Combined Multi-Path And Clustered Routing In Wireless Sensor Network For Efficient Load Balancing

R.Anandha Lakshmi, Dr.T.Suresh

Abstract: Many of limitations and issues in Wireless Sensor Network (WSN) arise mainly because of the limited availability of energy or processing and storage capacity. Due to this limitation all the operations in the WSN aims at conserving the energy by reducing the consumption in the network and must much of energy is spend in general to send data packets from the cluster heads and receiver station in a cluster-based routing approach. This paper focus on proposing an efficient routing technique aimed at balancing the energy expenditure in the network. The proposed routing approach follows a hybrid routing strategy where a hierarchical clustering scheme divides the network in to clusters and data packets are received by the cluster head from the sensor nodes and then they are forwarded to the base station using a multi-path routing scheme. The sensor nodes belonging to a cluster sends their sensed data to cluster heads present with in the same cluster via a one-to-one communication. The data from head node to the control or base station will be forwarded through intermediate cluster heads. The multi-path routing scheme estimates multiple routes between a cluster head and base station. Then selects an optimal path based on multiple factors including total remaining energy available in the intermediate cluster heads, count of data packets already waiting in the forward and send buffer and the hop count between the head node and control station. The overall performance of the routing approach is found to be better when compared to the single path routing.

Keywords: wireless sensor network, hybrid routing, hierarchical clustering, multi path routing, hop count.

INTRODUCTION

Recent advancements in wireless sensor networks have made it possible to create new types of applications that can be used in building smart cities. WSN comprises of sensing nodes for monitoring the environment and they forward either the raw captured data or processed data to the base station. The sensing nodes are connected to the base station through intermediate nodes in a hierarchical pattern so that the data from them reaches the base station in a multi-hop fashion. The data packets are routed from the mobile sensing nodes to the control station through intermediate cluster heads. A single-hop route connecting sensor to the base station consumes more energy as the data packets have to travel a long distance. The multi-hop routing strategy helps to balance the energy spending in the network uniformly. This approach increases the life span of certain nodes in the network which sends data packets frequently to the control station. The other routing approaches for reducing or evenly maintaining the energy available in the network include technique to limit number of control packet and reduction of frequent packet drops aimed at increasing the reliability of the wireless network. In all most all routing strategy the main objective is to find the optimal between the sensor node and the control station with less energy expenditure and prolonged life- time of the WSN. Majority of the proposed routing approach in the literatures utilizes a complex multi-objective optimization method.

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The objective of the wireless network design with respect to a specific application should be energy conservation [1]. To increase the life cycle of the network it becomes essential to follow an optimal routing method [2]. The optimized routing method not only focuses on detecting a shortest path but also balancing the consumption of energy in the overall network [3, 4]. In conventional approach optimized route estimation problem is solved using a dynamic programming approach such as Dijkstra [5] and Floyd-Warshall [6]. These conventional approaches produce optimal solution at an expensive computational cost. In the recent past a variety solution for route optimization in WSN are proposed using meta-heuristic algorithms based on evolutionary or nature inspired approach. Designing a single algorithm to estimate optimal route solving multiple issues is not possible. In general, the routing techniques are classified as either single or multi path routing. Single path routing are less complex to implement and scalable in nature. They are not efficient to satisfy the requirements of network due to resource constraints. The route between the mobile node and the base station will be established in a specific period of time. The complexity of the route estimation remains same irrespective of the node density in the WSN. When the unique characteristics of the WSN are considered the single path, routing is not efficient due to the following reasons,

i. In single path routing approach, the source node selects the intermediate nodes in the route from the same part of the network repeatedly without much effort. This makes the certain part of the network to spend more energy and thereby reducing the overall life time of the network.

ii. In WSN especially when single path routing approach is adopted the failures are common because of limited availability of power, limited storage, unreliable wireless communication and interferences in the channel. When such failures occur in the network then the single-path routing method cannot deliver the data successfully to the control station due to unavailability of fault tolerant mechanism to react in sudden failures.

iii. The single path routing mechanism followed in majority of the routing techniquesexplored in the literature suffers when a malicious node is present on the chosen path and breaks the flow of data packets from the sensor the control station.

