Paving the Road to Interactivity

How today's technology is anticipating the business needs of tomorrow

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ABSTRACT

As India prepares to launch broadcast television services for the new millennium, broadcasting is evolving from more than delivering television programs to providing a rich and comprehensive entertainment and information experience for the viewer. The selection of technology for the upcoming conversion from analog to digital broadcasting will govern to a large extent how well-prepared broadcasters are to provide the services of the future.

This paper looks at recent technological advancements which assist the preparedness for interactivity. Efficient allocation of bandwidth in a multi-channel digital television service provides the resources for a wider variety of services. Variable Bit Rate video encoding is seen to be an important means of grooming video for statistical multiplexing, whilst third generation statistical multiplexing technologies enable bandwidth savings of over 40 percent.

Open loop operation of encoding systems allows statistical multiplexing of remote sources, greatly simplifying the provision of a balanced network of national and regional transmissions. Available Bit Rate (or opportunistic data) capacity is a byproduct of statistical multiplexing, and provides a transmission medium for data broadcasting, including IP-based data services to enable interactivity.

Together, these technologies pave the road for the introduction of interactive television to fully exploit the benefits of the conversion to digital.

INTRODUCTION

The recent announcement of India's selection of the DVB standard for terrestrial television broadcasting will bring about a revolution in broadcasting in the country. Digital technology enables applications which could only be dreamed of in the analog world.

In the coming months India's broadcasters will be actively engaged in selecting the technologies to provide the exciting services of the future. The timing could not be better, since by introducing digital services at this time India will be able to take advantage of exciting technology developments which will streamline the introduction of interactive and multimedia broadcasting services.

Careful consideration of the digital broadcasting architecture during these planning stages will enable Indian broadcasters to provide a rich programming experience to their viewers in a very cost-effective and bandwidth efficient manner.

EFFICIENT BANDWIDTH ALLOCATION

If international experience is any guide, bandwidth should still be regarded as a limited resource in planning a digital television service. At first sight, planners may be satisfied that digital conversion would enable a fourfold increase in the number of program services delivered in a terrestrial television channel. This is a very conservative planning approach which assumes constant bit rate encoding at a high-quality level without the use of statistical multiplexing.

This approach, which has been the baseline for planning the introduction of digital services in the United States and Australia, is by today's standards an inefficient use of bandwidth. Through the use of technological advancements, including video preprocessing, variable bit rate encoding, and advanced intelligent statistical multiplexing, the same digital terrestrial channel can be used to provide a larger number of high-quality program services and still have available bandwidth for data broadcasting.

VIDEO NOISE REDUCTION

The video encoder is the most significant element in determining the bandwidth efficiency of the total multiplex. The true measure of that encoder's efficiency is the average bit rate required to encode any given picture content at the desired quality level.

Random noise present in the video signal, unless eliminated, will appear to the encoder as fine detail and will significantly impair encoding efficiency. In the past, the practice of using external noise reduction equipment to eliminate random noise prior to encoding has been a common practice. The sophisticated spatio-temporal filtering employed in the latest generation of MPEG-2 video compression systems now enables the noise reduction burden to be managed by the encoder itself.

In recent tests conducted at Scientific-Atlanta's research laboratories in the United States, it was determined that over 75 percent of the encoding efficiency benefit of external noise reduction has now been realized in the encoder. Thus the important first step in ensuring bandwidth efficiency is now possible without the expense of external noise reduction equipment.

VARIABLE BIT RATE ENCODING

The bit rate required to encode the video signal varies significantly as a function of the amount of detail and motion in the image at any instant in time. If it were to produce a constant quality encoded signal over time, an MPEG-2 encoder would have a bit rate output that varies significantly as a function of time. Peaks of bit rate for scene changes and sequences of fast motion can exceed the bit rate required for static sequences by a factor of five to one, or even more.

The nature of the program content is therefore a significant factor in determining the bandwidth required. It is well-known that sports programming such as hockey is far more demanding than talk shows, for instance. Objective test equipment is now available, such as the Tektronix PQA series picture quality analyzer, to enable engineers to quantify the bit rate demands of various types of program content.

The chart shown in Figure 1 depicts the picture quality rating (PQR) for various preprogrammed test sequences as a function of average bit rate, from tests conducted at Scientific-Atlanta. The PQR scale rates picture degradation, so a lower number represents higher quality, and a degradation of one PQR unit is regarded as imperceptible. The tests were conducted using constant bit rate (CBR) encoding.

