2011 IEEE 10th Malaysia International Conference on Communications (MICC)
2nd – 5th October 2011 | Sutera Harbour Resort, Kota Kinabalu, Sabah, Malaysia

A Smooth Forwarding Operation in Wireless Mesh Network

Vigneswara Rao Gannapathy* , Mohamad Kadim Bin Haji Suaidi*, Muhammad Syahrir Bin Johal*, Lim Kim Chuan*, Nordin Bin Ramli†, Hafizal Mohamad†
*Faculty of Electronics and Computer Engineering (FKEKK), Universiti Teknikal Malaysia Melaka (UTeM), Melaka, Malaysia, Email: vigneswara@utem.edu.my
†Wireless Network & Protocol Research (WNPR), Wireless Communication Cluster, MIMOS Berhad, Technology Park Malaysia, 57000 Kuala Lumpur, Malaysia
Email: nordin.ramli@mimos.my

***Abstract*—The IEEE 802.11 Distributed Coordination Function (DCF) Medium Access Control (MAC) protocol is designed to efficiently facilitate the limited communication bandwidth of wireless channel. This protocol uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism. This mechanism continues suffer from throughput degradation when directly applied in multihop Wireless Mesh Network (WMN). The major reason for this poor performance is due to larger signaling overheads (RTS and CTS signaling packet) introduced in order to forward a single data packet in multihop WMN. This inefficient forwarding operation caused the throughput degradation significantly. Therefore, an efficient forwarding operation is proposed in this paper to reduce the amount of signaling overheads which are needed to forward a single packet in multihop WMN. The proposed protocol uses the capability of overhearing in order to forward the data packet from one hop to another hop. This process will continue until the data packet reaches the respective destination. As a result, the enhanced protocol reduces the latency caused by signaling thus improve its throughput in multihop WMN. The multihop network performances are evaluated analytically in terms of throughput and delay. Through the simulation, it is proven that the proposed protocol provides significant improvement in throughput and delay. The results show that the proposed protocol outperforms the existing IEEE DCF MAC protocol when it is evaluated in multihop WMN.**
Keywords: Medium Access Control (MAC) protocol; Signaling Overheads; Multihop Wireless Mesh Network (WMN)

I. Introduction

Wireless communication between network nodes has become more popular in recent years and has been integrated into peoples daily life, e.g. wireless internet connection, hands free and etc. Wireless Mesh Network (WMN) is a wireless communication network that consists of network nodes connected in mesh-style topology. It become an emerging technology and plays an important role in the next generation wireless communication. WMN architecture is built based on the principles of multihop communication with addition of mesh topology to link all the nodes inside the network.

Medium Access Control (MAC) protocols employed in multihop WMNs to resolve contentions for accessing the shared medium which is encountered many issues especially exposed node problems in multihop communications [1], [2]. Apart from that as the number of hops in WMNs increases, the optimal overall throughput of existing MAC protocol and its derivatives are not achievable. So, the enhancements of the existing IEEE 802.11 Distributed Coordination Function (DCF) MAC protocol have been proposed in this work. Since the source node in WMN relaying its data packets over multiple hops until reach destination node, the large number of overhead due to signaling at each intermediate hop will degrade the throughput significantly. In this paper, we are focusing on how to reduce the large signaling overhead problems in multihop networks with high traffic scenario. This can be done by reducing the number of signaling packets needed at intermediate hops until the data packet reaches its destination in multihop WMNs. This approach is expected to reduce the signaling overheads thus improve the performance significantly.

The rest of this paper is organized as follows. Section II presents the problem definition and the network model of the proposed system is presents in Section III. Then section V describes the proposed operations and section VI presents the performance model. Section VI explains the performance results and conclusion are given in Section VII.

II. Problem Definition

One of the reasons behind throughput degradation in multihop communication is number of signaling packet that required when transmitting a data packet from one node to destination via multiple intermediate nodes. As shown in Fig. 1, lets consider source node A has data packet to be transmitted to destination node E. Since node E does not include node As transmission range, node A has to transfer its data packet via some intermediate to reach its destination. In this case, the data packet must go through three intermediate nodes, which are node B, node C and node D in order to reach the destination. When the existing MAC protocol employ in this type of multihop communication, the four way signaling handshake (i.e RTS/CTS/ACK/DATA) will be performed at every each intermediate nodes thus increasing the delay and reduce throughput. This is the nature of IEEE 802.11 MAC protocol that is initially designed for single hop transmission in mind. However, this approach degrades the throughput of WMN significantly.

