Comparison of Different Topology of Wireless Mesh Access Network Using Cross Layer Solution for Performance Improvement

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ABSTRACT : *Wireless Mesh Network (WMN) is a communications network, which is of radio nodes organized in a mesh topology. Wireless mesh networks often consists of mesh clients, mesh routers and gateways. The range of router is greater than that of the client in the WMN and may cause link asymmetry, leading to degradation in network performances. Link asymmetry in WMN causes unidirectional Link problem, Heterogeneous Hidden Terminal problem and Heterogeneous Exposed Terminal Problem.   Cross-layer design is the promising method to improve the efficiency of the network performance, which uses the multihop path   to establish a reverse path between the client and the router. Different topology may be tested to check the effectiveness of cross-layer approach for improving the network performance*

Keywords - Cross-layer design, WMN

1. Introduction

A wireless mesh network (WMN) is a special type of wireless ad-hoc network with all the nodes immobile. The mesh routers are highly mobile and often the mesh routers are not limited in terms of resources compared to other nodes in the network and can be exploited to perform more resource intensive functions. In this way, the wireless mesh network differs from an ad-hoc network as all of the nodes are often constrained by resources.

Wireless Mesh Network consists of a three tier network and provides access to the internet. The mesh network has many applications but also poses significant technical challenges as it requires decentralized control, dynamic topology and the characteristics of the wireless channel. The range of router is greater than that of the client resulting in link asymmetry, and leading to degradation of network performance. The link asymmetry results in three main problems Heterogeneous Hidden Terminal problem, Heterogeneous Exposed Terminal Problem and Unidirectional Link problem,.[1] [2]
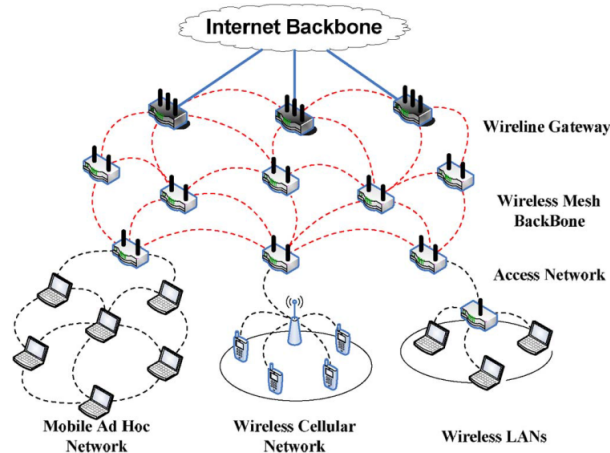

Fig.1. Wireless mesh Network [1]

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Cross-layer design can be used to satisfy the network requirements. The mesh networks have many design challenges even with all its advantages. Considering network as a hierarchy of layers that are independent and non-cooperating does not take the advantage of the interactions between the different layers. It is better considering joint optimization across the various layers of the network resulting in greater network performance than considering each layer by itself.

In order to meet the energy constraint, bandwidth constraint and delay constraint requirements, a cross-layer protocol design that supports adaptively and optimization across layers of the protocol can be implemented. In such an adaptive cross-layer protocol stack, the link layer will adapt rate, power, and coding in order to meet the requirements of the application such that current channel and network conditions are given. The Medium Access Control (MAC) layer of the data link layer will adapt on underlying link and interference conditions in addition to the delay constraints and priorities. Adaptive routing protocols are thus developed based on current link, network, and traffic conditions. Cross-layer networking can improve performance by as much as by a factor of two.[1]

The remainder of this paper is organized as follows. Section 2 discusses the problems in WMN. Section 3 presents the proposed cross-layer approach in handling the link asymmetry problems. Section 4 discusses the different topologies that have been used to compare the cross-layer approach to without cross-layer system. Section 5 presents our simulation based evaluation and Section 6 concludes the paper.