The most obvious finding is clear confirmation that a fast motion sports sequence with lots of detail such as "Cheer Leaders" requires the highest bit rate in order to achieve any given quality level. At the other end of the scale the sequence “Susie”, which is representative of a news reader sitting at the news desk, requires a significantly lower bit rate to achieve the same quality level.

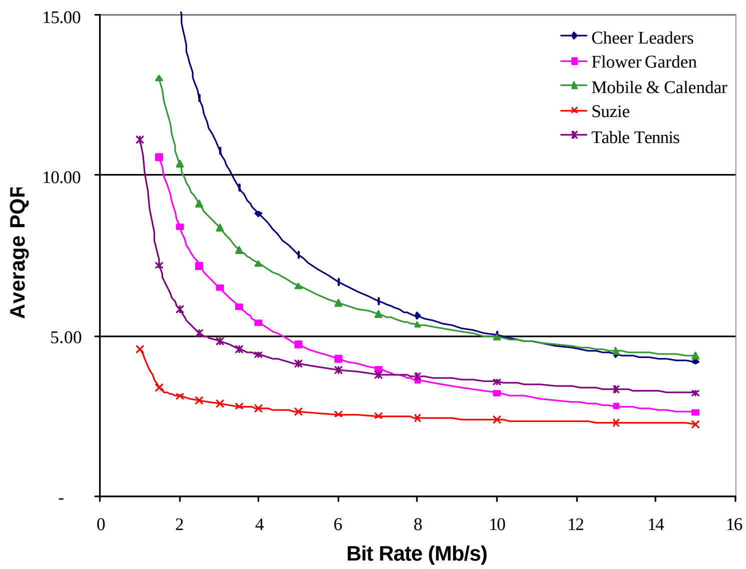

Figure 1 - Picture Quality Rating vs Bit Rate for various test sequences

Realistically, a broadcasting service over the period of a day will transmit a variety of programming which includes sporting content equivalent to the sequence “Cheer Leaders” as well as news content with less substantial bandwidth demands, and the full gamut of possibilities in between. The video encoder must be allowed to manage the bit rate it produces consistent with the objective of producing constant quality. This means that for those periods when undemanding content is being broadcast, bandwidth can be made available to meet the needs of other programs which may share the same multiplex.

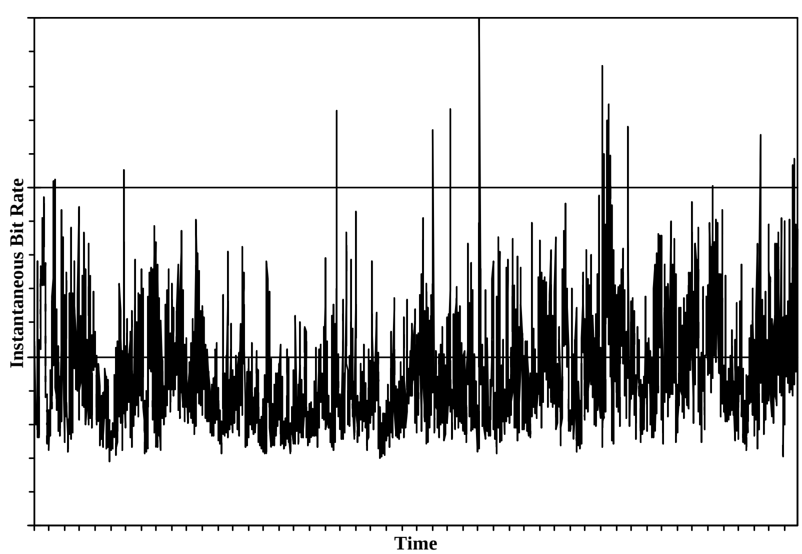

Figure 2 - Instantaneous bit rate demand of a sample video program

Moreover, a time domain analysis of the demand for bit rate in a true variable bit rate encoder shows that the demand peaks are quite sharp and relatively widely spaced (refer to Figure 2). This factor can be exploited in the multiplexer to further enhance efficiency in a multi-program transport stream – as shall be discussed later. The important function performed by the encoder is to produce only that bit rate which is necessary to achieve the quality objectives for transmission at each and every instant during the encoding process.

