Provision of true VoD services via a broadband wireless networking infrastructure

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Abstract: - The evolution of MPEG-2 compression technique has made possible the communication of full motion video as a type of computer data. However, how to access the video from anywhere at anytime using a band-limited network, while maintaining the Quality-of-Service (QoS) at high levels has become the main research topic in recent years. This paper proposes a broadband wireless network architecture that enables access to full motion video programmes, and also provides fast access to Internet. It describes the system architecture and configuration adopted for the provision of digital MPEG-2 video programmes via a broadband wireless network, using Frequency Hopping Spread Spectrum (FHSS) technology in the ISM frequency band. It elaborates on the provided picture quality and evaluates the system's Quality-of-Service (QoS) in a multi-client environment.

Key-Words:- MPEG-2, Picture Quality, Broadband wireless networks, Spread Spectrum technology, VoD service.

1. Introduction

The evolution of MPEG-2 compression technique and the emergence of wireless network technologies have fade the classical boundaries between telecommunications, consumer electronic products and computing. The aim of this convergence is to create a single platform that will allow the consumer to access the latest digital TV programmes from anywhere at anytime, while enabling for interactivity. The provision of interactive video services forms a new kind of media service that is commonly known as Video-on-Demand (VoD). In such a system, the client is able to choose and play a movie on a TV set or on a PC screen at any given time like watching it by the video player machine. In the current VoD applications each client is individually served. That means that the system dedicates a transmission channel (down-link), a return path (up-link) and a set of server resources to each client. This data delivery method is known as unicast.

The MPEG-2 MP@ML standard refers to encoding standard definition television at bit-rates from 1.5 to 15Mbps [1] [2] [3]. In a reliable system that provides MPEG-2 video services to one client by the unicast method, the network should efficiently support a *Minimum Throughput* (MT) of at least 1.5Mbps plus an amount of data for the return channel. In a multi-client system the MT is linearly increased with the number of simultaneous clients. Furthermore, the system should remain efficient when more than one clients access the same video programme. Also, in this case the system resource requirements increase linearly with the number of the contemporary clients. Therefore, the unicast delivery method for providing this kind of services requires a broadband network and efficient system resources.

Consequently, the multicast delivery method comes to the foreground. In this method one stream (down-link) is used to serve a number of simultaneous clients, while the system resource requirements are reduced to a minimum. However, this method features the disadvantage that it can not provide effectively full VCR functions (fast-forward, fast-rewind, etc.). Furthermore, the multicast delivery method provides the video programme that the service provider has chosen, which opposes the idea of on-demand services.

In this paper, a prototype system was developed, which is capable of providing true interactive VoD services with full VCR functions to a number of simultaneous clients, via a wireless broadband networking infrastructure. Additionally, it can provide fast access to Internet. The system operates in the ISM frequency band (2400-2483.5GHz) and makes use of a broadband access technology that follows the IEEE 802.11 standard using FHSS modulation technique. The bit rate of the wireless link is 3 Mbps, which guarantees a network throughput of about 1.6Mbps to each client (half duplex operation). Furthermore, the system is based on the TCP/IP protocol and is built around standard technology equipment that keep the operational and maintenance costs at a minimum, while making it very attractive to the clients. The paper also explores and evaluates the system's performance in real condition environment, and presents useful data concerning its efficiency and the quality of the provided VoD service. The paper is organised as follows. In Section 2 the overall system architecture is described and the network throughput is measured in a real conditions environment, where a client located 5 Km away from the service provider accesses wirelessly the provided VoD service. Section 3 evaluates on the picture quality at low bit rates (1.6 Mbps). Section 4 elaborates on the Quality of the provided VoD service and defines the MPEG-2 encoding stream rate for a pleasant viewing. Section 5 describes the system configuration for a multi-client environment, measures its performance and evaluates its limits in respect of the maximum number of clients. Finally, Section 6 concludes the paper.

