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Abstract

Multimedia streaming applications are a demanding and challenging service to deliver over wireless networks. Such services have a large impact on the resource requirements of the WLAN. However, there are many variables involved in video streaming, such as the video content being streamed, how the video is encoded and how it is sent. This makes the role of radio resource management and the provision of QoS guarantees extremely difficult. In this paper we investigate the network resource requirements for unicast video streaming in a WLAN environment. We investigate the resource requirements for three scenarios: a single unicast video streaming session; multiple unicast video streaming sessions and finally multiple unicast streaming sessions in the presence of background traffic. We present several key findings: We show the effect that the hint track MTU values has on the access and load requirements of the WLAN. We show that the WLAN becomes saturated when the offered load reaches a certain threshold that is related to the hint track MTU setting. Finally we present some preliminary results that show how the access and load requirements of the WLAN are affected when there is background traffic contending for access to the medium.

1. Introduction

In recent years there has been an explosive growth in the use of wireless LANs arising from the advent of the IEEE 802.11b standard. Streaming multimedia over wireless networks is becoming an increasingly important service. These applications impose stringent demands on the network in order to ensure that users enjoy an "acceptable level" of QoS. In wired networks the QoS targets for multimedia applications can be met by over-provisioning. However, such an approach cannot be adopted with wireless networks due to the limited network resources. Support for such traffic with QoS requirements is being addressed by the IEEE 802.11e Task Group. However, IEEE 802.11e is only a QoS enabling mechanism that requires some higher level management functionality in order to deliver QoS guarantees. Typically, some form of radio resource management is required to allocate the available resources among the contending users in accordance with their respective needs and priorities.

In order to address the issue of radio resource management for the provision of statistical QoS guarantees, it is first necessary to understand the resource usage of multimedia traffic in IEEE 802.11b networks. There are a number of multimedia streaming applications that need to considered such as video-conferencing, multicast and unicast video streaming with real-time constraints or near real-time constraints. Furthermore, there are a large and diverse number of variables that must be taken into consideration each of which has an impact on the resource requirements video stream on the WLAN. Such variables include:

- The actual content and complexity of the content being streamed which in turn affects the efficiency of the encoder to compress the stream.
- The compression scheme being used, that is, different compression schemes have differing levels of efficiency.
- The encoding configuration. There could be any number of possible encoding configurations possible such as the error resilience, frame rate, the I-frame rate, the quantization parameter, the target bit rate (if any) supplied and target stream type i.e. VBR, CBR or near CBR.
- If the file to be streamed is .MP4 or .3gp, then a hint track must be prepared that indicates to the server how the content should be streamed.
- The streaming server being used, the rate control adaptation algorithm being used, and the methods of bit rate adaptation used by the server [1-2].

In this paper we evaluate the network resource requirements for unicast streaming over WLAN networks with near real-time constraints. This paper is structured as follows. Section two gives a brief discussion of MPEG-4 encoding, MP4 files and the importance of hint tracks. Hint tracks are required to stream MP4 and .3gp multimedia files as it tells the server how to packetise and transmit the encoded elementary stream. The next section describes the test bed used for the experiments and the WLAN probe used to measure the resource requirements of the WLAN. The next section describes the experiments conducted. We show the impact on the resource utilisation of unicast video streaming for a single client. We show how the demands of the network resources are increased with an increased number of video clients. We present some results that demonstrate how the resource requirements are affected when there is background traffic contending for access to the medium. Finally, we present some conclusions and directions for future work.

