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Optimized Congestion Aware Energy Efficient Traffic Load Balancing Scheme for Routing in Wireless Sensor Networks

Sunitha G P[1], Vijay Kumar B P[2], and Dilip Kumar S M[3]

[1]*Dept. of Information Science and Engineering, Jawaharlal Nehru National College of Engineering, Shivamogga, India*
[2]*Dept. of Information Science and Engineering, M S Ramaiah Institute of Technology, Bangalore, India*
[3]*Dept. of Computer Science and Engineering, University Visvesvaraya College of Engineering, Bangalore, India*

***Abstract*—Load imbalance among hot spot nodes causes network congestion and earliest energy depletion of nodes in wireless sensor networks. This increases the probability of disconnecting or partitioning the network and premature death of entire network. The inefficiency in the WSN is more attributed to load imbalance or unbiased traffic. In this paper, an optimized congestion aware (OCAEE-LB) energy efficient traffic load balancing scheme for routing in WSN is proposed. The scheme utilizes the neglected information during route discovery process and considers a composite routing metric to determine congested status of a node and to enforce the traffic load balancing. The proposed scheme is simulated using *ns-2* and the results demonstrate that the proposed mechanism performs better than the existing AODV-LB algorithm of various performance metrics such as, packet delivery ratio, throughput, routing overhead, end-to-end delay, load distribution and energy consumption.**

Index terms: Wireless sensor networks, Congestion aware, Load balancing, Multi-path routing, Energy efficiency

I. Introduction

Wireless sensor networks are envisaged for industrial, civil, and military purposes to monitor, detect, and track events according to application requirements. The highly dynamic nature of WSN applications requires self-organized, autonomous behavior to overcome their fundamental resource challenges. One of the possible reason for congestion in WSN is because of unfair distribution of data traffic in the network. The effect of unfair traffic utilization will result in unstable paths that can overload the nodes and quickly deplete the energy of sensor nodes resulting in partitioning the network with the creation of hotspots. The hotspot problem [1] in a network can exhaust a node's resources such as bandwidth, processing power, battery energy and memory storage. Furthermore, if one of the heavily loaded node is congested, it can lead to packet loss and buffer overflow, resulting in longer end-to-end delay, degradation in throughput, and loss of transport connections. The inefficiency in the wireless networks is mostly attributed to load imbalance. Therefore, effectively managing the distribution of the networking workload will be of great concern in WSN. Load balancing [12] is considered as one of the mechanism to mitigate congestion in multi-hop WSN. By extending the workload across a sensor network, load balancing reduces hotspots in sensor nodes and increases the direct communication between nodes in the sensor network. The main motivation behind load balancing is to reduce the execution time of the load and to make sure that all resources in the network are utilized optimally and efficiently.

To manage the problem of hotspots using proper distribution of traffic load and mitigation of congestion, in this paper a novel optimized congestion aware energy efficient traffic load balancing scheme for WSN is proposed. OCAEE-LB is an on-demand routing protocol that utilizes a composite metric by integrating two parameters, namely consumed-energy and packets in the node buffer. These two parameters represents the node status. OCAEE-LB appropriately distribute the traffic of congested nodes during routing.

The rest of the paper is organized as follows. Section II gives a brief review on the related work. Section III presents our network model and the proposed routing protocol. In Section IV, energy efficiency and congestion minimization features of the proposed routing protocol is analyzed. The simulation environment and experimental results are discussed in Section V. Conclusions are given in Section VI.

II. Related work

Load balancing is an essential requirement of any multi-hop wireless network. The most obvious benefit of load balancing is manifested in increasing the life of a battery operated node which can eventually increase the longevity of the entire network. In this Section, we review some of the routing protocols that use multiple paths with loadbalancing proposed for wireless sensor networks.

Numerous research studies have been conducted in order to propose algorithms, protocols and solutions for load balancing with multi-path routing to extend the lifetime of the network. To reduce the burden on the nodes close to the sink, Rahid et. al. [3] combined load balancing with transmission power control in order to find the good traffic proportions between the nodes to ensure a best balancing of their energy consumption. They focused on transmission power control but ignores the throughput and delay aspect of the network.

