Impact of End-to-end QoS Connectivity on the Performance of Remote Wireless Local Networks

Veselin Rakocevic
School of Engineering and Mathematical Sciences
City University
London EC1V 0HB, UK
V.Rakocevic@city.ac.uk
Phone: +44 20 7040 8136
Fax: +44 20 7040 8568

Abstract: This paper presents results from ns-2 simulation of an integrated wireless – wired – wireless network architecture, in which wireless stations attached to a wireless LAN transmit UDP video traffic and TCP data traffic to wireless stations attached to some other, remote wireless LAN. The communication between the two LANs is achieved through a sequence of wired routers. This paper evaluates the end-to-end network performance in terms of the packet delay, loss and throughput of both video and data traffic for the case when intermediate fixed routers support priority CBQ/WRR scheduling and for the case when they perform only first-in-first-out scheduling. The paper investigates the improvements priority scheduler introduced to high-priority UDP video traffic and, importantly, the effect of the priority scheduler on the end-to-end performance of the low-priority TCP transfer.

Keywords: Wireless Networks, Quality of Service, Multimedia over Wireless, Network Simulation, IEEE802.11

1. Introduction

IEEE802.11 standard [11] has become a de-facto standard for the wireless local area networks (WLANs), which are being installed at an increasing rate. Main benefit of wireless networks comes from the added mobility, which enables users to move around with their hand-held laptops or other mobile devices, and receive high-speed data when they are in the range of a local Access Point (AP). Many design challenges for the future of wireless networking still exist. These challenges include end-to-end Quality of Service (QoS), security, availability and reliability. These issues are particularly important in the case of business network applications.

QoS has been an important research problem in the field of networking for a long time, with many QoS-enabled architectures and protocols claiming to solve the main problem – how to guarantee the end-to-end performance of real-time audio/video applications and ‘premium’ data services (e.g. secure data transactions). The performance is usually evaluated in terms of network delay, throughput, delay variation and packet loss.

The QoS issue in network design is even more important in the wireless network environment. Wireless medium is not reliable – packet loss is larger while the bandwidth is generally smaller than in fixed networks. Inherent problems of wireless communications – interference, fading and handover – make things even worse.

More recently, issues of network reliability, security of communications, and end-to-end QoS deployment have emerged as crucial in QoS-aware network design. Vendors are often reluctant to be the first to install complicated (and expensive) QoS-enabled equipment – regardless of its technical quality - knowing that numerous best-effort bottlenecks that still exist in the network will cancel their effort.

This paper analyses this lack of ubiquitous QoS connectivity in a wireless-wired-wireless network environment. Knowing the low level of QoS provided by the wireless medium, we investigate whether implementing QoS-aware wired routers as intermediate nodes has any positive impact on the end-to-end QoS performance. We observe a network architecture enabling the communication between two mobile stations attached to remote small-size office WLANs.

The performance of both data and video applications is studied. Video applications require low and stable level of packet loss and limited delay. On the other hand, in the increasingly heterogeneous network that exists nowadays it is not only the real-time applications that have QoS requirements. Data transfer, although much more robust when it comes to delay, also needs bounded transfer time and near-zero loss.

It is well known that wireless networks are not optimal for either low-delay video or TCP-based data transfer. The problem of TCP congestion control over wireless links has been analysed thoroughly [1][3][10]. TCP recognizes all losses as congestion losses, and decreases its sending rate every time a loss was detected. In the case of wireless links, random losses due to the wireless medium are also recognized as congestion losses. A number of different schemes have been proposed to solve this problem [10]. All of the schemes can be divided into three main groups: *link-layer protocols*, which provide local reliability; *split-connection protocols*, which break the end-to-end connection into two connections at the base station; and *end-to-end protocols*, where the TCP sender is aware of the wireless link. This paper analyses the third case – we are looking at an end-to-end TCP connection, which recognizes any loss on the link as a congestion loss.

The paper is organized as follows. The next section describes the network model and the simulator that has been used. Section 3 analyses the simulation results and gives guidelines for successful design of priority schedulers. Section 4 discusses interesting future research directions that will follow this study.

2. The Model

We are observing a wireless-wired-wireless network architecture presented at Fig.1. Mobile stations in WLAN 1 send one data flow using TCP and one video flow using UDP. Both flows are destined for a mobile station in the WLAN 2. The wired nodes serve as intermediate routers. The first wired router has an option to use priority scheduling or to use standard first-in-first-out (FIFO) scheduling. The priority scheduler in the router uses the CBQ/WRR scheduling algorithm.

