CROSS LAYER BASED TEMPORALLY ORDERED ROUTING PROFTOCOL FOR WIRELESS MESH NETWORKS

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***Abstract*—In this paper a proactive protocol Cross Layer Based Temporally Ordered Routing Protocol (CL-TORA) is developed to measure the performance of the Wireless Mesh Networks by using a newly adopted routing metric NCLRM. CL-TORA considers four link quality impact factors in estimating the route selection through the cross layer strategy. The conventional layered-protocol architecture does not provide optimal performance for wireless mesh networks (WMNs). The method of optimization decomposition of the protocol stack can achieve optimal network performance. This method usually results in a clean-slate protocol architecture that is different from the protocol architecture of WMNs. The bandwidth available in the node, load on the node, delivery rate of the link and interference on the link factors are considered for cross layer design. By making use of these link factors the effect of route selection is greatly optimized. The developed CL-TORA protocol not only improve the network throughput to a greater extent it also reduces the end to end delay while achieving the load balance route results.**

Keywords- Cross Layer Design, Routing Protocol, Wireless Mesh Networks, Routing Metric

I. INTRODUCTION

Wireless Mesh Networks (WMN) consists of mesh routers and mesh client forming a distributed broadband multi-hop wireless network [1]. The basic idea is that every node in the network can be able to access network and also support services for the user at the same time. WMN has excellent scalability and can integrate both the ad hoc and infrastructure operation modes there by achieve high speed routing and high bandwidth transmission. In many application scenarios WMN can be applied to wideband local area networks, transport medical system networks, metropolitan area networks, and other places. WMN has many features that are different from wireless sensor and ad hoc networks and furthermore, it is more concerned with the scalable end-to-end throughput and good quality of service (QoS) to handle heterogeneous traffic. Many research institutions are carrying out extensive work on WMN and standards are going to be standardized. WMN has to deliver heterogeneous traffic and has to provide good quality of service (QoS), it is more difficult to optimize the overall network performance of the networks across multiple protocol layers.

The conventional traditional network design approach is not suitable for WMN and it is also difficult to decide whether it is a better option to optimize its performance. There is a openness of the wireless channel and time variability of channel parameters and the traditional design method cannot guarantee the utilization of the network resources and quality of service (QoS). The protocol transparency perspective has several advantages over layered protocol design where the one layer design can be designed, enhanced or even replaced without any impact on other protocol layers. But such methodology does not provide a mechanism for performance optimization between different layers which significantly degrade the network performance. The minimum hop based routing protocol has the drawback that it cannot effectively control congestion, cannot realize the load balance and also has poor fairness [2]. There is a need of designing and implementing new routing protocol and improve the performance of WMN which can meet the requirements of load balance and fault tolerant routing. The new routing protocol must be able to handle the increase in network capability while maintaining the minimum QoS guarantee.

The overall network performance may be considered by developing new protocol later as long as each protocol in each layer works as an optimal module to achieve the best network performance. The cross layer optimization is considered in protocol layering to carry out optimization decomposition [3]. The decomposition of protocol layer does not necessarily meet with the existing protocol stack which is widely adopted in WMNs. The different decomposition structures may be derived depending on the different representation of the optimization problem. This may result in different architectures for protocol layering. The critical issues must be considered for cross-layer design [4] since it has the risks due to loss of protocol layer abstraction and incompatibility with existing protocols and also unpredicted impact on the future design of the network.

The rest of the paper is organized as follows. The main ideas and research issues are discussed in the section 2. The cross layer design schemes and cross layer route metric are discussed in Section 3. The cross layer based temporarily ordered routing protocol (CL-TORA) is described in the section 4. In section 5, the performance of CL-TORA protocol is analyzed and simulated results are presented. This paper is concluded and future research work is proposed in Section 6.

II. RELATED WORK AND MOTIVATION

There have been a several research approaches of combining cross layer idea into the WMN routing protocol design. The idea has increase the utilization of the network resources to a greater extent and enhances the guarantee quality of services. In recent study [5] cross layer based proactive routing protocol CL-OLSR based on OSLR routing protocol for WMN is proposed. The protocol exploits a brand new routing metric called Cross Layer Metric (CLM) was used and it takes four impact factors into consideration. The node available bandwidth, load on the node, delivery rate and link interference were taken into account through cross layer operation mechanism for route calculation. The effect of route selection is optimized and network performance is drastically improved. Simulation experiment results demonstrate that CL-OLSR dramatically improves the network performance, efficiently increases the network throughput, reduces the end-to-end average delay, and achieves load balancing route results.

