensure that all nodes have close neighbours is difficult as this problem is similar to the travelling salesman problem. The greedy approach to constructing the chain is done before the first round of communication. It shows better results as compared to LEACH by removing the overhead of dynamic cluster formation, reducing the number of transmissions, and using only one transmission to the base station per round. and shows better improvement if the network size increases.

[4] proposed PEACH (Power-efficient and adaptive clustering hierarchy), a clustering protocol for maximizing the network lifetime of the wireless sensor networks. Clustering protocols enable sensor nodes to reduce data packets by data aggregation on WSN. In wireless sensor networks, a node can recognize the source and the destination of packets transmitted by hearing the neighbouring nodes. Based on the heard information, this protocol forms the clusters without additional packet transmission head such as advertisement, announcement, joining, and scheduling messages. This is designed to operate on probabilistic routing protocols, in order to provide an adaptive multi-level clustering. As a result of the protocol design, it is generally more scalable and efficient to the various circumstances than the existing clustering protocols of the wireless sensor networks. This protocol can be used on both location-unaware and location-aware wireless sensor networks. The location-unaware protocol can be used when the location information of each node is unavailable on the network. The location-aware protocol operates when the localization mechanism such as a GPS-like hardware is available on sensor nodes. The communication cost in WSN is decreased by the reducing the data packets, and the clustering protocols improve the lifetime and the energy consumption of the wireless sensor networks. PEACH has no overhead on cluster head selection and forms adaptive multi-level clustering as compared to the existing clustering protocols.

[5] proposed TEEN (Threshold sensitive energy efficient sensor network protocol) which is the first protocol developed for reactive networks. In this, at every cluster change time, the cluster-head broadcasts to its members. Thus, the hard threshold tries to reduce the number of transmissions by allowing the nodes to transmit only when the sensed attribute is in the range of interest. The soft threshold further reduces the number of transmissions by eliminating all the transmissions which might have otherwise occurred when there is little or no change in the sensed attribute once the hard threshold. TEEN is well suited for time critical applications and is also quite efficient in terms of energy consumption and response time. It also allows the user to control the energy consumption and accuracy to suit the application. The main drawback of this scheme is if the thresholds are not achieved, the nodes will never communicate, the user will not get any data packet from the network and will not come to know about the nodes if they die. Thus, this scheme is not well suitable for applications where the user wants to get data regularly. Another problem is that a practical implementation would have to ensure that there collision-free cluster.

[6] proposed SOP (Self-organizing protocol) protocol which includes cluster architecture of LEACH with multi-hop routing to decrease transmission energy. In many WSN multi-hop routing is adopted. This makes a node that wants to transmit data to a destination node find one or multiple intermediate nodes. The communication occurs among all the nodes until the data packets reach the destination [7]. In brief, the data packets take several hops among the nodes in the network. The main advantage of this approach is that transmission energy consumption is reduced. But at the same time latency of the network and delay of data packets will increase. In some cases, no rigid requirements on latency, the multi-hop routing can lead to high energy efficiency. In this protocol when clusters are organized, the cluster heads form a multi-hop routing backbone. Every cluster member node sends data to the cluster head directly for the communication purpose. While for the communication between the cluster head and the base station, a multi-hop routing is adopted to reduce the transmission energy and minimize the difference of energy consumption among all nodes in the network. In order to reduce the probability of collisions at setup phase, some collision avoidance mechanism is added to CSMA MAC protocol. Thus it is more suitable to WSN. The assumptions are considered same as LEACH about the network model as follows. This means that all nodes can use power control to vary their transmission power and range. At the same time, each node has enough processing power to support different protocols and signal processing tasks.

[8] described HEED (Hybrid energy-efficient distributed clustering protocol) in which tentative cluster heads are randomly selected based on their residual energy. Therefore, HEED cannot guarantee optimal head selection in terms of energy, since it uses the secondary parameter to solve the problems.

