Characterizing Medium Access Control (MAC) Layer in Multi-hop Wireless Mesh Network

[#] V.R Gannapathy, M.S.Zakaria, M.Muhammad, N.M Salleh, M.K Suaidi, M.S Johal, M.Z.A Abdul Aziz, M.R Ahmad

Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka

(GVnesh@gmail.com, Sharim84@gmail.com, mawaddah84@gmail.com, eikin_814@yahoo.com, kadim@utem.edu.my, syahrir@utem.edu.my, mohamadzoinol@utem.edu.my, dwen9460@gmail.com)

Abstract - *The wireless mesh network (WMNs) has been an emerging technology in recent years. WMN is characterized by dynamic self-organization, self configuration and self healing to enable quick deployment, easy maintenance, low cost, high scalability and reliable service as well as enhancing network capacity, connectivity and resilience. Some of these characteristic are depend on MAC protocol. This is because in WMNs the MAC layer concerns with more than one hop communication (Multi-hop). Multi-hop communication is common in WMNs. For multi-hop networking, it is well known that communication protocols suffer from scalability issues; when the size of the network increases, the network performances degrades significantly. Network self-organization is needed for MAC in WMNs because it should have the knowledge about network topology which can help better cooperative between neighboring nodes. This network self-organization can significantly improve the MAC performance in a multi-hop environment. Other than these issues, because of their dynamic characteristic, there is difficulty to design the MAC protocol for WMNs. The current MAC protocol and its derivatives cannot achieve a reasonable throughput as the number of hops increases in WMNs. So, this paper will focus on medium access control layers design of wireless mesh network protocol which was proposed by the researcher in order to improve end-to-end throughput and highlights key challenges that need to be addressed in the design of a cut-through MAC for multi-hop wireless mesh networks.*

Keywords – ***Wireless Mesh Network, IEEE 802.11 Distributed Coordination Function (DCF), Medium Access Control (MAC).***

1. INTRODUCTION

Nowadays, the development of next-generation wireless systems aims to provide high data rates in excess of 1 Gbps. The capability of enhancing coverage and capacity with low transmission power, wireless mesh networks (WMNs) play a significant role for broadband access with ubiquitous coverage. WMNs have emerged as a key technology for next-generation wireless networking. Because of their advantages over other wireless networks, WMNs are undergoing rapid progress and inspiring numerous applications. However, many technical issues still exist in this multi-hop communication field [2]. A common problem in multihop communication is hidden stations. The presence of hidden stations may result in significant network performance degradation and causes unfairness in accessing the medium because a station's location may result in a larger transmission privilege. The hidden station problem occurs when a station is causing interference due to not been able to detect the existence of a transmission from another station and thus assumes that the medium is free and available to transmit. As an example, let's assume that stations A and B are within communication range of each other and station C is within communication range of station B but not Of A. Therefore, it is possible that both Stations A and C could try to transmit to station B at the same time causing a collision. The influence of hidden stations on the performance of an IEEE 802.11 network has been studied [15]. Using the IEEE 802.11 Distributed Coordination Function (DCF) [16] as the MAC protocol for wireless LAN multi-hop networks has been shown to result in sub-optimal performance. This is because the broadcast nature of the wireless medium creates inter-flow as well as intra-flow interferences [17]. Solutions to this problem have focused on two main approaches such as modifying the MAC layer (e.g. [18], [19]) and increasing the number of interfaces available to mesh routers [20].

2. IEEE 802.11 MAC PROTOCOL

In the 802.11 protocol, the fundamental mechanism to access the medium is called distributed coordination function (DCF). In the distributed coordinating function (DCF) of the IEEE 802.11 MAC protocol, coordination of channel access for contending nodes is achieved with carrier sense multiple access with collision avoidance (CSMA/CA). Its design attempts to ensure a relatively fair access to the medium for all participants of the protocol. Retransmission of collided packets is managed according to binary exponential back-off rules. DCF describes two techniques to employ for packet transmission. The first technique is known as a two-way handshaking technique where it is also a default scheme. This scheme is called as a basic access scheme where it is characterized by the immediate transmission of a positive acknowledgement (ACK) by the destination station, upon successful reception of a packet transmitted by the sender station. This positive ACK is required in the wireless medium because a transmitter cannot determine whether a packet is successfully received by destination station or not. In later time, this basic access was upgraded to optional four way handshaking technique, also known as request-to-send/clear-to-send (RTS/CTS) mechanism. According to this mechanism, before the station transmitting a packet, it will reserve the channel by sending a special Request-To-Send short frame. The destination station acknowledges the receipt of an RTS frame by sending back a Clear-To-Send frame. Since the RTS/CTS mechanism can solve the hidden problem in multi-hop communication, so this mechanism is widely implement in wireless mesh network.