2. Problems in WMN

The mesh backbone and access network uses IEEE 802.11 protocol. Link asymmetry that arises between mesh router and clients of the access network is due to variable transmission range of nodes and this further affects the network performance. The link asymmetry raises the following three problems: 1) Hidden node problem, 2) Exposed node problem, 3) Unidirectional link problem [1]

2.1 Problems of Hidden Node (HN): Hidden nodes are those nodes which are not in the range of other nodes. Nodes are within the communication range of the access point and communicate with access point, but these nodes cannot communicate with each other as they do not have physical connection to each other. RTS/CTS acknowledgment and the handshake packets could be used to solve the hidden node problem. . RTS/CTS cannot be used as a solution in solving hidden node problems as it may decrease the throughput. [3]
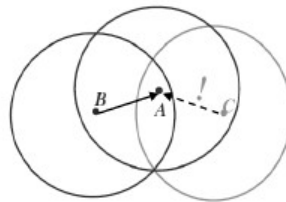

Fig 2. Node C remains hidden to NodeB

2.2 Problems of Exposed Node (EN): Considering wireless networks, Exposed Node Problem occurs when nodes are prevented from sending packets to other nodes because of neighboring transmitter. RTS/CTS mechanism can solve this problem only if nodes are synchronized. When node hears an RTS from its neighboring node, but not the corresponding CTS, that node is taken to be an exposed node and is allowed to transmit to other neighboring nodes. Cases when nodes are not synchronized, the problem is that the sender does not hear the CTS or ACK during the transmission of data of the other sender. [3]

2.3 Unidirectional Link Problem: In this case, clients with small transmission range will not respond to routers after receiving requests from routers.
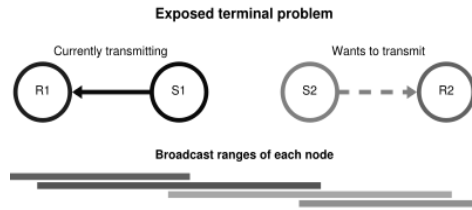
Fig.3.Nodes S2 and R2 remain exposed to Nodes R1 and S1

3. Cross-layer Approach in handling link-asymmetry

In order to simultaneously address the three problems, unidirectional links need to be eliminated. However, eliminating unidirectional links is not a simple task, as the chance of the mesh router to access the channel should not simultaneously increase. Thus, channel should be accessed by routers and clients without causing collisions and thereby not affecting network performance. The solution should consider the cross-layer design as well. This is because the three problems raised by link asymmetry is covered by both the network layer [4][5][6] and the link layer[7]. Existing approaches in the network layer and the link layer cannot completely address these problems and the desired approach needs the cooperation between the network layer and the link layer, i.e., the MAC protocol needs the topology information obtained in the network layer, and the routing protocol needs the MAC protocol to directly address the unidirectional link problem.[1]
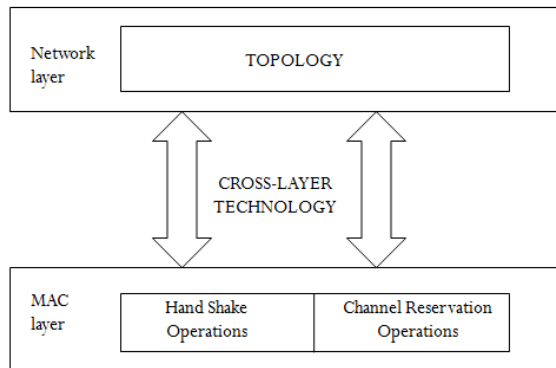

Fig 4.Cross-layer Approach

In cross-layer approach, new control frames are introduced: 1) delay to send (DTS) and 2) negative ACK (N-ACK). DTS is used to avoid collision on demand by canceling the transmission of a heterogeneous hidden terminal. N-ACK is used to request the source node to retransmit DATA when collision occurs on the data channel. Based on mechanisms provided in the network layer and the link layer and their interactions, three mechanisms to address the unidirectional link problem, heterogeneous hidden problem, and heterogeneous exposed problem, respectively are introduced. In particular, the unidirectional link problem is solved by routing clear to send (CTS) via multihop mesh clients, the heterogeneous hidden problem is solved by routing DTS on demand, and the heterogeneous exposed problem is solved by processing CTS from the mesh router, depending on whether the mesh router is a bidirectional neighbor or not.

