A Dynamic Bandwidth Allocation Algorithm for MPEG Video Sources in Wireless Networks

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ABSTRACT

In this paper, we propose and evaluate a new dynamic bandwidth allocation scheme for MPEG video sources suitable for wireless networks. The proposed scheme is dynamic and pro-active. It automatically adjusts the amount of reserved resources, while guarantying the required QoS. It exploits the structure of the MPEG video stream and allocates bandwidth on a scene basis. The presented dynamic bandwidth allocation algorithm is evaluated using simulation and actual MPEG video data. The performance evaluations showed a major improvement in bandwidth utilisation as compared to other proposed schemes.

Keywords

Dynamic Bandwidth Allocation, Wireless networks, MPEG, QoS.

1. INTRODUCTION

In a wireless network, bandwidth is perhaps the most precious and limited resources of the whole communication system. Therefore, it is of extreme importance to use this resource in the most efficient way.

Video applications produce large amount of data. As a result, video is transmitted in compressed format to reduce the generated data rates. Among the used compression techniques, MPEG is the standard that has recently gained a considerable attention. The MPEG coding scheme is widely used for any type of video applications.

Compressed video sources produce a Variable Bit Rate (VBR) with a considerable degree of burstiness. To guarantee Quality of Service (QoS) for such VBR applications when used over a wireless link, specific resource management solutions must be considered. Resource allocation could be performed according to the peak cell rate of the VBR sources. Such an approach leads to under utilisation of wireless resources due to the bursty nature of the sources. The wireless bandwidth will be wasted and the wireless network will experience high call blocking and forced termination probabilities. Resource allocation could be performed based on the sources mean cell rates. In such approach, video sources will suffer from unacceptable losses and delays (especially those with hard real-time constraints).

These problems can be solved using a dynamic bandwidth allocation algorithm. In this paper, we propose a predictive resource allocation scheme that provides high wireless network utilisation by dynamically reserving only those resources that are needed. The proposed scheme is dynamic and pro-active, i.e., the amount of bandwidth to be reserved is determined "on-the-fly". It requires some communication between the mobile terminal and the base station, but the amount of extra information generated by the mechanism is acceptable in comparison to the capacity gain obtained.

The proposed algorithm exploits the structure of the MPEG video stream and allocates bandwidth on a scene basis. This will result in a high bandwidth gain, which will affect the overall network performance.

The paper is organised as follows. Section 2 formulates the problem. Section 3 introduces the proposed approach. In section 4, the dynamic bandwidth allocation algorithm is described. Section 5 presents simulations and discusses the performance results. Conclusions and future directions are presented in section 6.

2. PROBLEM STATEMENT

Consider a wireless network system that is able to support mobile terminals running applications that require a varying range of bandwidth resources. The wireless network users expect good quality of service from the system, for example low call dropping and packet loss probabilities.

Whenever a mobile terminal connects to a base station, the base station will allocate bandwidth to this mobile terminal. This bandwidth will remain constant throughout the duration of the connection. In [5] the authors suggest the use of different amount of bandwidth depending on user requirements. For example, a voice call user will use a single bandwidth unit (BU) while a video mobile terminal will require several BUs, where a bandwidth unit is the minimum quota of bandwidth resources that can be assigned to any mobile user.

The above approach is a good solution for CBR sources, however it is clearly inadequate for VBR sources. The bit rate of this kind of sources varies over time and they have most of the time a bursty nature. Compressed video sources are known to produce a Variable Bit Rate (VBR) with a high degree of burstiness, which

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needs specific resource management solutions, especially for guaranteed Quality of Service (QoS) networks.

If resource allocation is performed according to the peak cell rate of the VBR source, the network will be most of the time highly under-utilised when the peak-to-average rate ratios are high. The wireless bandwidth will be wasted and the wireless network will experience high call blocking and forced terminations. On the other hand, if resource allocation is performed based on the source mean cell rate, it is expected for the source to suffer from unacceptable losses and delays (especially for video sources imposing hard real-time constraints).