For all the above-mentioned issues and challenges in WSN with respect to the single-path routing mechanism, multi-path routing is an alternative routing mechanism which initially discovers multiple routes and then selects an optimal route for data transfer. During route failures due to any of the above-mentioned reasons, the multi-path routing approach without discovering the route from the scratch selects an alternate route from the already discovered list. This reduces great deal of time spent in discovering the route again and again in case of frequent route failures. Multipath routing addresses the reliability and balances the load within the network. The section 2 of this paper explores a variety of literature related to the chosen objective and methodology and presented the systematic review of those literatures. Majority of the literature focuses on creating multiple path considering location and resource available within the network. Certain multi path routing techniques transfer the data packets hop-by-hop on the basis of available local knowledge. The other category of multi path routing algorithms utilizes a coding scheme to fragment the data packets at the sensor nodes and then forwards each fragment via estimated multiple paths. This paper focuses on analyzing the effectiveness of multipath routing technique in a WSN with mobile nodes. The multipath routing technique can be utilized even in the Cyber Physical Systems and Smart Grids.

LITERATURE REVIEW

In general, the clustering approach helps to reduce the traffic in the network and latency in the WSN. It tries to balance the energy consumption which improves the reliability of the network. Further multipath routing improves the stability and the life time of the WSN through available multiple communication paths from the cluster heads to the base station. In overall the energy-efficiency and the reliability of the network is increased because of the combined approach. In [8] a cluster head selection is proposed which utilized the energy level remaining in the node and the nodes are enabled with a GPS system. Multiple paths are estimated with cluster heads as intermediate nodes and the sending node selects a new path from the available list when there is link failure, an event based multi-path routing is proposed in [9] and when an event is triggered then neighboring nodes becomes active. The node with maximum energy near by the event declares itself as cluster head. The other nearby nodes treats this node as cluster head by joining the cluster. The head node in the cluster forms a multipath between the base station via a forwarding node and a backup node to take care of packet forwarding. In [11] a QoS based multipath routing was proposed which follows a hierarchical routing strategy. The nodes present within their transmission range reelect the head node depending on the hop count between the control station and the energy balance within in the node. A passive cluster based multi-path routing approach was suggested in [9, 10] where the neighboring nodes surrounding the event becomes the candidate for head node and waits until predefined duration of time. Within in the wait time if the respective node doesn’t receive any advertisement packets from other neighboring nodes then it sends a broadcast to its neighboring nodes advertising itself as the head node. The nodes which are in the transmission range R^2 becomes the cluster nodes and the nodes within R transmission range becomes the candidate for the head node and the head node selection procedure is iteratively repeated. In [12, 13] a branch-aware approach is adopted to estimate a multi-path route connecting the source node and the base station. During the event if any source node detects the event then it uses the existing cluster and but selects a different multi path route for transmission. In all the existing approaches proposed in [8, 15, 14] the overhead due to control packets is more and it causes more energy consumption within the network. The above all reviewed approaches ensures the reliability of the approach but some of the QoS parameters including delay or latency in the network, control overhead, and network lifetime were neglected. In [15] the WSN is partitioned among the different levels where one head node was elected at each level of the WSN. The head node gathers the packets from the sensors lying in the same level and transmits it to the head node present in the lower level using directional flooding technique [16]. In [7] a cross-layer information and clustered multi-path routing was proposed with different variety and distributed across the network area in a random fashion. To form the cluster, the control station in random select a set of candidates for head nodes. Among the candidates selected, the node with the high balance energy will actas head node the other nodes joins the group. For routing the data in a multipath, the cluster head selects the other cluster head within twice its transmission range. Choosing the next node in the multi path route without knowing the energy balance and the volume of data packets residing in the buffer reduces the reliability of WSN. The protocol does not maintain a proper path rather collects information from the neighboring nodes.

NETWORK MODEL

The different configuration parameters of the network and the model of the wireless network considered for experiments is shown in Fig. 1 where the mobile sensor nodes are grouped in to clusters using a dynamic clustering approach. The cluster heads will be static and once they are replaced by another cluster head after a period time then they shall move in and around the network region to collect data. The clustering decision is taken by a clustering technique which is briefed in next section. The head nodes gather data from the mobile nodes periodically and send them to the base station through the other intermediate cluster heads nodes. Multiple paths are estimated between the head node sending the packets and the control station. The routing decision is based on the total remaining energy level in the intermediate nodes on the path, total count of data packets waiting in the buffer of the cluster head nodes positioned in between, the hop count of the path.

In general, WSN consists of nodes which are characterized by low data transmission rate, and limited battery capacity. The availability of low energy within in the nodes limits the sending power of them and hence a multi hop routing scheme becomes essential to forward the sensed data to the control station. The multi-hop introduces several other issues and challenges while dealing with mobile sensor nodes especially. When the data travel from the sensor node through a multi hop path, it will reach the sink node with a much delay and this paper will aim to derive ways to distribute the energy expenditure in the network and reduce the overall energy spent thereby improving the lifespan of the WSN. The proposed model of the routing will help to balance the load in the network which indirectly helps to reduce the count of data waiting in the buffer of the nodes in between.