To address the Unidirectional Link Problem a reverse path should be established between the mesh routers and mesh clients. A multihop routing reserve path need to be established, as the range of the routers are greater than that of the mesh clients.

There are three basic handshake operations in our approach. RTS/CTS/DATA is used to handle normal data transmission. When a node needs to send DATA, it first checks the data channel and the control channel. When both channels are idle and the idle time lasts longer than the period of time that is equal to short inter frame space, RTS can be transmitted via the control channel. By receiving RTS, if the channel condition allows it to receive DATA, the destination node promptly replies to RTS by CTS. After receiving CTS from the destination, DATA is sent from the data channel. RTS/DTS/Backoff/. . . /retransmit is used when the channel condition of the destination does not meet the requirements for receiving DATA. After receiving DTS from the destination, the source node will delay its data transmission and retry after backoff. This way, the chance of collision can be largely reduced. RTS/CTS/DATA/N −ACK/Backoff/. . . /Retransmit is used to provide the reliability for DATA transmission. When collision occurs on the data channel, the destination will send N-ACK to the source. After the backoff procedure, retransmission will recover the collided DATA frame.

Along with the basic handshake operations, channel reservation operations are also performed in our protocol. To this end, the network allocation vector (NAV) as a period of time is used to determine how long the channel will be occupied. Each node maintains three NAVs. In particular, NAVC is used to monitor the control channel. When NAVC is positive, transmitting control frame is forbidden. NAVS and NAVR are used to manage sending and receiving operations on the data channel, respectively. RTS is not allowed to transmit when NAVS is positive, whereas data receiving is forbidden when NAVR is positive. Each control frame is appended with a Duration field to support channel reservation. Based on handshake operations, when handshake is conducted on the control channel, the duration information appended in each control frame can be used to update three NAVs (i.e., NAVC, NAVS, and NAVR) for channel reservation.[1]

3.1 Addressing Hidden Terminal Problem:

The main idea behind solving the heterogeneous hidden terminal problem is to route the control frames, which can either block or delay the transmission of the router. There are two schemes in order to solve the heterogeneous hidden terminal problem. One scheme involves increasing the coverage of CTS sent by the client. The second scheme is to delay the transmission of router on demand, this scheme involves low overhead. The second scheme is based on the fact that collision occur only when the heterogeneous hidden terminal access the channel while the client is receiving the DATA. The client senses any collision by listening to the control channel. When RTS from the router is received by the client on the control channel while it is receiving DATA, the client ensures that the DATA transmission from that router will collide with the DATA to be received. In this case, DTS is forwarded via a multihop path through mesh clients to the heterogeneous hidden terminal, i.e., the router, to cancel its current data transmission.

3.2 Addressing Exposed Node Problem:

The range of routers are large, due to this the CTS frame from the router may block data transmission from clients. . To prevent this, the coverage of the CTS frame has to be decreased; this is done by limiting the effective coverage of CTS frame from the router. Using the reverse path established in the network layer, each client determines whether the router is its bidirectional neighbor or not. When the router is not its bidirectional neighbor, CTS will be ignored. If the router is the bidirectional neighbor, the CTS frame will be processed.

