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Providing QoS for Symmetrical Voice/Video Traffic in Wireless Networks

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***Abstract*— Voice over IP (VoIP) and Voice/Video over IP (VIoIP) are becoming very popular and widespread. These types of real-time services produce streams that are almost symmetrical in nature. A new token passing Media Access Control (MAC) developed by our group, called Wireless Token Network (WTN) [1], has been designed with QoS guarantees in mind. We have previously shown in [1] that WTN supports a higher number of VoIP clients compared to 802.11e due to its higher channel efficiency. In this paper we show that WTN also provides superior QoS for bidirectional streams such as VIoIP due to a higher proportion of channel access given to the access point (AP). Performance results are generated by benchmarking WTN against IEEE 802.11 DCF, IEEE 802.11e EDCA and SpectraLink SVP MAC protocols. These results show that whilst appropriate for unidirectional traffic, these current popular solutions do not provide QoS for streams in both directions, due to design constraints which treat the access point as a single client node.**

I. Introduction

New multimedia services [2], [3] such as broadcast video and voice, Voice over IP (VoIP) and Voice/Video over IP (VIoIP) are becoming very popular. The demand for quality from users in these new areas is starting to approach the same level of quality demanded from commercial grade services. VoIP and recently VIoIP have been adopted by large manufacturers for use in wireless networks with companies such as SpectraLink offering wireless VoIP phone hardware. VoIP has also been implemented by many mainstream internet service providers as an alternative to landline services, with telephone numbers which are available from the plain old telephone service (POTS). Voice and video over IP hardware is now also emerging for wireless security cameras and as an alternative to mobile video phone services such as 3G phones. While broadcast services like security cameras or video streaming are unidirectional, voice and video phone calls that are highly compressed, made over IP, create streams which are near symmetrical [2], [3] and hence are bidirectional in nature. To achieve acceptable QoS a real-time stream requires a certain throughput, delay, and jitter, with the aim being a high throughput that is highly consistent for each node. Since VoIP and VIoIP require a stream in both directions the access scheme must guarantee that the correct throughput is available for both streams in the pair to achieve QoS. Failing to meet the demands of just one of the two streams means that meaningful two way communication is not possible and hence there is no QoS.

The media access control (MAC) layer is responsible for controlling which node of the wireless network is allowed to access the shared channel and how nodes communicate with each other, hence it is directly responsible for the throughput, delay and jitter characteristics observed at each node. Many different wireless MAC schemes have been developed to support a wide variety of services whilst trying to ensure that QoS is guaranteed. Each scheme has been optimized to support a particular application or set of applications. The optimization of a particular scheme leads to its inherent strengths and weaknesses. These strengths and weaknesses determine how effectively the scheme functions in real life for a particular mix of applications. These strengths and weaknesses also determine which applications each scheme is best suited to.

In this paper we have compared the distributed coordination function (DCF) as specified in 802.11, SpectraLink voice priority (SVP) which is a modification of DCF, the enhanced distributed channel access (EDCA) MAC as specified in 802.11e and the wireless token network (WTN) which has been developed by the Communications Research Group at Edith Cowan University.

II. Wireless Access Schemes

A. 802.11b - DCF

The IEEE 802.11b standard and its limitations are widely published and many extentions and modifications have been proposed to support real-time traffic [4]–[8]. Differentiation of services is usually all that is achieved. Furthermore, delay and jitter are still unpredictable due to the random nature of the waiting time. The DCF was originally designed to allow quick, easy and robust access to a wireless channel without complicated addressing or queuing techniques. DCF was not designed to support QoS, hence when faced with traffic of differing priority DCF does not differentiate between a high priority packet and a low priority packet. Throughput on average in a saturated network running 802.11 DCF MACs is equal for all nodes if they all have the same traffic pattern.

B. 802.11 - SVP

SpectaLink is one of the world's largest provider of VoIP telephony products and as such have developed their own scheme for providing quality of service in 802.11 networks, in the absence of a standard. SVP [9] is a modification of 802.11 which specifies that the back-off time for high priority packets should be set to zero. In the original specification of SVP, setting the contention window to zero for high priority traffic is only done at the access point. In this paper we also consider the possibility of setting the contention window to zero for high priority traffic at all nodes in the network. SVN also specifies that high priority packets should either be put at the head of the queue or put in a separate queue completely. Both these methods are designed to give priority access to packets which contain high priority data and allows them to access the network in a timely manner at the expense of causing more collisions. Unfortunately collisions may also reduce the total throughput of data in the system. Since SVP is based on DCF many of DCF's shortcomings are also present in SVP.