CBQ (Class Based Queuing) [5][6] is a scheduling mechanism that provides link sharing between traffic classes, and on a higher level between *agencies* that are using the same physical link. CBQ link sharing enables any excess bandwidth resulting from an agency that is not fully utilizing its share to be distributed to other agencies. CBQ defines the maximum percentage of the link capacity that each of the traffic classes can use. In this case, we are observing a single agency that is serving two traffic classes – UDP video and TCP data traffic. Weighted Round Robin (WRR) [7] scheduling is used to distribute the service time between classes.

In terms of user mobility, the wireless receiver is fixed – the speed of its movement is zero. This approximately models the real-life situation of an office worker who is enjoying the benefits of the wireless network, but keeps its mobility to the minimum, due to the nature of his job.

Network Simulator ns-2 [2] is used to simulate the described network architecture. The simulation lasts for 500 seconds, with both traffic sources active from $t = 10\,\text{sec}$. Video source transmits constant bit rate traffic at the rate of 409Kbps, while the data traffic is simulated as a file transfer application using FTP over TCP. For the preliminary results, the weight assigned for TCP traffic in the priority scheduler – the maximum portion of link bandwidth TCP traffic is allowed to use – is set to be $\omega_{TCP} = 0.4$. Section 3 will analyze the end-to-end performance when weight ω_{TCP} takes other values. Figure 2 shows the throughput comparison for the TCP traffic when the CBQ/WRR scheduler is used and when it is not used. Since the link bandwidth on wired links is set to be $B = 1.5Mbps$, in the case when priority scheduler is used, the throughput for the TCP traffic is limited to 600Kbps.

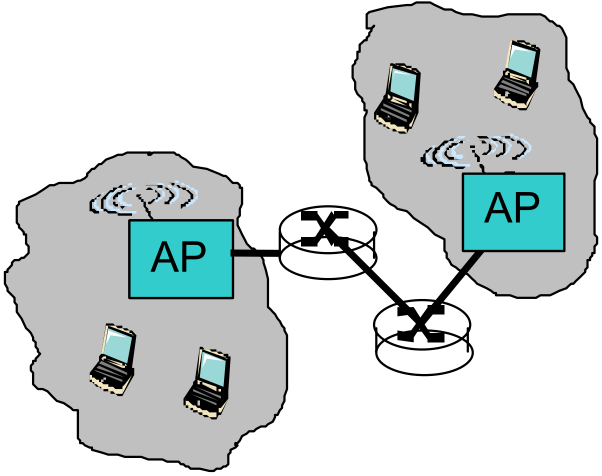

Figure 1. The Network Model

The metrics used for comparison are as follows. For the video traffic, average packet delay and packet loss are used to evaluate end-to-end QoS. For TCP traffic, the TCP throughput is evaluated using the value of the current sequence number.

3. Simulation Results and Discussion

Figure 3 shows that the packet delay is substantially greater when FIFO scheduling is used. In terms of the network performance evaluation, the two packet delay levels presented in Fig.2 are crucial. A negligible difference in the packet delay would not present a good case for deploying a single priority scheduler. Result on Fig. 2 shows that deployment of a single priority scheduler in the network model presented in Fig. 1 does generate substantial benefit by decreasing the average packet delay for video traffic approximately 10 times.