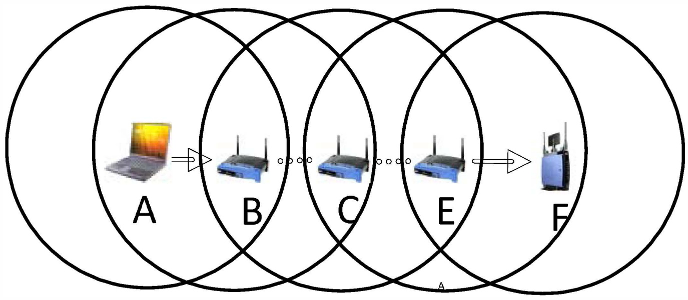

Fig. 1: Multihop transmission via intermediate nodes.

The amount of signaling packets is needed to transmit a single data packet in multihop network increase proportionally with number of hops. The latency caused by signaling overhead will drop the throughput significantly. A smooth and efficient data forwarding operation is require in order to improve the throughput in multihop WMN. This will reduce the signaling overhead thus improve the throughput accordingly. Therefore, an enhanced MAC protocol which is efficiently forward the data packet is introduced and presented in this paper. In our approach the RTS and CTS signaling exchange is only occurred at first hop when the node contending for the shared channel. Whereas at the subsequent hops, it will initiates its transmission according to the proposed technique and reduce the signaling overheads.

III. Network Model

The network we considered consists of n mesh routers, mesh clients and gateways. Gateways to the Internet are chosen from a set of n mesh routers. The other mesh routers are referred as intermediate mesh routers which is expanding the network coverage and providing reliable links to gateways. The network topology is shown in Fig. 2.

Each mesh router is equipped with single interface except the gateway (another interface to Internet) and has a common transmission range, r. Both the mesh clients and mesh routers use the same physical layer (PHY) frequency band by which in this work we consider the use of IEEE 802.11 PHY [3]. The transmission rate is constant and packets are forwarded in a multihop fashion to the gateway. For ease of explanation and without loss of generality, we consider unidirectional traffic, i.e., traffic only going from mesh nodes to the gateway.

We assume that each mesh router has a fixed transmission rate at 54 Mbps and range of 100 meters. Thus only two routers can set up a link (i.e within communication range) and communicate between them whenever possible. As for the mesh clients, some of them are associated to a certain mesh router forming a cell.

IV. Protocol Description

The novelty of the proposed protocol compared to the existing IEEE 802.11 MAC is its efficiency in forwarding the data packet in collision free manner. This approach reduces the amount of signaling overhead when the nodes relays the data packet to the nearest gateway in multihop fashion.

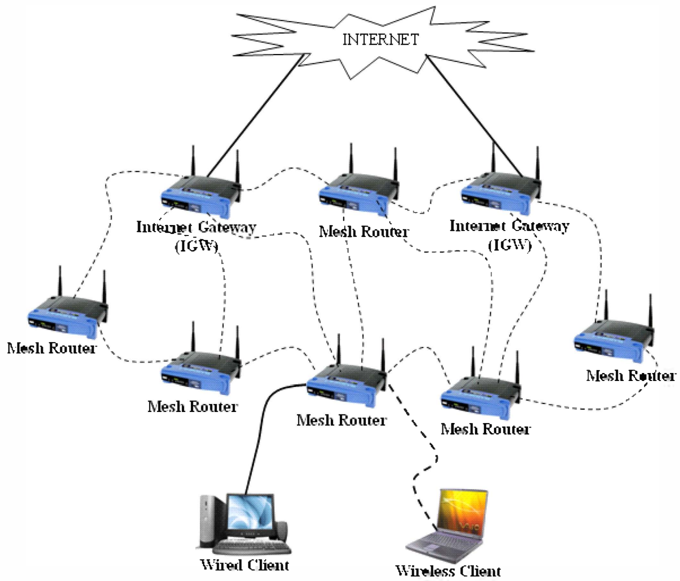

Fig. 2: The network topology of multihop wireless mesh network.

In this paper, we have proposed a simple enhancement to existing 802.11 MAC to reduce the amount of signaling packet that require at each intermediate nodes. Since every each node in the network has the omnidirectional characteristic, thus they can overhear the transmission activity which is going on around them. This advantage is used to convey the data packet to subsequent nodes.

Figure 3 illustrated the forwarding operation of proposed protocol. As shown in this figure, the data packet from client A has to be relayed via some intermediate nodes until it reaches its nearest internet gateway (i.e. node n). According to proposed protocol, the mRTS and mCTS signaling exchange only will be performed at first hop when the source node initiates the transmission. This exchange is requires to get a access to the channel. Upon successful transmission at first hop, the data packet will be relayed through subsequent relaying nodes to IGW_1 without require the mRTS control packet. Thus, in this protocol, the mRTS packet that suppose sent by subsequent relaying nodes can be suppressed accordingly.

