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An Opportunistic Routing Protocol for Wireless Mesh Networks to Improve TCP Performance

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Abstract: Multi path routing protocol such as AOMDV establishes multiple link disjoint paths between source and destination that provides reliable, fault tolerant network and improves TCP performance over multi hop WMNs. But TCP misinterprets the frequent link failure and wireless channel errors as congestion and slow starts the window size, even during the availability of alternate paths in the routing table. Presented in this study is the solution to the problem that arises when the TCP/IP protocol suite is used to provide internet connectivity through mobile terminals over emerging 802.11 wireless links. Taking into consideration the strong drive towards wireless Internet access through mobile terminals, the problem of frequent disconnections causing serial timeouts is examined and analysed with the help of extensive simulations. After a detailed review of wireless link loss recovery mechanism and identification of related problems, a new scheme with modifications at link layer and transport layer is proposed. The proposed modifications which depend on interaction between two layers: reduce the idle time before transmission at TCP by preventing timeout occurrences and decouple the congestion control from recovery of the losses due to link failure. Results of simulation based experiments demonstrate considerable performance improvement with the proposed modifications over the conventional TCP when a wireless sender is experiencing frequent link failures.

Key words: Serial timeouts, loss recovery, retry limit, fast retransmit, intermittent connectivity, bit error rate, round trip time

INTRODUCTION

Wireless Mesh Networks are a potentially valuable type of wireless network that have the capacity to provide ubiquitous internet access as well as broadband wireless coverage to large areas with minimal up-front investments and infrastructure requirements. WMNs are self organized and self configured in a dynamic way. WMNs share common features with ad hoc networks, the routing protocols developed for ad hoc networks can be applied to WMNs.

Based on the performance of the existing routing protocols for ad hoc networks and the specific requirements of WMNs an optimal routing protocol for WMNs must capture the following features (Akyildiz *et al*., 2005).

Performance metrics: Many existing routing protocols use minimum hop count as a performance metric to select the routing path. This has been demonstrated not to be valid in many situations. Suppose a link on the minimum hop count path between two nodes has bad quality, the throughput will be very low. If congestion occurs then the minimum-hop count will not be an accurate performance metric either.

Fault tolerance with link failures: One of the objectives to deploy WMN is to ensure robustness in link failures. If a link breaks, the routing protocol should be able to select another path to avoid service disruption.

Scalability: Setting a routing path in a very large wireless network may take a long time and end to end delay can become large.

Much more research work has been carried out on developing MAC, network and transport layer protocols on this type of network. Routing protocols are responsible for finding the route and forwarding data between computers. These protocols face many challenges due to the dynamic nature of WMN. Nowadays multi path routing protocols draw more attention than single path routing due to its advantage of improving throughput, end to end delay and reliability (Tachtatzis and Harle, 2008).

Multipath routing protocols build multiple paths for routing between a source-destination pair. It exploits the resource redundancy in the wireless networks to provide benefits such as fault tolerance, load balancing and improves the QoS metrics such as throughput and delay. There are three elements in a multipath routing-path discovery, traffic distribution and path maintenance. Path

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discovery involves finding the available paths using pre-defined criteria using a metric path disjointness. Traffic distribution strategy defines how the concurrently available paths are used and data to the same destination is split and distributed over multiple paths. Path maintenance specifies about when and how new paths are acquired if the states of currently available paths change.

The main objective of using multi-path routing is to perform better load balancing and to provide high fault tolerance (Mueller *et al*., 2004). Multiple paths are selected between source and destination. Packets flow in one of these selected paths. When link is broken on a path due to a bad channel quality or because of mobility on nodes, another path in the set of existing paths can be chosen. Using multi-path routing protocols, the waiting time for setting up a new routing path can be avoided which improves the end to end delay, throughput and fault tolerance. However, the improvement depends on the availability of node-disjoint routes between source and destination.

In this study, a cross layer mechanisms which is based on AOMDV (Ad hoc On demand Multipath Routing Protocol) is proposed. In which the intermediate node detects link failure and checks whether alternate paths are available and it notifies the source about alternate path and freezes its window size.

BACKGROUND

There are various multipath routing protocols available for wireless networks some of them are listed in Table 1 (Tsai and Moors, 2006). A new cross layer mechanism is proposed that extends the Ad hoc On demand Multi path Distance Vector (AOMDV) routing protocol (Marina and Das, 2006). In this study, researchers review two predecessor routing protocols that are useful to the discussion in this study.