2. MPEG-4

MPEG-4 dramatically advances audio and video compression, enabling the distribution of content and services from low bandwidths to high-definition quality across broadcast, broadband, wireless and packaged media [3]. In MPEG-4, frames are called Video Object Planes (VOPs), where a VOP may be the video component of an object within the scene. However, VOPs are commonly rectangular images and as such are equivalent to frames as used in other compression schemes. For the remainder of this paper, VOPs shall be referred to as video frames. In the MPEG-4 standard, there are a number of profiles, which determine the capabilities of the player to play out encoded content. The purpose of these profiles is that a codec only needs to implement a subset of the MPEG-4 standard whilst maintaining inter-working with other MPEG-4 devices built to the same profiles. The most widely used MPEG-4 visual profiles are the MPEG-4 Simple Profile (SP) and the MPEG-4 Advanced Simple Profile (ASP) and are part of the non-scalable subset of visual profiles. The main difference between MPEG-4 SP and ASP is that SP contains only I and P-frames whereas ASP contains I, P and B-frames.

MP4 files comprise a hierarchy of data structures called atoms and each atom has a header, which includes its size and type [4-6]. A parent atom is of type *moov* and contains the following child atoms: *mvhd* (the movie header), a series of *trak* atoms (the media tracks and hint tracks), and a movie user data atom *udta*. A *trak* represents a single independent data stream and an MP4 file may contain any number of video, audio, hint, Binary Format for Scenes (BIFS) or Object Descriptor (OD) tracks. Within an MP4 file, each video and audio track must have its own associated hint track. Hint tracks are used to support streaming by a server and indicate how the server should packetise the data. As with MP4 streaming, .3gp files use the "hint track" mechanism for streaming the content, although in .3gp files the BIFS and OD tracks are optional and can be ignored.

Hint tracks map media data to packets. These hint samples tell the server how to make a packet or group of packets and allow a server to stream media files without requiring the server to understand media types, codecs, or packing. This kind of knowledge allows the hint track to optimise the packetisation of the media data. Hint samples are protocol specific by specifying the protocol to be used and providing the necessary parameters for the server. The *stsd* child atom contains transport-related information about the hint track samples. It specifies the data format (currently only RTP data format is defined), the RTP timescale, the maximum packet size in bytes (MTU) and additional information such as the random offsets to add to the stored RTP timestamps and sequence number. In general most video-frames are quite large and so at most one video frame can be packetised into a single 1024B packet. If the video frame is larger than the packet, several packets are required to send the video frame resulting in a group of packets with a size of the hint track MTU setting and a smaller packet containing the remainder information. Figure 1 shows the payload size for same MPEG-4 video content streamed using a hint track MTU setting of 1024B and 512B. It can be seen that there is a large number of packets that are significantly lower than the hint track MTU setting. In the rest of this paper, we shall analyse the effects the hint track MTU setting has on the bandwidth requirements in the WLAN with the understanding that packets vary significantly in size but never exceed the hint track MTU setting.

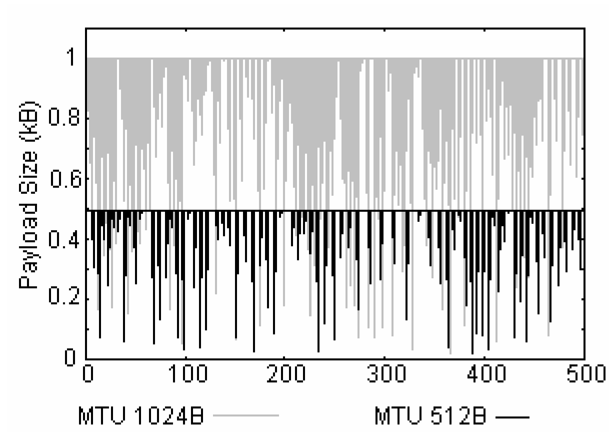


Figure 1: Variations in Packet Size with Hint Track MTU 1024B and 512B

3. Experimental Test Bed

To evaluate unicast video streaming a video server was set up on the wired network and streamed to wireless clients via the Access Point (AP) (Figure 2). There are