[9] proposed HEEP (Powered by ambient energy harvesting) and improved network performance using routing algorithm and improves relay node placement scheme for wireless sensors networks. This protocol uses super-capacitors instead of batteries as energy storage devices, by providing almost unlimited recharge cycles for endless deployment. This protocol is very helpful for the applications where sensor nodes are not easily accessed or replaced. In the proposed approach a multi-hop HEAP deployment that comprises three types of nodes: relay, source and sink nodes. All these three types of nodes are different from each other. The function of the relay node is to forward data packet from source to sink node. These relay nodes are required when the source node is not within the range of the sink for the communication purpose. The source node is similar to the relay node except that if it does not receive any packet in the reception time, it will send its own data packet in that transmission time. The sink node does not need to be charged, sink receives any data packet transmitted by the sensor nodes if sink lies in the range of the sensor.

[10] presented an approach for energy aware and context aware routing protocol of data. The researchers mainly focused on the adjustment of topology and the routing mechanism. Data is routed through multiple hops so as to conserve transmission energy. Sensor energy is the major issue while deciding for changes to network topology and for setting routes. Setting routes for sensor data can be obtained by the central node that knows the network topology, like the gateway, or distributed among the sensors themselves. Both centralized and distributed routing requires maintenance of the routing table every time the network topology changes by updating the routing table with the change in topology adopted. On the other hand, centralized routing is simple and is suitable for the wireless sensor networks. The sensor is committed to data processing and communication thus it is beneficial to offload routing decision from the resource-limited sensor nodes. Centralized routing can restrict scalability as the more gateways can be deployed if number of sensors per cluster increases. It is better for the gateway to send commands to the sensors directly without involving relays because the gateway is not energy-constrained as the sensors. The approach used is the transpose of a single-source routing algorithm, i.e. single destination routing. This can reduce the complexity of the problem using a least-cost or shortest-path unicast routing algorithm.

[11] proposed EEABR (Energy efficient ant based routing) which is based on the Ant Colony Optimization heuristic. Initially the forward ants are sent to no specific destination node, which means that sensor nodes must communicate with each other and the routing tables of each node must contain the identification of all the sensor nodes in the neighbourhood and the correspondent levels of pheromone trail. For large networks, this can be a problem since nodes would need to have big amounts of memory to save all the information about the neighbouring nodes. The algorithm can be easily changed to save memory. If the forward ants are sent directly to the sink, the routing tables only need to save the neighbour nodes that are in the direction of the sink. This reduces the size of the routing tables and, in consequence, the memory needed by the nodes. The quality of a given path between a sensor node and the sink-node, should be determined not only in terms of the distance, but also in terms of the energy level of that path.

BACCA (Based on ant colony clustering algorithm) as in [12] was proposed for radar sensors which consumes a better balanced energy and increase the life cycle of the radar sensor network. The difference between wireless sensor network and radar sensor network is that there is one more step in radar sensor network, which is radar scanning process, so deduce radar sensor network radio model can be deduced from wireless sensor network radio model. In this algorithm when the new cluster head is chosen, both the residual energy and aggregation of radar nodes are considered. At the same time, when the radar nodes choose to join the corresponding cluster head to form the new cluster, both the residual energy of radar node and energy attenuation of data transmission are considered. With the help of this algorithm, the radar sensor network lifetime can be increased effectively.

[13] proposed an Optimized Lifetime Enhancement Scheme which shows increased network performance by ensuring a sub-optimal energy dissipation of the individual nodes despite their random deployment. It employs modern heuristics like particle swarm optimization instead of the greedy algorithm as in PEGASIS to establish energy efficient routing paths .In this, chain is formed and the network lifetime is increased by allowing the individual nodes to transmit unequal number of times to the base station depending on their residual energy and location. This algorithm requires centralized knowledge about the sensor network, it would be best to carry out the algorithm in the base station and distribute the result in the network before initiating data gathering. This task is dependent upon the application itself. If frequent communication with the base station is not feasible for all the nodes, this chain formation algorithm can also be applied in individual clusters in the sensor field, where these computations can be done by a local leader in each cluster. This will not only use limited resources as the number of nodes in a cluster is limited but also results in equal energy dissipation among the local leaders. This sort of distributed computation will speed up the process of self-organization of the network. In the end, the base station could connect these local leaders to form the final optimized chain. [16] proposed an energy efficient protocol called EEHC (Energy efficient heterogeneous clustered scheme) which involves the advantage of presence of node heterogeneity. The goal of this protocol is to enhance the network lifetime and stability of the network in the presence of heterogeneous nodes. This protocol takes complete advantage of heterogeneity; the stable region is increased in comparison with that of LEACH because super and advanced nodes follow the death process of normal nodes as the weighted probability of selecting cluster-heads causes the energy of each node to be consumed in proportion to the node's initial energy. The simulation shows this protocol has 10% increased lifetime of the network as compared to LEACH in the presence of same setting of powerful nodes in the network. [17] described EAAR (Energy-aware ant-based routing protocol) protocol in which a set of paths with similar energy is obtained, but only some nodes