2. System architecture and performance

The overall system architecture is shown in Figure 1, and describes two core sub-systems: the *Service Provider* at the service origin and the *Client* at the client's premises. The service provider consists of a multimedia server, which provides access to the video programmes. The server runs under the MS Windows NT operating system and is equipped with an MPEG-2 encoder, which converts an analogue video signal to a digital one. Furthermore, this encoder compresses the digital signal using the MPEG-2 MP@ML standard and stores the produced stream onto the server's hard disk. The Ethernet backbone of the service provider is also linked to Internet through a 2 Mbps line.
The client consists of a multimedia PC (running under MS Windows 98 operating system), which is equipped with an MPEG-2 decoder. The communication between each client and the service provider is a half duplex point-to-point RF link, in the frequency band of 2.4GHz using FHSS technique. The system follows a Client/Server approach.

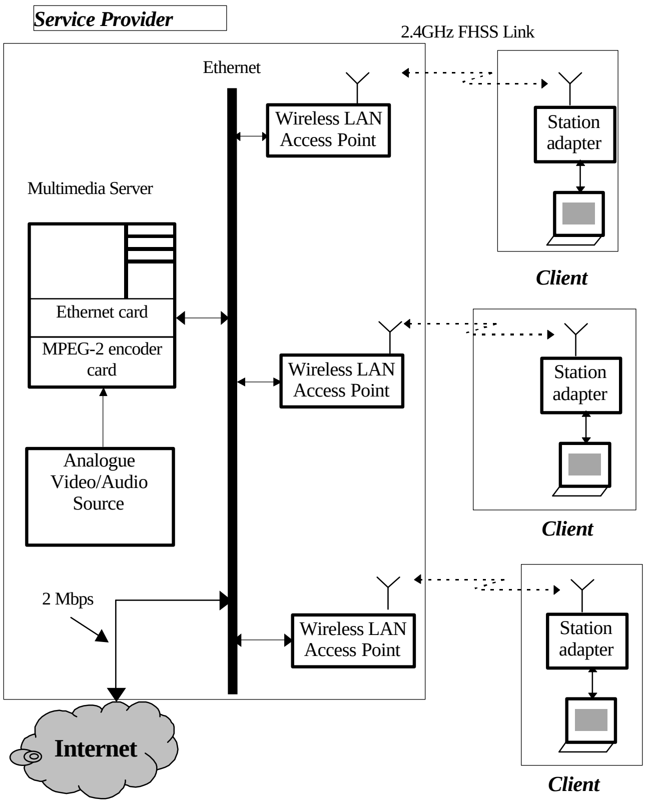


Figure 1. ***Overall system architecture***

The use of FHSS technique makes feasible a multi-client configuration, which is described in Section 5. Ôhe service provider and the clients form a wireless LAN that is based on the TCP/IP protocol using the IEEE 802.11 standard. The configuration of such a wireless LAN includes an access point dedicated to each client (the Wireless LAN Access Point shown in fig.1) at the provider's site and a station adapter at the client's site.
Using the MS Windows 98 networking facilities, the client gains access to a video directory, and is able to request any of the MPEG-2 video files hosted by the server at the service provider. By using a suitable media player software the client is able to start viewing the video file while featuring full VCR functions. The video composite output of the MPEG-2 decoder card enables the client to watch the selected video file on a TV set. Additionally, by using a common browser, the client has fast access to Internet.
In order to evaluate the system's performance in a real environment a prototype system was developed. It was ranging between a service provider (which is also an Internet provider) and a single client about 5 km away. The propagation environment was an urban area (city of Athens) and it was characterised by Line-Of-Sight

(LOS) conditions, during day-time and under dry climatic conditions. An Access Point (AP) was installed at the service provider site and a Station Adapter (SA) at the client site. Due to the long distance (~ 5 Km) directional antennas were used at both ends (service provider and client) with 24dBi gain and 6° dispersion angle. For the transmission, a power amplifier of 15dB gain was used, raising the transmitted power to 27 dBm.
The reception was achieved through the same antenna with the use of a Low Noise Amplifier (LNA) featuring a gain of 18dB and a Noise Figure (NF) of 3.5dB approximately. The same transmission and reception configurations were used at both ends.
In order to get an estimation of the network throughput of the established radio channel a file copy/paste procedure (MS Windows98 networking facility) was applied. The network throughput during this procedure was measured by the multimedia server, using a performance monitor software tool (standard tool) running over the Windows NT operating system. The results are shown in Figure 2, where it can be verified that the throughput is about 1.6 Mbps.