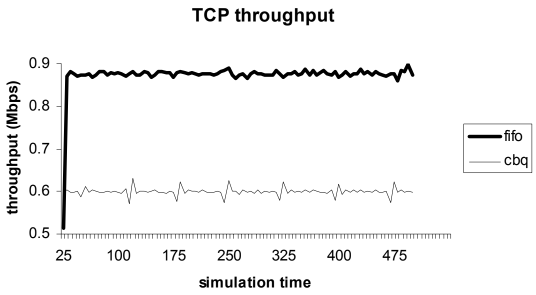

Figure 2 TCP throughput - comparison

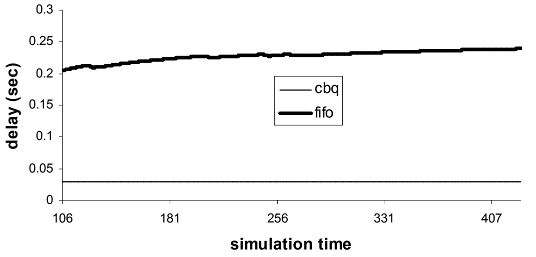

Figure 3 Packet delay for video traffic - comparison

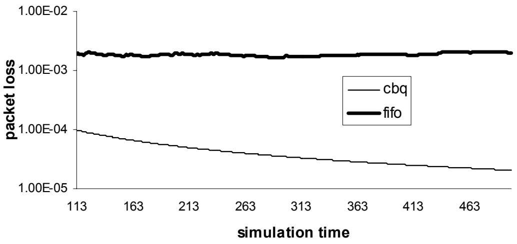

Figure 4 Packet loss for video traffic – comparison

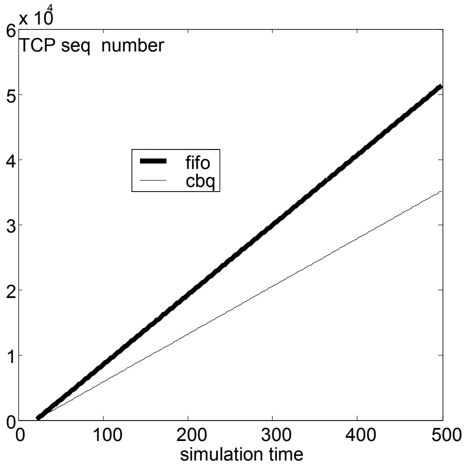

Figure 5 TCP throughput

Similarly, benefits of priority scheduling can be seen on Figure 4. Packet loss for the video flow is substantially (two orders of magnitude) smaller when priority scheduling is deployed. It is important to note that this packet loss comes mostly from the packets being dropped at the intermediate queues, rather than from the wireless medium. Priority scheduling decreases this loss.

When it comes to the throughput of the TCP data flows, the result on Fig. 5 is expected and can be easily explained. Capacity limitation for the TCP traffic introduced by the CBQ scheduler decreases the TCP throughput, generates larger packet loss due to congestion and thus decreases the amount of traffic that is transferred.

Figures 6-8 shows the impact of the weight ω_{TCP} on the end-to-end QoS. We can see from Fig. 6 and 7 that as the weight ω_{TCP} is increased from 0.2 to 0.8, the capacity dedicated to the TCP traffic is increasing which degrades the end-to-end QoS for video traffic. Interesting point is that when the weight for the data traffic in the CBQ/WRR scheduler is greater than 0.6, the end-to-end performance in terms of both packet delay for video and TCP throughput is approximately equal to the performance of the FIFO scheduler. Naturally, in such a case the implementation of the priority scheduler would not be optimal, since a much simpler scheduler can generate equal performance.

The question, however, is how beneficial the CBQ scheduler is in the integrated wired-wireless network when the Access Point is more heavily loaded. Our experiments show that the CBQ/WRR scheduler in the wired node can be of real benefit only when combined with a prioritized QoS-aware MAC. Figure 9 shows the comparison of the average packet delay for the video traffic flow in the presence of one extra TCP flow that is generated in the wired router closer to the WLAN 2. This TCP flow is mixed on the final wired link with the video flow and the TCP flow that originated at WLAN1. We can see from Fig. 9 that the CBQ/WRR scheduler in this case does not bring any important benefit to the overall end-to-end QoS. This result clearly shows that the implementation of QoS-aware wired infrastructure needs to be followed by an implementation of the QoS-aware MAC scheme in the Access Point. Therefore, and-to-end QoS connectivity is crucial.

This preliminary analysis presents the first step towards a more detailed analysis which will define the procedure for the precise QoS evaluation of the

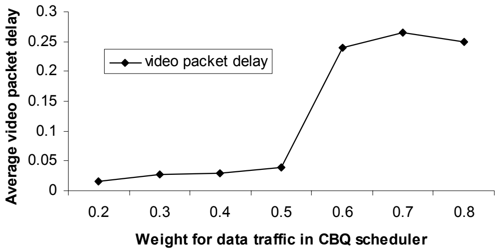

Figure 6 Average video packet delay for different weights for data traffic

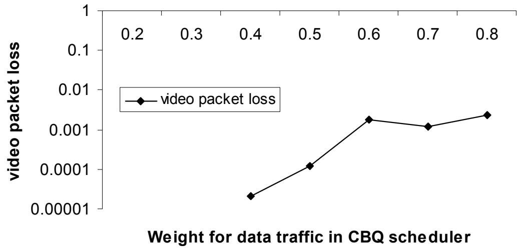

Figure 7 Average packet loss for video traffic for different weights for data traffic

