Routing Protocol using Cross-Layer Technique for Wireless Ad Hoc Sensor Networks

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ABSTRACT
Traditional ad hoc routing techniques do not fit the basic requirements of wireless ad hoc sensor network. So routing techniques used in sensor network are still under research. The proposed protocol is an on-demand, link-disjoint multipath routing protocol. During route establishment, the lower layer values like signal strength and coverage value are used to ensure the mobility of nodes and path quality respectively. The periodic update packets are unicast in each active path for route maintenance. The destination floods the control packet with lower layer values towards the source in case of both congestion and less number of multiple alternative paths. This protocol reduces route discovery latency which is an inevitable problem in ondemand routing protocol. The alternative paths decrease the route request overhead and increase the packet delivery ratio in the network. Simulation results show that the proposed protocol gives significant improvement in Quality of Service (QoS) parameter and gives better performance in large, high-mobility network.

Keywords
Link-disjoint, signal strength, coverage value, congestion, Quality of Service

1. INTRODUCTION
Wireless mesh networks are emerging to provide extended coverage, higher reliability and ease of setup. An ad hoc wireless network is a special type of wireless mesh networks, in which a collection of mobile hosts with wireless network interfaces forms a temporary network, without the aid of any established infrastructure or centralized administration [2]. In cross layer technique, the upper layer protocols directly parameters provided by a protocol more than one layer below [1].

Routing in ad hoc networks is difficult for two reasons: Highly dynamic network topology and limited scarce bandwidth and energy resources. To route packets in a dynamic ad hoc network environment adaptively, we may need more proactive ways to change some parameters of mobile nodes, which means the routing protocol may ask lower layers to adjust to the changing environment using cross layer technique. Ad hoc routing protocols can be classified into three categories like proactive (or Table driven), reactive (or On-demand), and hybrid, depending on how the source finds a route to the destination [3].

On-demand protocols are more scalable to dynamic and large networks. When a node needs a route to another node, it initiates a route discovery process to find a route. Two of the most widely used protocols are the Dynamic Source Routing (DSR) and the Ad hoc On-demand Distance Vector (AODV) [4] protocols. Destination sequenced distance vector (DSDV) is the most popular proactive protocol used in ad hoc networks.

Multipath protocols have a relatively greater ability to reduce the route discovery frequency than single path protocols [6]. This paper suggests a multipath protocol for ad hoc sensor networks which is adaptable to the mobility of sensor nodes in the network.

1.1 Motivation
The multipath extension of single path protocol AODV is Ad hoc On-demand Multipath Distance Vector routing (AOMDV) [5]. Multiple paths in AOMDV are guaranteed to be loop-free and disjoint.

AOMDV protocol removes both broken links and congested paths when they are noticed. In AOMDV, new flooding of RREQ is initiated after deleting the congested path entries from routing table. This procedure further increases load in the congested area and the paths that will be found are still congested [7]. So removing congested links would not be appreciable in the protocol. An attempt has been made to solve this congestion problem in the proposed protocol.

1.2Contribution
AOMDV was developed using both link-disjoint and node-disjoint approaches. The link-disjoint approach is used in the protocol since it gives more number of alternative paths when compared to node-disjoint approach [5]. The proposed protocol has also uses cross-layer technique for reliable route establishment which is not followed in AOMDV. The aim of the protocol is to obtain the following requirements:

- Higher throughput
- Lower end-to-end delay
- Increased packet delivery ratio
- Lower control overhead

2. RELATED WORK

Many on-demand multipath routing protocols have been established for sensor ad hoc networks [1] [3] [6]. In enhanced AODV mechanism, the network mobility aware agents on each node modify the HELLO packet by adding the GPS coordinates of the location of node. In mobility aware routing, the REPLY is unicast to the best suitable neighbor instead

blindly to the one from which request has been received first [9].

The Signal Stability based Adaptive (SSA) routing protocol [14] performs on-demand route discovery by selecting longer-lived routes based on signal strength. The signal strength criterion allows the protocol to differentiate between strong and weak channels.

The goal of On-Demand, Link-State Multi-Path protocol (OLMP) is not only to take care of the bandwidth, but also to resolve the problem of radio interference [11]. The multipath routing is constructed by using multiple uni-paths. It reactively collects link-state information and a partial network topology is built at the destination.

