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Interference Aware Multi-path Routing in Wireless Sensor Networks

Vairam.T, Kalaiarasan.C

Abstract*—*Routing in wireless sensor networks has been considered an important field of research over the past decade. Wireless sensor network essentially consists of data Sensor Nodes and Video Sensor Nodes, which senses both sound and motion of events. Single path routing protocol has been used for route discovery. Though this protocol reduces computation complexity and resource utilization, there are some disadvantages like reduced network throughput, network performance, increased traffic load and delay in data delivery. To overcome these drawbacks a new protocol called Interference Aware Multi-path Routing(IAMR) is proposed to improve the reliability of data transmission, fault-tolerance, Quality of Service. Here, the traffic intersection spread out among the multiple paths. This technique is applied between the sources and sink to reduce routing overhead and energy consumption. The proposed protocol is simulated using NS2.

Index Terms*— *Wireless sensor network (WSN) , Single path routing, Mulitipath routing , path cost

I. INTRODUCTION

Routing in WSN has been considered as an important field of research over the past decade. Wireless Sensor Networks consists of light-weight, low power, small size sensor nodes. The areas of sensor network are distributed in various fields such as civil, healthcare, environmental and commercial issues. Some of the well-known applications are inventory control, surveillance, energy management etc. Nodes can be deployed in two ways namely random fashion or pre-engineered way. Since the price of the nodes is low, nearly thousand to million nodes can be deployed. The main responsibility of the sensor nodes in each application is to sense the target area and transmit their collected information to the sink node for further operations. Resource limitations of the sensor node and unreliability of low-power wireless links [1], in combination with various performance demands of different applications impose many challenges in designing efficient communication protocols for wireless sensor networks [2].

Meanwhile, designing suitable routing protocols to fulfill different performance demands of various applications is considered as an important issue in wireless sensor networking. Sensor nodes transmits the measured data after processing to a base station named sink node through a wireless channel. The sink node collects data from all other nodes and analyzes them to derive the results from the activity performed. Sinks are efficient data processor that acts as gateways to other networks. Key issues to be handled are energy constraints that are stringent in nature and the sensors that are vulnerable to dynamic environment. This leads to the need for an energy-efficient and a robust protocol designed with the unique features of sensor networks considered. Some of the protocols designed recently for WSNs use a single path to transmit data. The unique features to be considered are power limitation, addressing convention etc. Optimal path is selected based on some metrics like gradient of information, distance of destination. Network reliability is the feature prioritized in the design of routing protocols for multiple paths.

The need for routing process is that, most of the existing routing protocols in wireless sensor networks are designed based on the single path routing strategy without considering the effects of various traffic load intensities. The performance requirements needed for an application to transmit traffic towards the sink node are fulfilled by each and every source node in single path routing strategy. Although route discovery through single-path routing can be performed with minimum computational complexity and resource utilization, the limited capacity of a single path highly reduces the achievable network throughput. Furthermore, the low flexibility of this approach against node or link failures may significantly reduce the network performance in critical situations. In order to cope up with the limitations of single-path routing techniques, another type of routing strategy, which is called the multipath routing approach has become a promising technique in wireless sensor and ad hoc networks. Dense deployment of the sensor nodes enables a multipath routing approach to construct several paths from individual sensor nodes towards the destination [3]. Discovered paths can be utilized concurrently to provide adequate network resources in intensive traffic conditions.

The new protocol named Interference Aware Routing Protocol (IAMR) has been proposed to reduce the energy consumption and routing overhead during the transmission of data between the sources and sinks that is common in Multi-path concepts. The rest of this paper is organized as follows. The related work with a brief description about the multipath routing is presented in Section II. Section III includes Problem Statement, which gives the need for the whole process and how it is done. Section IV specifies Routing protocol, which explains the design, the modules with its input and the framework of the IAMR. Performance evaluation, its analysis and the results in graph format are described in Section V. Section VI concludes and provides directions for future works.

