QoS improvement in Mesh networks using Adaptive Channel Assignment, Scheduling and Routing protocols

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Abstract

In wireless mesh networks (WMNs) the most widely used random channel access mechanisms are IEEE 802.11 DCF and EDCA. These two mechanisms are based on CSMA/CA and inefficient to eliminate effectively hidden terminal and exposed terminal problems. In this paper, we propose a set of efficient multi-radio multi-channel (MRMC) assignment, scheduling and routing protocols based on Latin squares for WMNs with MRMC communication capabilities, called ''M4'', i.e., the Multiple access scheduling in Multi-radio Multi-channel Mesh networking. M4 uses nodal interference information to form cliques for inter-cluster and intra-cluster in WMNs, and then applies Latin squares to map the clique-based clustering structure to radios and channels for communication purposes. The M4 again uses Latin squares to schedule the channel access among nodes within each cluster in a collision-free manner. We also design the corresponding MRMC routing to support M4 communication. Simulation results show that M4 achieves much better performance than other channel access control protocols.

Keywords: Wireless mesh networks, Hidden terminal and Exposed terminal problems, Multi-radio multi-channel, Latin squares.

1. Introduction

The CSMA/CA [1] based IEEE 802.11 MAC protocols include three coordination functions, DCF (distributed coordination function), PCF (point coordination function) and EDCA (enhanced distributed channel access) [2]. Unfortunately, due to overwhelming network congestion and severe hidden-terminal interference [3] in multi-hop wireless mesh networks (WMNs), these mechanisms are unable to guarantee basic data services. The scheduled and traffic-adaptive channel access mechanisms are required than the simplistic CSMA/CA mechanisms in current IEEE 802.11 MAC protocols.

Multiple non-overlapping channels are available in each of the IEEE 802.11 communication standards a/b/g—around three at 2.4 GHz band, and thirty at 5 GHz band [1]. Nodes equipped with multiple radios can communicate with multiple neighbors simultaneously over non-overlapping channels. Therefore, MRMC could reduce interference and increase network capacity. WMNs with single-radio multi-channel (SRMC) capabilities were addressed in [4], and WMNs with multi-radio multi-channels (MRMC) were addressed in [5].

As nodes in a WMN are increasingly equipped with multiple radio interface cards to harvest the full capacity of the channels, practical and efficient channel allocation and switching mechanisms are highly desirable to continue the success of IEEE 802.11 networks. Clustering in WMNs with MRMC capabilities could handle the network partition for dynamic radio/channel assignments, and facilitate radio/channel negotiation for data communications. In [6], the connectivity-based k-hop clustering problems have been addressed.

Multi-hop connectivity and radio/channel selection in a route could influence the communication quality, due to the scheduling features of multi-radio multichannel WMNs. Corresponding routing protocols are desired to choose the valid radio and channel to support efficient data forwarding path. Topology control and flow control for MRMC wireless networks were considered in [7, 8]. Joint design of channel assignment and routing for MRMC wireless mesh networks were discussed in [9]. Multicasting for multi-channel multi-interface wireless mesh networks was proposed in [10]. Because the close relationship between MAC and routing in MRMC applications, MRMC routing cannot simply choose the path with the minimal hop count without considering the link quality.

In this paper, based on Latin squares [11] , we propose M4 (Multiple access scheduling in Multi-radio Multi-channel wireless Mesh networking), that is a joint MRMC assignment, scheduling and routing protocol from a holistic perspective in order for WMNs to achieve their full potentials at two scales. In the macro-time scale, we design radio and channel resource allocation algorithms to provide dynamic and adaptive conflict-free radio and channel assignments to active clusters in WMNs; in the micro-time scale, we specify multiple channel access control protocols to provide collision-free packet transmissions within each cluster.

MRMC routing specification has been designed based on the MRMC link quality. Our MRMC routing exploits and integrates physical propagation models, location information and radio utilization efficiency to provide near optimal routing paths to guarantee the quality of service (QoS) in M4 applications.

