# Supporting Multimedia Streaming in VANs*

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*Abstract:* - This paper deals with the problem of multimedia streaming for mobile users. In particular users are thought as part of a group of customers located into a common public vehicle, e.g. a train or a bus connected to the network via a satellite link, and requesting either video-on-demand-like services, or (slightly deferred) real-time diffusive streaming services. This work is built on a proposal of resource management mechanism aimed at improving the effectiveness of streaming services in a vehicular networks. We show that a proxy server, devised to introduce an elastic buffer aimed at decoupling the information retrieval download speed on the outer network from the natural play-out speed used in the vehicular network, results to be an extremely effective approach in reducing the outage probability given by link failure in the outer network (e.g. tunnel crossing). The proposed resource management mechanism, namely A2M, is applied to both video-on-demand and diffusive services, and its performance effectiveness is evaluated through simulation.

*Key-Words:* - Proxy, Multimedia Streaming, VoD, Broadcast

## 1 Introduction

Mobile networking not only tackles the problem of providing a networking infrastructure for mobile customers, but also includes the ability of managing moving networks. This is the case of Vehicular Area Networks (VANs). These networks are formed by customers located on the same moving vehicle, e.g. a moving train or bus, and interconnected to the rest of the world via one or more wireless links (e.g. satellite, or UMTS connectivity, but also emerging wireless standards for metropolitan networks, such as IEEE 802.16 and IEEE 802.20, may become in the near future important technologies in the VAN arena).
The scenario considered here is that of a VAN in which users connectivity to the rest of the network is managed by a specialized on-board gateway. The role of this gateway is to provide internetworking between the internal network and the technology adopted for the outer network. For sake of simplicity, in this paper we assume that the outer network is implemented through a single high-capacity wireless link (e.g. a satellite link). The internal network architecture can be either wireless or wired: its implementation details are out of the scopes of the present paper, but an overall view of the system is given by Figure 1.
In addition to internetworking functions, the gateway may act as proxy server and provide a number of supplementary facilities, including caching and/or pre-fetching algorithms to maximize the probability that a customer requesting an object to download (e.g. a web page or a video segment) may find it stored into a repository associated to the proxy, and thus reducing utilization over the outer network link. Effective Caching and Pre-fetching mechanisms have been

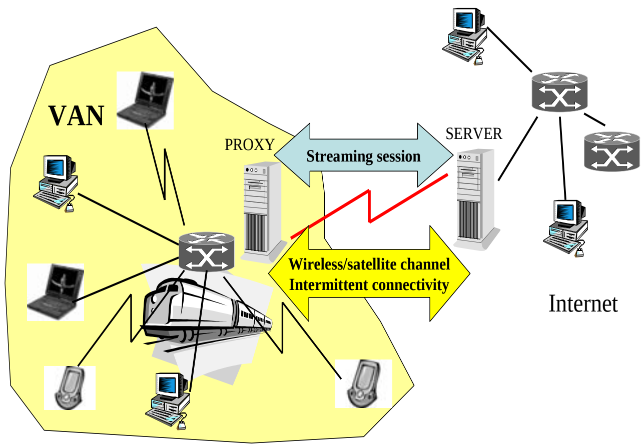


**Figure 1 mobile VAN framework**

thoroughly studied in [1-10], and they may be applied also in the VAN scenario considered in our work.
A problem typical of the VAN scenario is the possible outage of the outer network link, also named "channel outage".
Such an outage may occur while the vehicle crosses areas characterized by severe fading conditions, e.g. tunnels. This is a very critical issue when dealing with streaming services, which experience possibly long (order of several seconds) interruptions, thus causing highly negative performance impairments (service disruption) in terms of the end customer point of view. In what follows we'll refer to the event of service interruption as "connection outage".
We argue that, other than caching and pre-fetching, a further

