Thesis Overview

QUALITY OF SERVICE IN MOBILE AD HOC NETWORKS

Khaled Abdullah Mohammed Al Soufy
Advisor: Ash Mohammad Abbas
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Department of Computer Engineering
Aligarh Muslim University, Aligarh – 202002, India
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Email: kalsoufi@gmail.com, am.abbas.ce@amu.ac.in

To support multimedia applications, it is desirable that an ad hoc network has a provision of *Quality of Service* (QoS). However, the provision of QoS in an ad hoc network is a challenging task due to its inherent characteristics. In this thesis, our main focus is on the provision of QoS in an ad hoc network where there can be multiple hops from a given source to a destination. The contributions made in the thesis are as follows.

In *Chapter* 1, we provided an introduction to the problem and described the motivation and objectives of the thesis. We discussed an extensive survey of the related research work carried out by other researchers from different perspectives. We grouped the related research presented in the literature into different categories and compared the research works of each category based on their basis, focus, and features.

In order to provide QoS in terms of delay guarantees, one needs to analyze the end-to-end delays from a given source to a destination. A major portion of the end-to-end delay consists of the queuing delays and MAC delays added to the delays incurred by a packet at each node lying along a path from a given source to a destination. The devices using IEEE 802.11 DCF at the MAC layer can be configured either in *ad hoc* mode or in infrastructure mode. Therefore, to form an ad hoc network, IEEE 802.11 DCF is often used as a MAC layer protocol. In the first two ensuing chapters of the thesis after *Chapter*1, we analyzed IEEE 802.11 DCF.

In *Chapter* 2, we analyzed end-to-end delays along a path from a given source to a destination in an ad hoc network that uses IEEE 802.11 DCF as a MAC layer protocol under *saturation* conditions. The contributions made in this chapter are as follows. We decoupled the queuing delays at the network layer from the MAC layer delays experienced by an HOL packet in order to make the analysis simple. We analyzed the end-to-end delays along a path from a given source to a destination. We analyzed the effective end-to-end loss probability that incorporates packet losses due to buffer overflow and packet losses due to back-off process at each node along a path from a given source to a destination. We analyzed the throughput for single hop as well as for a path that may consists of multiple hops from a given source to a destination. The expression for the throughput incorporates the effect of losses due to buffer overflow and back-off process.

To validate our analysis, we carried out simulations and observed that the values of the average end-to-end delay obtained through simulations closely match to the analytical values. Specifically, for the basic access mechanism and for collision probability 0.01, the difference between the analytical and simulation values of the average end-to-end delay is 0.7036%. Moreover, in case of the RTS/CTS mechanism, for collision probability 0.01, the difference between the values of the average end-to-end delay obtained analytically and through simulations is 4.1422%. On the other hand, for the average throughput, the trend of the analytical and simulation curves is similar to one another. Further, we observed that the average end-to-end delay is significantly reduced in case of the RTS/CTS mechanism as compared to the basic access mechanism. This enables us to suggest the use of RTS/CTS mechanism for sufficiently large frames.

Under *saturation* conditions the queues of nodes are assumed to be never empty, however, all nodes in an ad hoc network might not always be saturated. In *Chapter* 3, we analyzed IEEE 802.11 DCF for an ad hoc network under *non-saturation* conditions where there is a possibility of an empty queue. The same parameters are considered for the analysis under non-saturation conditions as those for saturation conditions. To validate the analysis, we carried out simulations and observed that the values of the average end-to-end delay obtained through simulations are in accordance with the analytical values. Specifically, for the transmission range equal to 150m and for collision probability 0.01, the difference between the analytical and simulation values of the average end-to-end delay is 12.6192%. Moreover, for the basic access mechanism and for collision probability 0.01, the difference between the values of the average end-to-end delay obtained analytically and through simulation is 0.1484%. On the other hand, in case of the mechanism with RTS/CTS, the difference between the values of the average end-to-end delay obtained analytically and through simulations is 14.7168% for collision probability 0.01.