2. Problem formulation

In this section, we explicitly consider the problem of joint MRMC assignment, scheduling, and routing in multi-hop wireless mesh networks. We consider the network as a peer-to-peer WMN [12] as shown in Fig. 1.The network topology of a WMN is represented as an undirected graph *G = {V, E},* where *V* is the set of WMN nodes, each mounted with multiple omnidirectional radio interfaces and assigned a unique ID number. For each WMN node n € *V,* a value *R(n)* denotes the number of wireless radio interfaces that it has, and a value *C(n)* denotes the number of non-overlapping channels that its interface can operate on. Unless notified otherwise, a link (u,v) € *E* indicates node u and v are within the transmission range of each other so that they can exchange radio packets via the common channel, in which case the two nodes are called *one-hop neighbors*. Two distinct nodes having a common one-hop neighbor are called *two-hop neighbors* to each other.

The two-hop distance in WMNs is a good approximation of the carrier sensing range, and node access scheduling usually requires all neighbors of a node within two hops be silent when the node transmits. To better schedule MRMC resources in M4, nodes within each collision domain are fully connected with each other, and are clustered to be a clique in the network graph.

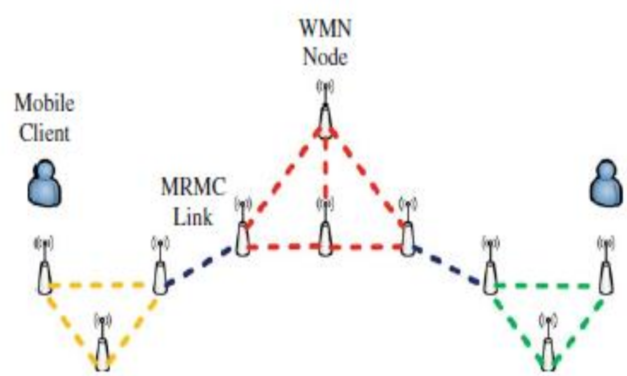

Fig. 1 A multi-hop WMN with MRMC capability. Different link colors represent for different channels

Clustering has partitioned the network graph into a number of clusters with various channels. We have **macro-time scale** channel scheduling for different clusters and **micro-time scale** channel scheduling for different nodes in each cluster. Because it is usually the case that only a subset of the clusters/nodes require channel access for data forwarding purposes, instead of assigning a Latin square row to each cluster/node in a WMN, we map the Latin square row indices to different colors, and in turn assign colors to clusters/nodes with traffic forwarding demands using graph coloring schemes. There are two types of graph coloring schemes: node coloring and cluster coloring. Node coloring schedules channel access time for the nodes in the same clique. Cluster coloring is used to allocate channels for different cliques.

The nodes are equipped with multiple radios can communicate with multiple neighbors simultaneously over non-overlapping channels. It is not feasible to assign one fixed channel to each radio at all times. A radio interface may need to switch to different channels in its permitted spectral domain for better performance. Clustering based MRMC scheduling using Latin squares can achieve transmissions of multiple clusters at the same time. For end-to-end multi-hop communication in a clustered WMN, MAC protocol oriented routing design can jointly cooperating with the MRMC assignment and scheduling to further guarantee link connectivity, and select near optimal route for multi-hop fair and efficient packet transmission. At the same time, specific routing to choose valid radio and channel along the path can improve the MRMC communication quality on load balancing and forwarding congestion, which will also influence the performance of end-to-end throughput and delay.

Because of the close relationship between MAC and routing in MRMC applications, MRMC routing cannot simply choose the route with the minimal hop count without considering the link quality. We describe the location-aware and link-adaptive route discovery using a *forwarding speed* metric, and alternative routing scheme based on the MRMC scheduling status. Before completing the orderly communication in M4, we assume that WMN channel access is bootstrapped over a common channel for WMN nodes to exchange control information, regarding one-hop link connectivity and two hop neighborhood information. The nodal location information [13], which will be used for the MRMC routing also can be obtained and exchanged via the common channel.