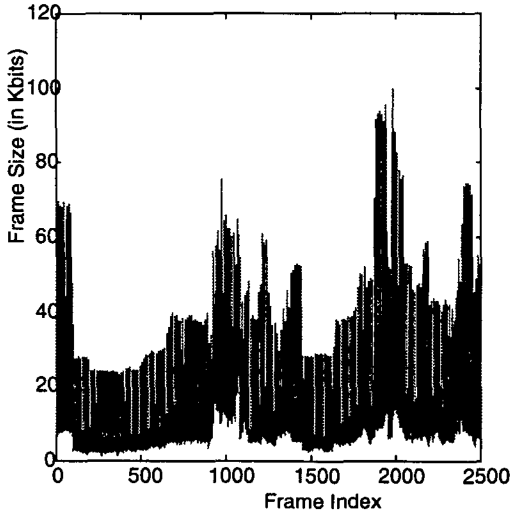

Figure 1: Segment of the frame size sequence for Bond trace.

In the case that the model of the VBR source is known, we can calculate the required capacity[1] C to have a certain CLR (Cell Loss Ratio). Even with this approach big frames are more likely to be affected by a cell loss than small ones, which will affect the visual QoS. For example, consider the VBR source depicted in **Figure 1** offered to a bufferless switch (we consider only hard real-time services) on a wireless link of capacity C. Frames around 2000 will experience a very high cell loss which will be noticed by the user.

A way to solve such problem is the use of a dynamic bandwidth allocation algorithm. Therefore in the next section, we will propose a new approach that alleviates some of the problems described above.

3. PROPOSED APPROACH

Instead of allocating the wireless bandwidth for the lifetime of the connection (as in traditional wireless systems using FDM or CDMA channel access schemes) we will allocate capacity dynamically for each scene. Here a scene represents a group of successive GOPs with close sizes. This capacity will remain constant and will not change until the beginning of another scene. This allocation scheme allows, as we shall see in section 5, a better bandwidth management. It will lead to an increase in the number of users that can be supported by a mobile wireless network cell without affecting the QoS of the connections.

In subsection 3.1, we will introduce the concept of scene and after we will quote the assumptions that we supposed for our algorithm.

3.1 The Scene Concept

An MPEG encoder generates three types of compressed frames: Intra-coded (*I*), Predictive (*P*), and Bi-directional (*B*) frames. An *I* frame is encoded independently of other frames based on DCT (Discrete Cosine Transform) and entropy coding. A *P* frame uses a similar coding algorithm to *I* frames, but with the addition of motion compensation with respect to the previous *I* or *P* frame, and is used as a reference point for the next *P* frame. A *B* frame is an interpolated frame that requires both a past and a future reference frames (*I* or *P*).

Typically, *I* frames require more bits than *P* frames. *B* frames have the lowest bandwidth requirement. After coding, the frames are arranged in a deterministic periodic sequence, for example "*IBBPBB*" or "*IBBPBBPBBPBB*", which is called Group of Pictures (GOP).

From **Figure 1**, it is observed that an MPEG trace consists of several segments such that the sizes of I frames in each segment are close in value. In [1][14], such segments were referred to as scenes. In this paper we consider scenes with respect to GOP sizes. The goal behind this choice is two folds. First, it will facilitate the task of allocating bandwidth since we don't have to distinguish between frame types (*I*, *P* or *B*). Second, it will allow for a uniform characterisation of the scene elements.

To model the length of a scene, the authors in [1][14] proposed a method that computes scene duration using the fact that a "sufficient" difference between the sizes of two consecutive *I* frames is a strong indication of the start of a new scene. But this approach requires the availability of the VBR trace. It takes into account only *I* frames and do not permit a uniform characterisation of all frame types (*I*, *P* and *B*) within a scene.