Cross layer optimization schemes and algorithms between different protocol layers are investigated with an objective of shedding light on open research problems and new approaches are covered in [6]. In this work, authors feel that even though there are many cross layer design schemes shows greater performance through simulations or prototypes but when it comes to actual implementation they face several complexities in modifying the protocols in different layers. These modifications can impact the maintainability of the software, stability of different protocol modules, and flexibility of porting codes to different platforms. They also found that the standard working mechanism in the protocol stack is broken and cross layer design can be easily be incompatible with other networks and thus, the interoperation between difficult networks is difficult to maintain. In case of layered protocol architecture, protocols in one layer can evolve separately without disrupting the functionalities of protocols in another layer. The upgrade or change in protocols must be coordinated among different protocol layers when cross layer design is adopted.

Capacity aware routing (CAR) protocol which adopted a routing metric called bottleneck link capacity was proposed in [5]. This metric can increase the network throughput and reduce the end-to-end delay to a certain degree by the cross-layer operation of considering the link interference, the link load, and other link quality information. QoS-aware routing with a congestion control and load balancing protocol (QRCCLB), which by introducing the cross layer operation considering dynamic source routing protocol in Ad hoc network as the prototype and making the network traffic bypass the networks business was proposed in [6]. In [7], a wireless fidelity Ad hoc on-demand distance vector (WiFi-AODV) routing protocol was proposed, which fully exploits the adaptive rate switching mechanism of IEEE802.11 by introducing the cross-layer mechanism, in which nodes use the data transmission rate of the physical layer as a metric and are able to establish a route with a high data rate and low transmission delay.

The cross layer design to provide frame delivery rate, extra bandwidth, and the node load of the media access control (MAC) layer for the network layer routing algorithm was proposed with an integrated metrics based extended dynamic source routing method (EDSR) in [8]. This improves the throughput rate and load balance capability of the network and satisfying users' QoS requirements by promoting the network's overall performance. These routing protocols are all proposed based on existing on-demand routing protocols of Ad hoc network, such as dynamic source routing, and Ad hoc on-demand distance vector routing. But for WMN, the network node is relatively fixed. There was no recent reactive or protocol was considered for performance study. Only node failures, as well as joining, leaving, and the uncertainty of wireless links will result in changes in the network topology. The change rate of network topology is far below the arrival rate of the data flow and the main business in WMN is the Internet business with certain delay requirements. These routing protocols have jumped out of the traditional route of taking the minimum hop as the routing metric and introduced the idea of cross-layer design. But there is a lack of systemic knowledge for the cross-layer design of WMN, in which the implementation process is complex and the practicality is low.

A. Motivation

There has been lack of systematic layered protocol architecture approach to analyze whether layering of protocols is optimal or not. The gap between theoretical methods and practical aspects of protocol design is filled with layering as optimization decomposition. The various protocol layers are integrated into single coherent theory in which asynchronous distributed computation over the network is applied to solve a global optimization problem in the form of generalized network utility maximization [9]. The optimization decomposition for generalized network utility maximization is categorized into vertical decomposition and horizontal decomposition. In vertical decomposition the entire network functionalities are decoupled into different modules such as congestion control, routing, scheduling, MAC, power control, error control, and so on. Different modules can be classified into different layers in the protocol stack. Horizontal decomposition aims at devising a distributed computation solution to individual module. More specifically, this step will work out a specific distributed mechanism and algorithm for protocols such as congestion control, scheduling, MAC, and so on.

III. CROSS LAYER DESIGN SCHEME

A. Idea behind the Protocol

The idea behind the CL-TORA protocol for WMN is based on the Temporary Ordered Routing Algorithm (TORA) protocol. CL-TORA based on [10] constitutes the idea of cross layer design and also proposes a new routing metric CLM applicable to Wireless Mesh Networks. The routing metric introduces cross layer operation mechanism which considers four cross layer factors such as node available bandwidth, node balance, link delivery rate, and link interference. The load balance and network throughput is achieved by considering these four factors. The TORA [12] attempts to achieve a high degree of scalability using a "flat", non-hierarchical routing algorithm. In its operation the algorithm attempts to suppress, to the greatest extent possible, the generation of far-reaching control message propagation. In order to achieve this, the TORA does not use a shortest path solution, an approach which is unusual for routing algorithms of this type. TORA builds and maintains a Directed Acyclic Graph (DAG) rooted at a destination. No two nodes may have the same height. Information may flow from nodes with higher heights to nodes with lower heights. Information can therefore be thought of as a fluid that may only flow downhill. By maintaining a set of totally-ordered heights at all times, TORA achieves loop-free multipath routing, as information cannot 'flow uphill' and so cross back on itself. This algorithm is relatively efficient and robust and more suitable for WMN.