II. RELATED WORK

Energy-Efficient and Collision-Aware Multipath Routing Protocol (EECA) is an on-demand multipath routing protocol and uses the location information of all the sensor nodes to establish two collision-free paths between a pair of source-sink nodes [4]. EECA aims to reduce the negative effects of wireless interference through constructing two

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Vairam T, Information Technology, PSG College of Technology, Coimbatore, India.
Dr.C.Kalaiarasan, Principal, Tamilnadu College of Engineering, Coimbatore, India.

paths in both sides of the direct line between the source-destination pair. Furthermore, the distance between these two paths is more than the interference range of the sensor nodes. In the first stage of the route discovery process, the source node checks its neighboring nodes to find two distinct groups of the nodes on both sides of the direct line between the source-destination pair. After finding the neighboring sets, the source node broadcasts a Route-request packet towards these nodes to establish two node-disjoint paths.

Although EECA tries to discover the two shortest paths such that their distance from each other is more than interference range of the sensor nodes, it needs the nodes to be GPS-assisted and relies on the information provided by the underlying localization update method. These requirements increase the cost of network deployment and intensify the communication overhead, specifically in large and dense wireless sensor networks. In addition, as low-power wireless links exhibit significant signal variations over time, calculating the interference range of the sensor nodes based on the distance may not result in an accurate interference estimation. Moreover, while transmitting data over minimum-hop paths can theoretically reduce end-to-end delay and resource utilization, however, using such paths in low-power wireless networks increases the probability of packet loss and intensifies the overhead of packet retransmission over each hop.

Ad hoc On Demand Multipath Distance Vector Routing extends AODV to provide the multipath. Here each Route Request and Route Reply defines an alternative path to the source or destination. Node-disjointness is achieved by suppressing duplicated Route Request at intermediate nodes. Routing entries contains the list of next hops in which the multiple paths are maintained. AOMDV introduces the maximum hop count value which is the advertised hop count for a node i in destination d. Alternative paths at node i for destination d is introduced with a lower hop count value than the advertised hop count. Since sensor nodes have limited energy capacity, the quality of some applications is influenced by the network lifetime and the energy consumption. The multipath routing protocol utilizes a multipath routing approach to provide energy-efficient communications through balancing of the network traffic over multiple paths. To this aim, the residual battery lives in the nodes are the most important metric considered in the route discovery phase. Nevertheless, as this protocol neglects the effects of wireless interference and assumes error-free links, it cannot achieve significant performance improvement in throughput and data delivery ratio.

III. PROBLEM STATEMENT

In WSN, designing routing protocols is a big challenge because of the stringent QoS requirement of throughput and delay. Designing an energy efficient low-overhead communication protocol to satisfy the performance requirement of different application in wireless sensor node is a limited process. Most of the existing routing protocols are based on single path routing strategy which are failed to support high data rate. End-to-End throughput is limited here and due to constant flow data it consumes more amount of energy. In contrast, multipath routing protocols enable the source nodes to discover several paths towards the destination. Since in multipath routing technique data packets are propagated over several paths, it provides higher throughput, more balanced energy consumption and improved latency [5,6].The broadcast nature of the wireless medium to estimate inter-path interference and establish interference minimized paths in a localized manner. Since the existing protocols mainly utilize the node residual battery life to determine the optimal traffic rate of the paths, they do not account for the effects of wireless interference on the capacity of individual paths. Through including the experienced interference level in the load balancing algorithm, we consider the effect of interference on the tolerable traffic rate of the paths.