Meisam Nesary et. al. [9] suggested a proactive multi-path routing algorithm $MRPL$. In the proposed method a destination oriented directed acyclic graph $(DODAG)$ is constructed then, a k-connective rate adjustment mechanism is imposed, for load distribution a heuristic mechanism is introduced to achieve balance in energy consumption and minimizing total transmission cost. Heuristic mechanism of selecting the path lacks the ability of reducing congestion.

A multi-path routing algorithm with minimum energy consumption is proposed by Samra Boulfekhar et. al. [2]. Their method consists of three phases, generation of a routing table consisting of neighbor node and path cost information in the first phase. Choosing of optimal path in the second phase and minimum cost route maintenance in the third phase Maintaining a set of good paths and choosing best one increases storage and computational costs.

Another important sink monitored delay based load balancing mechanism is proposed in U. B. Mahadevaswamy et. al. [7] In this protocol sink distributes the data rate over paths for optimizing the network resources. It monitors the inter arrival delay of data packets on each path and detects the path failures. It gives feedback to the source with new paths and cost of the paths. Distribution of equal flow on paths limits their ability to reduce congestion.

Extensive research has been carried out on traffic distribution on sensor nodes deployed in dense and sparse topology to guide network-wide energy allocation and design of routing algorithms. Qinghua Wang et. al. [14] proposed a probabilistic approach to send the packets to different relays based on the current traffic loads experienced by the relays. The proposed method adaptively adjust the residual energy of the sensor nodes and make the protocol energy efficient. Traffic distribution approach limited to distance of the node from the sink.

Majority of works in the literature focus on network survivability by minimizing energy consumption during routing. Ming Tao et. al. [13] introduces mechanism to balance the traffic load over the selected paths using a weighted traffic scheduling algorithm considering their transmitting capacity. This method claims to reduce the computing and storage resources of the sensors. Sofiane Moad et. al. [8] proposed a energy efficient load balancing metric for routing in multi-radio WSNs. The metric is related to both the link quality and the energy cost. The mechanism does not control the degree of distribution(DoD).

Other energy efficient load balancing mechanism include the efforts of German A Montaya et. al. [10] In this paper authors put forward a mathematical formulation and heuristic to support connectivity, flow conservation constraints and splitting constraints in order to balance the energy consumption. The single routing metric used for making routing decisions may overload some nodes's in the network.

Efforts of Parth et. al. [11] mitigated hot-spots in WSN using power control. They estimated the traffic of relay load in advance and assigns suitable transmission power to the relay nodes. The congested nodes are skipped over. Path stretching is the limitation of the proposed mechanism.

Kim et. al. in [5] developed a Multi-path Energy-aware Routing Protocol (MERP) which only uses the localized information to find node-disjoint paths and takes into account the network reliability. It introduces load balancing scheme to adjust traffic flows. In this meyhod storage and computational overhead at each sensor node is more.

Most of the existing routing protocols not exploit the service-oriented architecture in WSN Shancang Li et. al. contributed [6] service oriented architecture for WSN. A secure adaptive load balancing multi-path routing protocol $(SM-AODV)$ based on AODV is designed to enhance the routing scheme with security. To balance the load a metric path vacant ratio is defined to route the packets on multiple paths based on providing service and security to different applications. SM-AODV can be applied to a network where topology is already known and multi-path between source and destination should have at least three hops.

Research in this area concludes that unbiased distribution of load on nodes especially on nodes nearer to sink causes adverse and undesirable effects.Non-adaptive-congestion, path length stretching, even distribution of packets on multiple paths, lack of degree of distribution and load balancing at hot spot nodes may cause congestion at the peripheral nodes are the drawbacks identified in the existing routing protocols from the literature. The proposed mechanism overcomes the afore said drawbacks.