C. 802.11e - EDCA

The IEEE 802.11e standard [10]–[13] implements an enhanced version of DCF. This is still a contention based MAC using carrier sense multiple access with collision avoidance (CSMA/CA). Traffic at each node is differentiated into up to eight queues. Each of the queues has a different arbitrary interframe space (AIFS) and a different minimum contention window time. Traffic classes with a shorter AIFS and window size will have a higher probability of getting access to the medium. This scheme guarantees bandwidth for high priority traffic very well, whilst still maintaining connectivity for low priority traffic. EDCA also achieves quite good delay performance. However each queue essentially works like its own DCF, meaning that as the number of users rises the collision rate rapidly increases. Where high collisions are present data throughput drops markedly with retransmission attempts causing further collisions. The random nature of the back off time means that, just like DCF, the jitter is not well bounded. EDCA strives to make access to the network more fair than DCF and as such all clients in a saturated network generally maintain equal throughputs even with differing traffic patterns.

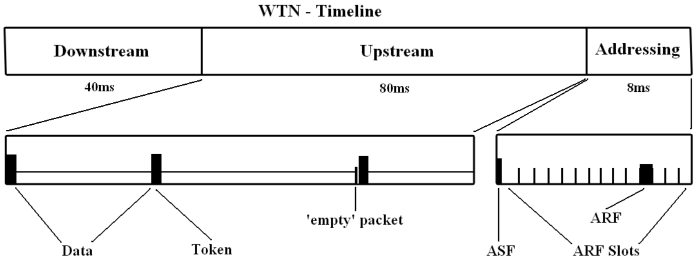

Fig. 1. The time divisions of WTN

III. Wireless Token Network

WTN [1] is a clean sheet design which only incorporates the overheads that are absolutely necessary to provide good throughput and QoS. All decisions during the design phase leant towards lower transmission overhead and hence WTN is more efficient with the bit rate available to it when compared to 802.11. WTN is a time division multiplexed (TDM) token passing network with separate address negotiation. Due to the TDM nature of the upstream and downstream traffic at the access point; WTN provides a dedicated portion of network access time to the access point's traffic. The network is centralized with all management functions taking place in the Access Point (AP). A client can only send when they hold the token, thus removing the possibility of collisions.

A. WTN - Time divisions

As shown in Fig. 1, a typical WTN cycle consists of 3 time division multiplexed activities: addressing, downstream traffic and upstream traffic. In a round robin cyclical network the average delay experienced by each node is approximately the cycle time. The delay requirements of conversational voice and video traffic have an upper bound of 200 ms [2]. To allow for jitter and codec delay 70 ms has been removed from this budget, leaving 130 ms. The cycle is set to 128 ms when addressing takes place and 120 ms when addressing does not take place. This cycle time is divided between 40 ms downstream, 80 ms upstream and 8 ms addressing. Due to the lower overhead of downstream traffic a much shorter time has been allocated to it than upstream traffic. The timing has not yet been fully optimized however future research will be conducted to optimize this area. A cycle starts with downstream traffic from the access point. This traffic is sent in a continuous manner until either the access point runs out of traffic or 40 ms expires. This is significantly different from most schemes, where the AP must compete like any other station to have access to the channel. This allows more symmetrical traffic patterns without a bottleneck at the AP for received traffic.

After the downstream time division is complete the upstream sequence commences, where tokens are passed to each client in turn. The token contains information about how long the client can transmit for. This time can be fully utilized, or if a client runs out of traffic a small empty packet is sent to indicate that it is relinquishing the token.

After the upstream traffic time division is complete the access point checks to see if a free address is available. If an address is available addressing takes place. Once addressing is complete the cycle repeats. If no address is available then no addressing takes place and the cycle repeats.

B. WTN - Upstream Time Division

Both the AP and all clients have a dual queue system that allows best effort and real-time traffic to be separated and hence differentiated to provide QoS. By differentiating traffic at the node and giving the appropriate time slice to each client, stringent QoS can be obtained in terms of throughput for each stream. During the upstream sequence each client embeds information about the change in its queue lengths in the data frames that are being sent. This information is stored in the management list.