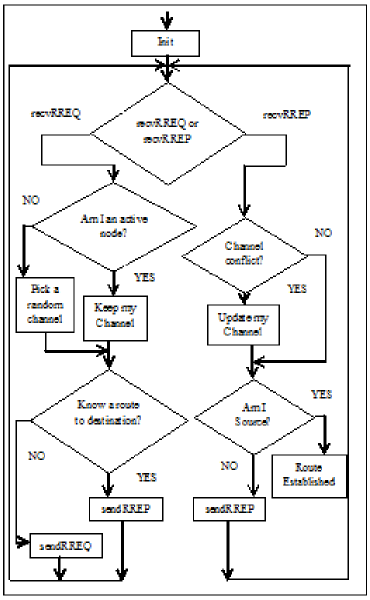
The neighborhood information is acquired by each node in the initialization phase. This information will be used in the route discovery and establishment phase to find the next best hop node towards the sink. The route discovery and establishment phase is triggered whenever an event is detected. The outcome of this phase is multiple-interference-minimized paths between the source and the sinks. Finally, the route maintenance phase handles path failures during data transmission. The load balancing algorithm is taken here by distributing the traffic over the multiple established paths. When a route is established the node starts transmitting data.

IV. IAMR ALGORITHM

In the effort to support QoS demands, there are many algorithms and protocols for different layers of the WSN protocol stack. In contrast, IAMR protocol enables the source nodes to discover several paths towards the destination. Since in multipath routing technique data packets are propagated over several paths, it provides higher throughput, more balanced energy consumption and improved latency.

A. Design

The design of the process is given in the Figure 1 which explains how the working process is taken over. The neighborhood information is acquired by each node in the initialization phase. This information will be used for the route maintenance and establishment phase to find the next-hop node towards the sink. The route discovery and establishment phase is triggered whenever an event is detected. The source node starts the route discovery by transmitting a route request packet towards the sink node.



Whenever a node receives Route Request (recvRREQ), it checks whether it is an active node or disabled because of low transmission cost or a new node.For a new node, it computes the transmission cost and compares it with the previous cost. If the new node cost is minimum than existing node then it will precede the route discovery with new path which is random channel. Otherwise, it will keep the previous node itself.

The next step is to check whether it know a route to destination. If yes it will send a Route Reply(sendRREP). If not it will send a Route Request(sendRREQ) and it will repeat the process. Whenever a node receives RouteReply (recvRREP), it checks for the channel conflict that the node is currently using by other path. If yes, it will update its channel and check whether it is a source, if it is a source then, the route is established between the source and destination. Else, it won't update its channel but if it is not a source then it will send a Route Reply(sendRREP) and repeat the process.

B.Initialization phase

In IAMR protocol, each node obtains its neighbourhood information, which also includes the ETX cost of its neighbour towards the sink. The ETX value of a link indicates the required number of transmissions for successful packet reception at the receiver. Thus, ETX is affected by the link loss ratio, the difference between forward and backward reception rates and the interference level of successive links (i.e., intra- path interference)[8].

The ETX is the Estimated Transmission cost of each node is used to calculate the path cost. Thus the ETX value is calculated, which gives the cost of the neighbor towards the sink[7]. This value indicates the required number of transmission for successful packet reception at the receiver. The ETX value of the link is defined as follows:

$$ETX = \frac{1}{p*q} \quad (4.1)$$

Where p and q are the probabilities of forward and backward packet reception over that link. Each of the node calculates its own accumulatedETX value to the sink node

$$accETX_i = accETX_i + \frac{1}{p_{ij}q_{ij}} \quad (4.2)$$

Node i receives a broadcast packet from node j, it saves the cost included in this packet as the accumulatedETX cost of node j to the sink. The path cost is calculated here for each path and the transmission of data packet is based on that cost. Initially a set of data packets are forwarded to other nodes and the number of successful packets received is recorded. So that, it will record p and q value in the neighbourhood table. Then, the sink node sets its cost as zero and broadcasts to the neighbours. Whenever a node receives packet with cost, it records the retrieved cost as the accETX cost of the neighbour node. For example, when node i receives a broadcast packet from node j, it saves the cost included in this packet as the accETX cost of node j to the sink.