3. Multiple access scheduling in multi radio multi channel wireless mesh networking

M4 is a joint MRMC assignment, scheduling and routing protocol proposed in multi-hop WMNs, which is mainly composed by following schemes: interference and bridge clustering, on-demand coloring based multiple access scheduling, Latin square based MRMC assignment, and MRMC scheduling oriented routing.

3.1 Clustering

It is well-known that CSMA/CA mechanism cannot fully guarantee collision-freedom due to hidden terminal problems in multi-hop wireless networks. Instead, a hierarchically organized, cluster based spatial division multiple access scheme has to be applied so as to resolve the hidden terminal problem at macro-time scale, while the CSMA scheme is limited to micro-time scale channel access control amongst nodes within individual clusters.

For clustering purpose, we use the concept of interference graph, where two nodes have a link between them if they can carrier-sense each other's transmissions. In addition, we define a collision domain of a node as the set of adjacent nodes that can interfere and damage the packet receptions of the node. Nodes within each collision domain are fully connected with each other in the two-hop range, and form a clique in the corresponding interference graph. Assuming that the nodes of a large-scale WMN are grouped into non-overlapping collision domains, it is easy to see each collision domain forms a clique of the network graph.

For collision avoidance and communication purposes, we structure the WMN according to types of clusters, namely the interference cluster (IC) and the bridge cluster (BC). Nodes in the same interference cluster form a collision domain of each other, and share a common channel. Nodes in the same bridge cluster form a collision domain as well, except that they are chosen among adjacent interference clusters so as to facilitate communications between interference clusters that use different channels.

3.2 On demand multiple access scheduling

In the previous section, we have constructed the interference clusters and bridge clusters for a WMN. To provide a collision-free environment in the network, we allocate different channels for neighboring interference clusters, and only one node in each interference cluster is allowed to transmit at any time. We utilize the basic schemes in MALS for inter-cluster transmission by assigning Latin square indices to the nodes in each cluster. Because it is usually the case that only a subset of the network nodes require channel access for data forwarding purposes, instead of assigning a Latin square row to each and every node in the wireless networks, we map the Latin square row indices to different colors, and in turn assign colors to nodes with traffic forwarding demands using graph coloring schemes. There are two types of graph coloring schemes in our MRMC mesh networks for channel access scheduling, node coloring and cluster coloring. Node coloring schedules channel access time for the nodes in the same collision domain. Cluster coloring is used to allocate channels for different interference clusters.

3.3 MRMC assignment and scheduling

In the previous section, we have colored the network such that neighboring clusters will obtain different colors. Using the color information, we can now set up a collision-free multiple access schedule for different radios and channels in the network. In this section, we will first explain the schedules between clusters and channels. Because each neighboring cluster uses different channel to avoid collisions, we will then talk about how to utilize multiple radio interfaces to connect neighboring clusters

3.3.1. Scheduling between clusters and channels

Once the color assignment of the clustered network is finished, M4 distributes the color information to the clusters, including the color of every cluster and the total number of colors required in the network. Using the color information and the number of available channels in the large-scale WMN, each cluster can independently generate its channel access schedules. We use a Latin squares based method to assign channels. Once a cluster in the clustered graph is assigned a channel, the WMN nodes inside the cluster can communicate using the specified medium access protocol .WMN nodes without any channel allocation have to remain silent during the corresponding time slots. Fig.3 shows our Latin Squares based channel assignment scheme.