In this work, we consider two requirements that will lead us to a new algorithm for determining the scene duration in an MPEG stream: First, the proposed algorithm must work "on-the-fly", which means that the decision of determining the scene boundaries must only take into consideration the past GOPs. This will make our algorithm support MPEG streams independently from the knowledge of the trace. One advantage of such algorithm is the ability to handle MPEG streams for which we do not have a trace. The second requirement concerns the size of the first GOP in each scene, which has to be as close as possible to the mean GOP size of the scene. This will be used in the dynamic allocation algorithm (section 4).

With respect to the above two requirement we compute scene duration differently (see **Figure 2**). Let $\{GOP(j): j=1, 2, \ldots\}$ be the GOP sequence in an MPEG stream. This sequence consists of the sizes of consecutive GOPs in a given MPEG trace. Suppose that the current scene is the i^{th} scene that started with the k^{th} GOP. The $(n+k+1)^{th}$ GOP of the sequence indicates the start of the $(i+1)^{th}$ scene if

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[1] The terms 'capacity' and 'bandwidth' are used interchangeably throughout the paper.

$$|GOP(n+k+1) - GOP(k)| \geq T * GOP(k) \quad \text{(eq. 1)}$$

where T is a thresholds ($T \geq 0$). $n + 1$ in this case represents the length of the i^{th} scene. Notice that the length of a scene is measured by the number of consecutive GOPs in that scene.

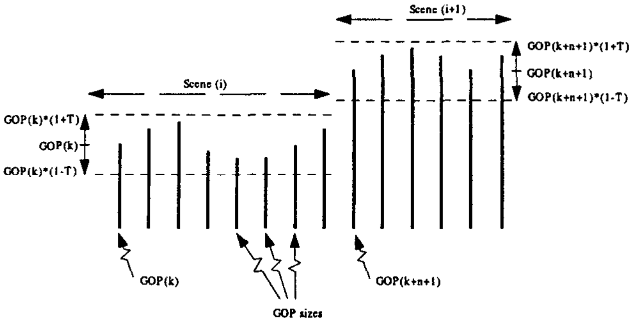

Figure 2: Scene duration

With this definition of scene, all the GOP sizes within a scene *i* are located between First_GOP(*i*)*(1-T) and First_GOP(*i*)*(1+T). Where First_GOP(*i*) is the size of the first GOP in scene *i*.

Clearly, the value of T impacts the shape of the scene length distribution. It determines the amount of correlations between successive scenes; the larger these value, the less correlated the scenes. The value of the T parameter impacts also the number of scenes in a particular trace. Larger values of T produce smaller number of scenes. For example, for the MTV2 trace, a value of T=20% i.e. (0.2) produces 1200 scenes while a value of T=80% produces 100 scenes (see **Figure 4** (c)).

3.2 Assumptions

As illustrated in **Figure 3**, we consider a mobile terminal that wants to send or receive an MPEG video stream over a wireless link. We assume an underlying mechanism that allows us to allocate bandwidth dynamically throughout the duration of a connection between a base station and a mobile terminal. An example of such scheme is the ETSI UMTS Terrestrial Radio Access (UTRA) [8].

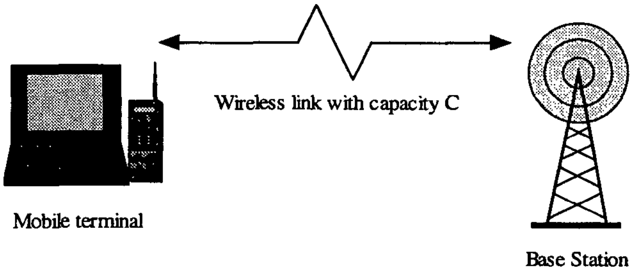

Figure 3: Mobile terminal wireless access

In addition, we assume that when the required capacity, if known, is allocated to the mobile terminal without any delay. In this study we do not take into account the delay between the demand and the acquisition of the capacity.