B. Implementation of TORA Protocol

The distribution method is used to gather or collect the information of the available bandwidth of the node, delivery link rate, node balance and node state. The collected information is exchanged through the distributed cooperative mechanism in the neighbor discovery phase in CL-TORA. The route calculation and optimized selection is based the inferences about the link state according the results realizing the load balance of the network.

The network model is considered as a WMN consisting of N wireless mesh access points with directed edges from one node to another. The mesh access points are fixed and homogeneous in nature. They are also equipped with multiple wireless adapters and can communicate in multiple channels simultaneously. The channel allocation scheme can remain stationary in a significant of time. Each mesh access points have three additional cross layer modules, as shown in Fig. 1.

The data collection module is responsible for gathering the information about the quality of signal and links from one node to another. It also collects the node available bandwidth, node balance and link delivery rate and link interference. Statistics information module is responsible for providing data interface with different log details information for network layer routing protocols. End to end link module is responsible for a tradeoff between packet loss probability and round trip time at the transport layer.

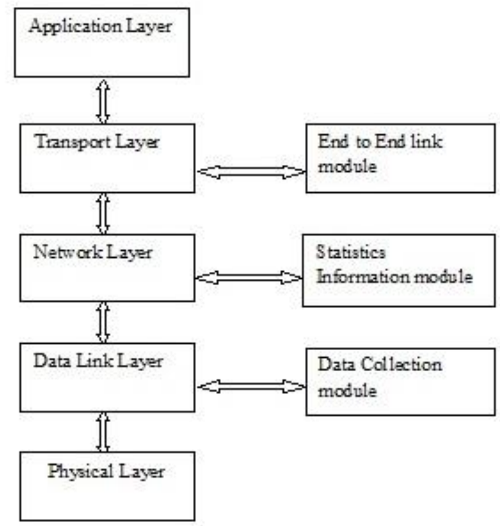


Figure 1: Cross Layer Module for CL-TORA

IV. CROSS LAYER DESIGN SCHEME

The network is modeled as a graph $G = (N, UL)$, where N is a finite set of nodes and UL is a set of initially undirected links. Each node $x \in N$ is assumed to have a unique node identifier (ID). Every link $(x, y) \in UL$ is assumed to have two-way communication. The mobility of the nodes and set of links UL keeps changing with the instant of time. The node failure is same as serving all links incident to that node and initially undirected link can have undirected or directed from node x to node y or directed from node y to node x. If link $(x, y) \in UL$ is directed from node x to node y, node x is said to be "upstream" from node y. The node y is said to be "downstream" from node x. The neighbor node z is one which has direct link $(x, z) \in UL$.

The protocol CL-TORA can be distinguished with three basic functions: forming routes, maintaining routes and erasing routes. The route is formed from a given node to the destination requires establishment of a sequence of directed links leading from the node to the destination. This is done when the initiated node with no directed links does not require route to the destination. The creating or forming a route is essentially corresponds to assigning directions to links in a undirected network or portion of the network. The adaptation of the query/reply process method is described in [14] which builds a directed acyclic graph (DAG) rooted at the destination. In case if there is a topological change in the network, reacting to it in such way that the routes to the destination are reestablished within a finite time. This is nothing but the directed portions return to a destination oriented DAG within a finite time. CL-TORA protocol makes use of three distinct control packets to carry out the three functions: (QRY), update (UPD), and clear (CLR). QRY packets are used for creating or forming routes, UPD packets are used for both forming and maintaining routes, and CLR packets are used for erasing or deleting routes.

(i)Node Available Bandwidth: The bandwidth of surplus extent of an upstream node x_i of a direct edge is calculated with available bandwidth of the node x_i to the basic data bandwidth of the Multiple Access Point. If the basic data bandwidth of a Multiple Access Point is different, then surplus bandwidth should be multiplied by a weighting factor to reflect the basic data bandwidth situation [15, 16].