Eq. 1 is the full calculation of a timeslice for each user. This formula is broken down into two steps which are given in Eq. 2 and Eq. 3. Step one is shown in Eq. 2, the previous cycles timeslice for the client is scaled and added to the sum of the the scaled queue information stored in the management list. By completing this calculation for each client we get a list of uncorrected timeslice values. Since the sum of all client timeslices must equal the upstream division time we then pass these uncorrected timeslices through Eq. 3. The uncorrected times are scaled so that their sum is equal to the upstream division time.

$$C_{cur}(i) = \frac{Cyc(\beta C_{prev}(i)) + \sum(\gamma_i(j)Q_i(j))}{\sum C_{cur}(i)} \quad (1)$$

$$C_{uncorrected}(i) = \beta C_{prev}(i) + \sum(\gamma_i(j)Q_i(j)) \quad (2)$$

$$C_{cur}(i) = \frac{Cyc(C_{uncorrected}(i))}{\sum C_{uncorrected}(i)} \quad (3)$$

where:
$C_{cur}(i) =$ client timeslice.
$C_{uncorrected}(i)$ is the uncorrected client timeslice.
$C_{prev}(i) =$ client timeslice from the previous cycle.
$Cyc =$ the upstream division time.
β is the previous cycle scaling factor.
$\gamma_i(j)$ is the queue scaling factor vector.
Q_i is the queue information vector.
j is the queue number.

C. WTN - Addressing

Since WTN is tightly controlled and a node wanting to send traffic can only do so when handed a token, an addressing time has been set aside to allow unassociated nodes in the network to associate with an AP. At the end of the upstream time division the AP checks for a free address and if one is found it sends an Address Send Frame (ASF). This signals to unassociated nodes that an addressing period has begun and an address is free. Unassociated nodes then calculate a random backoff slot in which to transmit an Address Reply Frame (ARF). The first reply without error received at the AP wins the address. If there is not a free address available no ASF is sent and the AP commences a downstream division.

IV. Results

The scenario for our simulations is described as the following topology and traffic. A single access point has four clients. These four clients have two way traffic consisting of 500 bytes every 20 ms in each direction. The 500 bytes is made up of 80 bytes for audio and 420 bytes for Video. This is a very low bit rate for video however we are considering each client to be the equivalent of a 3G phone where frame rates and resolutions are much lower than normal. Each realtime stream is roughly 200 Kbps giving a total of 800 Kbps from the access point and 200 Kbps from each client.

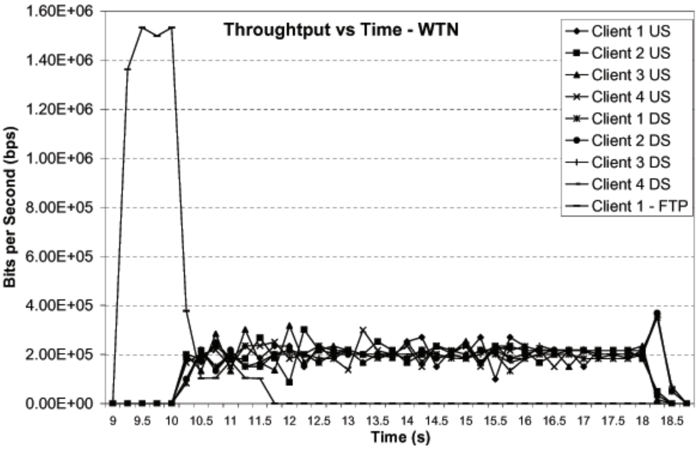

Fig. 2. Throughput - WTN

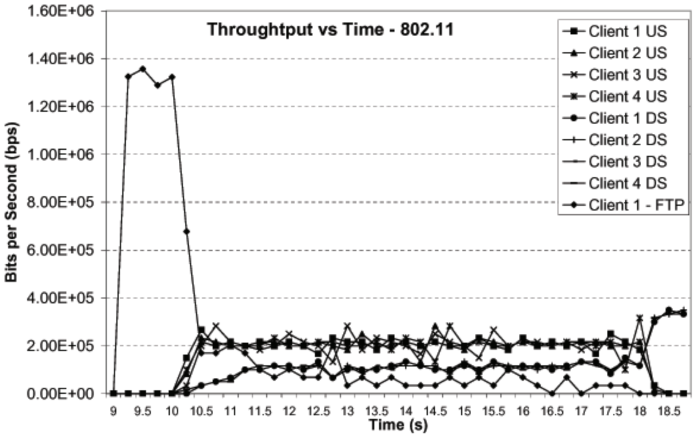

Fig. 3. Throughput - 802.11b

The data rate is set at 2 Mbps hence the low user numbers needed for saturation of the channel. Client 1 also has an FTP transfer to the access point; this is used to show how well each scheme differentiates traffic. The sum of each of these streams individual throughput just saturates the network.