3. IMPROVING MAC PROTOCOLS

Currently several MAC protocols have been proposed for multi-hop ad hoc networks by enhancing the CSMA/CA protocol [2, 3]. These schemes usually adjust parameters of CSMA/CA such as contention window size and modify back off procedures. They may improve throughput for one-hop communications. However, for multi-hop cases such as in WMNs, these solutions still reach a low end-to-end throughput, because they cannot significantly reduce the probability of contentions among neighboring nodes. As long as contention occurs frequently, whichever method is take to modify back off and contention resolution procedures, the end to- end throughput will be significantly reduced due to the accumulating effect on the multi-hop path. In order to fundamentally resolve the issue of low end to- end throughput in a multi-hop ad hoc environment such as WMNs, innovative solutions are necessary. Determined by their poor scalability in an ad hoc multi-hop network, random access protocols such as CSMA/CA are not an efficient solution. Thus, revisiting the design of MAC protocols based on TDMA or CDMA is an important research topic as proposed in [2, 4]. To date, few TDMA or CDMA MAC protocols have been proposed for WMNs. This is probably because of two factors such as the *complexity* and cost of developing a distributed and cooperative MAC with TDMA or CDMA. The other is the *compatibility* of TDMA or CDMA MAC with existing MAC protocols. For WMNs, TDMA MAC protocols are usually difficult to implement because network nodes are not accurately synchronized. Without enough accuracy in timing synchronization, a large percentage of bandwidth must be used as guard time in TDMA MAC. In WMNs based on IEEE 802.11, how to design a distributed TDMA MAC protocol overlaying CSMA/CA is an interesting but it also challenging problem [2]. For distributed TDMA or CDMA MAC protocols, network self-organization based on topology control and/or power control must also be considered.

4. CROSS-LAYER DESIGN

Cross-layer design can be performed in two ways [2]. The first way is to improve the performance of a protocol layer by taking account parameters in other protocol layers. The second way of cross-layer design is to merge several protocols into one component. The second way can achieve much better performance by considering an optimized interaction between protocol layers. However, Cross-layer design can significantly improve network performance as mentioned and proved by author R. Bhatia in [7]. In WMNs, network topology constantly changes due to mobility and link failures in mesh network. Such dynamic network topology impacts multiple protocol layers. Thus, in order to improve protocol efficiency, cross-layer design becomes indispensable. There are two types of interaction that can be considered in cross layer design approach, which were called Variable Interaction and Algorithmic Interaction [8]. Variable Interaction between two factors is said to exist when effect of a factor on the response variable can be modified by another factor in a significant way. Alternatively, in the presence of this interaction, the mean differences between the levels of one factor are not constant across levels of the other factor. The absence and the presence of this variable interaction had been proved in this paper. Meanwhile, algorithmic interaction exists between two protocols (algorithms) operating at individual transceiver nodes of a communication network. Here the author use the word interaction to mean that the behavior (semantics) of a protocol at a given layer in the protocol stack varies significantly depending upon the protocols above or below it in the protocol stack. The author had illustrated this interaction via the simulation experiment [8]. The performance of the protocol is measured in term of various qualities of service measures including latency, throughput, and number of packet that received and also long term fairness. In this paper three different commonly studied protocols are used are Ad-Hoc On-demand Distance Vector Routing (AODV), Dynamic Source Routing (DSR) and Location Aided Routing (LAR) scheme1 and for MAC protocols that were used are MACA, 802.11 and CSMA. These protocols need to fulfill a designed and functional requirement including high throughput, low average latency, heterogeneous traffic such as (data, voice and video), preservation of packet order and also support for priority traffic. So, this paper characterized the interaction between the MAC and the routing protocol that also called as cross layer approach in order to provide better throughput. Such interactions demand a cross-layer design among different protocols. In paper [10], the authors proposed a novel scheme for route selection that, by using cross-layer interactions that will improve throughput performance. Whenever a source node requires a route to reach a destination node, this proposed scheme determines the best source-destination path based on the MAC parameters such as the collision probability and the available bandwidth. It meant that, the scheme selects the route with the lowest collision probability and, among routes with about the same collision probability; it selects the one with the highest available bandwidth. Thus, by exploiting the synergy between network layer and MAC layer, the author mentioned that the route providing the highest throughput is selected.

5. CONCLUSION

Although WMNs can be built up based on existing technologies, field trials and experiments with existing WMNs prove that the performance of WMNs is still far below expectations. As explained throughout this article, there still remain many research problems. In this paper, we focus on IEEE 802.11 MAC protocol in wireless mesh network. According to papers that were reviewed, all authors mentioned and proved that the IEEE 802.11 MAC protocol is not the standard for WMN. Although it can support some kind of *ad hoc* network architecture, which only means a distributed networking as opposed to a centralized one, it is not intended to support the WMN, in which multi-hop connectivity is one of the most prominent features. As we discussed in this papers, CSMA/CA did not function well in a wireless multi-hop environment. The causes include the hidden terminal problem, exposed terminal problem and binary exponential backoff scheme, which results in transmission problems much worse in wireless multi-hop networks. The backhaul networking needs capacity, throughput, latency, and reach guarantee. Therefore, the mechanism of CSMA/CA must be enhanced if it is to be running in wireless mesh networks. Other than that, we also indicate the specific problems existing in this protocol when it is used in a multi-hop network. Based on this analysis, we point out the potential direction to resolve those problems.