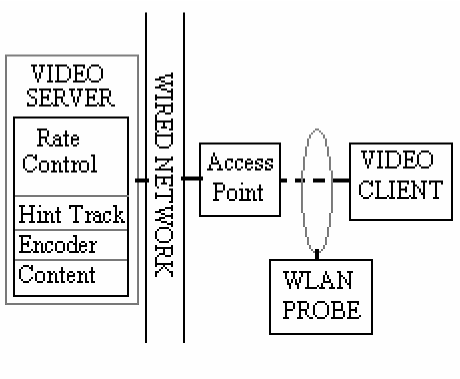


Figure 2: Experimental test bed

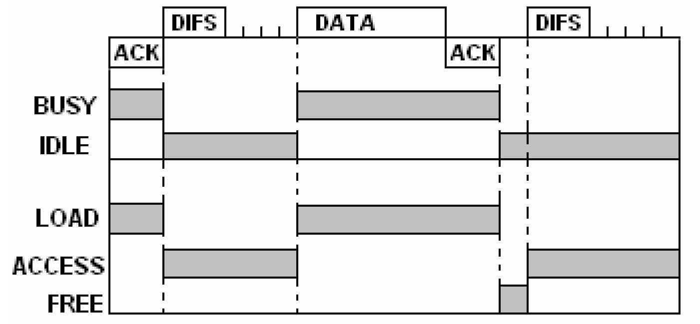


Figure 3: MAC Bandwidth Components

two open-source streaming servers available, Helix from Real [7] and Darwin Streaming Server (DSS) from Apple [8-11]. There have been several papers that have evaluated the performance of the Helix streaming system [12]. In this paper, we have chosen DSS to be the streaming server for our experiments. Although, our future work will investigate the behavioural and performance-related differences between streaming servers with differing adaptation algorithms. DSS is an open-source, standards-based streaming server that is compliant to MPEG-4 standard profiles, ISMA streaming standards and all IETF protocols. The DSS streaming server system is a client-server architecture where both client and server consist of the RTP/UDP/IP stack with RTCP/UDP/IP to relay feedback messages between the client and server. The client can be any QuickTime Player or any player that is capable of playing out ISMA compliant MPEG-4 or .3pg content. The client connects to the server via RTSP to establish a unicast video streaming session. The video content was encoded using the commercially available X4Live MPEG-4 encoder from Dicas.

Each video clip was encoded using MPEG-4 SP at 25fps and then hinted using MP4Creator from the MPEG4IP Project [13]. In the experiments reported here, the client used a 3 second pre-buffering delay such that upon connection-establishment with the server, the client stores 3 seconds of media before playout of the media begins. This buffering delay minimized the effects of any quality degradation due to delay and/or loss and more importantly, it ensured that the server did not use any transmission rate adaptation as a result of RTCP feedback messages from the client. Thus the resource usage of video streaming applications could analysed in isolation of any server adaptation mechanisms.

At the wireless side, a WLAN resource monitoring application reported in [14-15] was used to measure the resource utilisation of the video streams. This application non-intrusively monitors and records the busy and idle intervals on the wireless medium and by analysing the temporal characteristics of these intervals infers the resource usage on a per-STA basis. The WLAN resource utilisation is characterised in terms of MAC bandwidth components that are derived from the line rate (Figure 3). Specifically, three MAC bandwidth components are defined: A load bandwidth (BW_{LOAD}) associated with the transport of the traffic stream and is related to the throughput, an access bandwidth requirement (BW_{ACCESS}) that represents the "cost" of accessing the wireless medium, and a free bandwidth (BW_{FREE}) that gives a measure of the likely QoS. An access efficiency may be defined as the ratio of the BW_{LOAD} to the BW_{ACCESS} and gives an indication of how efficiently a STA accesses the medium. The intervals during which the medium is busy correspond to the intervals during which frames are being transmitted on the medium (i.e. data and management frames) and is associated with the transport of the traffic load. The busy bandwidth (BW_{BUSY}) is the portion of the transmission rate used for the transport of the total traffic load, that is, the sum of the BW_{LOAD} overall STAs. Similarly, when the medium is not busy, it is said to be idle. The idle bandwidth (BW_{IDLE}) represents the portion of the transmission rate that is idle and may be used by any STA to win access opportunities for its load. The sum of BW_{BUSY} and BW_{IDLE} must equal the line rate i.e. 11Mbps in IEEE 802.11b. This technique has been shown to be particularly effective in characterising WLAN resource utilisation in a manner that is both compact and intuitive.