will be of distinct type of nodes. Authors used the concept of naturally occurring behaviour of real ants [18] and on this basis an energy aware routing protocol is designed. This help in obtaining the better paths because parameter used in this approach is not limited to hop count only. This protocol has very less number of dead nodes as compared to other algorithms. This is multi-path energy-aware routing protocol which demonstrates the better results because once a route has been established it is reliable as far as the energy of that route is concerned.. This uses more packets to find routes and large numbers of routes are discovered in a more mobile state. Unlike other protocols, this protocol delivers a constant ratio in comparison with other protocols. The energy consumed, energy per packet, packet loss in this protocol is less as compared to other protocols in small and medium mobility networks. The packet delivery ratio and energy per packet in high mobility networks are not better for this protocol as the other parameters because energy awareness increases the time to estimate the best route for the packet transmission. The results get better for lager data packets. Packet delivery ratio is much improved with the help of this protocol. [19] intentionally described EMAR (Environmental monitoring aware routing) which adapt to external node errors. The node's health is most applicable routing criteria affected by sensing. There is an additional criteria like link quality that helps in efficient routing when all the nodes in the network are equally healthy. These parameters are indicating towards exact direction and connectivity to the destination. This approach has demonstrated good performance, if considered in forest fire scenarios. This type of routing can bear multiple sinks excluding additional overhead. This approach is more adaptable than standard protocols the additional environmental parameters can be added simply to the routing algorithm.

[20] proposed ECRPW (Energy efficiency clustering routing protocol based on weight) to prolong the lifetime of the network, residual energy of the nodes is to be considered during the election process of cluster-head. The cluster-heads were distributed uniformly as they consider the distance that had been forced to optimize the cluster scheme. The constraint of distance is considered in formation of cluster to avoid extra energy consumption. The network lifetime of this protocol is longer than that of LEACH. The lifetime curve increases with node density. This protocol considers the current residual energy of nodes and the distances among the cluster-heads to optimize the cluster scheme which enhances the lifetime of the network along with load balancing and also equalizes consumption of energy. In the data transmission phase and routing tree can balance the energy consumption of cluster-heads. This protocol has better performance results.

[21] proposed an adaptive clustering protocol for wireless sensor networks called ADRP (Adaptive decentralized re-clustering protocol) in which cluster-heads and next heads are elected based on residual energy of each node and the average energy of each cluster having nodes. Cluster-heads rotate to balance the energy released from the sensor nodes. This protocol is used for collecting data from distributed sensor nodes and transmits data to the base station. This protocol is helpful in supporting periodic remote monitoring sensor networks. The sensor nodes switch directly to next heads without communicating with the base station. This protocol has least amount of energy and reduces communication overheads. If single hop communication is used to reach the base station, the sensor nodes located farther away from the base station will be having the highest energy load because of long range communication. If multi hop communication is used to reach the base station, the sensor nodes closer to the base station is having higher load of relaying packets.

[22] proposed energy efficient unequal clustering for large wireless networks which balance the power of node consumption and increase the network lifetime as long as possible. This protocol focuses on inter-cluster routing protocol. Fuzzy logic system is used to determine node's chance of becoming cluster-head and adaptive max-min ant colony optimization is used to construct inter-cluster routing between cluster heads and base station which further balances the energy consumption of cluster-heads. Base station broadcasts a beacon message to all the sensor nodes at fixed power. Each sensor node can compute the approximate distance to the base station based on the received signal strength. This proposed clustering scheme is divided into rounds and the main feature of this algorithm is the application of Fuzzy Logic called unequal clustering Fuzzy logic improved ACO algorithm (UCFIA). ACO is used to find the optimal path between cluster head and base station. UCFIA improves the network lifetime over LEACH and EEUC.