Consider a hard real-time VBR service where the stream produced by the VBR source is directed to a bufferless switch on a wireless link of capacity C. Let this VBR source bit rate at time t be Rt. The Cell Loss Ratio (CLR) can be then estimated by the fluid approximation [12] as follows:

$$CLR = \frac{E\{(Rt - C)^+\}}{E\{Rt\}} \quad \text{(eq. 2)}$$

Where *E(.)* represents the expectation operator and X^+ is defined as $X^+ = X$ if $X>0$ and $X^+ = 0$ if $X<0$. If the probability density function (p.d.f.) of the source rate is defined by $f(u)$, then **(eq. 2)** can be written as:

$$CLR = \frac{\int_C^\infty (u - C) f(u) du}{\int_0^\infty u f(u) du} \quad \text{(eq. 3)}$$

It is worth noting that in this work the problem of call admission is not addressed and that the capacity gain is obtained supposing that the required capacity is always available. Future works will address aspect related to call admission.

4. THE DYNAMIC BANDWIDTH ALLOCATION ALGORITHM

Our bandwidth allocation algorithm is based on the idea that the GOP sizes within a scene are close. We propose to allocate bandwidth requirement for each scene depending on the GOP sizes mean and variance within the scene. As will be shown in section 5, the proposed approach requires less capacity than the traditional scheme while guaranteeing the same and even better user QoS requirements.

We consider the variance and the average of the films as known values for two reasons: Either we have these films beforehand, hence we can calculate these values, or use an encoder that allows us to specify a desired variance. A number of works [2-4, 12, 13] have been done on designing rate control (or rate shaping) mechanisms to enforce the encoder to respect some predefined characteristics like a certain mean rate and target variance.

Based on our definition of a scene, **(eq. 1)**, the sizes of GOPs within a scene could be considered close. The GOP sizes fluctuate around an average value that represents the level of activity of the scene. In our previous work [16] we showed that the GOP sizes within a scene can be modelled by a normal distribution with mean μ and variance σ^2 ($\aleph(\mu,\sigma)$). μ varies from one scene to another while σ is invariant to scene changes and depends only on the T parameter.

For a normal distribution $\aleph(\mu, \sigma)$ with a p.d.f. f and a cumulative distribution function (c.d.f.) F and using **(eq. 3)** we have:

$$CLR = \frac{\mu * (1 - F(C)) + \sigma^2 * f(C) - C * (1 - F(C))}{\mu}$$

(eq. 4)

Using **(eq. 4)** we can calculate the required capacity C for a pre-specified CLR using binary search.

We have also shown in [16] that σ can be approximated by $T * \sigma\_GOP$ when T is bellow 1, where σ_GOP^2 is the variance of the film, and that μ for some scene *i* can be replaced by First_GOP(*i*) + σ_GOP to calculate the capacity required for a specified CLR without violating user requirements, where First_GOP(i) is the size of the first GOP in scene i.

We can then use $(First\_GOP(i) + \sigma\_GOP, T * \sigma\_GOP)$ as an approximation for (μ, σ) for the scene i to compute the required capacity and as confirmed by simulation the predetermined CLR is still respected.

The following algorithm can be used to allocate bandwidth dynamically for each scene and can be used either in the mobile terminal or in the mobile station depending on the transfer direction.

The algorithm begins by allocating the required capacity (for a pre-specified CLR) for the first scene depending on scene's first GOP size. Then, it checks the following GOP sizes to detect the beginning of a new scene using **(eq. 1)**. And, depending on the size of the first GOP of the new scene it allocates a different amount of bandwidth using **(eq. 4)**. This capacity will remain constant until the beginning of another scene, and can be, for example, used by neighbouring base stations to reserve bandwidth for the mobile terminal in case it emigrates to another cell.