3.1. Analysis of BW_{ACCESS} and BW_{LOAD} for a single Unicast Video Streaming Session

The WLAN probe was used to measure the resource usage of the WLAN for a single unicast video streaming session with no background traffic present so that the relationship between the load and access bandwidth could be analysed. Table 1 shows the encoding configuration parameters of the video sequences used in these experiments. The second column indicates the mean bit

Table 1: JR Content Type at Different Resolutions

Clip	Mean Bit Rate (Mbps)	I-Freq	PeakFr (B)	F	I	P
JR1	0.969	10	17299	3.57	1.92	3.02
JR2	1.099	10	17299	3.15	1.92	2.60
JR3	1.098	10	17299	3.15	1.92	2.60
JR4	0.980	5	17635	3.59	1.98	3.15
JR5	0.945	25	16403	3.47	1.81	2.92
JR6	0.934	50	15715	3.36	1.75	2.91
JR7	0.930	100	15363	3.30	1.70	2.89

rate of the video sequence at the encoder; the third column indicates the I-frame frequency. The fourth column shows the peak frame size in bytes, the fifth column shows the Peak-to-Mean ratio overall frames in the sequence, the sixth and seventh columns show the Peak-to-Mean ratio for the I and P frames respectively. Each clip was then subsequently hinted with a hint track MTU setting of 1024B and/or 512B. Although, the test clips used were only 5 minutes long, the video was streamed continuously in a loop for the testing period.

Table 2 shows the BW_{ACCESS} and BW_{LOAD} as measured by the WLAN probe. It can be clearly seen that by using a hint track MTU setting of 512B increases the BW_{LOAD} by 20% due to the additional packet header overhead that needs to be sent and the increased number of ACKs that need to be sent to acknowledge each packet. This difference in BW_{LOAD} can be related to the different packet sizes using the throughput analysis in [16]. For example, given that the video clip contains the same encoded video data with the same mean video bitrate but has different hint track MTU settings. An integral number of, *N*, packets are required to send the video data is related to the amount of payload (*PayloadSz*) that can be encapsulated into each packet. However, the true bandwidth required to send the video data, BW_{VIDEO}, is the number of packets, *N*, by the total WLAN frame size ($FrameSz_{VIDEO}$) that includes the various packet headers, where *IPHdr* includes RTP, UDP, and IP headers and *MACHdr* includes the MAC header and preamble. The time required to send a single video packet (T_{VIDEO}) is given as the size of the video data frame divided by the line rate which for IEEE 802.11b is 11Mbps. The total time it takes to send the video data, (T_{STREAM}) is the time it takes to send a single WLAN frame of video data (T_{VIDEO}) plus the time required for SIFS, ACK and DIFS multiplied by the number of packets, *N*. The total bandwidth required to send the video data, BW_{STREAM} is therefore the time taken to transmit the video data (T_{STREAM}) multiplied by the line rate.

$$N = \left(VideoDataRate / PayloadSz \right)$$

$$FrameSz_{VIDEO} = 8 * (PayloadSz + IPHdr + MACHdr)$$

$$BW_{VIDEO} = N * FrameSz_{VIDEO}$$

$$T_{VIDEO} = FrameSz_{VIDEO} / R$$

$$T_{STREAM} = N(T_{VIDEO} + T_{SIFS} + T_{ACK} + T_{DIFS} + Backoff * Slot)$$

$$BW_{STREAM} = T_{STREAM} / R$$

Using this analysis, we found that the difference between sending the same video data rate with a hint MTU of 512B and 1024B is approximately 15% which is very close to the observed difference in BW_{LOAD}.