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role of the proxy is to hide eventual outage periods to the final user, i.e. reduce the impact of channel outage in terms of resulting connection outage. As shown in this article, this can be accomplished by decoupling, from a service level point of view, the inner network service from the resource management occurring in the outer network segment. This in turns has highly beneficial effects in terms of network efficiency, as shown in the old work [11] where the advantage of the adoption of local storage and decoupling mechanisms has been pointed out for wired networks.
More specifically, this paper deals with two types of streaming services: video-on-demand-like services, where each user may retrieve its favorite video content, and diffusive services to access broadcast multimedia transmissions such as news, sports channels, etc. We show that, by inserting an elastic buffer within the proxy, it is possible to decouple the information retrieval occurring on the outer network link from the natural play-out speed used by the streaming service in the inner network. The same idea can be adopted for diffusive services, provided that an initial play-out delay is artificially inserted in the inner network streaming process. A key contribute of this work is the thorough performance evaluation of an effective resource management mechanism (called A2M) for the outer network link. This mechanism can be managed by the proxy, and is devised to minimize the probability that outage occurs in the streaming service experienced by customers in the inner network (a preliminary performance evaluation of the A2M algorithm, in a scenario restricted to video-on-demand-like services only, can be found in the related work [12]).
The rest of the paper is organized as follows: section 2 presents the working framework; section 3 affords the technical problem statement and introduces buffering algorithms and A2M. In section 4 it is shown how our mechanism, A2M, is able to improve VoD services performance in vehicular networks, while in section 5 we introduce Diffusive Services (actually we'll consider slightly delayed either Live events or Real Time services) and apply

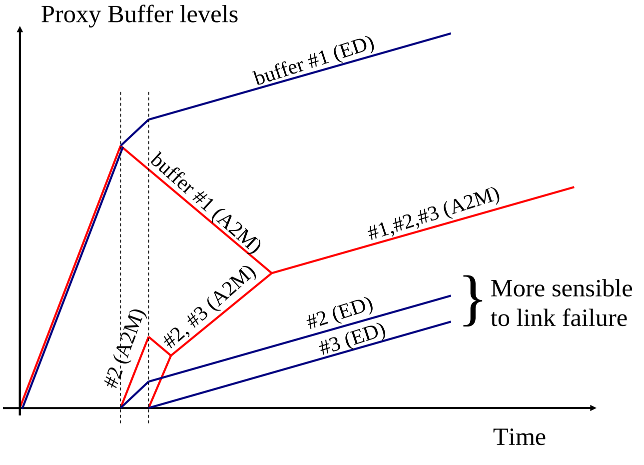


**Figure 2 A2M vs. ED operation**

## 2 Service Framework

We first discuss the case of video-on-demand (VoD) service support via proxy. We recall that the scenario considered in this paper is that of a Vehicular Area Network (VAN) where connectivity to the external network is managed through a proxy server. For convenience of presentation, we refer to the (single) wireless link connecting the VAN to the terrestrial network as “satellite link”, though we recall that the proposed model does not depend on the implementation technology adopted for such link.
The goal of our approach is to make the system robust to the uncertain behavior of the satellite link. In fact the satellite-to-proxy link is characterised by a wideband, high-performing channel, but it requires a line-of-sight connection, which cannot be always granted (e.g. while crossing tunnels). The adoption of an on-board proxy server is proposed to minimise outage periods. The idea is to split the video-on-demand connection into two separate segments. In the inner (vehicular) network, a normal streaming session is set-up between the end user and the proxy server. In the outer network (satellite link), the video information is downloaded at a rate higher than the natural play-out speed of the video information. This is of course possible provided that the sum of the play-out rates for the concurrent streaming sessions is lower than the satellite link capacity, i.e. provided that extra bandwidth is available on the satellite link. The excess information downloaded from the satellite is then dynamically buffered in a suitable storage area made available at the proxy. When the satellite link is in outage (e.g. when no line-of-sight is available), the proxy stops receiving data from server. However, clients connected to the proxy continue to receive data. Connection outage occurs only when the satellite link is in outage and the buffered data terminates. The described operation gives raise to an “elastic” buffer, which is filled during the periods in which the satellite link is active, and whose buffered data is consumed at a fixed rate given by the play-out speed for each streaming session, multiplied by the number of concurrent streaming sessions.
We'll show in the next section 3 that a very important role is played by the strategy adopted in managing the satellite link capacity, and specifically we will show that a uniform allocation of the extra available bandwidth to the concurrent downloads is a highly sub-optimal strategy. In addition to video-on-demand like services, delivery of broadcast information (hereafter referred to as Diffusive Services - DS) may also take significant advantage of the availability of a proxy server. To compensate for satellite link outage, it suffices to introduce a delay in the on-board play-out of the diffusive service. In other words, if an event is scheduled to be broadcast at a given time **t**, on-board transmission will start at time **t+D**, and the proxy will buffer all the information related to the **D** seconds of delay introduced. Clearly, when outage occurs on the satellite link, recovery of the missing information must be provided via a dedicated

proxy-to-network download connection, which will use the extra bandwidth available on the satellite link.