(ii)Node Load: The load on a busy degree of an upstream node x_i of a direct edge is represented by the number of data packets waiting to be sent in a sending queue to the maximum length of the wait queue. In real time scenarios, the contents of the node load should be made appropriate adjustments according to specific circumstances.

(iii) Link Delivery Rate: The efficient packet delivery ratio (PDR) is denoted number of frames successfully received by the receiving node to the overall of frames sent by the sender node at MAC layer. If the frame is not received successfully due to collision or wrong checksum, the frame is considered to be lost.

(iv) Link Interference: The interference extent of a direct edge to its surrounding nodes is estimated as the number of nodes in the set of a network which may have interference with wireless transmission on the direct edge to the number of nodes contained by the largest set in the network of which the value can be estimated through the specific network environment [17,18]. Each node in the network checks the surrounding networks in its own channel and captures the node set using the existing channel to transmit in a period of time.

From the above definitions Cross Layer Metric (CLM) for CL-TORA is termed as

CLM (e) = φ (1-avaialble bandwidth) +χ node load + ψ (1-PDR) +ω Link Interference.

Where ω, ψ, χ, and φ are the weighting factors and satisfy ω, ψ, χ, and φ is equal to 1. These values are decided by the specific environment and applications.

V. PERFORMANCE ANALYSIS AND SIMULATION RESULTS

The simulation environment used to carry out simulation tests of the CL-TORA routing protocol is NS2. The multiple interfaces, adapters and channels configuration are added to extend the support in the simulations. The pointer pointing to the cross layer object is obtained by calling the lookup method of the corresponding C++ object in TCL script and then the cross layer mechanism is realized through this pointer. The performance evaluation of the CL-TORA routing protocol is compared with other three standard protocols: TORA and AODV in order to have a deep understanding of the protocols. At the end of compilation, two output files are generated- the Trace file and the NAM file (Network Animator). Trace file includes various fields thereby giving all the details of the behavior of the network created, such as the packets sent and received, drop packets, type of packet(routed or data packets), sequence number of the packet etc. NAM file gives the visual representation of the behavior of the network created.

The simulation topology consists of totally 64 nodes, where node 29 is considered as a super gateway node. The transmission range is set to 200m and the interference range is 600m. The distance between adjacent nodes is 150m. The bandwidth of the wireless link is 2 Mbps and node buffer is 50 packets. The topology change is created by adding four wireless access points in the network. These four nodes uses random waypoint mobility model where the maximum speed is 15 m/s. The simulation area is 1500mx1500m. All nodes in the networks are equipped with multiple interfaces to facilitate the outcome and do not interfere with each other. The optimal route is selected using CLM route metric while making decision at every state.

The simulation results are discussed here. The simulation result is average of test scenarios of 15 experiments with a randomly generating channel pre-distribution scheme. In all the test scenarios CL-TORA obtain better results and overall performance is good. CLM parameters of the routing metric take moderate values. The simulation experiment randomly generates 10 constant bit rate data flows and data packet size is 512 bytes. The transmission rate of the data flow is change from 2 packets/sec to 25 packets/sec and it is taken as one of the important parameter to measure network load. The analysis of variation of throughput, end to end delay and routing overhead as network load changes. The total 600 seconds is allowed run the simulation extensively. The experiments results throughput with number of nodes is shown in Fig 2.

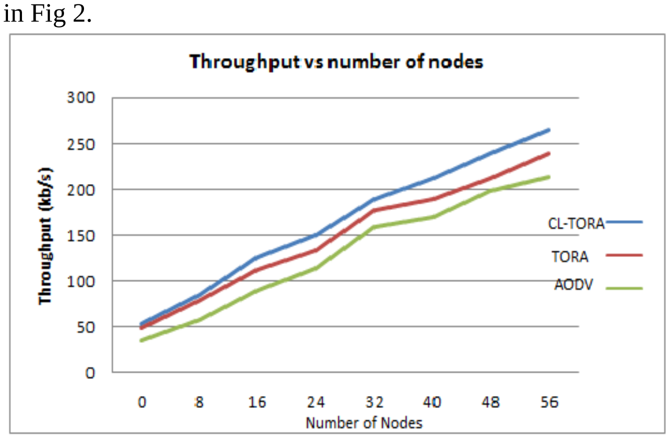
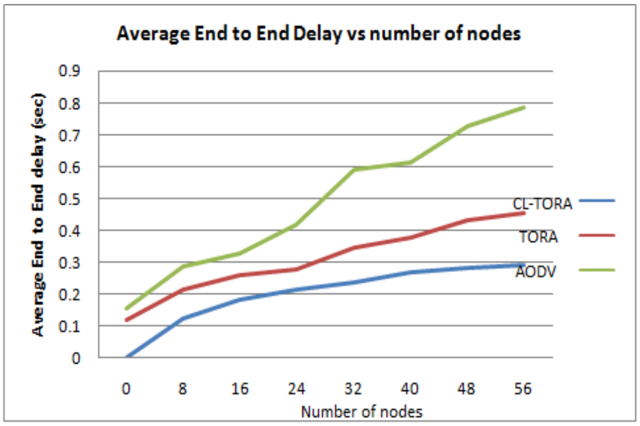