The BW_{ACCESS} is doubled by using a hint track setting MTU of 512B. This is an intuitive result since twice as many packets need to be sent by using the smaller packet size and therefore the AP must gain access to the medium twice as often. Therefore, by using larger packets the video stream accesses the medium on average 169% more efficiently. The results highlight the trade-off with the hint track setting as it is clear that by using larger packets, the AP accesses the medium and transmits the data more efficiently. However, if there are collisions or lost packets, a larger amount of data will need to be retransmitted. If the lost packet cannot be retransmitted in time for playout, this in turn affects the quality of the streaming session since in general, the more lost data there is, the harder it is for a decoder to mask, conceal or

Table 2: Mean values of BW_{ACCESS} and BW_{LOAD}

Clip	Hint MTU 1024B Mean Pkt Sz 912B			Hint MTU 512B Mean Pkt Sz 468B			Ratio (%)		
	BW_{ACCESS} (Mbps)	BW_{LOAD} (Mbps)	Access Efficiency	BW_{ACCESS} (Mbps)	BW_{LOAD} (Mbps)	Access Efficiency	BW_{ACCESS}	BW_{LOAD}	Access Efficiency
JR1	0.55	1.19	2.16	1.16	1.48	1.28	47	80	169
JR2	0.63	1.36	2.16	1.27	1.62	1.28	50	84	169
JR3	0.63	1.37	2.17	1.29	1.65	1.28	49	83	170
JR4	0.56	1.21	2.16	1.16	1.48	1.28	48	82	169
JR5	0.54	1.16	2.15	1.13	1.44	1.27	48	81	169
JR6	0.53	1.15	2.17	1.11	1.41	1.27	48	82	171
JR7	0.53	1.14	2.15	1.08	1.37	1.27	49	83	169

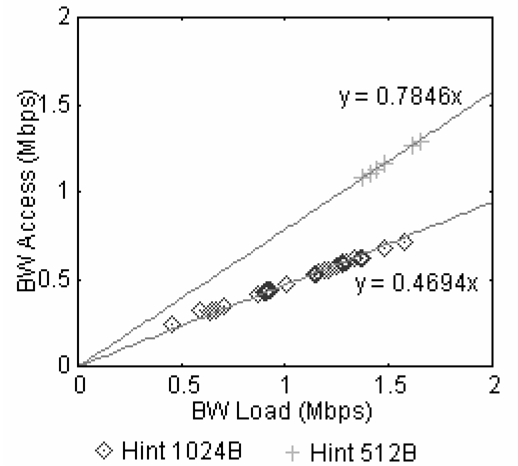


Figure 4: Relationship between BW_{ACCESS} and BW_{LOAD}

recover the lost data.