III. Network Model

We assume a wireless sensor network model where all the sensor nodes are randomly deployed and once they are deployed they become stationary. Following are the assumptions considered in the model:

1) The network is represented as a collection of large number of identical sensor nodes and nodes are randomly deployed.
2) WSN is represented as a directed graph $G = (V, E)$ of E edges and V vertices.
3) $\forall\, v \in V$ is characterized by a circular transmission range R and a carrier sensing range r.
4) $\forall\, v \in V$, $N_e(v)$ denotes its neighborhood, A duplex link exists between v and every $u \in N_e(v)$ and is represented by the directed edges (u, v) and $(v, u) \in E$.
5) Important WSN applications like continuous monitoring are considered.
6) The set of paths between source vertex s and destination vertex d is denoted as P.

A. Proposed OCAEE-LB Protocol

The proposed OCAEE-LB is designed based on the basic functionalities of AODV [4]. The algorithm retains the alternate paths discovered during route discovery. The algorithm establishes link disjoint paths from source to destination. The path selection is based on the *path_cost* metric. In OCAEE-LB, route request RREQ packet is initiated by the source node where as route path is established by the destination node. The transmission path is established in the reverse direction. To discover link disjoint paths, each node forwards only one route request RREQ packet in route discovery process. The RREQ packet format is modified to include a field first hop neighbor of the source through which route request is passed. Destination generates RREP packet and estimates path cost for each of its neighbors and forwards the packet to the neighbor with minimum cost and enters all the alternate path details in the routing table. Relay nodes after receiving the RREP packet, add their traffic to path cost and computes the resulting path cost after selecting its neighbor and chooses the minimum cost neighbor. The relay node forwards the RREP on primary path and caches other paths information in the routing table. This minimizes the routing overhead in the mean time maintaining the details of alternate paths. The RREP packet format is modified to include two fields *node_load* and *path_cost*. The *node_load* metric indicates current traffic of a node and is used to calculate the path traffic through the nodes from source to destination. The *path_cost* metric represents cost of the path from destination to downstream neighbor of the current node. A *pathlist* table as shown in TABLE I is created which stores all available routes for different destinations. Routes are sorted in the order of destination. Multiple routes for the same destination are sorted in the order of increasing *path_cost*. The *pathlist* table is used to find all the alternate paths and their respective costs. This information is stored in the table with destination node indexing and in a sorted order. This type of storage reduces path selection complexity and ensures that always a path with less traffic is selected first. The probability of path selection is calculated as in Eq. (3).

The routing table contents are *source_id*, *destination_id*, *node_id*, *traffic*, *next_hop_neighbor* and *path_cost*. The sendReply function and pathfind functions of the proposed scheme are described in Algorithm 1. and Algorithm 2 respectively.

TABLE I
PATHLIST TABLE

Destination_node	First_hop_node_from_source	path_cost
d	4	15
d	3	17
d	1	10

Functionality of this scheme is illustrated in Fig. 1. In this example, triplets inside a node represents node_id, node_traffic and *path_cost*. The sender s initiates route discovery through RREQ packets. In reply destination d generates RREP packet. d places its traffic 5 units in the packet header and checks nearest neighbor for packet forwarding. Nodes $6, 7, 8, 9$ are d's neighbors and their *path_cost* from d are $8, 10, 9, 13$ respectively. Therefore, d forwards RREP packet to node 6 and caches the other paths in the routing table. The path disjointness maintained in the proposed scheme is also described in this example. Node 1 receives RREP packets from both nodes 6 and 5. The *path_costs* are $d \rightarrow 6 \rightarrow 1 \rightarrow s = 10$ and $d \rightarrow 9 \rightarrow 5 \rightarrow 1 \rightarrow s = 21$ respectively. Node 1 inserts the path $d \rightarrow 6 \rightarrow 1 \rightarrow s$ as the primary path and deletes the other to maintain link disjoint paths. Paths with the solid lines indicates actual paths and paths with dotted lines are cached paths.