The algorithm pseudo-code:

```
Initialisation:
        Set the value for T
        Set the value for CLR
        $\sigma\_GOP^2$ = the stream variance
        N=1
        First_GOP = GOP (N)            // the first GOP size
        $\mu$= First_GOP + $\sigma$_GOP
        $\sigma$= T*$\sigma$_GOP
        Allocate the capacity for $\aleph(\mu, \sigma)$          // using   (eq. 4)
        Send GOP (N)
        N = N + 1
Loop:
        While not end of stream do
          S= GOP (N)          // the n^th GOP size
          If | S - First_GOP | > T * First_GOP then
                // another scene starts
                First_GOP = S
                $\mu$= First_GOP + $\sigma$_GOP
                Allocate the capacity for $\aleph(\mu, \sigma)$
                // using   (eq. 4)
          End if
        Send GOP (N)
        N = N + 1
        End while
```

5. SIMULATIONS AND RESULTS

In this section we will show how our dynamic bandwidth allocation algorithm surpasses the traditional scheme.

In [7], the authors concluded that the traffic p.d.f. of some VBR MPEG sources could be modelled by a Gamma distribution. In [15], the authors have shown that the Gamma and the Log-Normal distributions are good fits for the p.d.f. of I, P and B subsets of MPEG sequences. In [16] we have shown that the Log-Normal distribution can also be used as a model for some VBR MPEG sources.

In this work, we will compare the performance of our algorithm in terms of the used capacity with the ones calculated supposing a Gamma distribution MPEG source and a Log-Normal distribution MPEG source. Only the results obtained supposing a Gamma distribution MPEG source are presented. Similar results were found while using a Log-Normal distribution as a model for the MPEG sources.

The capacity gain is calculated as follows:

$$Gain = 100 * (1 - \frac{Dynamic\_Cap}{Static\_Cap}) \qquad \textbf{(eq. 5)}$$

Where *Dynamic_Cap* is the total capacity allocated by our dynamic algorithm and *Static_Cap* is the total capacity allocated by the static approach.

To clarify the meaning of the *Gain* variable, let's take the following example: suppose that we have allocate bandwidth to an MPEG stream for 30 minutes. Knowing that the considered MPEG source can be modelled by a gamma distribution source, the static scheme allocates the capacity C for this film (to have a certain CLR). And suppose that our dynamic allocation algorithm has identified three scenes that lasts 5, 15 and 10 minutes respectively, and allocates the capacity C1, C2 and C3 for the three scenes respectively. We have then the following capacities:

Static_Cap = 30*C and

Dynamic_Cap = 5*C1 + 15*C2 + 10*C3

and the *Gain* represents the percentage of the *Static_Cap* that the dynamic approach did not use. If for example, *Gain* is equal to 70% then if the static approach uses a particular amount B of bandwidth to have a certain CLR, our algorithm uses only 30 % of B to have the same CLR.

The traces used in our simulations were provided by Oliver Rose[2] [15]. Rose's movies were taken from VCR tapes, and were digitised at rate of 25 frames/sec using a Sun Video card. The movies were compressed using MPEG [6][9] Berkeley's software encoder [11]. Each MPEG video consists of 40.000 frames, which is equivalent to approximately half an hour.

Although we use traces that are already available, our algorithm remains valid for online traces. This is the case because we did not use any information already available on the used traces. We use only the variance that we consider as a known value.

We calculate the capacity gain for different values of T (from T=10% to 100% step 10%) and different values of CLR (from 10^{-10} to 0.1 step 0.1) and for different MPEG video streams.

In the following figures (**Figure 4**, **Figure 5**, **Figure 6**, **Figure 7** and **Figure 8**):

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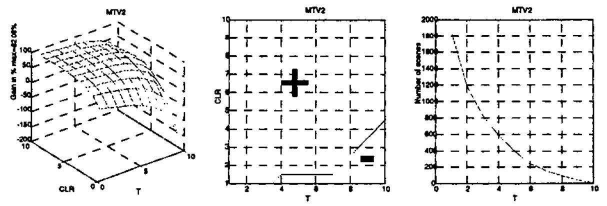
[2] The traces can be obtained from the ftp site *ftp-info3.informatik.uni-wuerzburg.de* in the directory /pub/MPEG/.