A. WTN

WTN employs a completely different method for assigning capacity to clients and access point. Since the access point is given dedicated access to the channel for a much longer period it is able to service traffic in the downstream direction much better than the other schemes shown in this paper. Fig. 2 shows the results when the above scenario is simulated with WTN being used by all nodes in the network. Both upstream and downstream traffic are very close in throughput. The average throughput for the upstream direction is 204 Kbps with a standard deviation of 38.7 Kbps which is 19% of the throughput. The downstream throughput averages 190 Kbps with a standard deviation of 20.8 Kbps which is 10.96% of the throughput. The FTP traffic in this simulation averages a throughput of 20 Kbps which is only 1.2% of the total traffic in the network. This shows that WTN provides great differentiation. However, this is at the expense of connectivity for low priority traffic when the channel is saturated (note that in this case no lower bound has been assigned to the low priority traffic in WTN, although it has a provision for it if required). With this many users with bidirectional traffic WTN is only just capable of providing QoS for the bidirectional streams. The throughput of 190 Kbps for the downstream data indicates that on average 5% of packets are lost during the simulation, which is acceptable for a VIoIP connection. The access point attains almost 4 times the throughput of a single client in this scenario.

B. 802.11 - DCF

The IEEE 802.11b standard has been used as our base line since it is generally regarded as a poor QoS provider. Fig. 3 shows the results of simulating the above scenario with 802.11's DCF MAC. Surprisingly the upstream data is very well serviced with an average of 204 Kbps for each stream and a standard deviation of 24.8 Kbps which is 12.14% of the average throughput. The throughput in the upstream direction is comparable to WTN. The downstream is where 802.11 fails. With 4 times the traffic of any single node, the access point achieves only about double the throughput of a single client (due to higher access attempts). However this is not enough to service all 4 streams correctly with throughput averaging at 100 Kbps. The standard deviation is slightly lower than for a client with 23.8 Kbps, which is 23.6% of the throughput. The throughput in the downstream direction compared to WTN is just over half. We also notice that the ftp transfer manages an average throughput of around 74 Kbps which is 5.6% of the total throughput of the system. This FTP traffic is transferred at the expense of real-time traffic. The low downstream throughput means that this scheme is unable to provide QoS for bi-directional streams. In fact, approximately 50% of packets would be lost on average in the downstream direction, for this scenario.

C. 802.11 - SpectraLink SVP

Figure 4 shows the results when the above scenario is simulated with 802.11 DCF MACs with SVP enabled on all clients and the access point. Once again the upstream