HWMP: The Default routing protocol for WMN is Hybrid Mesh Routing Protocol (HWMP) (Kim *et al*., 2012). HWMP is inspired by AODV and OLSR. Depending on the configuration HWMP supports two modes:

- On-demand mode: enables nodes to create and communicate over peer to peer link
- Proactive tree building mode: in this mode path request and Root announcement mechanism is used
- HWMP functions are carried on by management frames with the following set of information frames. Path Request (PREQ) elements are broadcast by a source node that wants to discover a path to a destination node
- Path Rely (PREP) elements are sent from destination node back to the source, in response to a PREQ. Occasionally, PREP elements can be sent from intermediate nodes that already know the path to the destination
- Path Error (PERR) elements are used to notify that a path is not available any more and Root Announcement (RANN) elements are flooded into the network in one of the proactive operation modes

AOMDV: The key difference of AOMDV over AODV is that it provides multiple paths to destination. These paths are loop free and mutually link-disjoint. AOMDV uses the notion of advertised hop-count to maintain multiple paths with the same destination sequence number (Marina and Das, 2006). In both AODV and AOMDV, receipt of a RREQ initiates a node route table entry in preparation for receipt of a returning RREP. In AODV, the routing table entry contains only one route to each destination. But in AOMDV, the routing table entry is modified to contain multiple route entries and multiple loop-free paths. Single next-hop id is replaced by a list of all next-hop nodes and corresponding hop-counts of the available paths to

Table 1: Summary of Multipath routing protocols

	DSR			AOMDV		ROAM
Base protocols	MultiPath Extension to DSR	SMR	MP-DSR	AODV	MPR-E	DUAL
Source or distance-vector routing	Source	Source	Source	DV	DV	DV
Route discovery	Multiple link-disjointroutes	Shortest delaypath it' smaximally-disjointroute	Set of maximally disjoint paths that satisfy QoS requirement	Link or node-disjointpaths	Maximally zone-disjoint shortest paths	Non-disjoint
Routing choice made at	Source and intermediate nodes	Source	Source	Intermediate nodes	Intermediate nodes	Intermediate nodes
Traffic distribution	Single path	Two paths concurrently	Not specified	Single path	Two paths concurrently	Single path
Allocation granularity	n/a	Per packet	n/a	n/a	Packet	n/a
Route maintenance	New discoverywhen all exhausted	Immediately attempt newdiscovery and only when both fail	All paths broken and QoS no longersatisfied	When last path fails	n/a	On change of link distance
Motivation/Application	Reduce frequency of route discovery floods	Splitting traffic provides better load distribution	QoS applications with soft end-to-endreliability	Discovers disjoint paths without using source routing	Increase throughput	Wired/wireless networks withstatic nodes

destination from that node. To obtain link-disjoint paths in AOMDV, destination can reply to multiple copies of a given RREQ as long as they arrive via different neighbours.

TCP MISBEHAVIOR ON ROUTE FAILURE

TCP (Transmission Control Protocol) is a connection oriented transport layer protocol that provides reliable in order delivery of data packets to the destination. If researchers use TCP without any modification on Wireless Networks, it results in serious drop of throughput due to the following reasons.

Un predictable nature of wireless medium-high bit error rate unexpected mobility of nodes-route failure high contention for wireless medium. Here, researchers analyse the behaviour of TCP during route failure on AOMDV protocol.

One of the well-known reasons for TCP performance degradation is that the classical TCPs do not differentiate congestion and non-congestion losses (Xylomenos *et al*., 2001). As a result, when non-congestion losses occur, the network throughput quickly drops. Moreover, once wireless channels are back to the normal operation, the classical TCP cannot be recovered quickly.

Link failure also degrades the TCP performance. Link failure may occur frequently in MANETS (Mobile Ad Hoc Networks) due to mobile nodes. As far as WMNs are concerned, link failure is limited because the WMN infrastructure avoids the issue of single point of failure. However, due to wireless channel quality and mobility in mesh clients, link failure may still happen. To enhance TCP performance, congestion losses and link failures also need to be differentiated.

A network topology with 7 nodes in ns2 using AOMDV as routing protocol is developed and the simulation is run for 100 sec. As AOMDV maintains more than one path to reach the destination, route failure occurs because of poor link quality it reroutes the packet through alternate path. Before this happens, TCP misinterprets route failure as congestion and congestion window will be reduced and timeout occurs for the lost data packets and makes TCP to enter slow start state that drops the throughput unnecessarily in the presence of alternate path which is shown in Fig. 1.