- for the axis labelled 'T', a value of *s* means that T = 10 * *s* %
- for the axis labelled 'CLR', a value of *s* means that the required CLR = 10^{-s}



(a) (b) (c)

Figure 4: Simulation results for MTV2 trace

Figure 4 (a) shows the capacity gain obtained for the MTV2 trace in comparison with the static allocation scheme with a Gamma distribution as a model for the MPEG source (the capacity needed for the static allocation is obtained using **eq. 3**). Similar results were found while using a Log-Normal distribution source model. We can notice a significant gain in the area where the required CLR is below 10^{-5} and where T is less than 70%.

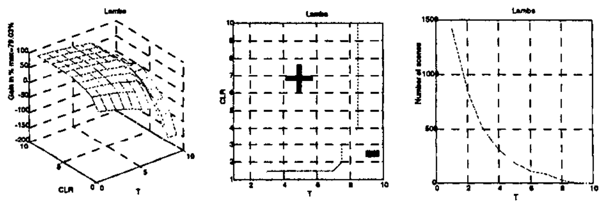
From **Figure 4** (a), we can notice that for T=10% and a required CLR=10^{-10} the capacity gain is 82.06%. This means that if the static approach uses a particular amount B of bandwidth to have a CLR=10^{-10}, our algorithm uses only 17.94 % of B to have the same CLR.

Figure 4 (b) shows when the gain obtained is positive and when it is negative. From **Figure 4** (b), we can notice that for high values of T (T > 70%) and high values of CLR (≈ 0.1), our algorithm use more capacity than the static approach. But this area (T > 70% and CLR ≥ 0.1) is not very important since in practice the required CLR is usually bellow 10^{-5}.

Figure 4 (c) shows the number of scenes depending on the value of the T parameter. A high number of scenes means many capacity request messages between the base station and the mobile terminal. But in comparison to the capacity gain obtained by our algorithm, a little overhead is acceptable.

For example, in a wireless ATM context, the total ATM cells for the MTV2 trace is 2080076 cells. But for a capacity gain of 82.06% (obtained for T=10% and a CLR equal to 10^{-10}), an overhead of 1800 ATM cells (corresponding to the number of scenes obtained for T=10%) is acceptable. We suppose that the capacity requests can be transmitted using ATM Operation And Management (OAM) [10] cells. We consider one OAM cell per request if the transfer direction is from the base station towards the mobile terminal, and two OAM cells otherwise (request-confirmation).

Figure 5 (a) shows the capacity gain obtained for the Lambs trace in comparison with the static allocation scheme. For this MPEG stream the maximum capacity gain is obtained for T=10% and a cell loss ratio CLR =10^{-10}. From **Figure 5** (a) and (c), we can notice that for an overhead of 1480 messages the capacity gain is 79.03%. This means that if the static approach uses a particular amount B of bandwidth to have a CLR=10^{-10}, our algorithm uses only 20.97 % of B to have the same CLR with an overhead of 1480 additional messages.



(a) (b) (c)

Figure 5: Simulation results for Lambs trace

As illustrated by **Figure 5** (b), our dynamic bandwidth allocation algorithm is always better than the static scheme for practical values of CLR (≤10^{-3}).

Figure 6 depicts the Lambs mean scene duration for different values of T. Higher values of T lead to a small number of scenes and hence to a high mean scene duration. It is interesting to notice that for T=50% the mean scene duration is around 10 seconds. This means that there is no overhead within this period. With our dynamic algorithm we obtain a 67.65% capacity gain for a CLR=10^{-10}.