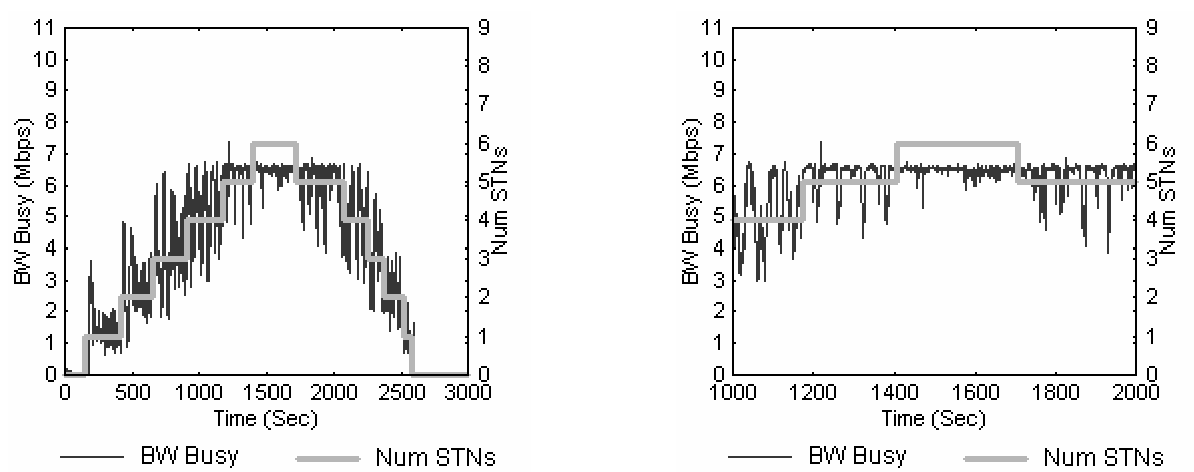
To test this relationship further, the experiment was repeated to include different video clips encoded in a variety of ways with the mean video bit rate ranging from 512kbps to 1.2Mbps. Figure 4 shows the relationship between BW_{ACCESS} and BW_{LOAD}., where each point represents the mean access and load recorded by the probe for each unicast video session across all video clips with a hint track MTU setting of 1024B or 512B. A best-fit linear curve was fitted for the two data sets with the general formula: $y=Ax$ where A is some constant. The relationship between the value for A of both linear fits is 1.67 and is approximately equal to the relationship of the access efficiency using the two different packet sizes.

$$Ratio = \frac{1}{\left(A_{1024} / A_{512} \right)} = 0.7846 / 0.4694 = 1.67$$

3.2. Analysis of BW_{BUSY} for a multiple Unicast Video Streaming Sessions

Using the same experimental test setup, the probe recorded resource requirements with increasing number of unicast video streaming sessions over time with no background traffic. A maximum of 6 video clients were used during these tests. Test 1 and 2 considered all clients requesting the same video file, JR1 and JR3 with a hint MTU of 1024B. Test 3 considered clients requesting random content with a hint MTU of 1024B and Test 4 considered clients requesting random content with either a hint MTU setting of 1024B or 512B. Figure 5(a) shows how the BW_{BUSY} varies over time as recorded by the probe in Test 1. As more clients are added, the busy bandwidth is increased. The busy bandwidth fluctuates greatly and is due to the VBR nature of video. Figure 5(b) shows a close-up of the trace during the period of saturation. It is noticeable that there is very little variability in the recorded BW_{BUSY} indicating that the AP is saturated and transmitting frames at the maximum rate.

Table 3 shows how the mean BW_{BUSY} varies as the number of video clients in increased. In Tests 1, 2 and 3 we find that the BW_{BUSY} does not exceed 6.5Mbps indicating that the AP has reached saturation and no more clients can be supported. However, the number of clients that can be supported is dependent on the bandwidth requirements of the individual streams. For example, in Test 1 each video streaming session had a bandwidth requirement of approximately 1.2Mbps, thus only 5 video clients could be fully supported. However, in Test 2 each video streaming session had a bandwidth requirement of approximately 1.6Mbps, therefore only 4 video clients could be fully supported. In Test 4, the AP becomes saturated at a lower level due to the fact that there is a mix



(a) (b)

Figure 5 (a): Variation in BW_{BUSY} over time during Test 1
(b) Close-up of BW_{BUSY} during the period of saturation time

Table 3: Mean BW_{BUSY} for Multiple Simultaneous Clients

#STNS	Test1 BW_{BUSY}	Test2 BW_{BUSY}	Test3 BW_{BUSY}	Test4 BW_{BUSY}
1	1.19	1.58	1.57	1.95
2	2.59	2.85	2.82	3.14
3	3.86	4.43	4.36	4.63
4	5.02	5.99	5.73	5.56
5	6.20	6.39	6.17	5.63
6	6.47	6.49	6.45	5.70

of hint track settings for the various video clips. As we have seen, greater throughput and access efficiency are achieved by using the larger hint track MTU setting. So it is expected that by reducing the mean packet size, the effective throughput is reduced. Thus, if the current value of the BW_{BUSY} and the mean bandwidth requirements for a new video streaming session are known, the radio resource manager can decide whether it can support the additional client. This is useful knowledge as once the AP becomes saturated and the BW_{BUSY} reaches its maximum, all video streaming sessions will be negatively affected incurring a reduced throughput, increased packet delays and packet losses, all of which negatively affect the perceived quality.