IEEE 802.11 DCF does not have an inherent support for QoS, therefore, one needs to use a protocol explicitly for the provision of QoS in an ad hoc network. In *Chapter* 4, we proposed a protocol called Multipath Quality of Service Routing (MQSR) for the provision of QoS in an ad hoc network. In our protocol, the source identifies multiple node-disjoint paths to the destination satisfying the QoS constraints in terms of the end-to-end delay. The performance of the protocol is evaluated through simulations and compared with an existing protocol called Ad hoc QoS On-demand Routing (AQOR). We observed that the performance of the proposed protocol, MQSR, is better than AQOR in terms of QoS success ratio. Specifically, for a *max speed* of 4 m/s, QoS success ratio of MQSR is 9.69% larger than that of AQOR.

Contrary to IEEE 802.11 DCF, IEEE 802.11e EDCA has an inherent support for QoS through the use of different priorities for different classes of traffic. In *Chapter* 5, we proposed a model for the analysis of IEEE 802.11e EDCA for an ad hoc network. Our model is based on the CW and AIFS differentiation. During the analysis, we focused on the average end-to-end delay incurred by a packet along a path from a given source to a destination, and the average throughput. We studied the effect of collision probability on the average end-to-end delays incurred by packets of different access categories. Also, we studied the effect of transmission attempt rate on the average throughput of a node that belongs to an access category. We observed that the average delays incurred by packets of different access categories increase with the collision probability and their throughput decrease with an increase in the transmission attempt rate. To validate the analysis, we carried out simulations. We observed that the values of the average end-to-end delay obtained through simulations are in conformance with the analytical values. Specifically, for collision probability 0.01, the differences between the analytical and simulation values of the average end-to-end delays for the traffics of AC3, AC2, AC1, and AC0 are 6.9591%, 6.0320%, 0.05466%, and 2.9846%, respectively. For the average throughput, the trend of the simulation curves and analytical curves is similar to one another.

In *Chapter* 6, we proposed a protocol for providing QoS in an ad hoc network that uses TDMA at the MAC layer. We proposed a routing protocol that we call Contention-Aware Quality of Service (CAQS) routing for the provision of QoS in a mobile ad hoc network that is based on TDMA. In our protocol, the source tries to identify a path that is capable of satisfying QoS requirements of a flow of packets in terms of end-to-end delay. We evaluated the performance of the proposed protocol through simulations and observed that the proposed protocol performs better as compared to the existing protocols in terms of QoS success ratio. QoS success ratio of the proposed protocol, CAQS, is significantly larger than that of an existing protocol. Specifically, for the *max speed* of 1m/s, QoS success ratio of CAQS is 2.246% larger than that of the existing protocol.

As future works, we pointed out new research problems in the thesis, which are as follows. A key approximation that is common in the analytical models of IEEE 802.11 DCF and IEEE 802.11e EDCA described till date is the assumption of constant and independent collision probability of a packet transmitted by each station, regardless of the number of retransmissions already suffered. It has been shown in most of the analytical models that this assumption produces accurate results by comparing analytical results with those obtained through simulations. However, there might be a situation where the collision probability depends on the number of retransmissions already suffered by a packet. In future, one may propose a model where the dependencies among collision probability and the number of retransmissions already suffered by the packet are taken into account.

The effect of mobility on the performance of a QoS routing protocol has been evaluated using simulations. One may propose a model for an ad hoc network that addresses the effect of mobility analytically. For that purpose, one may need to combine a mobility model with the analysis of IEEE 802.11 DCF or IEEE 802.11 EDCA and may design a routing protocol for providing the desired QoS. Further, one can design an admission control algorithm and can see the effect of allowing newly arrived packets on the delay or throughput guarantees of the flows already existing in the network. Another direction for future work can be that one may physically deploy the network and may study the effect of different parameters by running different audio/video applications.

Khaled Abdullah Mohammed Al Soufy
kalsoufi@gmail.com

Ash Mohammad Abbas
am.abbas.ce@amu.ac.in