The Disjoint Pathset Selection Protocol (DPSP) [8] uses path reliability metric which guides the route selection process. Each node continuously monitors the reliability of each of its incident links.

In AOMDV [5], multiple link-disjoint paths are computed from the source to destination through a modified route discovery process. The destination responds to only those unique neighbors from which it receives a route request. Each node in the network maintains a list of alternate next hops that are sorted based on the hop count. If one of the links between two nodes breaks during routing, then the immediate upstream node switches to the next node in its list of next hops. If the upstream node does not have an alternate next hop, it sends a RERR to its upstream neighbor. The alternate paths could become stale and outdated by the time they are actually utilized.

CHAMP maintains multiple shortest loop-free paths at each node, and the upstream node of the node which has invalidated paths, recovers the data packets using an alternate path [12].

Sung-Ju Lee and Mario Gerla [15] propose a scheme to calculate alternate paths such that when a link failure occurs, the intermediate node searches for an alternate path to circumvent the broken link. In [10], a distributed loop-free routing protocol, called TORA is proposed. It is based on diffusing computations and multiple routes are computed mainly to alleviate congestion on links. TORA requires reliable and in-order delivery of control messages.

Saranya et al developed e-AODV protocol [13] that enhances the route discovery of AODV through local route enhancement.

3. PROPOSED WORK

The same as other on-demand routing protocols; the proposed protocol also contains two major phases for reliable packet transmissions are:

i. Route establishment

ii. Route maintenance

3.1 Route Establishment

In this enhanced multipath routing protocol, signal strength value is used with hop count value for reliable route selection, as in [16]. The usual hop count metric of a route is not sufficient to determine the quality and stability of the path. In contrast, since the signal strength metric is based on the signal strength of each individual link in the path, it provides information about both the quality and reliability of the path. This signal strength value of links is obtained using cross-layer technique. A single poor link will yield very low signal strength for the entire path, thus making it less favorable for routing.

Link-disjoint paths are more applicable in sparse environment since it provides many numbers of alternate paths. Link-disjoint paths are more numerous than node disjoint paths. The link-disjoint mechanism of AOMDV is used in this protocol: If two paths from a node P to a destination D are link- disjoint, then they must have unique next hops as well as unique last hops for any given node [5]. So paths are allowed to have nodes in common, but the links still must be unique.

In the proposed protocol, to discover link-disjoint paths, source node broadcast Route Request (RREQ) to their one hop neighbor. The figure 1 shows that the intermediate node which receives RREQ would unicast it to the immediate next hop node.

Each node maintains a queue of the previous hop nodes for each RREQ received from a unique one hop neighbor of the source. Each RREQ contains a field indicating the first hop neighbor of the source through which the RREQ is passed. The destination node caches neighbor hop address from which it receives RREQ and sends Route Reply (RREP) back to those nodes. The intermediate node forwards it to the nodes of the next hop queue and then removes the node from the queue. This forwarding scheme is repeated for subsequent RREPs received at this intermediate node. Once the queue is empty, all the received RREPs are dropped. This method ensures that an intermediate node forwards each RREP it receives through a different upstream link. Thus, each intermediate node maintains a one-to-one mapping between its upstream and downstream neighbors. All packets are forwarded using this mapping. By this mechanism, each node now maintains a list of alternate next hops.

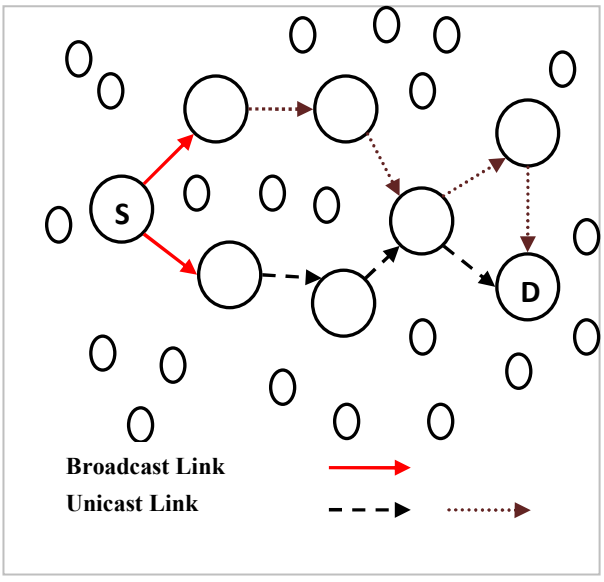

Figure 1. RREQ flow from Source to Destination

In AOMDV, hop count metric is used for route selection. The main drawback of Hop Count metric is that it does not allow selecting the highest throughput paths [17]. In the protocol, when forwarding RREQ and RREP, each node calculates the signal strength metric of its link with next hops.