AOMDV finds out multiple link disjoint paths to improve fault tolerance and reliability. Due to TCP misbehaviour, it is not been utilized in the above cases which is described in Fig. 2 (Francis *et al*., 2012).

If the ACK is not received within congestion timer period, TCP misunderstood as the data is lost due to congestion and activates congestion control and it reduces the congestion window size. But data loss may be due to either congestion or link failure which is not discriminated here. Following observations related to performance degradation are made based on the earlier study:

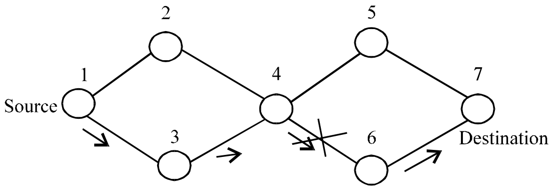

Fig. 1: Network topology illustrates route failure

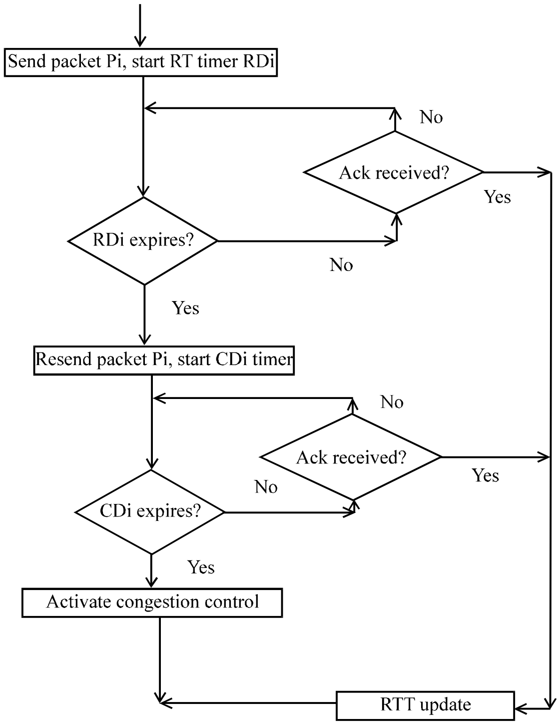

Fig. 2: Flow chart of TCP behaviour with serialized timers

- TCP is unable to utilize link immediately even though the availability alternate path and its restoration
- In the initial period the network capacity is underutilized, immediately after resuming of transmissions

These problems are elaborated with the help of Fig. 3 where the disconnection interval is from T0 to T4. After transmitting the last packet from current cwnd (congestion Window) at time T1, TCP has to wait either for arrival of acks or expiration of RTO (Retransmission Time Out).

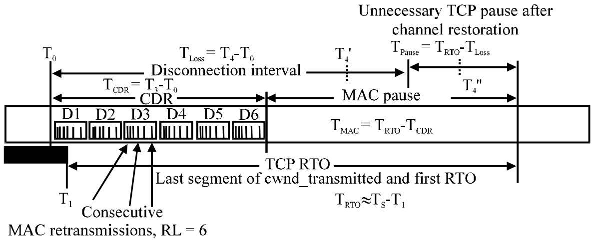

Fig. 3: Illustration of T_{CRD} and T_{Loss}

CROSS LAYER DESIGN SYSTEM MODEL

During RTO period MAC layer attempts transmission of all outstanding TCP packets from IFQ (Dalal *et al*., 2011). This duration is referred as Consecutive Retry Duration (T_{CRD}). After T_{CRD} there is no transmission at MAC layer until another transmission attempt at TCP, resulting into idle time at MAC layer. Under this condition, retransmission at TCP resumes only after expiration of RTO and introduces idle time at TCP, after restoration of the link as shown in Fig. 4. Idle time at TCP after restoration of the link can be mathematically related with RTO and the disconnection interval (TLOSS) as shown:

$$T_{PAUSE} = \text{RTO-}T_{LOSS} \tag{1}$$

Equation 1 holds true whenever $T_{LOSS}>T_{CRD}$. T_{LOSS} is the time period until which TCP waits for ACK. For $T_{LOSS}>T_{CRD}$, TCP retransmission occurs after TCP timeout with considerable delay following the restoration of the channel, i.e., T_{PAUSE}. Thus, TCP performance degrades due to non-utilization of the channel during T_{PAUSE}. Here, it may be noted that with increase in T_{LOSS} within RTO, T_{PAUSE} reduces.