Node i should broadcast the newly calculated accumulated ETX cost if it is lower than the current cost of node i towards the sink. In fact, whenever a node receives a broadcast packet from one of its neighbour's, it should calculate its accumulated ETX by equation 4.1 and broadcast that value if it is lower than its current ETX cost towards the sink. In addition to the initialization phase, the cost update process should also be performed during normal network operation whenever a node finds a new transmission cost to the sink.

B. Route Discovery and Establishment phase

Whenever the event is detected the route discovery phase is triggered. After the discovery, it uses the neighborhood table and update it. The source node starts data transmission by sending Route Request to the neighbor node. After receiving the route request packet, the node will calculate its transmission cost for the neighboring nodes which are not included in any path from the current source to the sink. This avoid the same node included in the different path. The node with minimum cost is included in the path selection. Transmission of packets is through the node which having lower cost.

$$cost_{i,j} = \left(accETX_j + \frac{1}{p_{i,j}q_{i,j}}\right).\ K \quad (4.3)$$

Where $K = \left(\frac{1}{resBatt_j}\right).\left(1 + ilevel_j\right)$

In Equ (4.1), accETX*j* is the ETX cost of node *j* to the sink, which is contained in the neighborhood table of node *i*. *pi,j*and *qi,j*are the forward and backward packet reception rates between node *i* and node *j*, respectively. resBatt*j* is the remaining battery level of node *j* expressed in percentage .Interference Level *j* is the maximum interference level that node *j* has experienced. Path memebership variable is used where it sets 1 for Route Request, it will show that the particular node is already used by another path. Automatic Repeat Request is used for ensuring packet delivery. Receiving a Route_request packet at the source node indicates that the algorithm cannot establish another node-disjoint path. When the sink receives a Route_request packet, it replies by transmitting a Route_reply packet along the reverse path. Here the Path membership variable for Route_reply is set as 2 to indicate an active path passing through this node.

In order to reduce the end-to-end latency, it starts packet transmission immediately after the first path is established. To initiate the second path, route discovery will send Route_request to another path. The source node distributes data packets over the first and second path using the load balancing algorithm. Received Packet Throughput(RPT) is used at the sink node to measure the performance improvement. It is calculated for each data packets from source node separately. Positive feedback is send to the path which is having higher RPT and sends negative feedback which has lower RPT. Suppose if there are n numbers of paths are established and data packets are being transmitted through n paths, then it compares RPT of n paths with the RPT of n-1 paths and decides if transmitting over the n paths results in higher performance.

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V. PERFORMANCE EVALUATION

We conducted simulations of the proposed IAMR protocol using NS2 network simulator and its performance is compared with EECA[4], which is the only protocol available in the literature . Table 1 show the parameters used in the simulation.

A. Simulation Parameters

TABLE I
ASSUMED PARAMETERS

Parameters	**Value**
Transmission range	250 m
Simulation Time	>800s
Topology Size	1000m x 1000m
Number of Sensors	25 & 50
Number of sinks	1
Traffic type	Constant bit rate
Packet size	512 bytes
Bandwidth	2Mb/s
Transmission range	250m
Interference range	550m
Initial energy in batteries	10 Joules
Energy Threshold	0.001mJ

B. Simulation Results

1) *End to End Delay:* The capability of IAMR to meet the delay requirements is shown in Figure 4 (a) and Figure 4(b). As the offered load grows, the average queue length at each node increases and data packets suffer longer queueing delays. Figure 4(a) and Figure 4(b) shows the comparison of end to end delay of IAMR and EECA protocols.