# 3 Resource Management Algorithms

This section gives an insight of the relation between buffering schemes and bandwidth assignment strategies. We'll assume a VoD scenario, while extensions to diffusive services will be dealt with in section 5.

When a customer requests a file, and resources are available (i.e. when a possible admission control mechanism is in accept state) the proxy firstly checks if the requested file is locally stored, and then eventually retrieves the file from server at the available rate while delivering the content to the client. The wireless channel is shared between all active connections: according to the specific user data rate, the proxy reserves a proportional satellite bandwidth to each download. If a new connection is accepted, the available bandwidth is fairly reallocated and redistributed to all connections. We call this proxy operation bandwidth “Equal-Distributed”, namely ED.

The novelty of our approach is propose in a different approach that consists in the dynamical adaptation of the bandwidth allocated to each connection between server and proxy. In particular, we monitor buffers at the proxy side and assign all the available bandwidth to the flow, or the group of flows, suffering the lower buffer-level. In contrast with the ED-mode, this is the A2M operational-mode, in which the bandwidth is fully reserved to streams at minimum buffer-level (“All to Minimum”).

Thus the A2M operation can be summarised as follows: when a client requests a file, the proxy checks if the requested file is locally stored, and eventually starts retrieving it from the server as fast as possible; while delivering the file, the proxy checks for flows with lower buffer-level and makes the total server bandwidth shared among these flows.

The temporal behavior of proxy buffer-level is plotted in figure 2, and a comparison between A2M and ED operation is given. In that figure, the proxy starts from an idle state and then progressively accepts three incoming VoD connections requesting non-pre-fetched files, and requiring the same data rate. The figure plots the buffer-level for each connection vs. the simulation time, and it shows the system evolution in both cases of A2M and ED is used. Firstly let's consider the A2M case, i.e. red thin lines in the plot. All the available bandwidth **C** is reserved to the first incoming connection, so that the buffer-level grows with a rate **C-R**, where **R** is the proxy-to-client rate: this is shown in the leftmost side of the figure 2, where A2M and ED act in the same way since a single stream is present.

When a second connection is accepted, all the bandwidth **C** is switched to this new stream, so that first stream buffer decreases with a rate **R**. After a third connections is accepted, and A2M operates a re-distribution of the bandwidth, as in the previous case. When a buffer-level grows and reaches an upper buffer-level, the overall bandwidth is shared between corresponding streams, and their buffers start growing together at rate **C/n-R**, being **n** the number of buffer at the same level. In the figure 2 we can see cases of **n=2**, in the middle part of the picture, and **n=3** on the right side.

As to the ED operation, while the satellite server is in line-of-sight, blue thick lines in the picture shows that each buffer grows without stopping, and the actual growing-rate is **C/m-R**, being **m** the number of active streams. Note that **n<=m**, thus a newer stream grows at a reduced rate when it starts, i.e. in the phase in which data have to be quickly cached on the proxy.

A similar dynamic bandwidth allocation mechanism for circuit-switched satellite network, proposed in [13], shows the improvements due to the adoption of such a scheme in terms of bandwidth utilization and QoS guaranties.

Nonetheless, there is a probability that a stream is blocked while running, and this is due to the probability that satellite and mobile proxy are not in line-of-sight $\mathbf{P_{ch}}$ for a long time. For what it concerns the effects of A2M on the connection outage probability ($\mathbf{P_{co}}$), it is shown in section 4 that a beneficial impact is obtained. In fact, using A2M each new connection is temporarily privileged and made able to accumulate a certain buffer-level on the proxy. Since the higher is the buffer-level, the lower is $\mathbf{P_{co}}$, A2M tries to fill proxy buffers as fast as possible, preventing outage occurrences.