3.3. Analysis of BW_{BUSY}, BW_{ACCESS} and BW_{LOAD} for a multiple Unicast Video Streaming Session with Background Traffic

In this section, we present some preliminary results that show how the resource requirements of unicast video streaming applications are affected when there are background traffic sources. The test setup is shown in Figure 6. The traffic generator, MGEN [17] was used to transmit background traffic packets (Bak STN) on the uplink via the AP to a sink on the downlink. The background traffic had a packet size of 1024B at a rate of 50 packets per second resulting in an offered uplink load of 0.41Mbps and downlink load of 0.41Mbps which gives a total load of 0.82Mbps.

Table 4 presents a summary of the results for unicast streaming services with increased number of video clients and number of background traffic sources. Each test was conducted for streaming the same video clip encoded with two different configurations. As expected, the BW_{BUSY} is increased with the increased number of background traffic sources and video clients. However, an interesting relationship between the BW_{ACCESS} and BW_{LOAD} emerges. Figure 7 shows this relationship more clearly. It can be seen that when there is no background traffic, the relationship between the access and load remains as previously observed where each point on the line

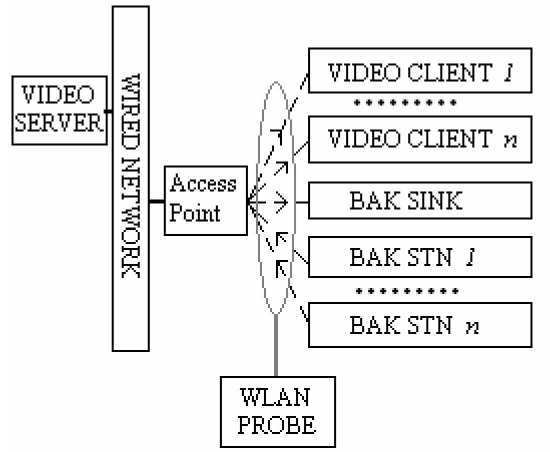


Figure 6: Experimental Test bed with Multiple Video Clients and Background Traffic

represents the number of video clients. However, when the number of background traffic sources is increased, the overall load bandwidth is increased by an offset corresponding to the increased load of the background traffic (approximately 0.82Mbps). In addition, given that the number of contending stations has increased, the access requirements are also increased. The access bandwidth is strongly affected by the dominant packet size rather than the offered load as observed in the results of the hint track MTU settings for the video. However, in all cases, it can be seen that the access-load slope remains relatively unchanged.

4. Conclusions

In this paper, we have demonstrated the effect that the packet size has on the access and load requirements of WLAN networks for unicast video streaming applications in three situations. We have shown that there is a linear relationship between the load and access requirements for video streaming applications and that this relationship is additionally affected by the hint track MTU setting. We showed that the AP becomes saturated at approximately 6.5Mbps when there is no background traffic contending for access to the medium using a hint track MTU setting of 1024B but this maximum is further reduced by using a smaller hint track MTU. However, the number of clients that can be supported is dependent on the bandwidth requirements of the individual streams. Finally, we presented some preliminary results that show how the relationship between access and load are affected by the level of background traffic sources. Currently work is in progress that investigates this aspect of the resource requirements for multimedia streaming applications. Future work is planned to apply knowledge of resource requirements for multimedia streaming applications to enable radio resource management and the provision of statistical QoS guarantees in IEEE 802.11e.