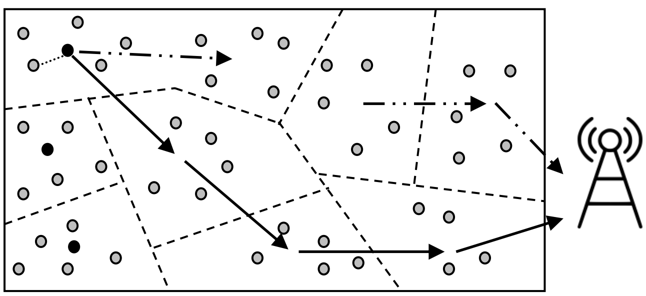

Fig. 1 *Schematic view of the multi path routing in the clustered network*

The energy consumed by the physical layer in a sensor node can be mathematically represented as:

$$E_{PHY} = \left(\frac{P_{send}}{\eta} + P_{amp} + PAC + PSC\right) * Tall \quad \text{Eq. 1}$$

where

Psend – sending power is determined by using the error rate ρ_{send} and signal-to-noise ratio k measured at the receiving end.

Signal-to-noise ratio $k = (\frac{P_{accept}}{2BN_0})$ [Paccept – receiving power, N0 – Power spectral density, and B – signal bandwidth]

PSC - the power consumption in the sending node end, PAC - the power consumption on the receiving end, and Tall – total time required for complete data transmission.

With respect to the constant frame error rate ρ_{send} the sending power of the sensor node can be expressed as given in Eq.2

$$P_{send} = f(\rho_{send}) \times \lambda \times PN \times \mu \quad \text{Eq. 2}$$

where as $\rho_{send} = e^{-P_{send}}$, $\lambda -$ attenuation co-efficient of wireless channel, PN noise power at the receiving node, μ – noise factor at the receiving node. The frame-error rate represents the quality of the channel directly and it is influenced by the routing mechanism indirectly. It is the ratio between the volume of data packets received with errors and the total data packets received. The loss in energy due to re-transmission of erroneous packets can be reduced by keeping a better frame to error rate.

PROPOSED CLUSTERING ALGORITHM

This section presents the weighted clustering mechanism used in this work. Consider that the links between the nodes are represented as an undirected graph G = {V, E}. The number of vertices remains constant always but the number of links connecting the wireless nodes as they are created and deleted when the nodes move in and around the network region. Clustering the nodes in a wireless network can be solved using a graph partitioning algorithm with some additional constraints. A fixed structure is not present in a network with mobile nodes and partitioning the network optimally is a NP-hard problem [17]. The set of nodes $S \subset V(G)$ can be used to prove that

$$\bigcup_{v \in S} N[v] = V(G) \quad \text{Eq. 3}$$

Where N[v] is the neighboring nodes v which is defined as

$$N[v] = \bigcup_{v' \in V, v' \neq v} \{v' | dist(v, v') < tx_{range}\} \quad \text{Eq. 4}$$

where $t_x$range is the maximumcommunication range of node v.

The nodes which are in the transmission range of a node are considered as the neighboring nodes. The set S used in the mathematical equations above represents the set which dominates the network such that each vertex in the set Gis in set S or a neighboring nodeis available in the list S. The set S consists of the cluster heads in the network. With this clustering approach it may be possible that a node close to one cluster head may belong to another cluster in the same network. The current dominant set cannot cover the entire network for a longer duration as the mobile nodes drift away from the cluster and it may not be possible for them to attach itself to any other cluster in the network. One of the important challenges in clustering the network is to choose an optimal set of head nodes so that the throughput will be increased and simultaneously the latency is reduced.