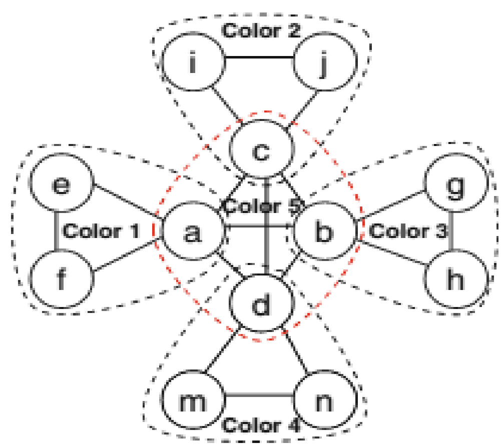

Fig.2 Clustered Network Graph

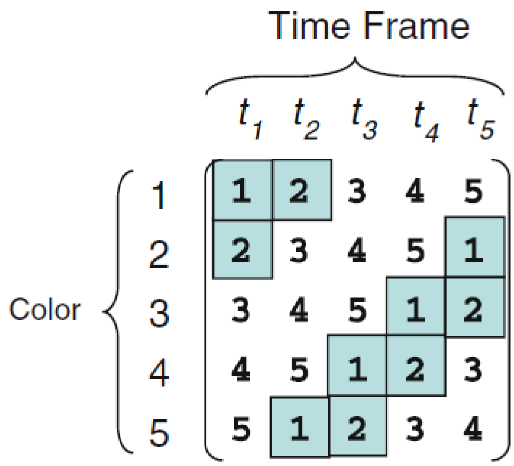

Fig.3 MRMC assignment using Latin square

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3.3.2 Scheduling between clusters and radios

As shown in Fig.2, nodes in the bridge cluster can be connected with multiple neighboring interference clusters. If we have multiple radios on each node, inter-cluster and intra-cluster communications may be activated at the same time. Thus increase the network throughput and reduce the end-to-end delay. According to the number of interference clusters which are overlapped by the bridge cluster, we can assign different radio interfaces to support intra-cluster communication. Using the coloring information of each interference cluster, the maximum number of colors, and the number of available radios, each node in the bridge cluster can independently generate its radio access schedules.

3.4 MRMC routing

Since a WMN is organized into interference clusters and interference clusters are connected by bridge clusters with different radio interfaces on nodes, we group the cluster ID and corresponding radio interface ID for each node, and specify these information in the routing packets for MRMC communications.

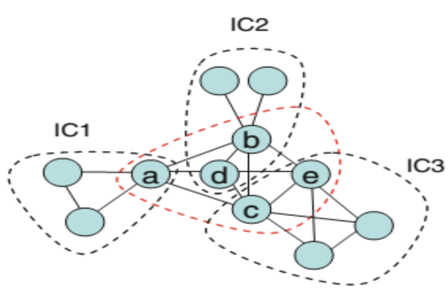

Fig.4 MRMC routing in a clustered graph

3.4.1. Location Awareness route discovery

In M4, a route is established when the source node sends a RREQ message in search of a path to a certain destination, and receives an RREP message in return. To find a near optimal route, we define a new metric, called *forwarding speed*, for a RREQ receiver to evaluate the quality of the potential path through itself. The forwarding speed $S_{forward}$ is a vector, defined by

$$S_{forward} = \frac{D_{RREQ}}{T_{Queue} + T_{MAC}} - (1)$$

It is worth noting that (1) eventually combines several path evaluation criterion into a single metric for route selection. The criterion combines information from several layers, like the MAC layer latency, DLL layer queuing delay, PHY layer transmission rate, and WMN node location information, thereby providing a comprehensive cross-layer perspective to the routing protocol designs. In general, (1) enables a route selection mechanism to choose faster routing path with less forwarding hops, higher data rates and lower queuing delays. Accordingly, intra-cluster next-hop node that is located in a interference cluster and a bridge cluster at the same time will be preferred to forward the data in WMNs. Fig.4 shows MRMC routing in a clustered graph.

4. Results Analysis

We implemented the proposed multiple access scheduling in Multi-radio Multi-channel Mesh networking using the network simulator 2.33 (ns-2.33), and evaluated its performance in terms of overall network throughput, average packet delay, No .of packet drops and packet delivery ratio. We also compared its performance with IEEE 802.11 standards and some state of-the-art multi-channel and routing protocols under multi-hop multi-flow networks with MRMC communication capabilities. End simulation was carried out for a duration of 30s, with 75 nodes **and** network throughput ,end-to-end delay, packet delivery ratio were collected by gradually increasing network data rate from 10 – 50 kb/s.