What just described can be easily extended to a framework with flows characterized by different data rates. The only difference is that buffer-level has to be metered in terms of play-out time, i.e. in terms of time to reproduce a content on a user's terminal. Note that, for a VoD flow, in the case of channel outage, the buffer-level represents the margin before an outage occurs. For this reason we will use also the term “outage margin”.

# 4 A2M benefits for VoDs

Here we firstly present a VoD-service scenario for vehicular area networks, and corresponding analysis issues; secondly we show how A2M can be used in order to enhance the performance experienced by end-users using VoD.

## 4.1 Simplified VoD service scenario

A very basic scenario was tested, in order to clearly show the influence of the A2M scheme. Nonetheless, a great amount of parameters has to be considered. In our scenario, the client rate is almost fixed, while the proxy can store bytes at a variable rate. Thus, different protocol could be used on the server-to-proxy connection and on the proxy-to-client one. As to channel behavior, the satellite transmits data over a reliable channel. Anyway, the satellite transmission requires a line-of-sight between sender and receiver; otherwise a channel outage event occurs. Statistics of such event is related to the VAN mobility; in particular, a channel outage event occurs when the train, with proxy aboard, enters a tunnel. Thus, the channel outage probability depends on route, and we consider satellite link as an on/off function with both on and off periods exponentially distributed. Further results have been also obtained using deterministic paths from the Italian Railways Network. In the evaluation process it is relevant the statistical characterisation of requests. A very common approach consists in assuming the file request process as a Poisson arrival process. Since we want to stress the A2M mechanism, in our simulation we adopted a number of arrival rates for the Poisson process, also considering the case of infinite load, i.e. a "continuous load" is offered to the proxy, and performance results proposed here were obtained in such conditions, thus obtaining a worst case performance. Moreover the continuous load assumption allows us to study the intrinsic beneficial effects of A2M, since the $\mathbf{P_{co}}$ performance is a function of the buffering scheme instead of both proxy buffering and variable accepted load conditions. Finally, we investigated about proxy cache strategy as it is responsible for channel usage optimisation and for clients connections outage prevention, as previously shown in section 3.

The proposed scenario has been tested by means of a fluidic C++ event-driven simulator, acting on parameters like server-to-proxy download rate **C**, single-buffer fill rate (a percentage of **C**), proxy-to-client download rate **R**, maximum number of admittable connections, content request-rate (continuous load), channel outage probability $\mathbf{P_{ch}}$, VoD content duration (here set to 300s).

For sake of simplicity, a neat admission control rule has been used: a maximum number of clients is set, and a new connection request is accepted only if the number of already admitted connection is lower then the maximum, while transport protocols were not explicitly considered[1], even if they determine the effective file download rate[2].

## 4.2 A2M performance improvements

Figure 3 and 4 give a performance comparison between A2M and ED operation effects. In particular in figure 3 no pre-fetch was considered, while figure 4 depicts a scenario in which 30% of users' requests matches with a pre-fetched file; in addition, we considered the case that files are pre-fetched only for an half. In both figures 3 and 4, each VoD stream requests a 2 Mbps bandwidth, while overall satellite resources are 32 Mbps. A continuous load was adopted in order to stress the system, and the number of simultaneous connections is limited to eight[3].