Table 4: Summary of results with multiple simultaneous clients and background traffic with a hint MTU setting of 1024B

#BAK STN	#Video Clients	Clip: JR1				Clip: JR3			
		BW_{BUSY} (Mbps)	Access Efficiency	BW_{ACCESS} (Mbps)	BW_{LOAD} (Mbps)	BW_{BUSY} (Mbps)	Access Efficiency	BW_{ACCESS} (Mbps)	BW_{LOAD} (Mbps)
0	1	1.19	2.13	0.62	1.32	1.58	2.20	0.70	1.54
	2	2.59	2.11	1.22	2.58	2.85	2.15	1.30	2.79
	3	3.86	2.12	1.81	3.84	4.43	2.14	2.03	4.35
1	1	2.65	1.67	1.21	2.02	2.83	1.71	1.28	2.19
	2	3.62	1.84	1.65	3.03	4.04	1.87	1.83	3.43
	3	4.63	1.95	2.13	4.15	5.55	2.04	2.43	4.96
2	1	3.71	1.51	1.65	2.49	3.91	1.56	1.74	2.71
	2	5.23	1.65	2.40	3.96	5.36	1.67	2.46	4.11
	3	5.84	1.72	2.68	4.61	6.17	1.75	2.81	4.93
3	1	4.87	1.40	2.18	3.06	4.86	1.46	2.15	3.14
	2	5.99	1.57	2.70	4.23	6.21	1.61	2.76	4.46
	3	6.21	1.64	2.76	4.53	6.29	1.62	2.82	4.57

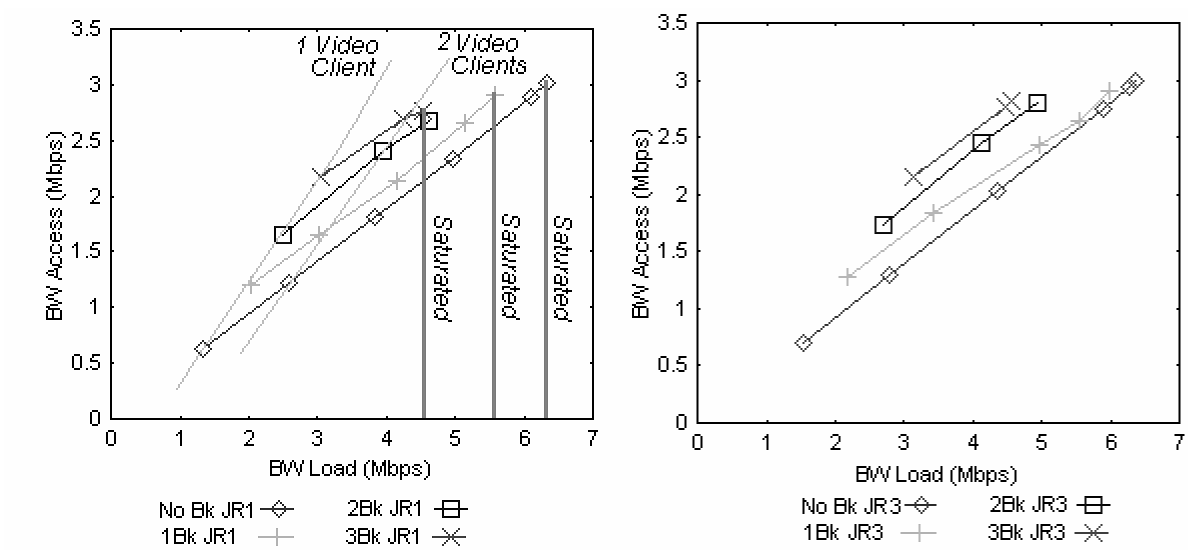


Figure 7: Plot of BW_{ACCESS} and BW_{LOAD} with increased number of video clients and increased number of background traffic sources for the video clips JR1 and JR3

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