Signal strength is computed as given in [16]:

$$MP = \frac{MP_{AB} - MP_{\min}}{MP_{\min}} \quad (1)$$

$$MP_{path} = \varepsilon_i = pathMP_i \quad (2)$$

where,

MP_{AB} - the power of the signal from node A as received by node B,

MP_{min} - the minimum threshold power with which the signal must be received for valid transmission.

Cumulative signal strength value is given to the source along RREP packets. The source selects the active path based on the signal strength of each path. The higher signal strength value shows more stable path [16]. Signal strength value of the first reply is compared with the signal value of consecutive replies. The minimum of two routes with higher signal strength value is taken as active path for packet transmission. The number of active path varies based on the number of nodes in the network. The packet transmission starts immediately when active paths are found. The alternative paths are also kept based on signal strength and hop count.

3.2 Route Maintenance

Coverage value and link quality value are the two metrics used for route maintenance in this protocol. Heartbeat messages are sent periodically along each of the active and alternative paths. Each node uses the one-to-one mapping between its upstream and downstream nodes to forward the heartbeat messages which are created during route discovery. The heartbeat message accumulates the signal strength information when it is unicasted in the established route between source and destination. This accumulated value is used to order the multiple paths between the source and destination. Based on this heartbeat packet, the source switches the active path among the alternate and current active path. Path oscillation follows a hysteresis mechanism where path switches only if the difference in the corresponding path stabilities is greater than some predefined threshold. This path switching ensures the reliable packet delivery to the destination by selecting strong active path every time.

3.2.1 In case of link breakage

Link failure is rectified by Route Error (RRER) message as in the other on- demand multipath routing like AOMDV. Link failure in the active path is immediately notified to the predecessor node by RRER message. RRER is forwarded towards the source through intermediate nodes. The source switches the active path to alternative path which is selected during route discovery process.

3.2.2 In case of Congestion

The node overlay [20] in active route can be notified by RRER to both the source and destination to avoid congestion. During the node overlay Congestion Indication (CI) field of RRER is set. This CI field in RRER is used to notify the congestion in the proposed protocol. Source switches to the alternate route after node overlay notification. At this time, as in congestion avoidance of sensor network [18], the destination floods control packet to one hop neighbor which is not in its cache. This control packet will be forwarded towards the source. The nodes which receive the control packet, calculate coverage value with the signal strength value as calculated in route establishment phase. The coverage values are found to avoid the congestion in the network where disjoint paths have same intermediate node.

The coverage value of each link is determined as follows [19]:

$$C(e) = \left|\left\{w \in V, |v,w| \le |u,v| \cup |u,w| \le |u,v|\right\}\right| \quad (3)$$

$$MaxEdgeCoverage(G) = \max_{e \in E} C(e) \quad (4)$$

Equation (3) shows that the coverage of a given node link is defined as the number of nodes that are affected by the transmission over that link, regardless of their distance to u and v. Here, (u, v) is the active link and (v, w), (u, w) are possible links of node w under the transmission range of the link (u, v). These links are used to obtain the number of nodes within the transmission range of (u, v).

The cumulative coverage metric of the path will be calculated as [19]:

$$TotI(path) = \varepsilon_{e \in path} C(e) \quad (5)$$

The coverage value is taken from the MAC layer. When the source receives control packet from its neighbors through flooding, it selects the alternative route based on both signal strength and coverage value of links. The authors proposed a new metric called Link Quality (LQ) [21], which is determined by the following formula:

$$LQ = MP + C(e) \quad (6)$$

The route with higher signal strength and minimum coverage value is added with alternate path list. This process avoids often RDP process and it reduces route discovery overhead.