When more number of head nodes are elected then the data packets have to travel extra hops when they are routed through intermediate head nodes to the control station. This also increases the latency in the network and overall power consumption. A set of cluster heads are elected with reference to the communication range of the nodes which maximizes the resource utilization covering the whole geographical area. A less number ofhead nodes is sufficient provided the nodes are distributed uniformly within the network area. The number of mobile nodes within a cluster should also be restricted so that the cluster head shall manage them efficiently. Zone based clustering approaches selects cluster heads typically by selecting a node located centrally in the zone. If the cluster head node moves away and at times there may not be any node available in the central location. If the nodes are not uniformly distributed within the network region the cluster head managing a crowded cluster might be inefficient to handle the request from all the sensors present in the zone. The head node selection is based on the density of the neighboring nodes, communication power, mobility, and energy level. In the proposed clustering approach, the cluster heads will not be changed frequently. This approach helps to reduce the energy expenditure in the network. The clustering process is initiated invoked when the distance between the sensors and their respective cluster head goes above a threshold level. In a cluster-based approach the head node shall cater only to a limited set of sensor nodes (threshold denoted as $'\delta'$). This limitation is due to the fact to ensure easy access of transmission channel instead of sensor nodes waiting longer time to transmit their sensed information to their respective head node. An optimal value of the degree of each cluster head helps to achieve better throughput. If the node lies within a certain transmission range then the battery power can be effectively used as only less power is consumed when a sensorneeds to forward its data to cluster head. The cluster head spends more power as it sends or forwards data packets to the base station. The load of a head node depends rely on the sensor nodes and volume of data sent by the sensor nodes lying within the cluster. The cluster head also relays the packets from various other clusters to the base station. Perfect load balancing within the network cannot be achieved as the sensor nodes move frequently within the network region. The Load-Balancing-Factor (LBF) helps to estimate the level of data load distribution within the network. The cluster head node's load will be expressed using the density in the cluster and the variance of the node density will represent the distribution of the load. The load factor can be taken as the reciprocal of the variance of the density.

$$LBF = \frac{n_c}{\sum_i (x_i - \mu)^2} \qquad \text{Eq. 5}$$

where n_c is the count of cluster heads, x_i is the density of cluster i, and $\mu = (N - n_c)/n_c$, (N being the density of nodes in the system) is the average count of neighbors of a cluster head. When the load is evenly distributed within the network then the value of LBF will be higher and it will be infinite if the load is perfectly balanced [18].

EXPERIMENTS AND RESULTS

As per the proposed algorithm each node consists of a send buffer of size 64 packets which is essentially used during route discovery. The maximum wait time for the packets in the send buffer during estimation of the multipath route in the network will be 30 seconds. The packets whose waiting time is more than 30 seconds in the buffer then it is dropped. During simulation the length of the interface buffer is maintained as 50 packets. The simulation environment is constructed with varied sizes of the sensors in the network and the data transmission will happen between cluster nodes and the cluster heads at different period of time. Each communication in the node was traced in a log file and al the required parameters were extracted. The sensor nodes are configured with a Constant Bit Rate (CBR) and each sensor node is capable of sending 4 data packets every second with a packet size of 512 bytes. Mobility of the nodes was defined in a scenario file separately following the random waypoint model. The initial position of the nodes is selected based on a random distribution and during simulation the pause time of the nodes are varied. The other network related parameters configured in the simulation of the routing approach within the network areType of Communication Channel – Wireless Channel
Model of Wireless Radiopropagation – Two RayGround
Medium Access Controlstandard –IEEE 802.11
Type of send or forward buffer – Priority queue
Type of link layer - LL
Radio Antenna – Omni-Antenna
Queue Size (Max. length) in queue - 50
Size of Network (# of nodes) – Min. - 500. & Max. - 1000

PERFORMANCE METRICS:

The performance of the combined clustering and multipath approach is analyzed using the following performance metrics. Throughput - It is the average rate of data packets sent successfully over the wireless channel. The data packets travel through multiple paths and reach the base station without latency. This metric is calculated in bits per second (bit/s or bps), and at times in data packets per second or data packets transmitted over a period of time. Routing delay can be estimated by finding the difference between the route selection and the delivery of last data packet from the source to the base station. Also it can be defined as time taken to transfer data packets from sending cluster head to control stationvia the intermediate head nodes. The routing delay or latency in the WSN is due to many factors, including the achieved throughput in the network, send and forward queues in the intermediate nodes along the route, traffic and congestion in the wireless links, and the hop count between the sender and receiver. As routing delay is influenced by multiple factors it is considered as one of the most important metric in assessing the quality of the network. Data packet delivery ratio can be estimated by dividing volume of data packets received at the control station with the volume of data packets transferred from the source. Energy consumed in the network can be determined by estimating the quantity of energy consumed during transmission of data packets from source to sink. On comparing multi path with the single path routing approach the multi path routing strategy is complex due to the path discovery is more challenging. The overhead due to the packets sent to request route and the packets sent in response those request and also the hello packets used to share their position information to their neighboring nodes must be analyzed. The Fig. 2 presents the plot of average number of route request packets received by the different cluster head nodes during path estimation. For normalization the number of route request flowing in the network is divided by the total number of cluster heads. The routing paths are discovered using an iterative approach and hence the number of route request packets flowing in the network will be lesser. The main goal of the multi path approach is to reduce the energy consumption within the network and results of the energy efficiency analysis is presented in Fig. 3 which shows the amount of consumed energy within the network. The consumed energy in the network is high when the density of the node starts increasing and saturates at a point. As per the energy model adopted in our experiments the consumed energy is same in spite of different size of the network. At times when some of the sensors are inactive the corresponding cluster will be made inactive and the energy consumption within the network will be reduced. When there are a greater number of nodes present in the network then multiple nodes will be available in the transmission range and hence the energy consumed will be lesser. The overall lifespan of the WSN is improved.