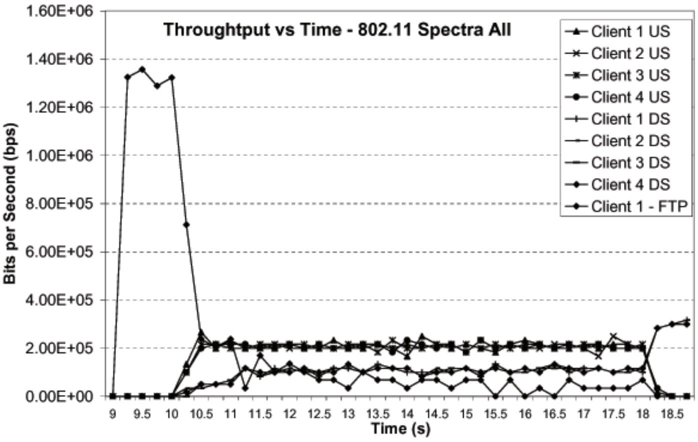

Fig. 4. Throughput - 802.11b with Spectralink on all nodes

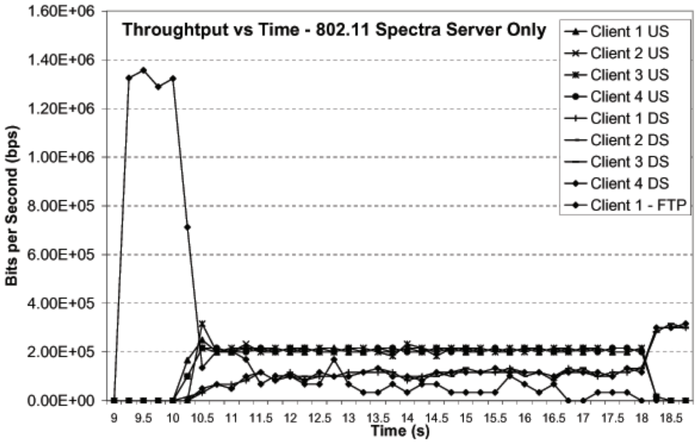

Fig. 5. Throughput - 802.11b with Spectralink on AP only

data is serviced very nicely with an average throughput of 204 Kbps. The standard deviation is markedly improved, coming in at 13.8 Kbps which is 6.8% of the throughput. The throughput is comparable to WTN, however the standard deviation is very low, making the stream very stable in this direction. Downstream throughput has dropped off slightly compared to 802.11, averaging 99.9 Kbps with a standard deviation of 20.8 Kbps which is 20.8% of throughput. This throughput once again is around 50% of that achieved by WTN. The FTP transfer has actually increased slightly to 77 Kbps which represents 5.8% of total throughput. These results show that SVP, when used at all nodes, can significantly reduce jitter and make the streams more stable. However it does not provide the throughput or differentiation required to support bi-directional QoS. As with 802.11, SVP would drop approximately 50% of packets in the downstream direction on average.

Fig. 5 shows the results when the above scenario is simulated with 802.11 DCF MACs with SVP enabled only at the access point as originally specified by SpectraLink. The upstream average throughput is once again 204 Kbps and the standard deviation is 12.58 Kbps which is 6.2% of the throughput. This is a further improvement over the previous results in Fig. 4. SVP once again proves that it can make streams highly stable. Upstream data rates are once again comparable to WTN. Downstream average throughput is also slightly higher at 100.7 Kbps with a standard deviation of 21.1 Kbps which is 21% of the throughput. As with 802.11, this is roughly 50% of the required throughput. Ftp throughput is lower at 73 Kbps which is 5.5% of total throughput. These results show that SVP works best when only enabled at the access point. It also shows that the inherent weakness of DCF is still present making the access point a major bottleneck and hence not servicing the bi-directional traffic correctly. SVP does however produce a very stable connection for real-time traffic especially in the upstream connection. This scheme would be highly suited to a situation where traffic is broadcast from client nodes in one direction and high stability is required. A good example of this would be remote wireless security cameras feeding a set of monitors attached to the access point, where image arrival is critical, and two way traffic is not a factor.

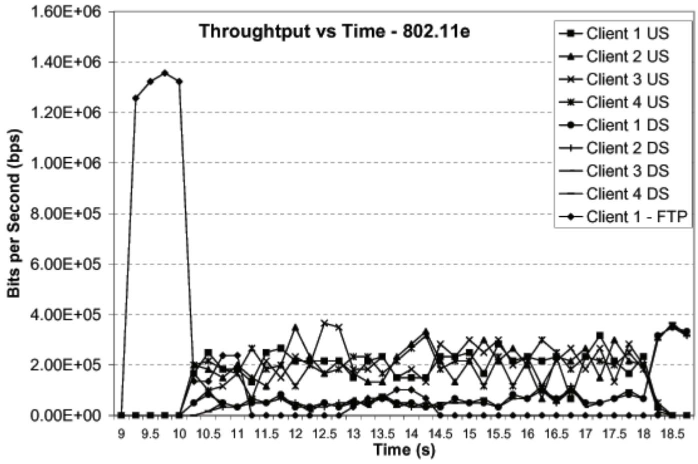

Fig. 6. Throughput - 802.11e EDCA

D. 802.11e - EDCA

802.11e is the ratified standard for QoS in 802.11 networks. ECDA tries to fairly distribute bandwidth among clients when the channel is saturated. Unfortunately the access point obtains access to the channel in the same way as any other client. Fig. 6 shows the results when the above scenario is simulated with 802.11e EDCA MACs used for all nodes. Once again the upstream flows are serviced very well, achieving an average throughput of 203 Kbps. This is comparable to all the other schemes presented here. Standard deviation however is quite high at 57.4 Kbps which is 28.3% of the throughput, this is markedly higher than any other scheme. This indicates that the streams are actually quite unstable in 802.11e with EDCF compared to 802.11, SVP and WTN. Due to the 'fair' sharing in 802.11e the downstream suffers badly only achieving an average of 53 Kbps and having a large standard deviation of 20.6 Kbps which is 38.9% of the throughput. This is only a quarter of the throughput required for proper servicing of the downstream traffic. On average almost 75% of packets in the downstream direction would be dropped. What 802.11e does very well however, is differentiation between real-time and best effort traffic. The FTP transfer in this simulation has an average throughput of 36 Kbps, which was only 3.3% of the total throughput of the system. This is an improvement over 802.11 and SVP, however WTN still manages to reduce low priority traffic to 1.2% of total throughput. While the advances in differentiation are clear, EDCA is incapable of supporting this many streams at this data rate when the streams are bi-directional, thus QoS cannot be guaranteed.