The strength of the path is increased when the link quality of each link in that path is increased as shown in figure 2. This flooding of control packets by the destination is also followed when less number of alternate routes between source and destination are identified in this protocol [22]. Number of available alternate routes is notified to destination through heartbeat message and the flooding is followed as in the case of node overlay when it is lower than the threshold value.

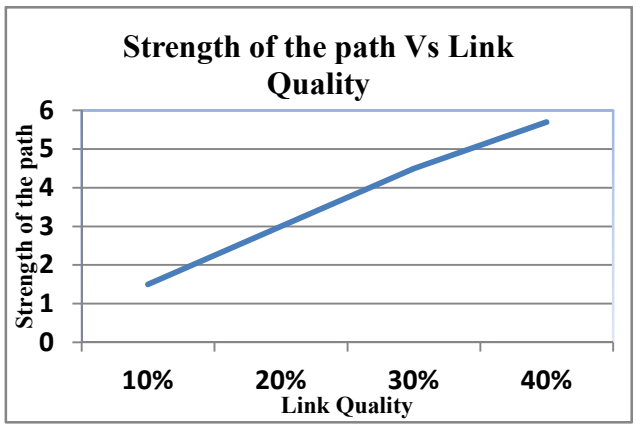

Figure 2. Strength of the path Vs Link Quality

3.3 Proposed Flooding Scheme from Destination

In the proposed protocol, flooding is initiated by destination towards to source. Notations used in the following section are:

Ni: Node i

CP_{Ni}: Control Packet passed through node i

Route from Destination D is considered as follows

D- -N1- -N2- -N3- -S

Where, the intermediate node N1 receives control packet from destination D. It estimates the metrics as described in the previous section.

The node N1 calculates the link quality using (6) when it receives control packet from D.

$$CP_{N1} \xrightarrow{(LQ_{N1})} N2$$

N2 then calculates its link quality LQ_{N2} in the same way and adds it to the link quality of N1. N2 then forward the control packet with the added link quality.

$$CP_{N2} \xrightarrow{(LQ_{N1}+LQ_{N2})} N3$$

Finally, the control packet reaches the source node S with the sum of link quality of the path.

$$CP_{N3} \xrightarrow{(LQ_{N1}+LQ_{N2}+LQ_{N3})} S$$

Similarly, the source S receives several control packets from destination D through several different routes. Then the source selects the routes which have the higher LQ metric value.

4. PERFORMANCE EVALUATION

Network Simulator 2(NS2) is used to evaluate the performance of the proposed protocol.

4.1 Simulation Environment

The simulations are performed using Network Simulator2 (NS-2) [23], particularly popular in the ad hoc networking community. The source-destination pairs are spread randomly over the network. The rate of the packet is 4 packets per second for 15 and 30 sources, 3 packets per second for 45 sources.

The data packet size is 512 bytes. The mobility model uses random waypoint model. In this mobility model, each node starts its journey from a random chosen location to a random chosen destination. Once the destination is reached, another random destination is chosen after a pause time. The speeds of nodes are varied between 0 and 75m/s. Simulations are run for 100 seconds and repeated for 10 times. The figure 3 depicts the wireless sensor network topology in NS-2 simulation.

The important simulation parameters are as follows:

- Number of nodes: 15, 30, 45, 60, 75, respectively
- Testing area: 1000m x 1000m
- Mobile speed: uniformly distributed between 0 and MAXSPEED (chosen MAXSPEED = 2, 5, 10, 25, 50,75m/s, respectively)
- Mobility model: random way point model (when the node reaches its destination, it pauses for several seconds, e.g., 1s, and then randomly chooses another destination point within the field, with a randomly selected constant velocity)
- Traffic load: UDP, CBR traffic generator
- Radio transmission range: 250 m
- MAC layer: IEEE 802.11