ADVANCED STATISTICAL MULTIPLEXING

Once we can produce true variable bit rate (VBR) video transport streams, the job of a statistical multiplexer is in some ways greatly simplified. Because the instantaneous demand for bit rate of the various programs being combined in the multiplexer is statistically independent, the multiplexer can take advantage of lulls in the demand from one channel to transmit peaks of demand from another channel. The more programs that are combined in the multiplexer, the more effective this process is.

Through the magic of statistics, the wide variation of bandwidth demand which can be observed on the individual programs is reduced once the programs are multiplexed together. This assists in matching the individual program bit rates, which are continuously changing, to the transmission rate, which is fixed by the RF modulation standards.

The chart below (Figure 3) illustrates an example of a five channel multi-program transport stream, based on time domain measurements of bit rate demand made during Scientific-Atlanta's VBR encoding tests. The bit rate axis is normalized to the peak bit rate of the programs. In CBR encoding, the bit rate of each channel would be set to the level of peak demand for the program, to achieve the desired quality (freedom from MPEG artifacts) at the time of the peak. The peak level is indicated as 1x on the vertical axis in Figure 3.

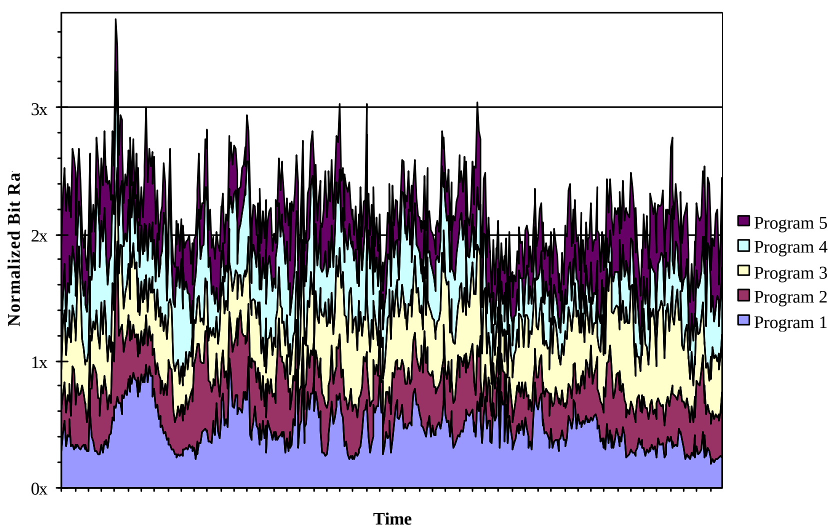

Figure 3 - Illustration of a five channel statistical multiplex

With statistical multiplexing, the peak bit rate demanded by the five programs is only 3.7 times the peak bit rate of a single program. In this illustration the efficiency gain is approximately 26 percent, which is in line with our experience. This value approaches 40 percent as the number of channels increases to around eight to ten. It can also be observed that the variation in maximum bit rate of the total multiplex is now only around 60 percent whereas this difference exceeds 80 percent for the individual programs.

Intelligence is required in the multiplexer to manage the situation where the sum of the individual program bit rates exceeds the output bit rate available. Third generation statistical multiplexers are now available which manage this by time-shifting the demand peaks so that they do not align. This process exploits the short duration of these demand peaks which was previously described.

Such an advanced multiplexer will maintain for each program being statistically multiplexed a buffer model of the decoder which would be receiving that program. Since the decoder will have one or more pictures (frames) in its buffer ready to present to the viewer, the multiplexer can allocate the output bandwidth on a priority basis to those programs for which the decoders have the least amount of video in their buffers. For the vast majority of situations this temporal adaptive statistical multiplexing process is sufficient to maintain continuous error-free transmission and reception of all programs, maintaining a constant quality level.

REMOTE ENCODING

A side benefit of the process just described is that operation of the statistical multiplexing does not require a feedback loop from the multiplexer to the encoder. Previous generations of statistical multiplexing, with which the broadcast engineering community will already be familiar, did not employ true variable bit rate encoding but rather piece-wise constant bit rate encoding. This requires the statistical multiplexer to allocate bit rate to each channel on a continuous basis resulting in the encoder being instructed what bit rate to produce based on the multiplexer's best information about the demand from each channel.