From Fig.5 and Fig.6 it is seen that clients D and E are heterogeneous exposed terminals when router B replies CTS to client A. Client C and router F will be blocked after receiving CTS from router B, because they are bidirectional neighbors. However, clients D and E find that router B is not their bidirectional neighbor. Hence, they simply ignore CTS and initialize RTS for data transmission.
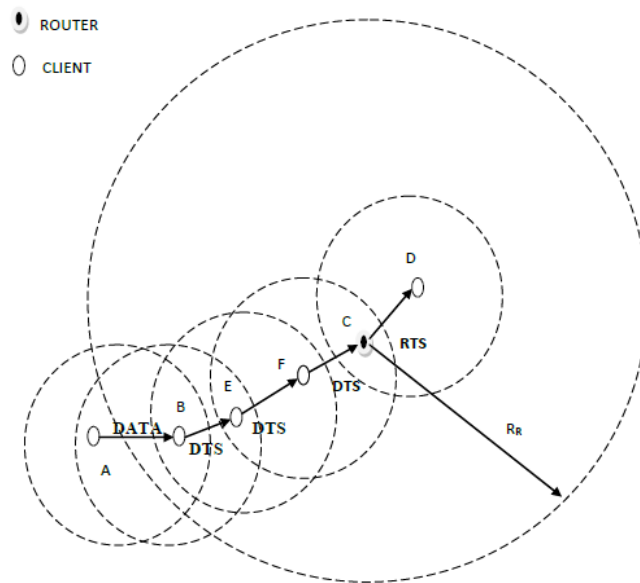
Fig.5. WMN with solution for hidden terminal problem
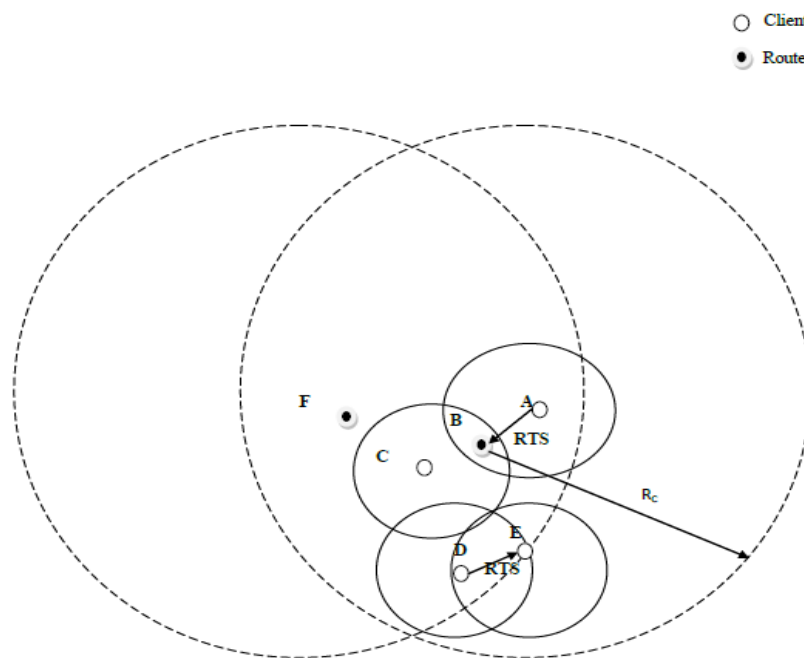
Fig.6. WMN with solution for exposed terminal problem

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4. Cross-layer under different topology

Three kinds of topology are experimented and compared. In static line topology, the effectiveness of cross-layer approach is validated considering both hidden problem as in Fig. 7 and exposed problem as in Fig. 8. On a star like topology shown in Fig. 9 and random topology, cross-layer approach is compared with the without cross-layer system in terms of various scenarios, including different packet size and data rate. Following, we present these simulations, respectively.

Static line topology includes two conditions to check, i.e., hidden problem and exposed problem. From Fig.7 we see that the node R is the mesh router and nodes C1, C2, C3 and C4 are the clients. CBR traffic flow from C1 to C2 and R to C4 are initiated considering the R to be the hidden node in our simulation.
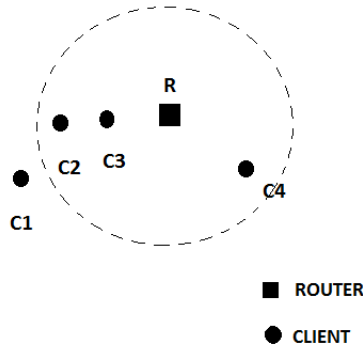