Furthermore, the packet loss is interpreted as a network congestion and the retransmission follows the conventional algorithm with reduced flow, i.e., halving the ssthresh (slow start threshold) and transmission starts from slow start phase (cwnd decreases to 1).

This reduction in transmission flow at TCP for wireless losses is inappropriate. Suppose the value of cwnd prior to link disconnection is cwnd (n) and the value using which TCP resumes its transmission is cwnd (n+1) then time required to raise cwnd from cwnd (n) to cwnd (n+1) is referred here as TCP response time (TRES), during which TCP under-utilizes the network capacity. This adversely affect on end to end TCP performance. As cwnd size is RTT dependent, over a network with larger RTT, longer is the TRES and similar will be the impact on its performance. In next study, the approaches are proposed to restart transmissions immediately after link re-establishment and to improve utilization of network capacity further by restoring cwnd earlier at the same instant.

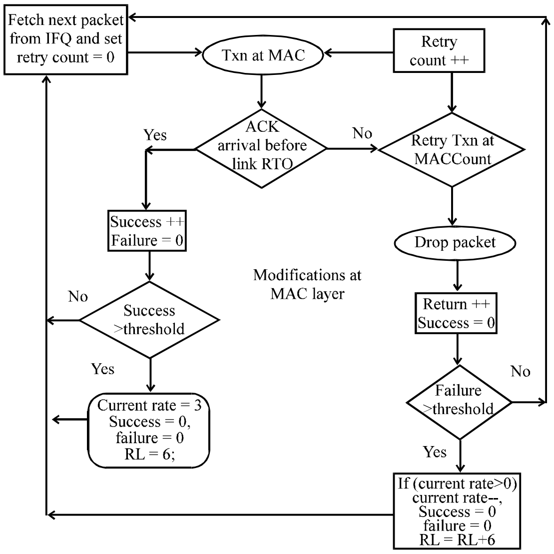

Fig. 4: Illustration of MAC layer modifications

Approach A (MAC layer modifications): Pause time TPAUSE can be reduced by increasing T_{CRD} over T_{LOSS}. T_{CRD} can be represented as (IEEE 802.11, 1999):

$$T_{CRD} = \sum_{n=0}^{s} ([RL+1]T_{LINK} + \sum_{k=0}^{RL} T_{(BACKOFF)})\,(k) \tag{2}$$

Where:

s = The number of outstanding TCP packets in an IFQ
RL = Retry Limit for Retransmission
T_{LINK} = The two way transmission delay over a link and processing delay

The second term of T_{CRD} corresponds to the sum of the back-off duration for each segment and its successive retransmissions according to the index k of the retransmission, decided by the MAC layer parameter Contention Window (CW) (IEEE 802.11, 1999). As per Eq. 2, T_{CRD} can be increased by tuning different TCP and MAC parameters like: enlarged cwnd at the TCP layer, a higher RL at the MAC layer, a larger CW at the MAC layer and an increased T_{LINK} by reducing data-rate. Enlarging cwnd is not desirable as it can lead to large number of TCP retransmissions in the case of network congestion. CW increase at the MAC layer is not suitable because the duration of this window is also used for contention resolution when several stations are competing to access the same channel (IEEE 802.11, 1999).

Approach B (MAC and TCP layer modifications): In earlier approach, T_{CRD} is increased on detection of successive MAC retransmissions and TCP triggers recovery for such losses using fast retransmit, earlier than the recovery after timeout. But here earlier retransmission is attempted at reduced rate, because the CWND is reduced to half when packet lost as per conventional TCP behaviour. This prevents TCP to utilize the available network capacity. In multipath routing protocols, if a packet lost due to link failures, the packet is retransmitted immediately through available alternate path and it is unnecessary to reduce the CWND.

A MAC aware cross layer design is proposed in which the multi path routing protocol AOMDV is used. A packet is lost due to link failure that packet is immediately retransmitted through available alternate path and link failure is intimated by MAC layer to TCP layer. Further, TCP increases the reduced window size by two times and transmission continues. A parameter link_loss is used to indicate link failures which is accessible in both MAC and TCP layers which is explained in Algorithm 1. Integration of approach A and B provides better performance (Fig. 5).