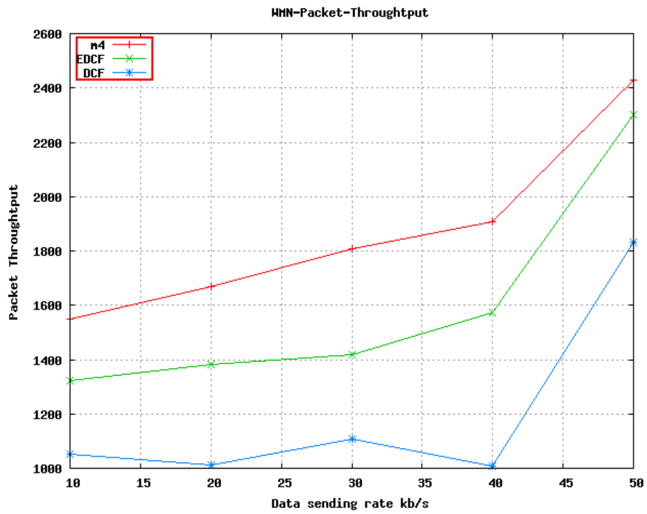

Fig.5 Throughput comparison

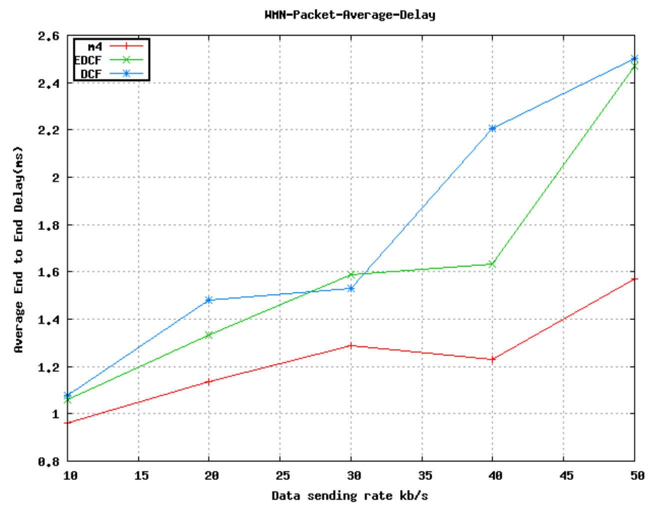

Fig.6 End to End delay comparison

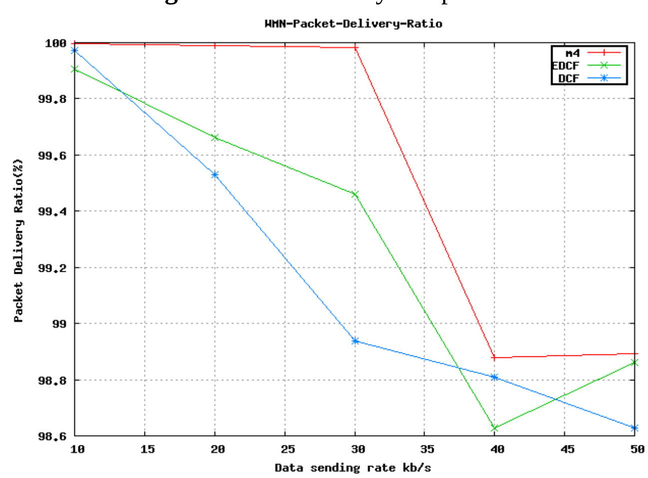

Fig.7 packet delivery ratio comparison

Fig**.** 5-7 show the performance comparison of MRMC with IEEE 802.11e EDCA and IEEE 802.11b DCF schemes in the mentioned simulation setting. Note that none of these compared schemes are capable of switching channels; therefore they are operated over a single channel in our simulation. As we can see, since the packet collisions caused by hidden terminal problems, IEEE 802.11e EDCA and IEEE 802.11b DCF all performed inefficiently and unstable in multi-hop scenarios.