Fig.7. Set up for solving hidden problem

To check whether exposed problem is being handled with cross-layering the set up is made with R as router and C1, C2, C3 and C4 as the clients as in Fig.8. CBR traffic is initiated from C1 and R and C2 to C3. Thus from figure we see that the nodes C2 and C3 becomes exposed terminals to node R and C1.
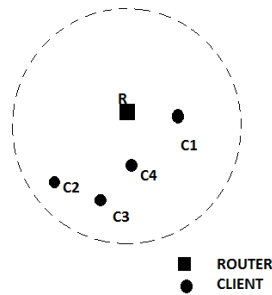

Fig.8. Set up for solving exposed problem

In star like topology as shown in Fig.9 the node R is the router and the nodes C1, C2, C3, C4, C5, C6, C7 and C8 are the clients. The flow is between C5 to R and R to C7.

All the topology discussed above is static in nature. In random topology the nodes are in random movement and the flow is taken between any two client nodes and client and router. The system with and without cross-layer is compared for all the three topology cases.
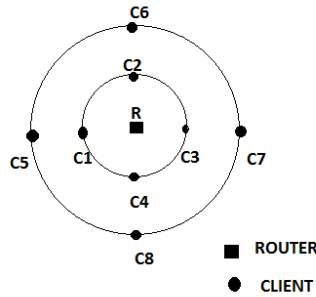
Fig.9. Star like topology

5. Experiment and simulation results

5.1 Experimental Setup:

        In our evaluation, we use, NS-2 simulator and the standard IEEE 802.11 protocol as the baseline protocols in comparison with our approach of cross-layer. In our experiments, we take three cases. In all cases clients are of same range and routers of range 250m.Here we use varying data rate and packet size to compare the throughput for without cross-layer and with cross-layer. We compare the static-star topology, Static line topology and random topology. We adopt a constant bit rate (CBR) traffic model because it is a very popular traffic model and has been widely used in the simulation of the MAC protocol by other researchers. To evaluate network capacity, we consider the throughput, which is defined as the total number of packets delivered to the destination.

5.2 Simulation Results:

        In the static line topology case where the comparison of with and without cross-layer approach is performed by varying packet size and data rate, we see an increase in throughput for cross –layer approach as shown in Fig.10 and Fig.11 for both hidden node scenario and Fig.12 and Fig.13 shows exposed node scenario. We have varied the packet size from 128 to 1024 bytes and data rate from 150 to 900kbps.

        Now considering cases with static star topology, with and without cross-layer approach is compared for varying packet size and data rate. An increase in throughput is seen in both cases for cross-layer approach. Throughput for varying packet size is shown in Fig. 14 and throughput for different data rate is shown in Fig. 15.

5.2.1 Hidden Node Scenario
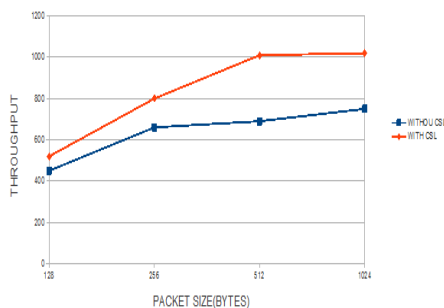

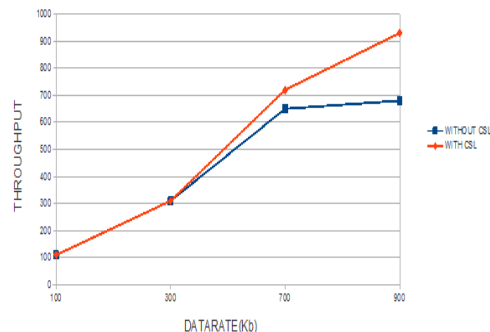Fig.10.Throughput (Line topology) for different packet size   Fig.11.Throughput (Line topology) for different data rate