The need for closed loop feedback imposes two serious limitations on the performance of such a system. One is that a communications path is necessary from the multiplexer to the encoder, which in practice means this equipment needs to be at the same location. Once the requirement for a feedback loop has been removed the possibility exists of statistically multiplexing remotely encoded material. This may originate from another studio in the same town, or across the country, or indeed across the ocean via an international satellite link.

The other drawback is that in situations where the aggregate bit rate would exceed the capacity of the channel, the quality of one or more encoders must be arbitrarily reduced by the multiplexer in order to accommodate an instantaneous high bit rate demand from another encoder. This produces a form of intermodulation distortion for which we don't even have a name yet, where MPEG artifacts are produced in one program based on the picture complexity of another program.

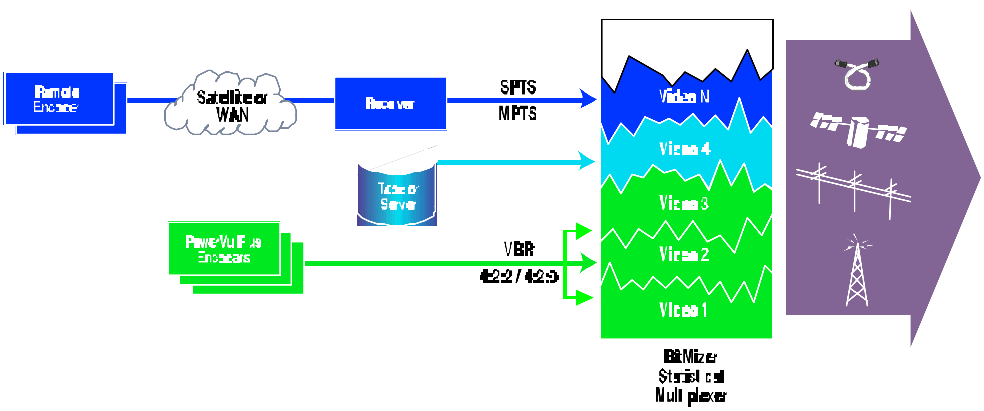

Figure 4 - Statistical Multiplexer with Remote Encoding and File Server

Remote encoding affords great benefits to the broadcaster in both operational flexibility and total system cost. Programs originated in one location, which may be part of a statistical multiplex or just a single channel feed, can be combined into the statistical multiplex at another location for the cost of a simple decoder. National programs distributed via a national satellite uplink, can be combined as required into the multiplexes serving individual states or cities.

Remote encoding capabilities also open the way for multiplexing MPEG-2 encoded server-based video content into a statistical multiplex. In such a scenario it is clearly impossible for the multiplexer to control the bit rate already encoded onto the server, so an open loop approach is the only feasible alternative.

DATA BROADCASTING

A byproduct of the combination of variable bit rate video encoding and advanced statistical multiplexing is that bit rate within the multiplex becomes available for the transmission of data in an opportunistic fashion. This so-called available bit rate (ABR) data broadcasting capacity exists in addition to the previously described efficiency gains in the video transmission through statistical multiplexing. This is illustrated in Figure 5, which is the same data that was presented in Figure 3 but now showing around 35 percent of the transport stream bandwidth available for data broadcast services.

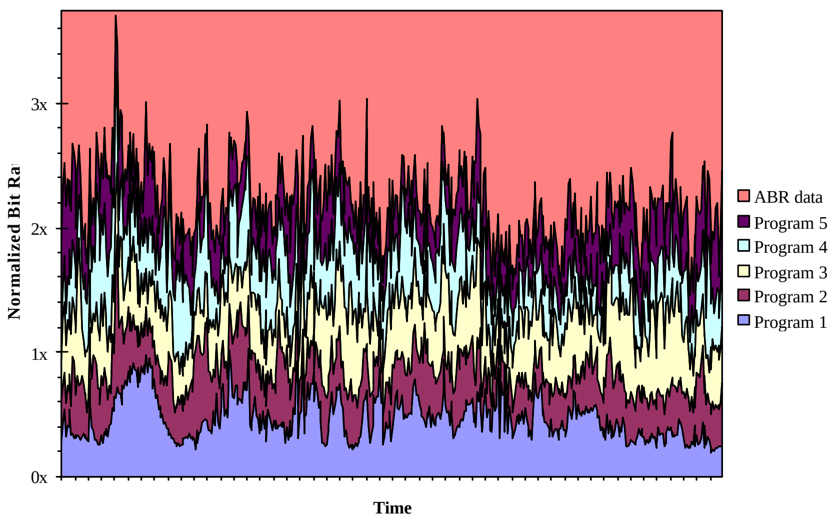

Figure 5 - Illustration of Available Bit Rate data capacity

A significant amount of data can be transmitted through such an ABR capacity. As an example, given a transport stream bit rate of 22 Mbps with even 25 percent ABR, over 5 Mbps is available for the transmission of data.