REFERENCES

[1] Byung-Jae Kwak, Nah-Oak Song, *Member, IEEE*, and Leonard E. Miller, *Senior Member, IEEE*. "Performance Analysis of Exponential Backoff " IEEE/ACM Transactions On Networking Editor Z. Haas.

[2] Ian F. Akyildiz , Xudong Wang , Weilin Wang, "Wireless mesh networks: a survey" IEEE Computer Networks 47, (2005) , pp. 445–487

[3] F. Cali, M. Conti, E. Gregori, Dynamic tuning of the IEEE 802.11 protocols to achieve a theoretical throughput limit, IEEE/ACM Transactions on Networking 8 (6) (2000) 785–799.

[4] J.W. Kim, N. Bambos, Power efficient MAC scheme using channel probing in multirate wireless ad hoc networks, in: IEEE Vehicular Technology Conference, 2002, pp. 2380–2384.

[5] S. Xu, T. Saadawi, Does the IEEE 802.11 MAC protocol work well in multihop wireless ad hoc networks? IEEE Commun. Mag. (2001) 130–137.

[6] H.-Y. Hsieh, R. Sivakumar, IEEE 802.11 over Multi-hop Wireless Networks: Problems and new Perspectives, Proceedings of IEEE VTC 2002 Fall, September 2002.

[7] R. Bhatia, M. Kodialam, "On power efficient communication over multi-hop wireless networks: joint routing, scheduling, and power control", in: IEEE Annual Conference on Computer Communications (INFOCOM), 2004, pp. 1457–1466.

[8] Chris Barrett, Martin Drozda, Achla Marathe and Madhav V. Marathe,"Characterizing the interaction Between Routing and MAC Protocol in Ad-Hoc Network" in MOBIHOC'02.

[9] Vivek P.Mhatre, Henrik Lundgren, Christophe Diot. "MAC-Aware Routing in wireless Mesh Network", 2007, pp. 46-49

[10] C.-F. Chiasserini and M.Meo, " An Innovative Routing Scheme for 802.11- based multi-hop Network". Vehicular Technology Conference, 2004.

[11] Y. Hu, A. Perrig, D. Johnson, Packet leashes: a defense against wormhole attacks in wireless networks, in: IEEE Annual Conference on Computer Communications (INFOCOM), 2003, pp. 1976–1986.

[12] L. Huang, T. Lai, On the scalability of IEEE 802.11 ad hoc networks, in: ACM International Symposium on Mobile Ad Hoc Networking and Computing (MOBIHOC), 2002, pp. 173–182.

[13] J. So and N. Vaidya, "Multi-Channel MAC for ad hoc Networks: Handling Multi-Channel Hidden Terminals using a Single Transceiver," *ACM Int'l. Symp. Mobile Ad Hoc Net. and Comp. (MOBIHOC)*, May 2004, pp.222–33.

[14] A. Adya *et al.*, "A Multi-Radio Unification Protocol for IEEE 802.11 Wireless Networks," *Int'l. Conf. Broadband Networks (BroadNets)*, 2004.

[15] K.Huang, K.Chen. "Interference Analysis of Nonpersistent CStvlA with Hidden Terminals in Multicell Wireless Data Networks", Proc. PIMRC, Toronto, pp.907-911, 1995.

[16] IEEE, *Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*, Std. 802.11-1999, August 1999.

[17] K. Xu, M. Gerla, and S. Bae, "Effectiveness of RTS/CTS Handshake in IEEE 802.11 based Ad Hoc Networks," *Ad Hoc Networks*, vol. 1, no. 1, pp. 107–123, 2003.

[18] A. Acharya, A. Misra, and S. Bansal, "MACA-P: A MAC for Concurrent Transmissions in Multi- Hop Wireless Networks," in *IEEE PerCom 2003*, Texas, USA, March 2003.

[19] X. Yang and N. H. Vaidya, "A Wireless MAC Protocol Using Implicit Pipelining," *IEEE Trans on Mobile Computing*, vol.5, no. 3, pp. 258– 273, 2006.

[20] A. Raniwala and T. Chiueh, "Architecture and Algorithms for an IEEE 802.11-based Multi channel Wireless Mesh Network," in *IEEE Infocom 2005*, Miami, USA, March 2005.