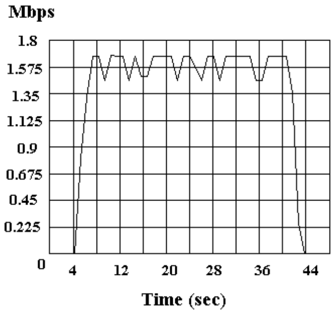


Figure 2. ***Network throughput during a file copy/paste procedure***

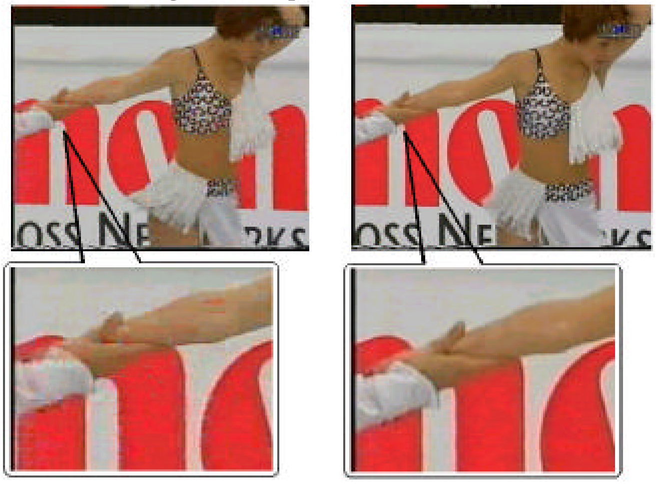
3. Picture quality at low bit-rates.

The MPEG-2 MP@ML standard refers to encoding standard definition television at bit-rates from 1.5 to 15Mbps. It's obvious that the higher the bit-rate the better the picture quality. However, the transmission of high bit rates requires a large bandwidth. As long as the described system offers a network throughput of about 1.6Mbps, an initial experiment was conducted, in order to evaluate the picture quality that the system can provide, and compare it to the quality of higher encoding bit rates (i.e., 4Mbps).
In this test an analogue PAL television signal was captured and encoded with two different encoding bit rates: 1.6 Mbps and 4 Mbps (transport stream bit rate). The produced MPEG-2 transport streams were saved in different files on the dedicated server's hard disk. Table 1 shows in more details the values of the MPEG-2 parameters used for each file.

MPEG-2 transport stream parameters	File 1	File 2
Video encoding bit-rate	1.513 Mbps	3.869 Mbps
Audio encoding bit-rate	64 kbps	64 kbps
Transport stream bit-rate	1.6 Mbps	4 Mbps
GOP size	12	12
I-Frame Distance	12	12
Reference distance	3	3
Audio sampling rate	44.1 KHz	44.1 KHz
Audio mode	Stereo	Stereo

Table 1. ***MPEG-2 transport stream parameters for two encoded video signals***

As there is not a certain objective way of evaluating the picture quality of a video signal [4], the picture quality was assessed by taking the opinions of ten people [5]. The spectators watched the two videos played back on a TV set and expressed their opinion for each, concerning the picture clarity (clearness) and pleasant viewing. The spectators assessed that for the 4 Mbps encoded video the picture quality was very good and the viewing was pleasant. For the 1,6 Mbps encoded video they assessed that the picture quality was good and the viewing was still pleasant.



Picture 1 **Picture2**

Figure 3. ***Comparison of picture quality for MPEG-2 encoding rates of 1.6Mbps (Picture1) and 4Mbps (Picture2)***

An estimate of the picture quality achieved for each encoding stream bit rate is presented in figure 3. It shows a punctilious comparison of the same frame -during a rapid movement- encoded with 1.6 Mbps (picture 1) and 4 Mbps (picture 2) respectively. Comparing the two pictures, it can be observed that the edges of figures in picture 2 are sharper than those in picture 1, while the overall picture quality is not significantly degraded.

Concluding, this initial experiment shows that an MPEG-2 video programme with transport stream bit rate equal to 1.6 Mbps can be pleasantly viewed.