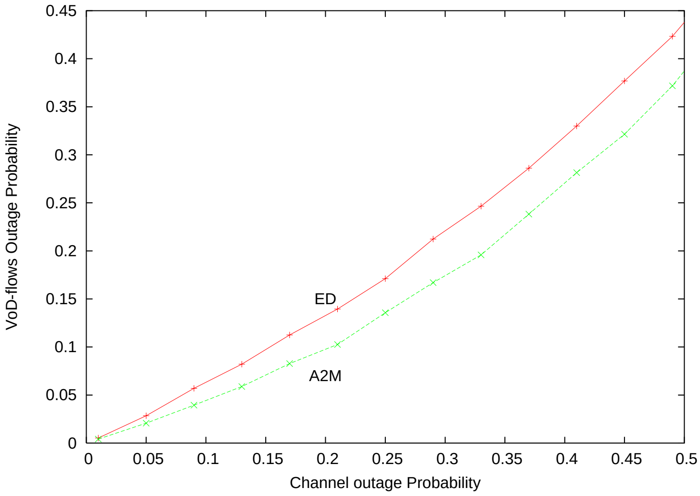


**Figure 3 A2M vs. ED in continuous load, and without pre-fetching**

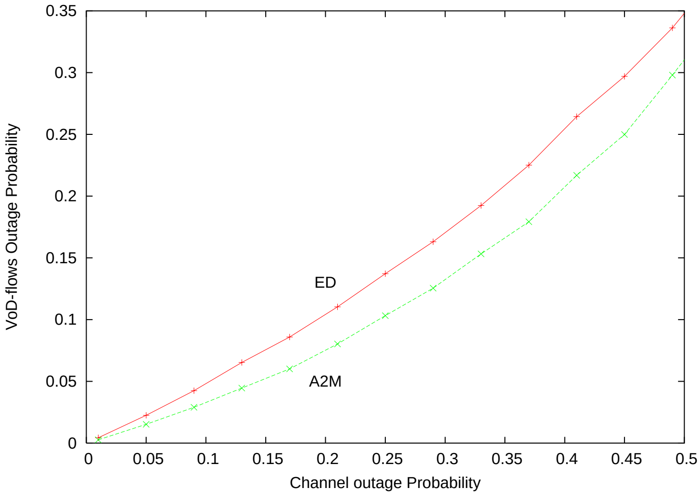


**Figure 4 A2M vs. ED in continuous load, and using a partial pre-fetching**

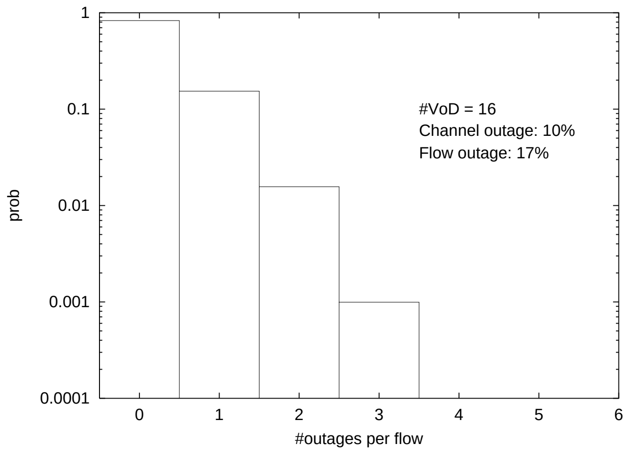


**Figure 5 Outages histogram for a VoD**

[1] Admission control schemes and transport protocol selection affect QoS performance in terms of reliability and download times. According to the selected admission control scheme it is possible to prevent congestions and optimise the channel utilization.

[2] For instance, a standard TCP protocol could severely affect the transmission over a satellite link, while an UDP protocol should maximise the data rate at the expenses of reliability, since no delivery checks are performed.

[3] Due to the continuous load adoption, the number of active connections sticks to the upper value, that in this case is 8.

For each bandwidth allocation scheme, curves show that A2M performs better than ED, with a remarkable gain in terms of outage probability. In other words, using A2M allows to reduce disruption occurrences experienced by end-user.

Furthermore, it is obvious that pre-fetching algorithms improve outage performance, due to the probability that a client request matches a pre-fetched file, and this remain clear by comparing figures 3 and 4, in which a gain of order of 10% is obtained by simply pre-fetching half the content of files that cumulate 30% of overall requests[4]. In case of outaged flows, it is interesting to observe the number of outages occurred. At this aim, in figure 5 the histogram of the outages per flow is reported. The figure was obtained by using the maximum number of simultaneous flows, lasting 300s each, and a 10% outage probability for the channel was set. All the available bandwidth is used by customers, since 16 connections at 2 Mbps are permitted in a 32 Mbps satellite scenario. A log scale was required in order to enlight the presence of more than one outage per connection[5].

## 5 Adding Diffusive Services over A2M

The behavior of Diffusive Services imposes the use of fixed buffers whose size is exactly equal to the one needed to store video data during the initial play-out time delay. Our studies focuses on the proxy parameter choice and on the coexistence of Diffusive Services and Video on Demand services on the same link, sharing the same bandwidth. Since that bandwidth is used by Diffusive service in order to selectively recover over the previously broadcast transmitted data, we also call that resource "recovery bandwidth".