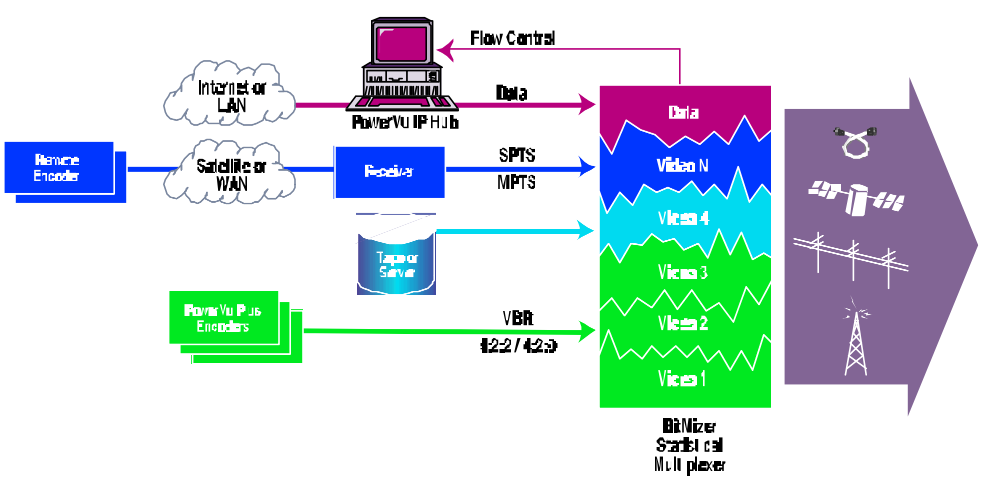

Figure 6 - Statistical Multiplexer with Remote Encoding, Video File Server and ABR Data Broadcast Server

To manage the flow control of data broadcasting services in MPEG-2 transport streams, the SMPTE has developed a standard (SMPTE-325M) for flow control between an MPEG-2 packet multiplexer and the data host, is shown in Figure 6.

The ABR data will encounter some transmission delays due to the need for the multiplexer to guarantee bandwidth for the video programs as the first priority. There are many kinds of data transmission which can be used for interactive television services that do not require a continuous guaranteed transmission rate. Indeed, with the exception of streaming video and audio services, nearly all forms of IP data are accustomed to this kind of bursty transmission through networks of packet routers.

Importantly, the significant bandwidth made available in this fashion enables the operation of interactive television services without reducing the bandwidth available for the primary video and audio program delivery. Our expectation is that broadcasters will find a bewildering variety of uses for this free capacity which arises as a side benefit of the conversion to digital, broadcasting regulations permitting.

INTERACTIVE SERVICES

It is not the intent of this paper to describe what kind of interactive services will be realized using this technology. Examples of interactive television services which are already being developed today include the following:

- Broadcast information services using IP multicasting
- Web-based content linked to the television program, for example advertising by suppliers of products featured in the programs, or lists of local dealers providing the products being advertised
- Audience participation for game shows
- Downloading of content to servers, for example for delivery of commercials or movies on a non real-time basis
- Electronic commerce applications

These, and many other applications, will be achievable utilizing the availability of a high bandwidth data transmission capability embedded in the digital television transmission service. Furthermore, a great deal of interactivity can be achieved without the need for a return channel from the viewer, where the viewer interacts with software resident in the interactive television receiver, using data broadcast from the transmitter.

CONCLUSION

The conversion to digital television provides exciting opportunities for broadcasters to enhance the services they provide. Through careful planning of the network and the selection of the most advanced technologies, the huge potential of data broadcasting and interactive television can be realized. The outcomes will be a richer viewing experience leading to increased viewer loyalty, and a more competitive positioning for broadcasters in this new era of convergence.

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