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Dynamic Traffic and Energy Aware Routing Algorithm for Multi-Sink Wireless Sensor Networks

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Abstract:

A distributed traffic-balancing and energy aware routing algorithm is proposed for multi-sink wireless sensor networks that effectively distributes traffic from sources to sinks. Each node has a gradient field that is used to decide on a neighbor node to reach a sink. The node's gradient index contains hop count from a source to a respective sink, traffic information from neighboring nodes and the residual energy of the node. The proposed algorithm considers the residual energy and traffic being faced by surrounding neighbors before forwarding packets to any sink and uses gradient search for routing and providing a balance between optimal paths, possible congestion on routes toward those sinks and also possible death of intermediary nodes due to being used as a relay node even though they are running with low residual energy.

The key objective of this work is to achieve traffic-balancing by detecting congested areas along the route and distributing packets along paths that have idle and under loaded nodes. And also to increase the life time of a node that was running with low energy by preventing the node to act as a relay node but only used for sensing event. Extensive simulations conducted to evaluate the performance of the proposed scheme indicate that it effectively reduces the overall packet delay, energy consumption and improves the packet delivery ratio under heavy traffic and also increases the network life time.

IndexTerms:

Dynamic Traffic Aware, Energy Aware, Routing Protocol, Wireless Sensor Networks, Gradient Based Routing Protocol, lifetime, multi-sink, residual energy, traffic balancing, traffic spreading.

I. INTRODUCTION:

In mission-critical applications, such as battlefield reconnaissance, fire detection in forests, and gas monitoring in coal mines, wireless sensor networks (WSNs) are deployed in a wide range of areas, with a large number of sensor nodes detecting and reporting some information of urgencies to the end-users. As there may be no communication infrastructure, users are usually equipped with communicating devices to communicate with sensor nodes. When a critical event (e.g., gas leak or fire) occurs in the monitoring area and is detected by a sensor node, an alarm needs to be broadcast to the other nodes as soon as possible,. Then, sensor nodes can warn users nearby to flee or take some response to the event.In large-scale applications of wireless sensor networks (WSNs) such as environment monitoring or agricultural scenarios, several hundreds of sensor nodes are deployed over a large covered-area [24, 27]. The large numbers of nodes becomes active and transmit data traffic, leading to congested areas. Congestion increases packet delay and energy consumption due to retransmissions thus limiting the network's lifetime and efficiency [14].

Additionally, the traditional centralized approach in which data traffic from sensor nodes gather toward a unique sink [1, 2] is not efficient in terms of energy consumption or packet delays, and may even be impossible due to limited network capacity. Therefore, the use of multiple sinks is proposed as a more feasible scheme for such networks [15, 21, 22, 28]. This approach balances traffic load and increases network utilization efficiency. Data traffic from a source to a final destination needs an optimal routing protocol that utilizes the limited power, memory, and processing resources of nodes effectively. Among the current solutions for routing in WSNs [8, 13, 18], gradient-based routing has been standardized by Internet Engineering Task Force (IETF) working group [10, 26] as an appropriate protocol for low power and lossy networks (LLNs) for which existing routing protocols such as OSPF, AODV, and OLSR cannot meet the requirements. In event-driven sensor networks, e.g., those used in detection and monitoring applications, nodes normally operate under low or idle load states. When events occur, these nodes suddenly become active, resulting in a part of the network becoming overloaded and causing congestion in some areas [12, 25]. Many studies have been conducted with the aim of using gradient search to solve routing problems in WSNs [3, 11, 17, 19].On the basis of observations of the gradient search scheme, we propose a traffic-balancing routing algorithm for multi-sink WSNs to route packets around congested areas made by other paths toward the sinks. Our proposal exploits two-hop information and enhances congestion detection ability owing to its monitoring of the buffer size at a node. The underlying concept of our algorithm is the construction of gradient field using three factors: number of hops, number of packets at one-hop neighbors and the minimum number of packets at two-hop neighbors. The number of hops (distance cost) is built conventionally as in other gradient-based routing protocols that find the shortest paths for packets. The second and third factors address the queue length at neighboring nodes that may become the next forwarder. Once the queue length, changing with network traffic exceeds a threshold, it means that there is congestion at a node in the path toward a specific sink. The node asks its surrounding nodes to increase (or decrease) their gradient field so that packets can flow along other paths. Thus, this method leads to a trade-off between shortest paths and packet delays caused by congestion at overloaded nodes.The rest of this paper is organized as follows. In Sect. 2, we summarize the studies related to gradient-based routing. In Sect. 3, we build a system model with the total gradient field and outline how the local cost and global cost models are combined in our proposed scheme. In Sect. 4, the implementation of our proposed algorithm is described in detail. The simulation model and performance evaluations are given in Sect. 5. Finally, Sect. 6 concludes this paper and infers some limitations and future work.