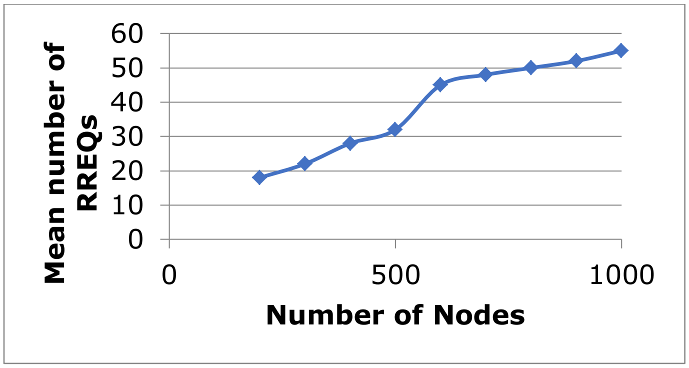

Fig. 2 *Analysis of RREQ packet overhead*

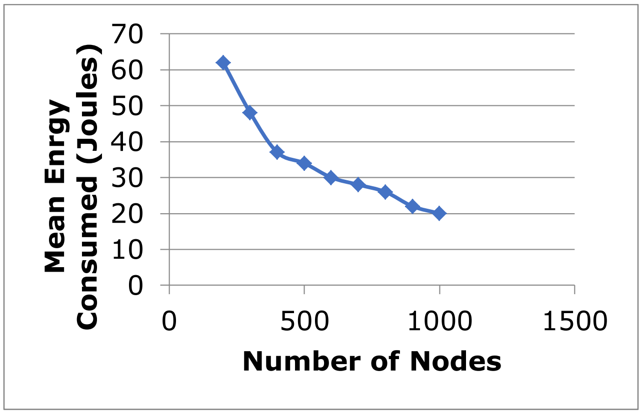

Fig. 3 *Comparison of Energy Consumed in Joules*

When the density of the number is increased the interference in the channel will cause more packet failures and re-routing of the lost packets will cause additional routing overhead. The success ratio in sending data packets when varied number of nodes are available in the network is presented in Fig. 4.

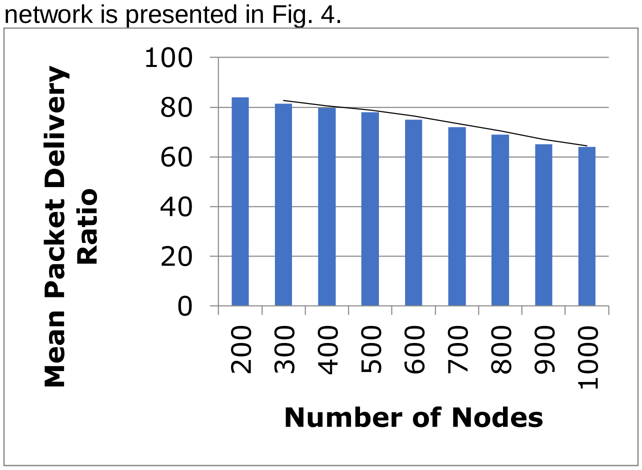

Fig 4. *Packet Delivery Ratio*

CONCLUSION

This paper demonstrates a multipath routing which is energy efficient and dynamic in nature. The mechanism to construct multipath is easy to implement and less complex. The overhead due to alternate path maintenance is comparatively low when compared to the re-route discovery initiated after every link failures. The multipath estimation approach balances the load and energy spent within the network. The proposed method of routing has great potential in providing high bandwidth for application with high data rate. The problem of the inter path and intra path interference was not handled in the approach to reduce the frequent packet loss. As future work energy efficient and interference aware multipath routing approach will be designed. Instead of parallel multipath routing approach the proposed approach followed an iterative route discovery mechanism which increased the overall performance of the network.

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