4. Performance measurements in a single client system.

The prototype system, described in section 2, was used as a test-bed for evaluating the Quality of a VoD Service provided through the proposed wireless network. In order to measure the impact of the wireless network throughput to the overall quality of the VoD service, the same analogue video signal was encoded at different MPEG-2 stream rates and stored each time as a file, on the server's hard disk. These video files were sequentially requested and played back (VoD procedure) at a client's PC, in front of a 10 people audience that formed the evaluation board.

During this test it was verified that the reproduction of the video signals was smooth and normal, as long as the MPEG-2 stream bit-rate remained below 1.6 Mbps. However, when the MPEG-2 stream bit-rate exceeded 1.6 Mbps, accidental picture pauses (still images) appeared on the screen during the viewing of the video file. Similar sound pauses occurred in the audio signal. These video and audio pauses degrade the quality of the VoD service. The amount of degradation in both quantitative and qualitative terms is measured in the following.

The reproduction of video and audio signals on the PC screen and speakers is based on the memory buffers of the corresponding video/audio cards. The data-loading rate of the video/audio buffers is approximately equal to the network throughput. The data-unloading rate of the buffers -for a continuous frame refreshment on the screen and sound at the speakers- is equal to the MPEG-2 encoding stream rate. If the loading rate of the buffers (network throughput) is less than the unloading rate (MPEG-2 stream rate), then there are periods of time that the buffers are totally empty. In this case, still images and sound pauses are inevitable, which degrade the Quality of the VoD Service.

A quantitative estimation of the QoS of the proposed system is the measurement of the volume of the buffers. In our tests, the volume of the video buffer was measured using the MS Windows 'Video FIFO Monitor' software.

Figure 4 shows the volume (content) of the video buffer while an MPEG-2 video file with 1,7632 Mbps transport stream was played back to a client's PC. The zero (0) values in the figure denote that there are moments that the buffer is empty of data, which is translated into video pauses. Consequently, the viewer will need more time to watch the whole file.

A series of measurements of the volume of the video buffer was performed, in order to calculate the total duration of pauses, occurred during the play-back of each video file

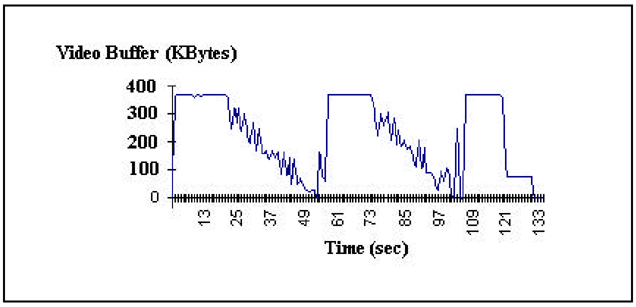


Figure 4. ***Volume of the video buffer while an MPEG-2 file with 1,7632 Mbps transport stream is played by the client***

encoded with different rate. Table 2 shows the results of these measurements. The following symbols are used:

- **Tp:** Total duration of picture pauses
- **Rt:** MPEG-2 stream bit-rate
- **Tv:** Actual duration of video file
- **Pd:** Tp/Tv

Pd represents the picture quality degradation factor that can be expressed as the fraction of the total duration of picture pauses (Tp) over the actual video duration (Tv).

Rt (Mbps)	Tv (sec)	Tp (sec)	Pd (%)
1.5588	112	0	0
1.6612	114	0	0
1.7632	116	4	3.4
1.8652	116	12	10.3
1.9676	116	18	15.5

Table 2. ***Picture quality degradation (Pd) for various MPEG-2 stream bit rates.***

A graphical representation of Pd Vs MPEG-2 stream bit-rate is shown in Figure 5. The vertical axis presents the picture quality degradation (Pd) and the horizontal axis the corresponding MPEG-2 stream bit-rate.