II. RELATED WORKS:

In gradient search, a node's gradient field is constructed in response to neighbor nodes in the direction of a specific sink. Data traffic then forwarded to the neighbor node with the least gradient value in order to reach the sink. The gradient field can be designed in terms of hop count from sink to node, energy consumption, physical distance, or cumulative delay, depending on the objectives of routing such as energy consumption, packet delay, or packet delivery ratio [28].Direct diffusion technique is the first routing protocol that uses gradient routing in WSNs. It was successful to save energy by storing and processing data. The direct diffusion technique uses data rate and duration information field from a node to its neighbors towards the sink for construction of its gradient. A lot of researchers have devoted their area of research to solve energy-aware routing for wireless sensor networks. One of the researchers proposes GLOBAL [28] to improve energy utilization in large-scale multi-sink wireless sensor networks. It constructs its gradient field by using a weighted factor of cumulative path load and traffic load of overloaded nodes over the path. And the source nodes select the least loaded path by selecting the neighbor node which has the least gradient value and so the next relay node does the same thing and finally the sink node gets the event information. But, this approach uses global information and we cannot guarantee the correctness of this information over the long path because of the network dynamics in high traffic scenarios.

An another gradient based routing protocol SGF was able to save a significant amount of energy savings by building the gradient fields for nodes without using routing tables. These gradient values are updated on demand by data transmission with little overhead. Another researcher Suhonen et al. used energy, traffic load, delay, and link reliability to build a nodes gradient value and gave rise to a new cost-aware multi-hop routing protocol. This algorithm was also focused on efficient usage of energy and it is very significant in saving lot of energy consumption. Finally, the authors in [6] formed clusters of nodes which have the same value of hop count away from the sink. Each node in the cluster takes its turn to become the cluster head too balance energy consumption and lifetime of sensor nodes in a cluster. Apart from energy-aware, traffic control is also a significant issue in wireless sensor networks. The main objective of the traffic-aware routing protocols is to achieve network balancing and congestion avoidance in WSNs. The earlier traffic aware routing algorithm [3] achieved in finding optimal routes by balancing congested areas and the shortest path. But, this method is hardly applies to WSNs, because it need an extensive communication and computation, and it was designed for traffic aware routing to the Internet.

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Another Gradient based routing protocol, GRATA [5] builds a nodes gradient value by using a cumulative cost model that uses packet delay at one-hop neighbor and the number of hops to make routing decisions. But, this protocol uses only the one-hop traffic information and lacks traffic information at two-hops and some hops away, which might lead the packet to a new congested area. TARP [16] focuses on improving the data transmission efficiency and energy consumption for WSNs by using a lightweight genetic algorithm that helps to distribute the data traffic away from congested areas. And it is only used for single-sink WSNs, and focuses on packet loss due to queue overflow, power efficiency.A distributed traffic-balancing routing algorithm [29] is designed for multi-sink wireless sensor networks, and it effectively distributes traffic from sources to sinks. In this every node maintains a gradient field for all its neighbor nodes through which it decides which node to be selected as a next forwarder. The gradient field of the neighbor contains the hop count from the source to a respective sink, number of packets present in the neighboring nodes and minimum number of packets present in its two-hop neighbor's queue. But in this method if there are two neighbors with the same gradient value it forwards the data randomly in a stochastic scheme.In this paper, we follow gradient-search model to solve the traffic-aware and energy-aware routing problems. Compared to the previous studies, it focuses on multi-sink WSNs applications with heavy traffic scenarios where the large amount of traffic may cause black spot on the paths to the sink. It uses the hop count from a node to sink and present traffic information of the nodes which are two hops ahead of the current node to construct gradient field at each node. If the two nodes have the same gradient unlike the other gradient based protocols it uses the residual energy field and forwards the data packet to the node with the highest residual energy. thus it improves network performance such as end-to-end delay, packet delivery ratio, and energy consumption through comparison to some gradient-based routing schemes.

III. SYSTEM MODEL:

In this section, we discuss about our new proposed gradient based routing protocol solves traffic-aware and energy-aware routing in multi-sink WSNs. firstly, a distance cost model is discussed which is similar to the shortest cost model. Next, we insert additionally two metrics into the nodes gradient field that reflects the traffic information and the residual energy of the neighboring nodes.