[23] proposed a distributed clustering algorithm, EC (Energy efficient clustering) which determines the cluster sizes depending upon the hop distance to the data-sink while achieving equal lifetimes of nodes and reduces energy consumption. Each sensor node produces a single data packet, transmits packet to its associated cluster-heads. Then each node collects those packets from its associated member nodes and combines to produce a cluster. Trade-offs, hop distances to the sink and approximate equalization of energy levels are three step processes which are referred to as a single data collection round (DCR) of the WSN operation. This protocol enhances lifetime of the network and provides equalization of energy level of nodes at different hop distances to the sink.

[24] proposed EAERP (Energy aware evolutionary routing protocol) in which authors reformulate the design of important feature of EA (Evolutionary Algorithms) so that the routing protocol provides more robust results as compared to the existing heuristics. The authors have presented a new evolutionary dynamic cluster formation in WSN. This protocol proves to be an important for deriving clustered routes with better trade-off between network stability and network lifetime with well-distributed energy consumption.

[25] proposed an analytical model for investigating the effect of mobility on a cluster-based protocol called LEACH. This evaluates data loss which can be used to estimate the balanced energy and data loss ratio. As LEACH is type of random clustering scheme so this is used for the applications of random clustering. This approach leads to the geometric model which is presented to evaluate the reliability of links between cluster-heads and cluster-members. Distance from cluster heads to cluster members is evaluated with the help of this geometric model. The results showed that packet loss ratio starts from 0.5 and then increasing. This model is highly accurate with or without buffer zone.

[26] changed the threshold function of the node so as to increase the network's lifetime and balance the energy consumption of nodes. The randomness of choosing head node, energy load imbalance in cluster-head nodes, energy utilization rate of head nodes are the problems of classical LEACH protocol. The improvement of LEACH protocol includes optimum factor, modified threshold function, and method for normal nodes joining the head nodes which leads to the formation of a new protocol called NEWLEACH. This protocol introduces the optimal factor by considering the residual energy of the nodes, times of the nodes to be elected as a cluster head node, the distance between nodes and base station. This improvement fines the quality of wireless sensor networks. This mainly extends the lifetime of the network. The even distribution of dead nodes exhibits the balanced energy in the network. Thus NEWLEACH protocol has an advantage over classical LEACH routing protocol.

[27] proposed a protocol based on Bayesian game to avoid uneven energy consumption in wireless sensor networks. The authors used the theorems of game theory for routing analysis in wireless sensor networks. Network initialization, cluster-head election, data transmission are the three parts of this protocol. In network initialization, nodes receive initial information from a sink node, then all the nodes broadcasts the data packets to the neighbouring nodes and the sink node. The packets include information like ID, residual energy etc. After this all the nodes form a routing table which consists of the information related to those nodes. The real time property of this protocol can be measured by average number of hops from source to sink. This protocol ensures the reliable communication under high real time requirements due to uniformly distribution of cluster-heads and the logical design of utility function.

[28] proposed EAP (Energy aware routing protocol) which includes the QoS (Quality of Service) of an energy efficient cluster based routing protocol in terms of lifetime, loss percentage, delay and throughput. EAP works like LEACH and each round consists of two important phases, set-up phase and data phase. The set-up phase is subdivided into two phases, cluster formation phase and cluster heads tree construction phase. The main disadvantage is that the protocol slightly degrades lifetime of the network. [31], [32] used the concept of ant agents i.e ACO implementing on LLEAP (Low Loss Energy-Aware Routing Protocol) so as to enhance the network lifetime of the wireless sensor network as well as to improve the QoS parameters of the sensor networks. The simulation results were improved from the previous algorithm and thus compared with LLEAP.

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IV. CONCLUSIONS

From the review protocols, it is clearly seen so far that, the performance of protocols is worth promising in terms of energy efficiency. There is very little research done in improving QoS parameters in a very energy constrained sensor networks. The sink node and sensor node are mostly stationary thus research can be done by assuming sink and source node as mobile Various topologies, routing algorithms can be used based on the different application of WSN. Results can be improved using multiple sink nodes.

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