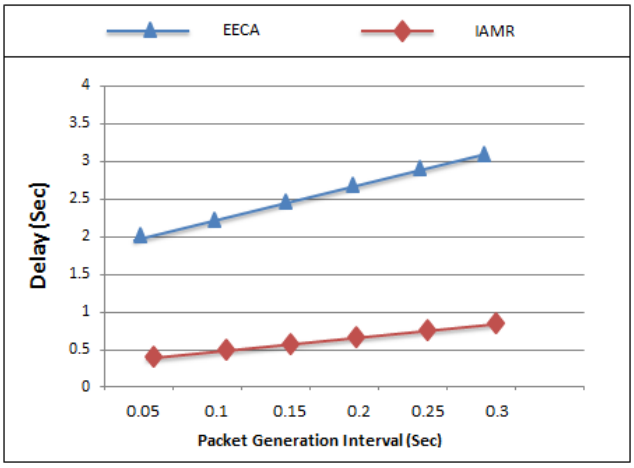

Figure 4(a): Delay for 25 nodes

The X co-ordinate is considered as Packet Generation Interval and the Y co-ordinate is considered as End to End delay. The scaling for X axis is 50ms per unit and Y axis is 5ms per unit. Initially, as interval increases the end to end delay of EECA increases, gradually to a higher level whereas IAMR has low end to end delay.

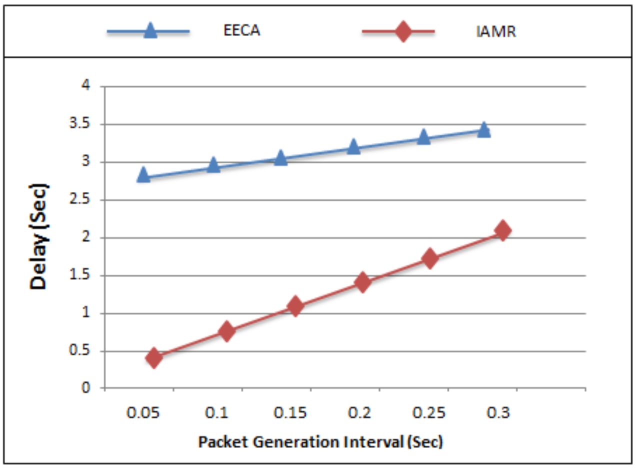

Figure 4(b): Delay for 50 nodes

2) *Packet Generation:* The number of packet generated with respect to the interval taken for generating the packets. Comparison of packet generation of IAMR and EECA protocols is shown in Figure 5(a) and Figure 5(b). The X co-ordinate is considered as Packet Generation Interval and the Y co-ordinate is considered as number of packets generated .

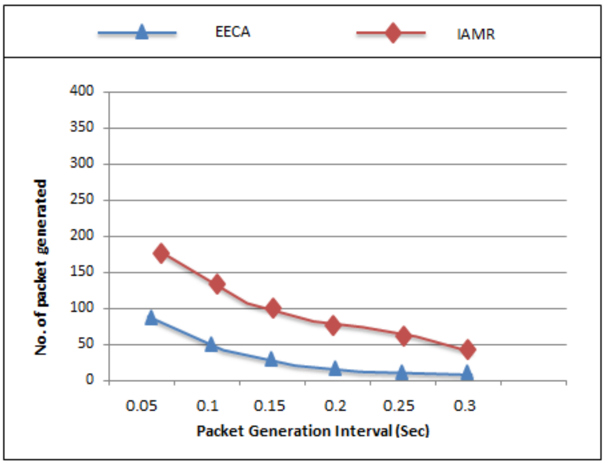

Figure 5(a): Packet Generation for 25 nodes

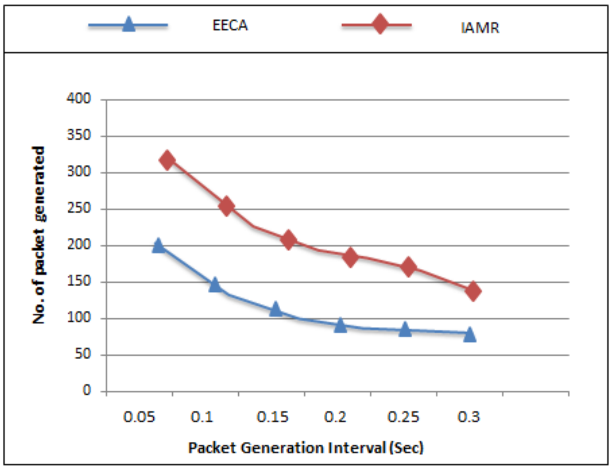

Figure 5(b): Packet Generation for 50 nodes

Initially, as interval increases, the packet generation of IAMR increases gradually to a higher level whereas EECA has low Packet Generation.