The traffic information can be know by monitoring the number of packets in queue and the residual energy of a neighbor node can be know by some means discussed below.

A.Distance Cost Model:

Each node defines a scalar field, called the node's height by advertising packets. A packet is forwarded on the link with the steepest gradient to the next nodes. Each node x maintains a distance cost with respect to each sink i (in a multi-sink scenario).

$$\nabla_i^d(x) = hop_{count}. \qquad (1)$$

The height of each node also implies the minimum hop count from the node to reach the corresponding sink. A node then forwards packets to the neighbor with the lowest gradient value. In a special case, if there are two or more next neighbors with the same lowest gradient values, the node with the highest residual energy is chosen as next forwarder.

B.Queue Length Field:

This study considers areas of collision by means of buffer monitoring. A node s sends a packet to another node x (neighbor of s) only when x has enough buffer size to store the packet from node s. The proposed concept avoids packets to be dropped at the receiver due to buffer overflow. The value of the buffer size field of a node is the average queue length obtained by sampling over a small time interval Δt_qto ensure the stability of the routing metric.An advertising packet (ADV) containing information about node's height and buffer size is generated after an update time to inform neighbor nodes about congestion. A node can detect congested areas in two-hop away by this routing technique using two-hop information. Moreover, it can also know about the congestion before the neighbor's buffer begins to overflow. This technique solves problems related to local information [5].The function Q(x) denotes the normalized buffer size at node x as defined by Eq. 2:

$$Q(x) = \frac{Number\ of\ Packets\ int\ he\ Buffer}{Buffer\ Size} \qquad (2)$$

The value of Q(x) is in the range [0, 1], which denotes nodes' traffic information. The buffer-based method indicates possible congestion at the destination node [25].

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When the number of packets in the buffer exceeds a threshold, the node also sends out ADV packets to inform its neighbors about this event. To ensure stability, the node should not react quickly to events. Therefore, the algorithm defines a time period, called the lower threshold (tLT), the buffer size has to exceed the predefined threshold for a specific time before generating an ADV packet.

C.Traffic-balancing Routing Cost Model:

The gradient field combines two types of information: geographic distance and traffic loading. Our main objective is to avoid possible congestion by not forwarding to the congested areas which leads to reduced end-to-end delays in the network. Our algorithm a node chooses one of its neighbor nodes to become the next forwarder by considering the buffer size at one-hop neighbour (x) and the next one-hop neighbor of x with minimum buffer size (x*). His means that a node takes into account both the one-hop neighbour and the two-hop neighbour that can possibly become the next forwarder after x.

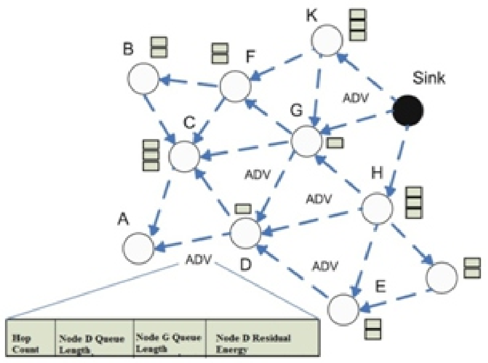

Fig. 1. Traffic Information Being Distributed.

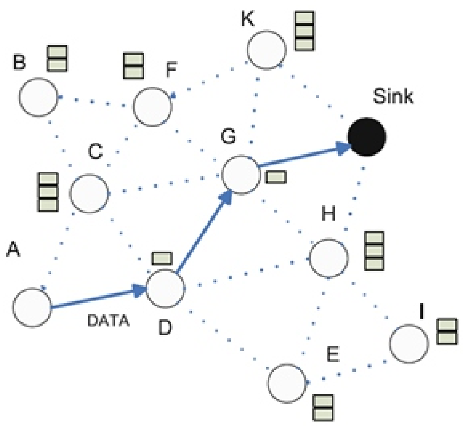

Fig. 2. Data being forwarded to sink

Once a node (s) has packet to send toward a sink, it calculates and compares the gradient field of its neighbours x ($x \in nbr(s)$) in response to each sink i following Equation

$$\nabla_i(s,x) = (1-\alpha)\,\nabla_i^d(x) + \alpha\nabla_i^c(x) + \beta\nabla_i^c(x^*) \qquad (3)$$

Where $\alpha$and β are the weighted factors of traffic costs, $\nabla_i^d(x)$is the gradient field with the number of hops. $\nabla_i^c(x)$, $\nabla_i^c(x^*)$ denote the traffic cost at one-hop and two-hop neighbors, respectively. As showed in Fig. 1, each node broadcasts ADV packet so that its neighbors can update the routing table. Whenever a node has data, it will use the routing table to choose the next forwarder.