V. Conclusion

As new voice and video technologies become available and are pushed into the wireless market 802.11 based technologies are becoming smarter and more QoS oriented. Due to the nature of DCF and EDCA the access points in these networks are only serviced as though they are a single client. When streams are bi-directional this means that the load at the access point is N times greater than at a single client, where N is the number of clients with real-time streams in the network. This means that the access point must be given N times the access to the channel if it is to successfully service its real-time traffic. We have shown that current popular and standardized MACs are unable to provide this throughput. We have shown that SVP, as developed by SpectraLink, gives exceptionally stable connections in the upstream direction which would make it suitable for use in unidirectional real-time broadcast services. However, it cannot support symmetrical bidirectional traffic with high load. EDCA proves to be a good traffic differentiator which manages to maintain a connection for best effort traffic, but it cannot provide the throughput at the access point required for symmetrical bidirectional traffic. On the other hand, WTN has been designed with this provision in mind and thus it is capable of servicing these streams if they fall within the bounds of the network throughput. We have shown that WTN also achieves a low standard deviation of throughput and high differentiation of traffic.

References

[1] J. Wyatt and D. Habibi, "Wtn - providing qos for voip in 802.11 networks," in *2006 IEEE Region 10 Conference TENCON 2006*, (Hong Kong, China), 2006.

[2] M. A. Miller, *Voice over IP Technologies: Building the Converged Network*. New York: M&T Books, 2002.

[3] J. Shin, D. C. Lee, and C.-C. J. Kuo, *Quality of Service for Internet Multimedia*. IMSC Press Multimedia Series, New Jersey: Prentice Hall, 2004.

[4] W. Pattara-Atikom, P. Krishnamurthy, and S. Banerjee, "Distributed mechanisms for quality of service in wireless lans," *IEEE Wireless Communications*, vol. 10, no. 3, pp. 26–34, 2003.

[5] L. Zhao and C. Fan, "Enhancement of qos differentiation over ieee 802.11 wlan," *IEEE Communications Letters*, vol. 8, no. 8, pp. 494–496, 2004.

[6] J. Zhao, Z. Guo, Q. Zhang, and W. Zhu, "Distributed mac adaptation for wlan qos differentiation," *Global Telecommunications Conference*, vol. 6, pp. 3442–3446, 2003.

[7] W. Liu, W. Lou, X. Chen, and Y. Fang, "A qos-enabled mac architecture for prioritized service in ieee 802.11 wlans," *Global Telecommunications Conference*, vol. 7, pp. 3802–3807, 2003.

[8] K. Kim, A. Ahmad, and K. Kim, "A wireless multimedia lan architecture using dcf with shortened contention window for qos provisioning," *IEEE Communications Letters*, vol. 7, no. 2, pp. 97–99, 2003.

[9] SpectraLink, "Spectralink voice priority - quality of service for voice traffic on wireless lans."

[10] S. Mangold, S. Choi, G. R. Hiertz, O. Klein, and B. Walke, "Analysis of ieee 802.11e for qos support in wireless lans," *IEEE Wireless Communications*, vol. 10, no. 6, pp. 40–50, 2003.

[11] Y. Xiao, "Enhanced dcf of ieee 802.11e to support qos," *Wireless Communications and Networking*, vol. 2, pp. 1291–1296, 2003.

[12] Q. Ni, L. Romdhani, and T. Turletti, "A survey of qos enhancements for ieee 802.11 wireless lan," *Wireless Communications and Mobile Computing*, vol. 4, no. 5, pp. 547–566, 2004.

[13] L. A. Grieco, G. Boggia, S. Mascolo, and P. Camarda, "A control theoretic approach for supporting quality of service in ieee 802.11e wlans with hcf," in *42nd IEEE Conference on Decision and Control*, vol. 2, pp. 1586–1591, 2003.