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5.2.2 Exposed Node Scenario
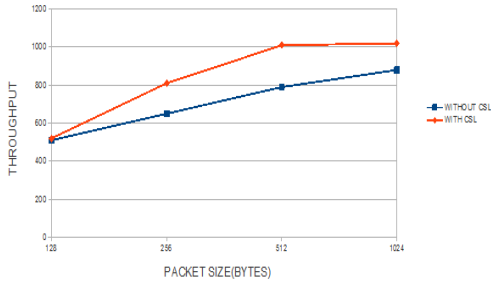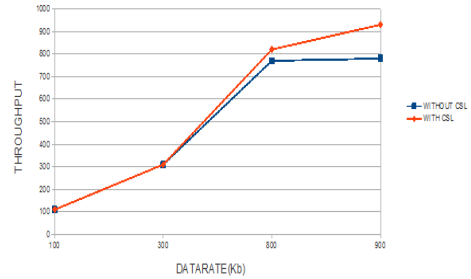
Fig.12. Throughput (Line topology) with different packet size

Fig.13.Throughput (Line topology) with different data rate
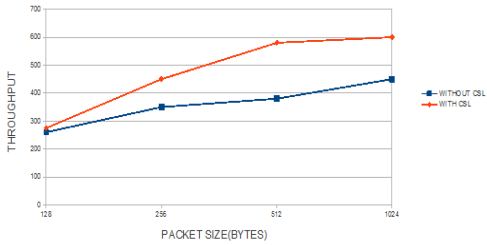
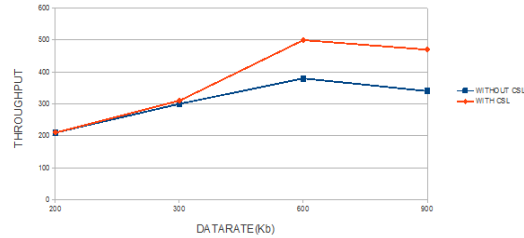Fig.14. Throughput(Star topology) with different packet size

Fig.15. Throughput(Star topology) with different datarate

In random topology also comparison is done for varying packet size and data rate and cross-layer approach is seen to have a better throughput in all cases. Throughput for varying packet size is shown in Fig. 16 and throughput for different data rate is shown in Fig. 17.

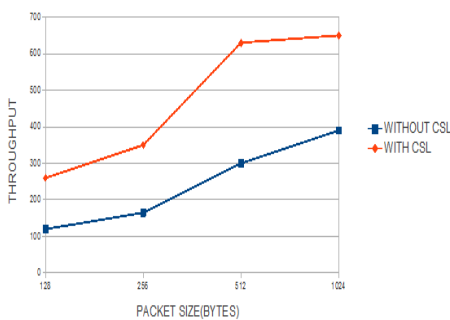Fig.16.Throughput (Random) for different packet size
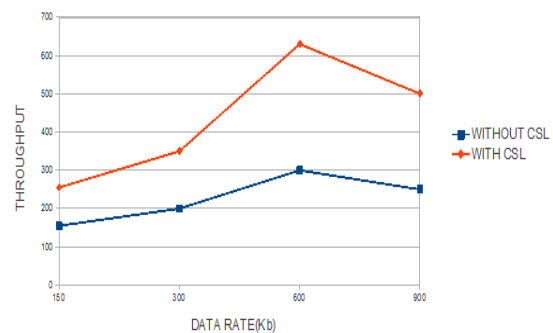
Fig.17. Throughput (Random) for different data rate

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6. Conclusion

From the above simulation results, we see that the network performance could be improved by using a cross-layer approach rather than using single layer independently. The throughput is seen to be higher for cross-layer considering the cases of both varying packet size and data rate. The cross-layer approach appears as best solution for improving network performance, by considering both hidden node as well as exposed node scenario for static line topology. The results have been verified even with static star and random topology. On the whole comparing the static topology system and random topology, we observed that throughput is higher for static topology systems. In random topology system the nodes are at constant movement and so throughput is reduced as there is a chance of packet loss due to random motion. Whereas in the case of static topologies, such as static line and static star throughput is much higher on comparison with the random topology.

7. Future Work

Cross-layering could be used along with other methods for improving the network performance, such as carrier sensing.

8. Acknowledgements

Authors like to thank for all support given by Mr. George M Jacob, Lab Instructor for providing the assistance in software implementation.

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