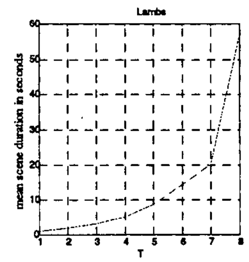
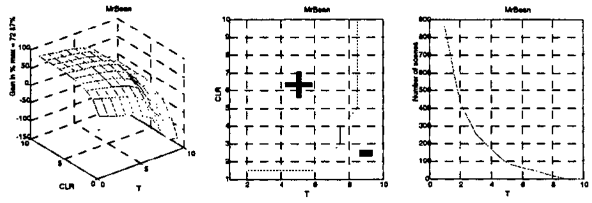


Figure 6: Lambs mean scene duration



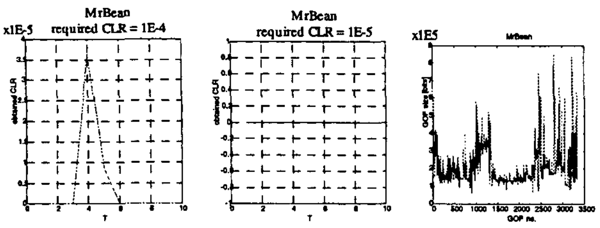
(a) (b) (c)

Figure 7: Simulation results for MrBean trace

Figure 7 (a) shows the capacity gain obtained for the MrBean trace in comparison with the static allocation scheme. For this MPEG stream the maximum capacity gain is again obtained for T=10% and a cell loss ratio CLR =10^{-10}. Similar results were found while using a Log-Normal distribution source model.

Here again (see **Figure 7** (b)), our dynamic algorithm surpasses the static scheme for practical values of CLR.

For this stream, the number of scenes and consequently the number of overhead messages is lower than the number of scenes for the two traces seen before (MTV2 and Lambs). This can be explained by the fact that MrBean trace has long segments that have a close GOP size values (see **Figure 8** (c)).



(a) (b) (c)

Figure 8: MrBean obtained CLR for a required CLR=10^{-4} and 10^{-5}

Figure 8 shows the obtained CLR for different values of T. **Figure 8** (a) shows the obtained CLR for a required CLR=10^{-4}. We notice that this requirement is always satisfied. In **Figure 8** (b) the obtained CLR is 0 even if the required CLR is 10^{-5}. Similar results (obtained CLR=0) were found for required CLR bellow 10^{-5}.

The following table shows the obtained results for other MPEG video streams.

Table 1: Some results for other films

Film	Gain for T=10%	Number of scenes for T=10%	Gain for T=50%	Number of scenes for T=50%
MTV1	74.61%	1962	61.56%	407
Asterix	72.59%	1745	58.86%	302
Dino	72.44%	1361	58.33%	191
News1	71.09%	667	56.29%	76
Simpsons	70.65%	1799	54.11%	302
Race	69.49%	1411	53.84%	211
Bond	66.33%	1154	47.95%	120

We have applied our algorithm to a total of 16 MPEG streams for different values of T (from T=10% to 100% step 10%) and different values of CLR (from 10^{-10} to 0.1 step 0.1). We always have a better capacity use than the static approach while guaranteeing the same and even better CLR for the region (CLR<10^{-3}).

To summarise, our solution has the following main advantages:

- It allocates much less capacity than the constant allocation scheme while guarantying the required QoS.
- For a required cell loss ratio below 10^{-5} we notice to have a much lower CLR. This will lead to a good visual quality.
- For 50% in capacity gain, we have only around 100 or 200 messages as overhead.
- With respect to video transmission on WATM, in average, we have an overhead in the order of 1 cell for each 1300 cell. We suppose that the capacity requests can be transmitted using OAM cells.
- With this method we have a distributed CLR over all the film scenes while with the constant allocation method the CLR is not distributed. This means that big GOPs are not disadvantaged by comparison with small ones. This will improve the visual quality of the film and hence solves the problem stated in section 2.
- It allows a higher number of users per cell since it uses less bandwidth.
- For scenes with a low level of activity (with GOP sizes lower than the peak cell rate). The leftover bandwidth can be used by other users. We believe that this will decrease the network call blocking and forced termination probabilities.
- It requires no complex computations.
- It can be easily added to the base stations and mobile terminals.
- It is easy to implement.