IV. THE PROPOSED SCHEME IMPLEMENTATION:

In our proposed scheme we divide the protocol in to two phases, initialization phase also called as setup phase and data forwarding phase. And this setup phase is run periodically also called as time to update. In the first setup phase sensor nodes come to know about their neighbor information such as hop count from a neighbor node to a specific sink, traffic information i.e., the number of packets that are already existing in the neighbor nodes queue also called as queue length and that neighbor's one hop neighbor which has the minimum queue length and the neighbor's residual energy. In each round we use this neighbor information to detect the congested nodes, the nodes that are running with low residual energy, and the nodes which are dead. Depending upon this information a sensor node decides its next forwarder and thus providing a balance between a shortest path and an optimal path. In this section we discuss about how setup phase has to be run, and discuss about the packet format used in setup phase. And how routing is done from a particular source to sink when a event occurs.

A.Distributing Traffic Information:

The sensor nodes interchange the traffic information by sending the advertisement (ADV) packets. The various fields present in ADV packet are as follows: neighbor ID, sink ID, hop count, one-hop neighbor queue length, two-hop neighbor queue length and residual energy of the neighbor. Every node maintains a gradient table and it is built using these ADV packets that were periodically broadcasted by all the nodes to their neighbors including sinks participate in this process.

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The sink node runs this setup phase every time. The setup phase is run various number of times. And this update time must be set in trade-off between the effects of updating information and the use of network utilization.The node processes the incoming ADV packet as follows, it checks whether the sink and source ID are in table G. Initially there will be neither connection status nor the network information relating to sinks and neighbors. So, after receiving the first ADV packet the node add these IDs in to Gradient Table G and update the field type of neighbor value to parent following that sink ID.

B.Route Discovery and Data Forwarding:

Algorithm 2 describes how the event information is forwarded to the sink. And after executing Algorithm 1 to process ADV packets, every node knows its neighbor information, such as hop count to specific sink and neighbors queue length. The proposed algorithm forwards the packets from a node to the predetermined sink through forwarding packets through intermediate nodes. The node, calculates the gradient value for the entries in the gradient table G except for the children nodes and the node that forwarded the event information using the Equation 3. Here comes the elimination of the nodes which has high traffic by eliminating the nodes whose queue length is greater than or equal to Q_{thres}. And a sibling node becomes a next forwarder only when the diffrence in queue length between parent and sibling is greater than or equal to ΔQ_{thres}. And if the nodes $RE(x)$ is less than or equal to E_{thres} then, that node is not considered for route calculation. And finally, a neighbor node which has the least gradient value will be selected as a next forwarder of the data message.

Algorithm 1 Updating gradient table G with each of its sinks:

1. Hop-Count = $\nabla_i^d(x)$
2. One-Hop-Traffic-Info = $\nabla_i^c(x)$
3. Two-Hop-Traffic-Info = $\nabla_i^c(x*)$
4. Residual Energy = $RE(x)$
5. If (G = ∅) **then**
6. Add new neighbor as Parent to table G including Hop-Count, One-Hop , Two-Hop Traffic Info and Residual energy.
7. Else
8. **If** Hop-Count < HC[i] **then**
9. Set Node Height is the Hop Count and the neighbor to be parent.
10. **Else if** Hop-Count = HC[i] **then**
11. Keep the Node Height and the neighbor to be Sibling.
12. **Else**
13. Keep the current Node Height and neighbor to be a Child.
14. Update table G with new $\nabla_i^c(x)$ and $\nabla_i^c(x*)$ values and $RE(x)$.
15. Update new Minimum Hop-Count and Traffic-Info and Residual Energy for sending ADV packets.

Algorithm 2Gradient index Calculation and Data Forwarding:

1. If Traffic-Info from neighbor $x \geq Q_{thres}$ or $\Delta Q < \Delta Q_{thres}$ or $RE(x) \leq E_{thres}$ **then**
2. Remove x from route calculation.
3. Else
4. Calculate Gradient indexes $\nabla_i(s,x)$ from neighbors;
5. Chose the node with $\nabla_i(s,x)$ minimum value;
6. If there are many nodes with the same gradient index **then**
7. Choose the node with higher$RE(x)$.
7. If the $RE(x)$ values are also identical then
8. Choose by random trail.

Time to Update Information:

The routing information is updated when after some period of time in next round, when the neighbour node queue size is greater than or equal to Q_thresalso when the node x's RE(x)value less than or equal to E_thres. In all these cases our protocol update the routing information in order to avoid congestion and possible death of a node.