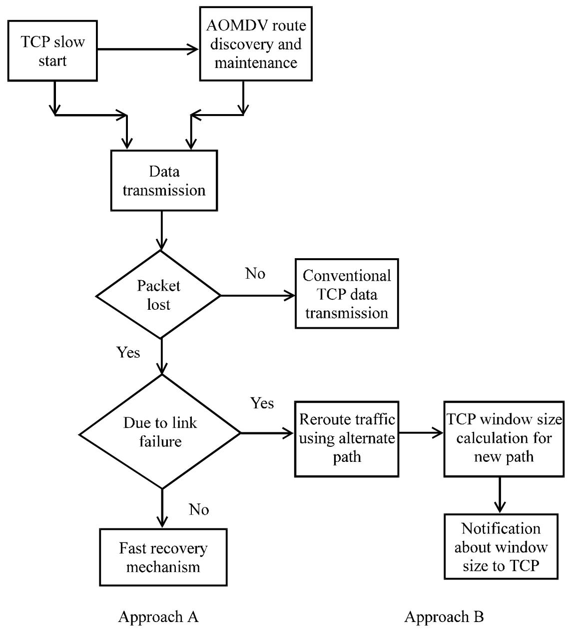

Fig. 5: MAC and TCP layer modifications

Algorithm for MAC and TCP layer modifications:

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At MAC layer
........................
...........................
Link_loss = 0
Transmission continues
If link failure occurs
Link_loss = 1
Signalling is done to TCP layer
...........................
...........................