These properties make our dynamic algorithm well suited for practical application.

6. CONCLUSION

In this paper we proposed a dynamic bandwidth allocation scheme that can significantly improve bandwidth utilisation in wireless networks. It automatically adjusts the amount of reserved resources, while guarantying the required QoS.

The proposed algorithm exploits the structure of the MPEG video stream and allocates bandwidth on a scene basis. This will result in a high bandwidth gain, which will affect the overall network performance. The proposed scheme is dynamic and pro-active. It requires some communication between the mobile terminal and the base station, but the amount of extra information generated by the mechanism is acceptable in comparison to the capacity gain obtained.

Future work will involve studying the impact of the delay on the performance of the proposed algorithm as well as aspect related to call admission. Studying the choice of the T parameter is also of great importance.

7. REFERENCES

[1] A. A. Lazar, G. Pacifici, and D. E. Pendarakis. "Modeling video sources for real-time scheduling". Technical Report 324-93-03, Columbia University, Department of Electrical Engineering and Center for Telecommunications Research, April 1993.

[2] A. R. Reibman and B. G. Haskell. "Constraints on Variable Bit Rate Video for ATM Networks," IEEE Transactions on Circuits and systems for Video Technology, vol. 2, no. 4, pp. 361-372, December 1992.

[3] Ayman A. M. Ibrahim and M. Hamdi, "Statistical Rate Control for Real-Time Video Multiplexing," in Proceedings of 8th Int. Workshop on Packet Video (AVSPN'97), Aberdeen, Sept. 1997.

[4] Ayman A. M. Ibrahim, "Statistical Rate Control for Efficient Admission Control of MPEG-2 VBR Video Sources," ATM'98, Fairfax, USA, May 1998.

[5] D. A. Levine, I. F. Akyildiz, and M. Naghshineh. "The Shadow Cluster Concept for the Resource Allocation and Call Admission In ATM-Based Wireless Networks," IEEE/ACM Transaction on Networking, vol. 5, no. 1, February 1997.

[6] D. Le Gall. "MPEG: A video compression standard for multimedia applications," Communications of the ACM, 34(4):46-58, April 1991.

[7] Daniel P. Heyman and T. V. Lakshman. "Source Models for VBR Broadcast-Video Traffic," IEEE/ACM Transactions on Networking, vol. 4, no. 1, February 1996.

[8] http://www.etsi.org/smg/utra/utra.htm

[9] ISO/IEC International Standard 11172-2. "Coding of Moving Pictures and Associated Audio for Digital Storage Media up to 1.5 Mbits/s Part2", Video, 1993.

[10] ITU-T I.610, "B-ISDN Operation and Maintenance Principles Functions", Geneva, March 1993.

[11] K. L. Gong. Berkeley MPEG-1 video encoder, user's guide. Technical report, Computer Science Division-EECS, 1994.

[12] M. Hamdi and W. Roberts, "Rate Control for VBR Video coders in Broadband Networks," IEEE Journal on Selected Areas in Communications, August 1997.

[13] M. R. Pickering and J. F. Arnold. "A Perceptually Efficient VBR Rate Control Algorithm," IEEE Transaction on Image Processing, vol. 3, no. 5, pp. 527-532, September 1996.

[14] Marwan Krunz and Satish K. Tripathi, "Modeling Bit Rate Variations in MPEG Sources". University of Maryland, Institute for Advanced Computer Studies, Dept. of Computer Science, Univ. of Maryland, December 1995.

[15] Oliver Rose, "Statistical properties of MPEG video traffic and their impact on traffic modelling in ATM systems". 20th Conference on Local Computer Networks (LCN'95), Minneapolis, MN, October 1995.

[16] Y. Iraqi, R. Boutaba and R. Dssouli. "Statistical properties of MPEG video traffic and their impact on bandwidth allocation in wireless ATM networks," accepted for publication in the IEEE Wireless Communications and Networking Conference WCNC'99.