Let assume node A will broadcast the mRTS control packet to start its transmission to node B. Next, node B will permit this transmission by responding the mCTS control packet back to it. Due to the overhearing capability, each of the neighboring nodes in the vicinity of node B (i.e. node C) will overhear this mCTS control packet. In order to identify the next relaying node, the R_{ID} mechanism is applied in this protocol. According to the MAC addresses and R_{ID} that contain in mCTS control packet, node C is able to recognize the next relaying node for that respective data packet. Thus, once node C overhears mCTS control packet, it will activate the timer to send the invitation and asked for the data packet to be forwarded (will explain in next paragraph). The timer will be activated to be equal to the time taken by node B to receive the $DATA$ packet from its upstream node and until it transmits mACK packet. All the neighboring nodes (in the vicinity of the node B) will be notified on upcoming forwarding operation through the mACK packet which is sent by node B at the end of its transmission.

The nodes which overhear the mACK packet merely increase the duration of its NAV based on the $Duration/ID$ field in that mACK packet to reserve the channel for subsequent forwarding operation. The increment duration will indicate for how long the nodes should further defer the transmissions on the channel. This NAV increment also performs by the target of the mACK (i.e. upstream node, node A). Thus, once node A received the mACK packet from node B, so it will increase its NAV duration and will remain silent until entire forwarding process (from node B to node C) completes. It will be set, to be equal to time taken for the transmission of mCTS, $DATA$, and mACK packets, plus three $SIFS$ intervals. Based on R_{ID} information in the mACK packet, the node C will aware that the corresponding mACK packet is from its upstream node and will refrain from increasing its NAV duration, thus continue decreasing its timer. Upon timeout, the node C will broadcast its mCTS control packet to send the invitation to the node B to forward the data packet. All other nodes which overhear the mCTS control packet (the nodes in the vicinity of node C) will updates their respective NAV and will remain until the entire forwarding process completes. Similarly, the next corresponding relaying node (i.e. node D) will overhear this mCTS control packet sent by node C and will activate its timer accordingly. The timer will be activated to be equal to the time taken by node C to receive the data packet from its upstream node and until it transmits mACK packet. Upon the timer expires, node D will send the mCTS control packet to invites the node C to forward the data packet. This mechanism continues to repeat at each intermediate relaying nodes until it reach the gateways (i.e. n). Thus, the mRTS packet that suppose sent by sender node can be suppressed.

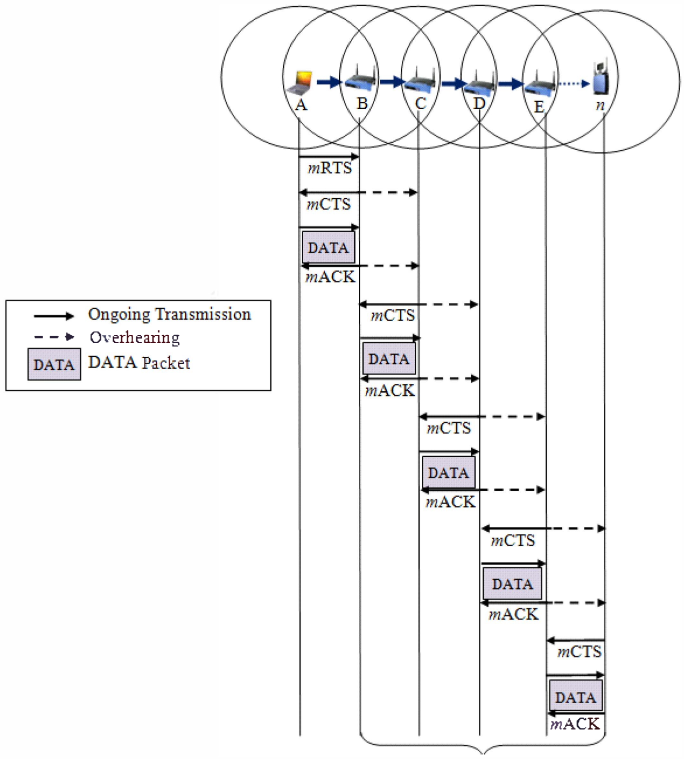

Fig. 3: Message sequence diagram for the proposed efficient forwarding operation.

