Chapter 7

Conclusion and Future Direction

WiFi-based long distance network has a great potential in extending Internet connectivity to rural underserved areas and hence to solve the digital divide problem. However, due to some inherent limitations, the existing WiFi does not perform well in long distance links. To resolve the performance issues of WiLD networks, TDMA-based MAC protocols are preferred over CSMA/CA. Multi-radio and multi-hop operation in WiLD networks pose some unique challenges in performance optimization and QoS provisioning. Like other networks, multi-hop WiLD networks are also required to handle a large volume of real-time traffic. We started this dissertation with an aim of developing QoS schemes to facilitate real-time applications over resource-constraint multi-hop WiLD networks. We began by investigating the QoS issues in multi-hop WiLD network setup and proposed a few QoS schemes for TDMA-based MAC and network layers to fulfill this goal. In this chapter, we summarize the main contributions made in this dissertation, discuss the limitations of the proposed QoS schemes, and provide directions for future research in this area of research.

7.1 Conclusion

In this dissertation, we have investigated many aspects of multi-hop WiFi-based long distance networks in the context of QoS provisioning. Our contributions

can be seen in four different angles: (i) optimizing network performance through efficient link transmission scheduling, (ii) resolving the issue of congestion, (iii) providing fine-tuned QoS for real-time traffic and (iv) provisioning of end-to-end QoS through the use of QoS-aware multi-path routing for real-time flows. Following conclusions are drawn from the contributions made in this dissertation.

7.1.1 TDMA-based Scheduling

Network performance enhancement through efficient transmission scheduling in multi-hop WiLD network is very important in supporting real-time applications. Distributed marker-packet based synchronization schemes unveils issues of dependency on neighbour nodes and can affect overall network performance. In Chapter **??**, we have proposed an efficient TDMA-based slot scheduling scheme which implicitly schedules transmissions over different links. The nodes belonging to consecutive levels of the tree topology are automatically assigned the alternate time slots. In this process, a dedicated 50% of the time slots are assigned to every node. The proposed protocol outperforms the most relevant protocol, *2P* [**?**], in terms of throughput and delay performances. CBR and FTP throughput have been enhanced by 67.54% and 44.5% respectively. Delay performance is also improved significantly by using the proposed scheme. WiLD networks can be extended upto four number of hops without significant performance degradation. Real-time applications can also run without any hassle.

The proposed protocol requires strict time synchronization among the nodes in the network which is difficult to achieve in larger networks. It is based on the assumption that by using only a few numbers of hops the entire rural areas can be covered. However, if such networks are allowed to grow exceptionally large, maintaining tight network synchronization and maintenance of tree topology may become difficult.

7.1.2 QoS-aware Dynamic Bandwidth Allocation

In multi-hop WiLD networks, avoiding congestion around the gateway node is a challenging task. In its presence, end-to-end QoS cannot be provisioned properly. To this end, we have proposed a dynamic QoS-aware bandwidth allocation scheme in Chapter **??**, which stretches the QoS guarantees for real-time traffic. The proposed dynamic slot scheduling mechanism efficiently distributes the unused time slots among the nodes having real-time traffic to transmit. It allows carrying time slots from the nodes belonging to different levels of the network topology. By doing so, end-to-end throughput and delay performances of real-time traffic are enhanced substantially. Further, the protocol provides assured packet forwarding for already admitted flows by allowing node's transmission according to the capacity of ancestral links. The simulation results have shown that the proposed protocol achieves a substantial performance improvement for real-time traffic.

7.1.3 Fine-granular QoS Provisioning

Link level scheduling can only assure a prioritized link level transmission but not the transmission at packet level. Therefore, in saturated load situation, transmission of real-time packets cannot always be guaranteed. To solve this problem, we have proposed a packet scheduling scheme for TDMA-based MAC protocols in Chapter **??**. In the proposed scheme, real-time packets are given differential treatment by dividing them into a few classes based on their QoS requirements. A two phase admission control is employed to ensure QoS for the ongoing flows. By using the proposed packet scheduling scheme, performance of real-time flows has been shown to improve to a great extent.

7.1.4 End-to-end QoS Provisioning

End-to-end QoS provisioning demands QoS-aware path establishment by the routing protocol employed. To address this issue, we have proposed a QoS-aware

gateway-based multi-path routing scheme in Chapter **??** which discovers multiple QoS paths and assigns them to real-time flows based on their QoS demands. The route maintenance procedure adopted takes care of the dynamic link quality. In the event of considerable change in link quality, the source is informed immediately. Our protocol improves end-to-end QoS of the real-time flows. Furthermore, by using packet aggregation technique, it can support upto three times more number of connections depending upon the network topology.

Due to integration of flow admission and route quality maintenance techniques, a little higher control overhead has been observed in the protocol.

7.2 Future Direction

In the following, we outline some of the possible directions of future research works in this field of research.

- We assume the use of single channel throughout this dissertation works. Using multiple channels for the different radios installed at a node may enable creating dedicated upstream and downstream channels. It may enhance the network performance in a big way but require recasting the scheduling problem in a new setting. This is left as a part of future work.

- Throughout this dissertation, we consider throughput and delay as QoS performance metrics. Uses of other parameters like jitter and packet loss are left as a part of future work.

- Since the periodicity of different real-time traffic is different, the load in each time slot may not remain uniform in the proposed packet scheduling scheme. Finding the congestion points (slots) and modifying the admission control mechanism accordingly has been left as a future work.

- We consider single gateway-based WiLD networks throughout this dissertation. However, in reality it is possible to design multi-gateway based

network which will boost the network performance by providing additional resources. Designing a multi-gateway based routing protocol to provide QoS with proper load balancing scheme has been left as a future work of this research.