In the proposed algorithm *node_load* is calculated as:

$$L_i = B_i / E_i \tag{1}$$

where,
B_i = number of packets buffered in the node i E_i = residual energy in the node i

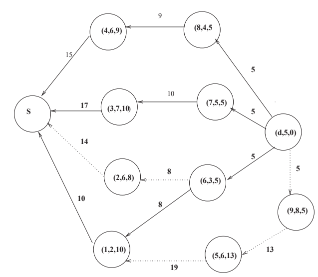

Fig. 1. OCAEE-LB Functionality

Algorithm 1 Algorithm for sendReply function

if *path does not exists for destination* **then**
  $insert\_path(d, p_j)$
end if
if $RREP(seq\_no) == rtable(seq\_no)$ **then**
  $cost_1 = RREP(path\_cost) + T_i + T_{n_{e(i)}}$
  $cost_2 = rtable(path\_cost) + T_i + T_{n_{e(i)}}$
  if $cost_1 < cost_2$ **then**
    $disjoint = check\_disjoint(RREP(p_j), rtable(p_j))$
    if $disjoint == true$ **then**
      $insert\_path(RREP(p_j))$
    else
      $delete\_path(rtable(p_j))$
      $insert\_path(RREP(p_j))$
    end if
  end if
end if
if $RREP(s) == index$ **then**
  $pathfind()$
end if

B. Comparison of AODV-LB and OCAEE-LB

In this Section, the single path load balancing routing algorithm AODV-LB is compared with proposed scheme OCAEE-LB. Comparison parameters and the differences are presented in TABLE II.

TABLE II
COMPARISON OF PROPOSED ALGORITHM OCAEE-LB WITH AODV-LB

	AODV-LB	**OCAEE-LB**
Nature	Reactive	Reactive
No. of paths	Single path	Multi-path
Load balancing	Yes	Yes
Load distribution technique	Centrality of the node	Path with minimum load is selected
Path selection probability	1 (Always 1 for single path)	Ψ_{p_j} (multiple paths)
Routing	Non-adaptive to congestion	Adaptive to congestion
Route creation	Frequent	Initiated only when all routes from source to destination fails
Route discovery	Source initiated	Reverse path
Data transmission	Next_hop information in the packet	Next_hop information, node_load, path_cost

Algorithm 2 Algorithm to find path with minimum cost

```
cnt ← pathlist(d)
//cnt stores total number of paths for a destination
if cnt == 1 then
    //if single path exists
    forward_packet(d, p_j, 1)
end if
if cnt == 2 then
    //if there are 2 paths
    forward_packet(d, p_1, Ψ_{p_1})
    forward_packet(d, p_2, Ψ_{p_2})
end if
if cnt >= 3 then
    //if there are more than three paths select first three paths from Pathlist table
    j = 3
    while j ≤ 3 do
        Ψ_{p_j} = select(Φ)
        forward_packet(d, Ψ_{p_j})
        j = j − 1
    end while
end if
```

IV. MATHEMATICAL FORMULATION FOR ENERGY EFFICIENCY AND CONGESTION MINIMIZATION

Energy efficiency is the main objective in a routing protocol as WSN have extreme constraints of energy. To ensure the energy efficiency of the proposed routing algorithm theoretical analysis is represented in this Section. The traffic load distribution among the sensor nodes is considered and is associated with average energy consumption of the node to process the traffic.

To estimate load on a node, its distance from the sink, residual energy and packets in it's buffer are considered. To derive traffic load distribution the following assumptions are made. Expected traffic at a node is calculated based on its distance from the sink. Sensor nodes are evenly deployed in a disk sensing area of radius R and load of a node includes both originating and forwarding packets.

The notations used in the mathematical expressions are represented in TABLE III. The traffic at a node i at a distance r from the sink is calculated in Eq. **??** [14]. From Eq. (2), it is inferred that the traffic at individual node is directly proportional to D and inversely proportional to h when $D \cong 0$ indicates bottle neck nodes and heavily loaded nodes. $D = 1$ represents lightly loaded or distant nodes. The energy consumption of the proposed routing protocol can be analyzed using traffic distribution as follows:

For each source s and destination d, there exists a set of paths $P = (p_1, p_2, p_3, ...p_n)$. To send packets from s to d along a path p_j a probability is assigned to choose that path p_j. In multi_path routing, probability of choosing a path is required because two consecutive packets might be routed through different paths. Probability of choosing a path is proportional to load of the path to sum of load of all n paths. Let the path probability be $\Phi = (\Psi_1, \Psi_2, \Psi_3, ...\Psi_n)$ for the set of paths P respectively and is calculated in Eq. 3. The energy consumption by a node in WSN is expressed in Eq. 4. The average energy consumption of node v is given Eq. 5 [1]. Total energy consumption of all the nodes along a path p_j is calculated in Eq. 6. If the same data transmitted on single path is distributed among n paths then average energy consumption is given in Eq. 7

$$T_i = \frac{1 - D^2 * R}{2 * D * h} * A \tag{2}$$

$$\Psi_j = \frac{L(p_j)}{\sum_{j=1}^{n} L(p_j)} \tag{3}$$

$$\mu = \mu_r + \mu_t + \mu_{idle} \tag{4}$$

$$\mu = \mu_r + \mu_t + \mu_{idle} \tag{5}$$

$$\mu_{avg} = \sum_{i=1}^{V} T_i * \Psi(p_j) * \mu \tag{6}$$

$$\mu_{avg} = \frac{\sum_{i=1}^{V} T_i * \Psi(p_j) * \mu}{|P|} \tag{7}$$

where | P | = Total number of paths in P

$$\eta = \frac{\mu_c}{\mu_i} \tag{8}$$

$$max(\eta) = min(max(\mu_{avg})) \tag{9}$$

From Eq. (6) and Eq. (7), we can conclude that proposed scheme consumes less energy than single path. Energy consumption is optimized in the proposed scheme as routing metric considered is energy aware. η in Eq. 8 represents life time of a sensor node. $\cong 1$ represents heavily loaded nodes or maximally utilized nodes in the network. To minimize energy consumption and to increase longevity of the network, traffic of these nodes is to be distributed and their utilization is to be minimized. The proposed scheme chooses lightly loaded nodes in discovering the path and uses more than one path to transmit the data. Hence, OCAEE-LB is energy aware and energy efficient.

A. *Congestion minimization*

In the literature, multi-path routing is considered as an optimization problem with an objective function that minimizes the congestion. If the length of the each path is restricted then, a feasible path flow on a route minimizes the congestion. Notations used in the discussion are represented in TABLE **??**. For any path $p_j \varepsilon\ P$ random flow on the path is calculated as in Eq. 11. Feasible traffic of the path p_j is calculated as in Eq. 12. The cost function to determine congestion on link is expressed in Eq. 13

$$\rho_e = E_{Th} + Q_{Th} \tag{10}$$

$$p_{j_{\varrho_e}} = \sum_{e\epsilon p, e\epsilon E, i=1}^{N} \varrho_e \tag{11}$$

$$p_{j_{\rho_e}} = \sum_{e\epsilon p, e\epsilon E, i=1}^{N} \rho_e \tag{12}$$

$$\sigma = \frac{\varrho_e}{\rho_e} \tag{13}$$

Here, $\sigma \cong 1$ represents highly utilized link in the network. If many such links are in the network causes network congestion. In the proposed mechanism *path_cost* is used check the utilization of the link. While establishing the path in the reverse direction links with minimum path_cost are selected. Therefore congested links are avoided for data transmission. This results in congestion minimization. Some of the notations used are ρ_e represents feasible traffic on a link. E_{Th} is the average threshold energy of end nodes of a link. Q_{Th} be average threshold queue length of end nodes of a link. ϱ_e is random traffic and σ is link congestion.

V. Simulation Results and Analysis

In this Section, the performances of AODV-LB and OCAEE-LB are evaluated through extensive simulations. Simulation environment used to evaluate the proposed protocol is presented in TABLE **??**. OCAEE-LB and AODV-LB performance is evaluated based on the performance parameters packet delivery ratio, throughput, end-to-end delay and distribution of load at nodes.