V. Performance Modeling

In this section, analytical models are developed and analyzed for IEEE 802.11 protocol [4] and the proposed protocol. The models are evaluated in terms of throughput and delay of the system. The delay is defined as the time consumes while the data packets travel from the source nodes (mesh clients) to destination nodes (gateways). Also the delay term includes inter-frame space (IFS), back-off time and transmission time of all signaling frames.

In order to get the maximum throughput of the system, the MAC Service Data Unit (MSDU or $Payload_{SIZE}$) must be divided with the total $delay\_per\_payload(Delay)$. Therefore the throughput provided at MAC layer can be given as:

$$MAC_{Throughput} = \frac{Payload_{SIZE}}{Delay} \qquad (1)$$

The $delay\_per\_payload$ is given as

$$Delay\_per\_payload = T_{DIFS} + Backoff\_Interval + T_{RTS} + T_{SIFS} + T_{CTS} + T_{SIFS} + T_{DATA} + T_{SIFS} + T_{ACK} \qquad (2)$$

where, the definitions of T_{DIFS}, $Backoff\_Interval$, T_{RTS}, T_{SIFS}, T_{CTS}, T_{SIFS}, T_{DATA}, T_{SIFS}, and T_{ACK} are given in Table I, respectively. . The times taken for the signaling packets RTS, CTS and ACK are given as:

$$T_{RTS} = T_{Preamble} + T_{Signal} + T_{SYM} \times \frac{L_{Service} + L_{Tail} + 8 \times L_{RTS}}{N_{DBPS}} + T_{EX} \qquad (3)$$

$$T_{ACK} = T_{Preamble} + T_{Signal} + T_{SYM} \times \frac{L_{Service} + L_{Tail} + 8 \times L_{RTS}}{N_{DBPS}} + T_{EX} \qquad (4)$$

$$T_{CTS} = T_{Preamble} + T_{Signal} + T_{SYM} \times \frac{L_{Service} + L_{Tail} + 8 \times L_{RTS}}{N_{DBPS}} + T_{EX} \qquad (5)$$

The time taken to transmit DATA packet is given as:

$$T_{DATA} = T_{Preamble} + T_{Signal} + T_{SYM} \times \frac{L_{Service} + L_{Tail} + 8 \times (L_{MAC} + Payload)}{N_{DBPS}} + T_{EX} \qquad (6)$$

TABLE I: IEEE 802.11g Parameters [3]

Parameters	Value	Description
$T_{Preamble}$	16 μs	Preamble Time
T_{Signal}	4 μs	Signal Time
$T_{Service}$	16 μs	Length of Service
T_{Slot}	9 μs	Slot Time
T_{SIFS}	10 μs	Short Inter Frame Space
T_{DIFS}	28 μs	DCF Inter Frame Space
T_{SYS}	4 μs	System Time
T_{EX}	6 μs	Extension Time
T_{Tail}	6 bits	Length of Tail
T_{ACK}	14 bytes	Length of Acknowledgement Packet
T_{CTS}	14 bytes	Length of Clear to Send Packet
T_{RTS}	20 bytes	Length of Request to Send Packet
T_{MAC}	34 bytes	Length of MAC Frame
CW	15 ~ 1023	Range of Contention Window

Thus the total delay per payload can be simplified as a function of payload size (χ) in bytes:

$$Delay\_per\_Payload(\chi) = [(a\chi + b) + c]\mu s \tag{7}$$

where $a\chi + b$ is the delay component for DATA packet and c is delay component for summation of signaling period, IFS and back-off period.

Therefore, we can get $MAC_{Throughput}$ as a function of payload size (χ) by simply divide the number of payload (in bits) by the total delay which is given as follow:

$$MAC_{Throughput}(\chi) = \frac{8 \times \chi}{[(a\chi + b) + c]} \times Mbps \tag{8}$$

By using Equation (8), we can execute the performance analysis for the following related models. Table I gives all the related system parameters.

VI. Simulation Study and Results

We investigate the performance of the proposed scheme through computer simulations. The simulation conditions are shown in Table I. In this simulation, both the length of RTS and CTS packets, L_{RTS} and L_{CTS}, respectively different for every each model. The proposed method define $L_{RTS} = L_{CTS} = 32$ bytes. The length of these control frames vary for each model due to the different approaches and modification that have been done for each protocol. The standard lengths for IEEE 802.11 MAC are as defined in the Table I.

Figure 4 and 5 depicts the variation of delay and throughput as a function of number of hops respectively. It can be observed from both results that the proposed protocol outperforms IEEE 802.11 MAC protocol. As depicts in Fig. 4, the delay which is consumed by the proposed protocol to transmit the data packet from source to destination is 7.37 ms, meanwhile the delay consumed by the existing protocol to transmit its data packet from source to destination is 8.27 ms. This is shows that the proposed protocol can reduce the delay approximately 10.88 % when it transmit its data packet through 10 hops.