At TCP layer
.............................
.............................
If Link_loss = 1
        Increase window size as CWND*2
        Continue
If link_loss = 0
        Performs conventional TCP operation
```

SIMULATION AND OUTPUT

ns2 simulator is used for simulating the environment. The earlier mentioned cross layer idea was implemented in AOMDV protocol which is named as cross layer AOMDV and its performance isanalysed using various performance metrics throughput, delay, overhead and its performance is compared with the basic WMN routing protocol HWMP and the protocol outperforms than the other one. Simulation parameters are shown in Table 2.

Scenario 1: A simulation environment using grid topology with 100 wireless nodes is developed and TCP throughput is observed for 5 TCP connections. The performance of the cross layer AOMDV is analysed with existing AOMDV and cross layer design outperforms than existing one (Fig. 6).

Scenario 2: The 100 wireless nodes in a grid topology is simulated and performance of crosslayer AOMDV design is analyzed by varying the number of nodes as 5, 100, 225, 400 and 625. Cross layer AOMDV performs better than AOMDV (Fig. 7 and 8).

Table 2: Simulation parameters

Parameters	Values
Simulation time	100 sec
Simulation area	1000×1000 m
Probagation model	Two-ray ground reflection
Maximum seed of node	20 m sec^{-1}
Traffic tye	FTP(TCP)
Packet size	1024 bytes
Number of nodes	100

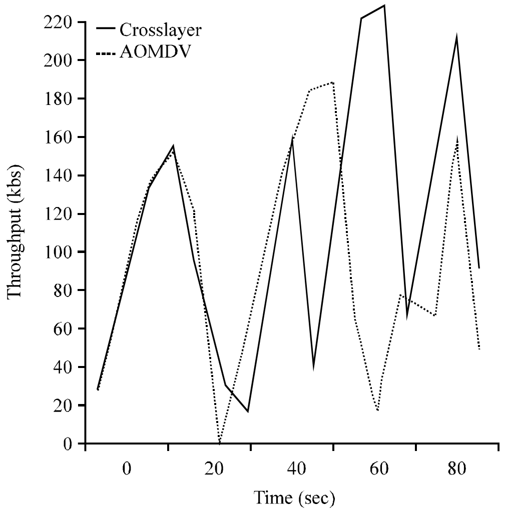

Fig. 6: Performance of crosslayer AOMDV vs. AOMDV

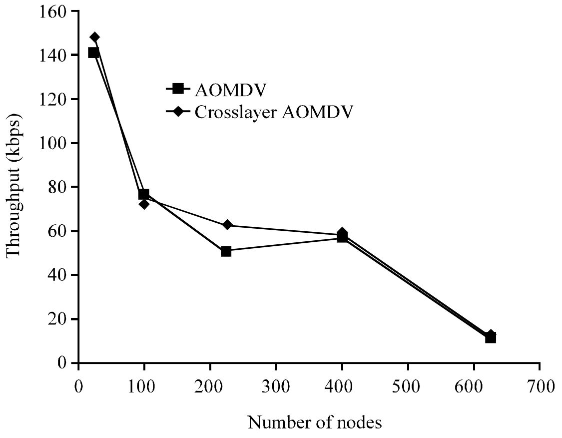

Fig. 7: Throughput-crosslayer AOMDV vs. AOMDV

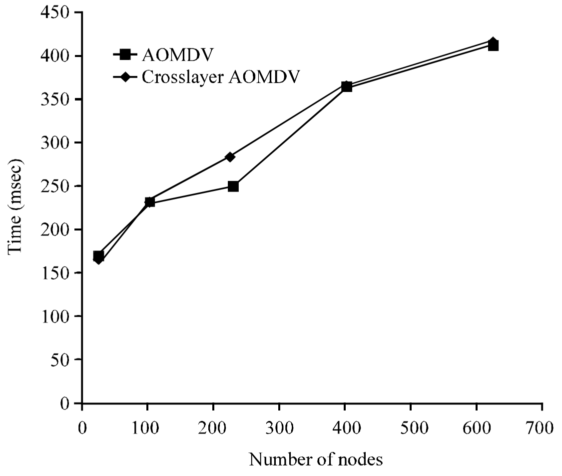

Fig. 8: End to end delay-crosslayer AOMDV vs. AOMDV

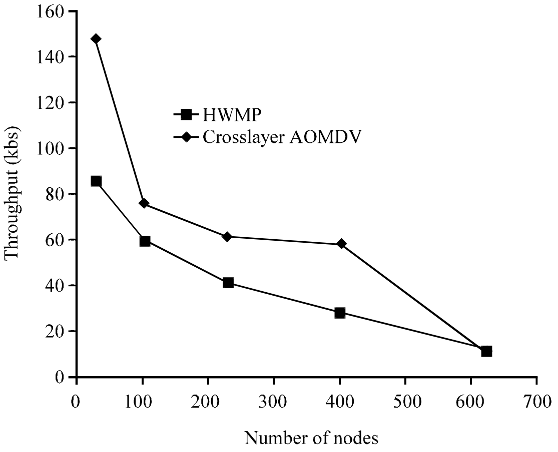

Fig. 9: Throughput-crosslayer AOMDV vs. HWMP

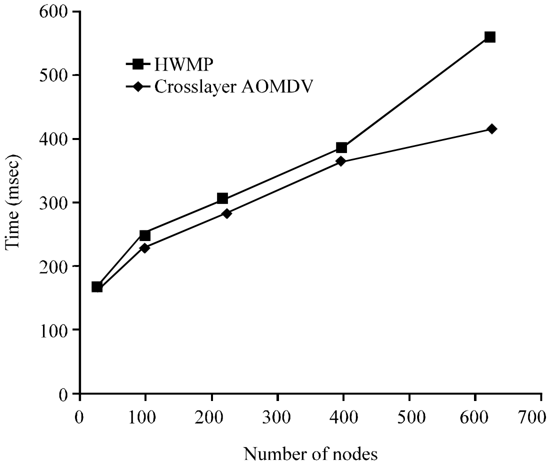

Fig. 10: End to end delay-crosslayer AOMDV vs. HWMP

Scenario 3: The cross layer mechanism concentrates on selecting better link quality path and fault tolerance with link failures, researchers have analyzed the performance the routing protocol over wireless mesh networks and compared with WMN default routing protocol HWMP. The protocol outperforms than HWMP which is described in Fig. 9 and 10.

Researchers simulate grid topology with 100 wireless nodes and performance is measured by varying the number of nodes as 25, 100, 225, 400 and 625. From the simulation results, it is understood that the protocol performs better until increasing the nodes upto protocol. Scalability issues to be considered.

CONCLUSION

In this study, researchers proposed cross layer mechanism which is based on AOMDV. It finds out multiple link disjoint paths and stores in a routing table but selects the next hop based on current wireless channel condition from physical layer. Each node dynamically changes the link rate based on channel condition to reduce the wireless channel errors on transmission. The intermediate node detects link failure on mobility and checks whether alternate paths are available and it notifies the source about alternate path and freezes its window size.

RECOMMENDATIONS

Scalability is the most critical question in WMNs. It has been shown that performance of the routing protocol may not satisfactory in this case. So, further research to be needed for scalability.

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