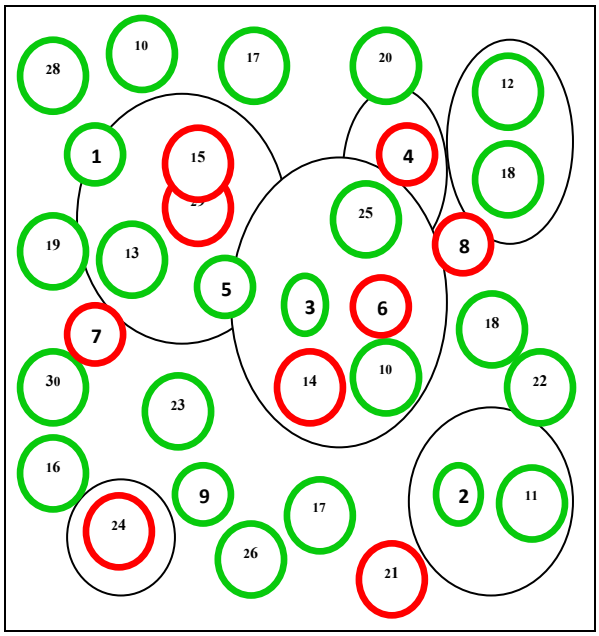

Figure 3. Packet transmission in wireless network

4.2 Simulation Results

The simulation result shows the improvement in packet delivery percentage even when the number of packets are increased. The following QoS metrics are used to compare the efficiency of the proposed protocol with AOMDV.

- Packet delivery ratio: The ratio of the data packets delivered to the destination to those generated by the

CBR sources. As shown in figure 4 the protocol have 20% higher packet delivery ratio than AOMDV.

- End to End delay: Average time between data packets received by the destinations and data packet sent by CBR source. End to end delay of the protocol is 10% lower than AOMDV which is shown in figure 5.
- Control overhead: The number of routing packets transmitted per data packet delivered to the destination. Figure 6 show that control overhead of the protocol is 11.6% than AOMDV.
- Throughput: The total size of data packets that are received in CBR destinations per second. Figure 7 show that throughput of the protocol is 12% higher than AOMDV.

Packet delivery ratio of the proposed protocol shown in figure 4 has linear improvement when the pause time is about 10 to 20 ms.