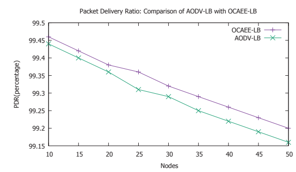

Fig. 2. A comparison of packet delivery ratio of OCAEE-LB and AODV-LB with growing network size

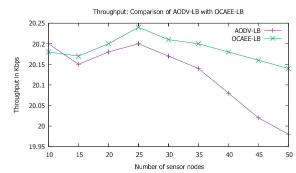

Fig. 3. A comparison of throughput of AODV-LB and OCAEE-LB with growing network size

In Fig. 2, OCAEE-LB demonstrates the highest PDR than AODV-LB. Higher PDR of OCAEE-LB is attributed to avoiding of congested nodes and preventing packet drops and timeouts. From Fig. 3, we can observe that OCAEE-LB outperforms AODV-LB for throughput. This may be attributed to efficient routing paths availability in OCAEE-LB. Single path routing algorithms have less routing overhead than multi-path algorithms Fig. 4. shows that AODV-LB has slightly lower routing overheads, when the number of nodes in the network is less when the network grows further, OCAEE-LB has less overhead because of the availability of multi-paths and minimization of control packets overhead in route discovery. A Normalized routing overhead is considered in the interval $[0.0, 1.0]$. From Fig. 5, we can infer that at smaller network size and low traffic AODV-LB has lower delay when compared to OCAEE-LB. As the network size increases and traffic increases multi-path routing algorithm performs better. Because, packets experience more delay in single path routing since they are transmitting through shortest path nodes where as in multi-path routing consecutive packets may transmitted by different set of nodes. From the simulation results presented in the literature it is confirmed that multi-path routing always results in end-to-end delay improvement in WSN. From Fig. 6, the visual interpretation tells us that OCAEE-LB maintains proper load distribution than AODV-LB. The sharp peeks at some nodes in the Fig. 6. OCAEE-LB shows less load distribution than AODV-LB. The difference in the load proves that OCAEE-LB is performing traffic load balancing in a better way.

VI. Conclusion and Future Enhancement

In this paper, a optimized congestion aware energy efficient traffic load balancing scheme for routing in WSN is proposed. The proposed scheme preserves all the benefits of shortest path routing and achieves a significance in load balancing. The

TABLE III
NOTATIONS USED FOR ENERGY MODEL

Notation	Meaning
D	$\frac{r}{R}$
h	Average routing hop length
A	Average sensing rate
T_i	Expected traffic at any node i
Ψ_{p_j}	probability of selecting a path p_j
Φ	Set representing probability selecting set of paths in P
$L(p_j)$	Traffic load on path p_j
μ	Energy consumed by a node u along path p_j
μ_i	Initial energy of the node i
μ_c	Depleted energy of the node i
μ_t	Energy consumed by the node i during packet transmission
μ_r	Energy consumed by the node i during packet reception
μ_{idle}	Energy consumed by the node i in idle time
η	Life time of a node i

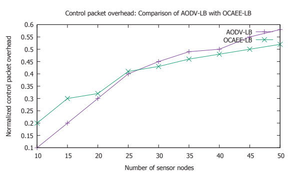

Fig. 4. A comparison of normalized routing overhead of AODV-LB and OCAEE-LB with growing network size

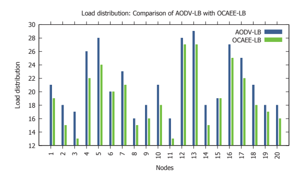

Fig. 6. A comparison of load distribution among sensor nodes by OCAEE-LB and AODV-LB when network size is 20

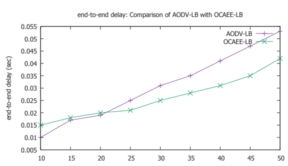

Fig. 5. A comparison of routing end-to-end delay of AODV-LB and OCAEE-LB with growing network size

route paths establishment in reverse path and node with the minimum traffic is selected from reverse direction guarantees that traffic on near sink nodes are minimized. This scheme ensures that alternate paths created are not much deviated from the shortest paths. Source always selects multiple paths in the order of their increasing path_cost. This ensures proportionate relaying of data in the network and alleviating congestion in the network. Simulation results show that our scheme is efficient in minimizing hotspot problems and network congestion.

In the proposed scheme source is selecting multiple-paths for data transmission hence, QoS can be provided for various WSN applications. All the alternate paths are maintained in routing table and best three paths are selected for data transmission. Minimal of paths can be stored in the routing table to reduce storage and computational overheads.

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