V. SIMULATION AND EVALUATION:

This protocol performance is evaluated by using NS2 2.35 simulator in comparison with SPF (Shortest Path Routing), in terms of end-to-end delay, packet delivery ratio, and energy consumption.

A.Simulation setup:

We deploy the sensor nodes in random topology 850 m x 350 m area with 96 homogeneous sensor nodes and four sinks placed in grid. The Table 1 below depicts the simulation setup and values of various constants.

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TABLE I. SIMULATION SETUP

Parameter	Value
Deployment Type	Random topology
Number of nodes	96
Number of sinks	4
Radio range	15 m
Packet length	30 B
Transmission rate	250 Kbps
Buffer size	20 packets
$\Delta Q_{thres}, \Delta Q_{thres'}, E_{thres}$	0.4, 0.1 , 5 J
α, β	0.7, 0.2
Time to update	0.5 – 5 s
Q_{thres}	0.7
Simulation time	200 s

Numerical Results:

The proposed protocol performance is evaluated by two different traffics: constant bit rate and exponential distribution. The simulation results are compared with the first routing protocol SPF.

1)Average end-to-end packet delay:

We evaluate the Average end-to-end packet delay for the both the proposed and SPF. The Fig 3 depicts a clear picture that our new routing protocol out performs the SPF routing algorithm. In x-axis represents Packet Inter-arrival Time and y-axis end-to-end delay.

2)Energy Consumption:

We evaluate the energy consumption for the both the proposed and SPF. The Fig 4 depicts a clear picture that our new routing protocol out performs the SPF routing algorithm. In x-axis represents Simulation time and y-axis energy consumption.

3)Effect of weighted factors on network performance:

The weighted factors α and β values are determined by many experimental trails. These weighted factors are also responsible for a high packet delivery ratio apart from the queue length thresholds. The Fig 5 depicts the how the packet delivery ratio varies for different α values under the traffic sending rate λ=0.4 and λ=0.6 and x-axis represents packet delivery ratio and the different Alpha values.

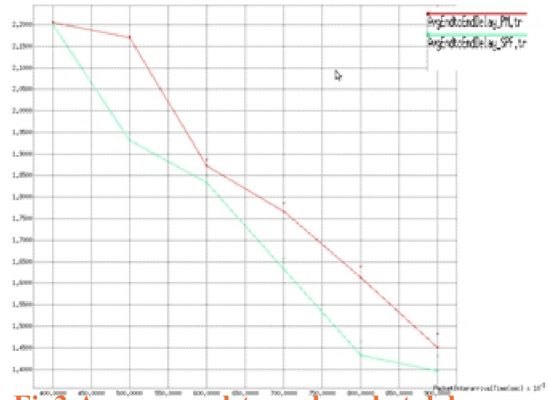

Fig3.Average end-to-end packet delay

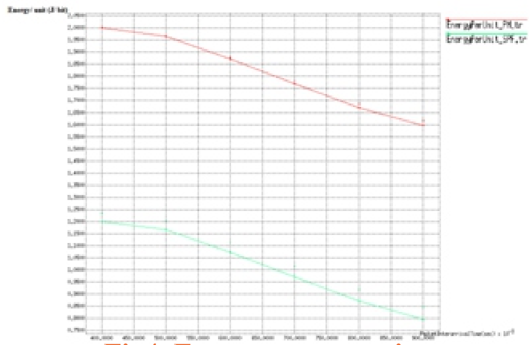

Fig4. Energy consumption

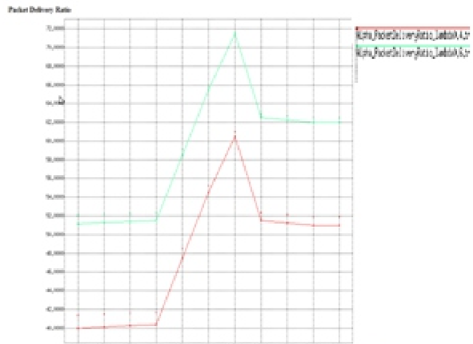

Fig5. Packet delivery ratio with various values of α

Fig6. Packet delivery ratio with various values of β/α

The Fig 5 depicts the how the packet delivery ratio varies for different α values under the traffic sending rate λ=0.4 and λ=0.6 and x-axis represents packet delivery ratio and the different β/α values.

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VI. CONCLUSION:

As many other gradient based routing protocols our protocol suffers from the problem of storing the extra information. But it was able to solve the problem that the other existing protocols could not solve and fail to address till now.

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