The throughput comparison is shown in Fig. 5. When we increased the total network traffic load the throughput of proposed M4 was about 1.5 times of other protocols. It is because that there are two types of nodes operated in different number of channels in M4. One type is the inter-cluster nodes and the other type is the intra-cluster nodes. The nodes for inter-cluster communication operate on one shared channel, and the bridge nodes for intra-cluster communication operate on two channels simultaneously to connect different clusters. These differentiated services of WMN nodes by clustering improve the throughput of M4 under MRMC schemes. If we also provide MRMC ability for the nodes in inter-cluster communication, M4 will further improve the throughput; however, it is beyond the scope of this paper. For end to end delay and packet delivery ratio metrics in Fig. 6, 7, M4 was also lower and more stable comparing with IEEE 802.11e EDCA and IEEE 802.11b DCF schemes.

5. Conclusion

We have presented M4, i.e., the Multiple access scheduling in Multi-radio Multi-channel Mesh networking based on Latin squares in WMNs. In M4, the network is organized into clusters according to two hop interference information, and guarantees the network connectivity using the interference clusters and bridge clusters. The radio and channel access efficiency and fairness were achieved by using compact Latin square based MRMC access and channel allocation schedules. From a systematic view, we also designed the corresponding routing specification to support data communication in M4 using a forwarding speed metric. Simulation results conclude that the proposed M4 will improve the quality of service (QoS) in wireless mesh network by improving Throughput, Packet delivery ratio and by reducing End to End delay.

References

1.IEEE Std 802.11. (2007). IEEE standard for information technology telecommunications and information exchange between systems local and metropolitan area networks-specific requirements— Part 11: Wireless LAN medium access control (MAC) and physical layer (PHY) specifications. Technical report, IEEE, 2007.

2. IEEE Std 802.11e. (2003). Wireless medium access control (MAC) and physical layer (PHY) specifications: Medium access control (MAC) enhancements for quality of service (QoS). Technical report, IEEE, 2003.

3. Qiu, L., Zhang, Y., Wang, F., Han, M. K., & Mahajan, R. (2007).A general model of wireless interference. InACM MOBICOM'07(pp. 171–82).

4. Aryafar, E., Gurewitz, O., & Knightly, E. W. (2008). Distance-1 constrained channel assignment in single radio wireless mesh networks. InIEEE INFOCOM'08 (pp. 762–770).

5. Ramachandran, K. N., Belding, E. M., Almeroth, K. C., & Buddhikot, M. M. (2006). Interference-aware channel assignment in multi-radio wireless mesh networks. InIEEE INFOCOM'06(pp. 1–12).

6. Chen, G., Nocetti, F., Gonzalez, J., & Stojmenovic, I. (2002). Connectivity based k-hop clustering in wireless networks. In35th annual Hawaii international conference on system sciences(pp. 2450–2459).

7. Liu, Q., Jia, X., & Zhou, Y. (2011). Topology control for multichannel multi-radio wireless mesh networks using directional antennas.Wireless Networks, 17(1), 41–51.

8. Mao, X., Li, X., & Dai, G. (2011). Flow admission control for multi-channel multi-radio wireless networks.Wireless Networks, 17(3), 779–796.

9. Alicherry, M., Bhatia, R., & Li, L. (2005). Joint channel assignment and routing for throughput optimization in multiradio wireless mesh networks. In ACM MobiCom'05 (pp. 1960–1971).

10. Lim, S., Ko, Y., Kim, C., & Vaidya, N. (2011). Design and implementation of multicasting for multi-channel multi-interface wireless mesh networks.Wireless Networks, 17(4), 955–972.

11. Denes, J. & Keedwell, A. D. (1974).Latin squares and their applications. London: Academic Press.

12. Akyildiz, I. F., Wang, X., & Wang, W. (2005). Wireless mesh networks: A survey.Computer networks, 47(4), 445–487. Wireless Netw (2014) 20:11–24 23 123

13. Wu, D., Bao, L., Du, M., & Li. R. Design and evaluation of localization protocols and algorithms in wireless sensor networks using UWB. InIEEE IPCCC'08 (pp. 18–25).