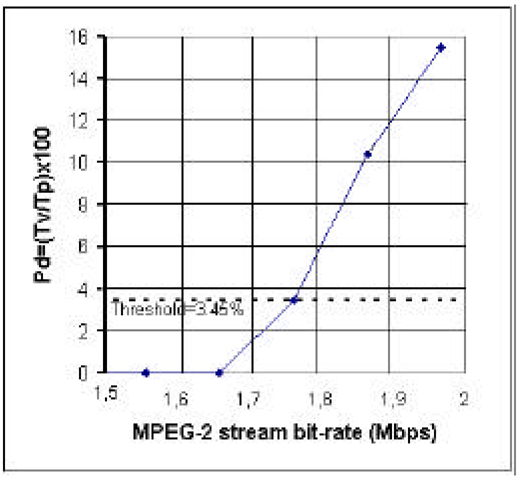


Figure 5. ***Picture quality degradation (Pd) Vs transport stream bit-rate***

In order to evaluate the effect of the video/audio pauses to the pleasant viewing, the 5 video files of table 2 were requested sequentially from the server and played back in full screen mode in front of the audience. The spectators expressed their opinion concerning the viewing of each file, by characterising it as pleasant or unpleasant.

The assessment of their opinions showed that the maximum value of Pd for a pleasant viewing, is 3.45% and is shown in figure 5 by the dashed line. This value of Pd corresponds to about 1.7 Mbps, which is the maximum MPEG-2 encoding stream rate for a pleasant viewing.

Resuming the conclusions from sections 3 and 4, the picture quality is good and the viewing is pleasant, if the network throughput is higher than 1.5 Mbps and the MPEG-2 encoding stream rate is less than 1.7 Mbps. Therefore, a VoD service is pleasantly viewed through the proposed wireless network, when the MPEG-2 encoding stream rate is typically 1.6 Mbps.

5. Multi-client configuration.

In the previous section the Quality of video Services was evaluated for a single client configuration. It is evident that in order to provide the same QoS to many clients, each one of them must be assigned a wireless link to the service provider that offers a throughput of at least 1.6 Mbps. In a multi-client structure as shown in figure 6, several access points (AP) are installed in the service provider site. Each AP has the same coverage area. A client in the overlapping area can associate and communicate with its dedicated access point in the frequency band of 2.4GHz. Since all communication links operate in the same frequency band, a mutual interference is inevitable. This interference is rejected (up to a certain level) due to the inherent capabilities of the spread spectrum technique.

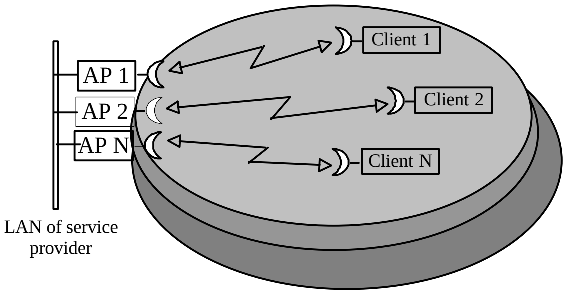


Figure 6. ***Multi-client configuration***

The rejection of mutual interference during simultaneous client access can be achieved by setting different parameters in each wireless LAN access point. These parameters are the hopping standard, the hopping sequences, and the Electronic Switching System IDentifier (ESSID).

The spread spectrum system used in this paper can support 11 hopping standards. The number of hopping sequences per standard is different for each hopping standard, as shown in table 3.

A hopping sequence is a pre-defined series of channels (frequencies) that are used in specific, pseudorandom order as defined in the sequence. The unit "hops" from frequency to frequency according to the selected sequence. In an overlapping environment (as the one in figure 6) all APs have the same hopping standard, but a different hopping sequence is assigned to each of them.

Hopping Standard	Number of Sequences per Hopping Standard
Netherlands	5
Europe ETSI	26
France	11
US FCC	26
Japan	4
Australia	20
Israel	11
Canada	10
Europe ETSI (DE mode)	10
Korea	4
Spain	9