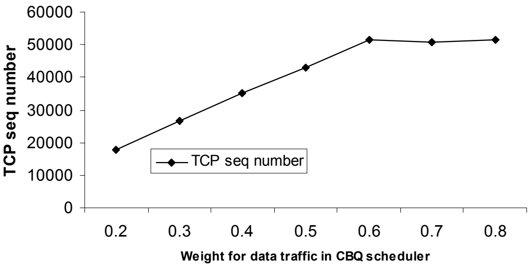

Figure 8 Comparison of TCP throughput for different weights for data traffic

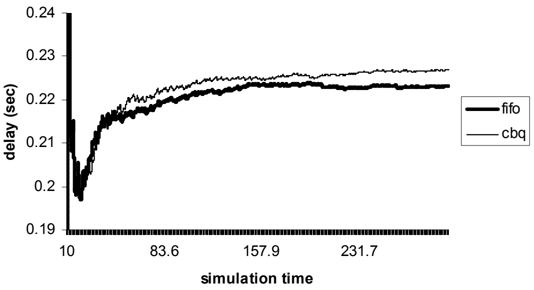

Figure 9 Average packet delay for the cbr flow when another TCP source is active

integrated solutions for wired-wireless networking. For example, design and evaluation of a dynamic algorithm for assigning weights in the priority scheduler presents an important research challenge. Such an algorithm would adapt the weights on the basis of the end-to-end packet delay, loss and throughput.

4. Integration of QoS-aware Network Domains

The most interesting research issue that can follow this preliminary analysis is the integration of QoS methods in the fixed and wireless network domains. Wireless LANs already have some limited QoS support, mainly through priority assignment to frames at the MAC level. Schemes that improve the performance of IEEE802.11 MAC protocol include [8] scaling the backoff contention window, assigning different interframe spaces and assigning different frame sizes. Enhanced DCF (Distributed Coordination Function) [9] combines assigning different values for the minimum contention window $CW_{\min}$ and different interframe spaces for different traffic classes.

5. Conclusion

This paper presented simulation results for a wireless-wired-wireless network architecture, serving both video and data traffic. The paper analyzed the benefit of introducing the priority CBQ/WRR scheduler in the intermediate wired node. End-to-end packet loss and average packet delay for video was monitored, as well as the of the TCP data transfer throughput. The simulation results show that while there is an obvious decrease in terms of the video packet loss and delay, the real end-to-end benefit in terms of QoS can be achieved only through an integrated wired-wireless QoS solution. The evaluation of this benefit and the integration of priority scheduling in wired nodes with some of the priority schemes in wireless LANs present the most important topics for research following this paper.

6. References

[1] H. Balakrishnan, V. N. Padmanabhan, S. Seshan, R. H. Katz, “A Comparison of Mechanisms for Improving TCP Performance over Wireless Links”, *ACM SIGCOMM ’96*

[2] ns-2 Network Simulator, available at *http://www.isi.edu/nsnam/ns*

[3] S. Vangala, M. Labrador, “Performance of TCP over Wireless Networks with the Snoop Protocol”, *27th Annual IEEE Conference on Local Computer Networks (LCN 2002), November 2002*

[4] V. Rakocevic, J. Griffiths, G. Cope, “Performance Analysis of Bandwidth Allocation Schemes in Multiservice IP Networks using Utility Functions”*, ITC17, Salvador da Bahia, Brazil, December 2001*

[5] Sally Floyd, Van Jacobson*,* “Link-Sharing and Resource Management Models for Packet Networks”, *IEEE/ACM Trans. on Networking, Vol.3, No.4, August 1995*

[6] F. Risso, P. Gevros, “Operational and Performance Issues of a CBQ Router”, *SIGCOMM99*

[7] Hui Zhang, “Service Disciplines for Guaranteed Performance Service in Packet-Switching Networks”, *Proceedings of the IEEE, 83 (10), October 1995*

[8] W-T.Chen, Y-M. Lin, S-C Lo, “Priority-based Contention Control in IEEE802.11 Wireless LANs”, *16th International Workshop on Communication Quality & Reliability 2002*

[9] A. Lindgren, A. Almquist, O. Schelen, “Evaluation of Quality of Service Schemes for IEEE802.11 Wireless LANs”, *26th IEEE LCN2001, November 2001*

[10] V.Rakocevic, “Congestion Control Algorithms for Multimedia Applications in the Wireless Internet”, *submitted paper, April 2003*

[11] IEEE, “*Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications”,* IEEE standard 802.11, June 1999