Moreover as depicts in Fig. 5, the throughput which is achieved by the proposed protocol in order to transmit the data packet through 10 hops is 2.9 Mbps, meanwhile the throughput

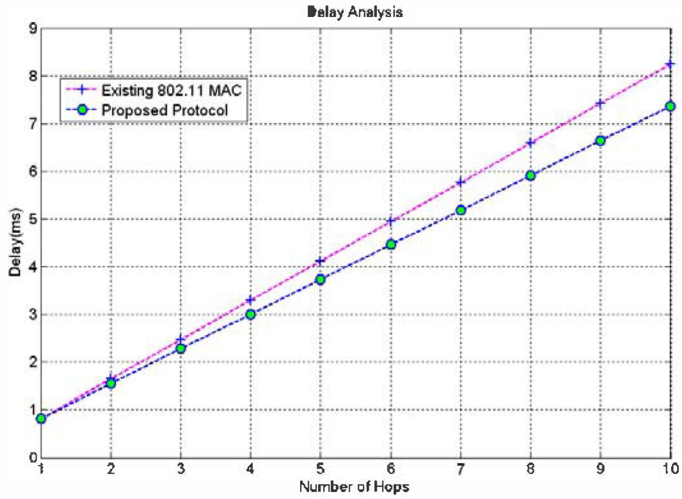

Fig. 4: Delay analysis.

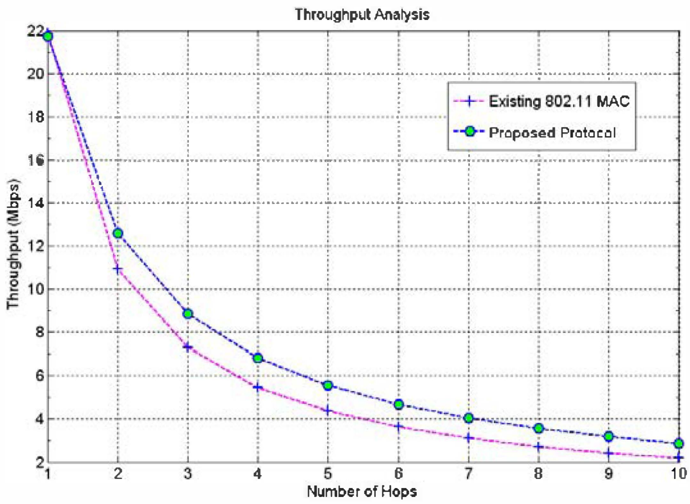

Fig. 5: Throughput analysis.

achieved by existing protocol is only 2.1 Mbps. Thus, it is shown that the proposed protocol can improve the throughput approximately 38.1%. Since the existing IEEE 802.11 MAC was designed with one hop communication in mind, it suffers throughput degradation when applied for multihop topology as shown in Fig. 3. This observation is due to the smaller delay per payload which is experienced by proposed protocol. Moreover the proposed protocol outperforms the existing when number of hops increasing as shown in Fig. 4 and 5, respectively. Obviously this observation shows that the proposed protocol reduced the delay caused by signaling overhead.

VII. Conclusion

By presenting the problem encountered in an IEEE 802.11-based multihop network, it can be concluded the current version of this MAC protocol does not function well in multihop WMNs. In order to overcome the problem, we have proposed an efficient forwarding operation to forward the data packet with a fewer signaling overhead. Therefore, a set of enhancement to the existing IEEE 802.11 DCF MAC was introduced to reduce the amount of signaling overhead required at every hop until the data packet reaches its destination. The analytical models were developed and the multihop WMN performances are evaluated in terms of throughput and delay. It proven that proposed protocol outperforms the existing IEEE MAC protocol in throughput of multihop WMN.

ACKNOWLEDGEMENT

The authors would like to take this opportunity to thanks those who are contributes directly or indirectly in completion of this article and also for their constructive comments

REFERENCES

[1] I. Akyildiz and X. Wang, "A survey on wireless mesh networks, IEEE Communications Magazine, vol. 43, pp. 2330, Sept. 2005.

[2] I. F. Akyildiz, X. Wang and Weilin Wang, Wireless Mesh Networks: A Survey, Computer Networks Journal, 2005.

[3] ANSI/IEEE, 802.11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, 2003.

[4] J. Jun, P. Peddabachagari, and M. Sichitiu, Theoretical maximum throughput of ieee 802.11 and its applications, in The 2nd IEEE International Symposium on Network Computing and Applications NCA, Apr.2003.