Table 3. ***Hopping sequences per Hopping Standard***

The ESSID is a string (up to 32 printable characters), which is used to identify an AP. In the multi-cell configuration of figure 6, each AP is assigned a different ESSID. Each client is assigned to the ESSID of the Access Point, with which it communicates.
In order to evaluate the performance of the system in a multi-client configuration a small scale experimental platform was set up. This included two Access Points (namely AP1 and AP2) operating in the same coverage area and two clients (C1 and C2) at a distance of about 50 m away from the APs. Due to short distance, omni-directional antennas were used. Power amplifiers and LNAs were not necessary. The Europe ETSI hopping standard was selected offering 26 different hopping sequences.
The criterion for the system performance is the picture quality and ultimately the pleasant or unpleasant viewing. However, as it was previously shown, the picture quality is directly influenced by the network throughput. Therefore, in a multi-client environment it is important to measure the network throughput assigned to each client, in the presence of other simultaneous clients operating in the same coverage area.
In order to measure the effect of mutual interference to the network throughput all combinations for the hoping sequences were tested. For this purpose, hoping sequence #1 was allocated to AP1 and C1 and all the other 25 hopping sequences (#2-26) were sequentially tested for AP2 and C2. For each new hopping sequence in AP2, both clients (C1 & C2) requested and watched a video file of 1.6 Mbps from the server. The wireless network throughput for the VoD service was measured each time using the performance monitor software tool, described in section 4.

The experimental results for client C1 are presented in figure 7. Similar results were obtained for client C2. It is evident that the network throughput remains constant at about 1,6 Mbps, when another wireless link is active in the same coverage area. No picture or sound pauses were detected during the viewing of both files.

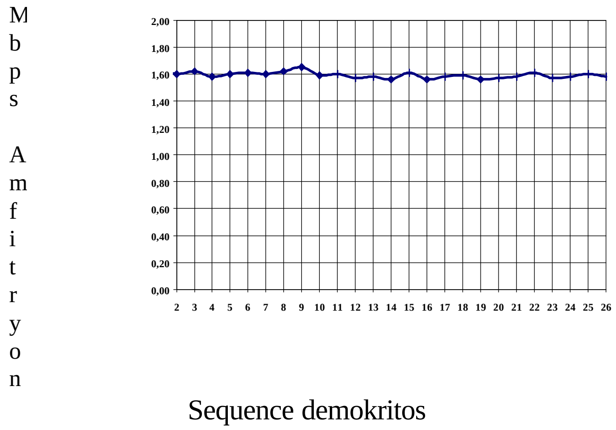


Figure 7. ***Network throughput of client C1 with hoping sequence #1, Vs all other hoping sequences in client C2.***

The evaluation of the network throughput was extended to three access points and three clients with different encoding sequences. A large number of combinations for hoping sequences were tested, and it was verified that the network throughput for each client was about 1.6 Mbps. The viewing was pleasant without picture or sound pauses.
The clients were able to access Internet, when they were not accessing the VoD service.
Based on the above experimental results, the number of concurrent clients in a multi-client configuration following the Europe ETSI hopping standard is 26. This number can be doubled (52) if half of the antennas are vertically polarised and the other half horizontally.
In the case where clients are spread in a wide area, the use of directive antennas pointing at different directions can further increase the number of concurrent clients. If the area to be covered is divided into n sectors of 360/n degrees each, then the maximum number of the concurrent clients that the system can support raises to $N=52\bullet n$. For example for n=4 sectors of 90 degrees each, the system can support $N=52\bullet 4=208$ clients with 1.6 Mbps throughput each. This sectorisation depends on the minimum angle between two antennas pointing at different directions and it is a matter of further research, which is beyond the scope of this paper.

At this point, two important parameters should be mentioned :
(a) Experimental measurements showed that the network throughput remains 1.6 Mbps up to a distance of 15 km between the service provider and the clients, provided that there are LOS conditions. In this respect, the wireless network can be used for the provision of VoD services in wide areas, like major cities.
(b) In a multi-client configuration, the system resources must be adequate to provide 1.6 Mbps to each client, that a true VoD requires. That means that when the number of clients increases, more and faster servers should be used and fast Ethernet (100Mbps) is mandatory.

6. Conclusions

This paper presents a broadband wireless network based on frequency hoping spread spectrum technology, which provides access to true VoD services and also to Internet. The overall system architecture and network configuration were described. A prototype system was developed, which served as a test-bed for conducting measurements concerning the quality of the provided VoD service. It was shown that in a multi-client environment the network can provide pleasant viewing of MPEG-2 programmes to a substantial number of concurrent clients.
A disadvantage of the proposed system is the relatively high cost of the equipment at the client's site (Station Adapter, antennas etc), which is presently about 1000 Euros. However, as spread spectrum technology is penetrating into the market more and more, it is expected that in the near future the cost will be significantly reduced.

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