3) Throughput: Figure 6(a) and Figure 6(b) shows the comparison of throughput of IAMR and EECA protocols. The X co-ordinate denotes the packet generation interval where the Y co-ordinate denotes throughput at each interval. From the plotted graph the throughput for IAMR is higher than EECA.

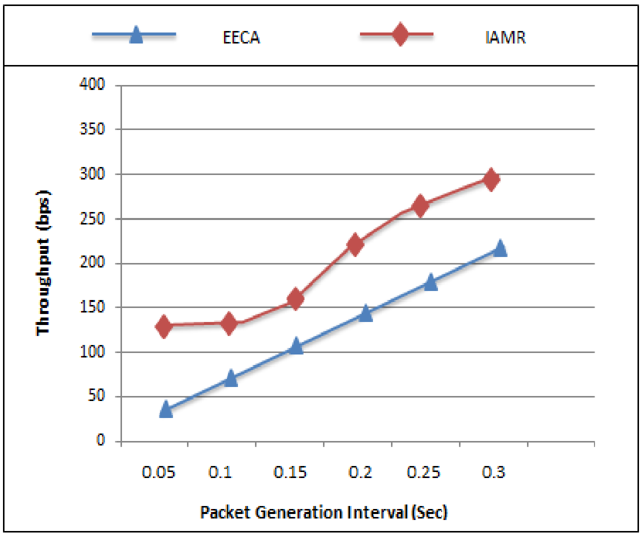

Figure 6(a): Throughput for 25 nodes

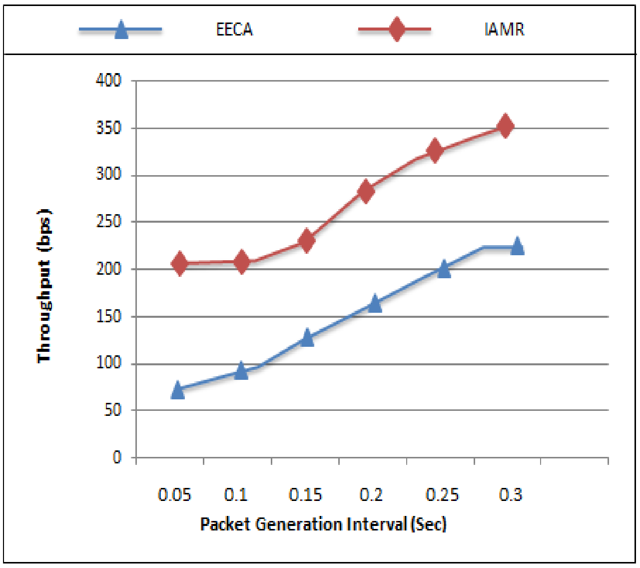

Figure 6(b): Throughput for 50 nodes

VI. CONCLUSION

A Multipath routing protocol is implemented to improve QoS demands for event-driven applications in Wireless Sensor Network. The nodes are generated and the ETX cost is calculated for each node by using the forward and backward probabilities of successfully received packets. Cost is calculated for each node based on which the packet transmission takes place. The graph plotted for the resultant values is compared with EECA based on the various metrics like End to End Delay, Throughput, and Packet generation. IAMR achieve low energy consumption since it employs the available energy resourcefully. The Interference Aware Multipath Routing protocol can also be applied for multimedia data and for the mobile nodes in future.

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