CITY UNIVERSITY OF HONG KONG

香港城市大學

# From Heterogeneous IEEE 802.11 DCF Networks to IEEE 802.11e EDCA Networks: Modeling, Differentiation, Optimization and Quality-of-Service Guarantee

# 從異構 IEEE 802.11 DCF 網絡到 IEEE 802.11e EDCA 網絡：建模，分化，優化和服務質量保證

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by

Gao Yayu
高雅玙

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# Abstract

IEEE 802.11 Wireless Local Area Networks (WLANs) have gained worldwide popularity in the past decade. Due to the explosive growth of multimedia applications, it is of crucial interest to provide quality-of-service (QoS) guarantee in WLANs. The medium access control (MAC) scheme in the IEEE 802.11 standard, Distributed Coordination Function (DCF), however, only provides best-effort services. To meet the soaring demand of QoS support, Enhanced Distributed Channel Access (EDCA) has been proposed as an extension of DCF by the IEEE 802.11 Working Task Group E to provide QoS enhancements for WLANs.

Over the last few years, a great deal of efforts have been made on the analytical modeling and performance evaluation of IEEE 802.11e EDCA networks. The modeling complexity is, however, much higher than that of the legacy IEEE 802.11 DCF networks due to varying traffic patterns, differentiated backoff parameter settings and the diverse QoS requirements of various traffic types, which makes it extremely difficult, if not impossible, to further optimize the network performance. A number of fundamental issues, such as the maximum network throughput and how to properly adjust the system parameters to achieve it and satisfy the diverse QoS requirements of distinct multimedia applications, remain largely unknown.

This thesis is devoted to modeling and throughput optimization of heterogeneous IEEE 802.11 DCF networks and IEEE 802.11e EDCA networks. It begins from throughput analysis of a heterogeneous IEEE 802.11 DCF network, where nodes are divided into different traffic groups and distinct groups have varying arrival rates and backoff parameters. The maximum network throughput is derived as an explicit function of the holding time of the Head-of-Line (HOL) packets in successful transmission and collision states, which is shown to be achieved by carefully adjusting the input rates of the unsaturated groups and the backoff parameters of the saturated groups. The analysis is further applied to address the optimal downlink/uplink throughput allocation issue. The optimal initial backoff window sizes of the access point and mobile stations are obtained to achieve the maximum network throughput and a target downlink/uplink throughput ratio simultaneously.

The analytical framework is extended to IEEE 802.11e EDCA networks with backoff window size differentiation and arbitration interframe space (AIFS) differentiation. The maximum network throughput of an IEEE 802.11e EDCA network is shown to be equal to that of an IEEE 802.11 DCF network, which is independent of the differentiation schemes. The optimal backoff parameter settings to achieve the maximum network throughput while satisfying pre-specified throughput differentiation requirements are obtained in both differentiation modes. It is revealed that the backoff window size differentiation could be a more preferable option as it requires fewer tuning parameters and provides better precision than the AIFS differentiation.

Finally, the analysis is extended to address a QoS provision issue for IEEE 802.11e EDCA networks, that is, how to adaptively tune the system parameters to maximize the aggregate throughput of non-real-time nodes with a certain mean access delay constraint on the real-time nodes. The maximum aggregate throughput of non-real-time nodes and the optimal initial backoff window sizes are obtained. It is further demonstrated that there exists a minimum achievable mean access delay for the real-time nodes, which increases as the number of real-time nodes grows. Therefore, to satisfy a given mean access delay requirement of the real-time nodes, the number of real-time nodes needs to be carefully controlled. An admission control scheme is further proposed, with which the maximum number of real-time nodes that can be enrolled increases linearly with its mean access delay constraint. The analysis offers important insights into performance optimization, QoS guarantee and network design for IEEE 802.11 WLANs.

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