Figure 2: Throughput vs. Number of Nodes

With CL-TORA, the throughput is increased as the network size increases incrementally. With TORA, the throughput decreased, but only marginally. With AODV, the throughput



dropped significantly at network sizes greater than 32 nodes.

Figure 3: Avg End to End Delay vs. Number of Nodes

The average end to end delay for variable number of node are shown in Fig. 3. It should be noted that the delay for all three routing protocols increases with increasing number of sources. From the illustrated graph, we can see a clear advantage of CL-TORA over AODV and TORA. ADOV and TORA attained high average end to end delay as it could not perform routing protocol efficiently as the number of nodes increases in this simulation scenario.

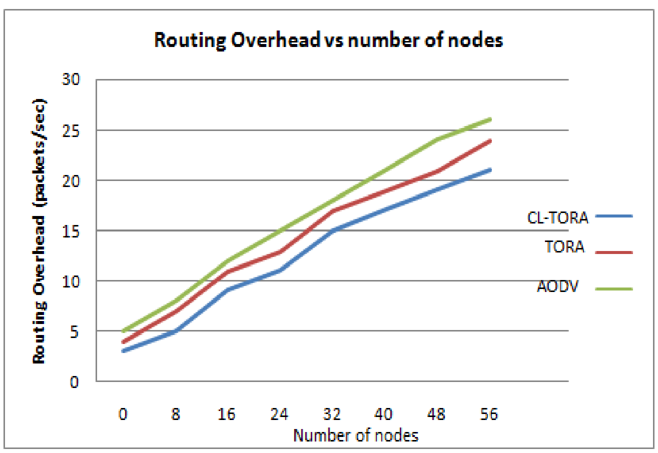


Figure 4: Routing Overhead vs. Number of Nodes

Figure 4 shows the performance of routing overhead using the same settings. At these node routing overhead, the performance of all three protocols was lower than in the beginning. The routing overhead of CL-TORA remained above low for all network sizes throughout. TORA, as well as AODV, suffered much more as network size increases, both of protocols suffered more than 50 percent of the control packets. TORA was affected heavily by mobility because it must propagate information about link state changes through the whole network. CL-TORA, in contrast, only requires local information exchange, and the early CL-TORA cross layer mechanism accelerates the convergence of the values as early as possible. Again, AODV performed the most poorly of the three, presumably due to the high overhead of route discovery broadcast messages.

VI. CONCLUSION

A cross-layer based proactive routing protocol CL-TORA is based on TORA routing protocol for WMN is proposed in this paper. We compared the performance of CL-TORA with AODV and TORA through extensive simulation experiments. In a large static mesh network scenario with 64 nodes covering an area of 1.5 km by 1.5 km, we found that both CL-TORA and TORA achieved good throughput, whereas AODV did not reach more. To evaluate the performance in mobile scenarios, we used a random waypoint mobility model and with nodes moving at different speed, CL-TORA outperformed both AODV and TORA in terms of throughput by more than a factor of two. Because the number of gateways determines the cost of a mesh network to a large extent, we evaluated how many gateways are required to throughput. CL-TORA protocol exploits a brand-new routing metric called CLM, which takes into account four impact factors: the node available bandwidth, the node load, the link delivery rate, and the link interference, through the cross-layer operation mechanism in route calculation. Thus the effect of route selection is optimized. Simulation experiment results demonstrate that CL-TORA dramatically improves the network performance, efficiently increases the network throughput, reduces the end-to-end average delay, and achieves load balancing route results to some extent.

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