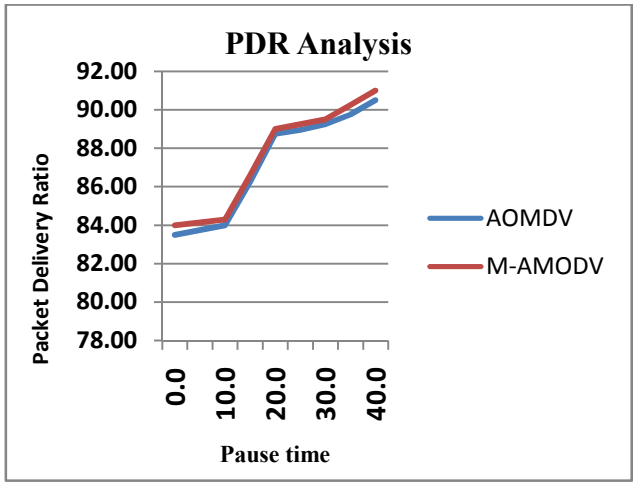

Figure 4. Packet Delivery Ratio analysis

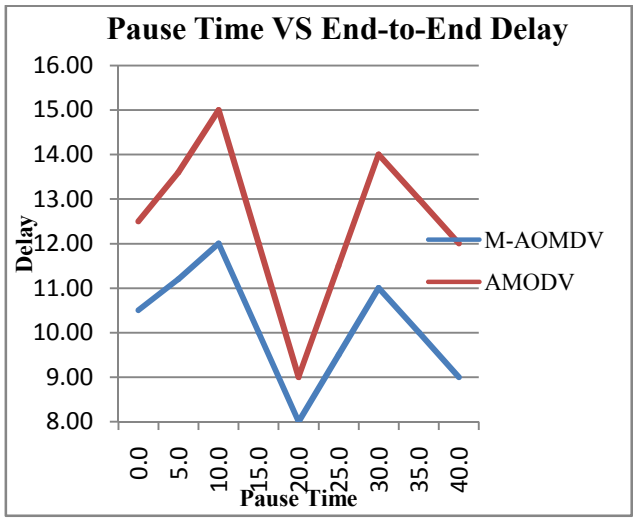

Figure 5. End to end delay analysis

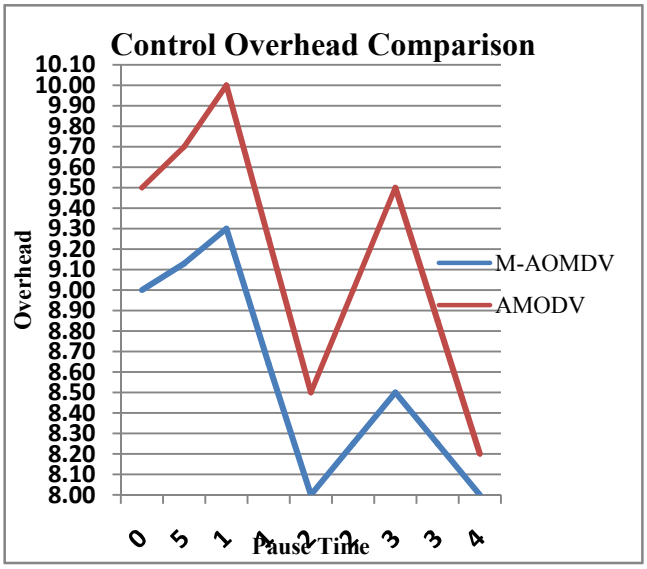

Figure 6. Control Overhead comparison

After that it gives slower improvement up to 30 ms pause time and again it increases linearly after 30 ms.

End to end delay of the proposed protocol is shown in figure 5. The delay decreases when the pause time is 10 ms and it gives Control overhead of the proposed protocol shows significant changes in the network as depicts in figure 6. Control overhead increases depend on the flooding of the packets in the network.

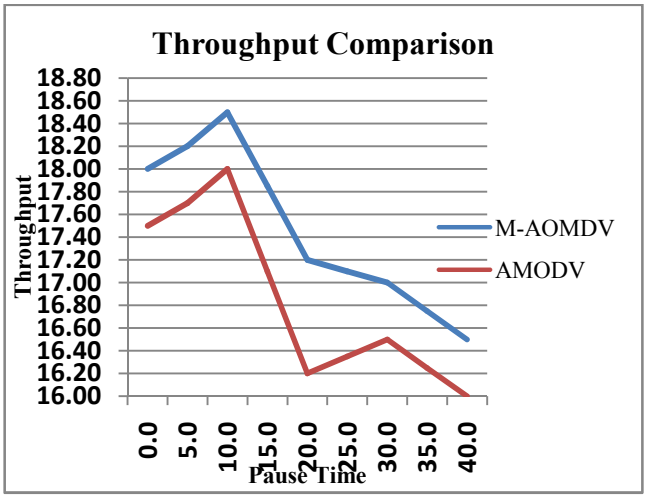

Figure 7. Throughput comparison

Control overhead gradually increased and decreased when the pause time is 20 ms to 40 ms. Throughput of the proposed protocol is higher than AOMDV as shown in figure 7. Throughput is higher since the delay is lower in the protocol.

The proposed protocol has 20% higher packet delivery ratio and 10% lower end to end delay than the AOMDV protocol. Thus the proposed protocol is more reliable than AOMDV protocol which is the popular multipath protocol in ad hoc networks.

5. CONCLUSION

In this paper, a new multipath routing protocol is proposed for wireless sensor ad hoc networks. The cross –layer technique is used to obtain the lower layer values for increasing the performance reliability in the network. A new metric called Link Quality (LQ) is proposed which is the sum of signal strength and coverage value metrics.

The proposed link-disjoint protocol dynamically adapts to varying network topology by monitoring the link quality of each path to the destination and chooses the best path for packet transmission. It is also possible to eliminate stale routes and thereby reduce the number of data packets dropped due to the use of these invalid paths. Though control overhead is introduced as in AOMDV through the periodic heartbeat packets and control packet flooding, results prove that 20% higher packet delivery ratio and 15% lower end to end delay is achieved when compared to AOMDV.

The future work will be based on the overhead issue due to the flooding of control packet overflow. Unicast can be used instead of flooding, by caching the address of all the nodes in the network. Load balancing issue can also be taken for the future work. Stability of routes and power conservation can also be considered to reduce packet drop in the network.

6. ACKNOWLEDGMENTS

The authors thank Dr.B.Sathyabhama and Dr.M.Renuga, Sona College of Technology for their valuable reviews.

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