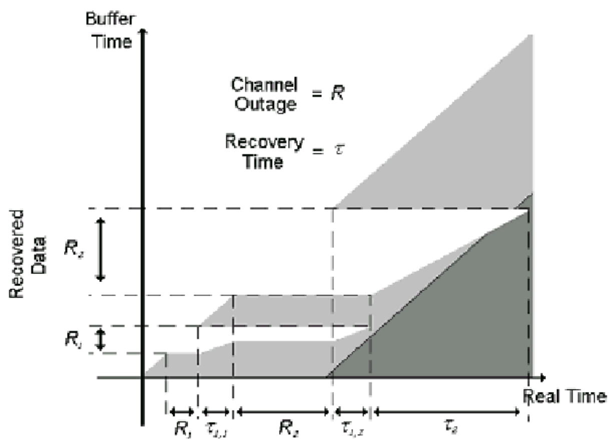


**Figure 6 Connection outage in DS service**

[4] As a reference, if a Zipf distribution is adopted for file popularity, and a 10.000 file population is given, 30% of requests is cumulated by the 10 most popular files. Thus a small amount of memory has to be dedicated to pre-fetched file.

[5] A more detailed performance evaluation of the A2M algorithm for VoD services can be found in the related works [12] and [14].

Unlikely, the presence of a buffer and the use of a play-out delay do not resolve the problem of temporary channel outages; in fact, connection outages are avoided only if the buffer contains all data needed during the outage period. But at the re-establishment of the link (i.e. immediately after the end of a tunnel), a transient period will be necessary to refill the buffer. The difference with the VoD scenario is that during the channel outage, the satellite broadcast transmission goes on. Thus, the proxy buffer has to store data and leave empty spaces ("unreceived windows") during channel outages. Unreceived windows are filled after the link is re-established using a "recovery procedure", lasting a transient period. This kind of application requires the logical division of satellite bandwidth into two parts: a fixed rate will be statically assigned to the retrieval of the latest data (common to all VANs in the same coverage area), while the remaining bandwidth (recovery bandwidth) will be used to fill "unreceived windows". The first part is a "diffusive transmission", i.e. it is the same for all proxies. The last part, on the contrary, is assigned to a specific proxy. Anyway, since the bandwidth available for recovery issues is limited and is shared with video downloads, it is mandatory to use algorithms able to avoid, as much as possible, flow outage events in both services.

An important parameter associated to the unreceived window is the "outage margin", that is the difference between the position (in the buffer) of the older unreceived window and the last data segment delivered to clients. The meaning of the outage margin is: in absence of recovery procedures, a connection outage would occur in a time equal to the outage margin. Of course, the outage margin of a VoD flow would be equal to the time needed to empty the buffer.

Our analysis is based on the integration between Diffusive Services (DS) and Video Download Services. To apply A2M algorithm to DS means that at any time all available bandwidth is assigned to the flows (VoD or DS) whose buffers have the lowest outage margin.

During the recovery of an "unreceived window" the bandwidth allocation is made as if the DS would be an unique VoD flow whose bandwidth is the sum of DS flows bandwidths. An important parameter is the ratio **K** between the bandwidth assigned to the recovery of DS data and the sum of the bitrates of DS flows. This parameter can be intended as the amount of video seconds that will be recovered in a second.

Connection outages can occur in a lot of situations difficult to preview and avoid. For instance, in figure 6 a scenario dealing with a multiple unreceived windows is depicted.

In what shown in figure 6, the recovery time of the first unreceived window, $\mathbf{R_1}$, is split into two parts: $\tau_{1,1}$ and $\tau_{1,2}$. The time $\tau_{1,1}$ is firstly employed to recover the first unreceived windows, but a second channel outage event occurs before the windows is fully recovered. At the link re-establishment, after the second tunnel, all available bandwidth is initially used to fill the former unreceived window, this is $\tau_{1,2}$. Then all available bandwidth is used to fill the latter unreceived window (for a time $\tau_2$). Unfortunately $\tau_2$ is too long, and the slope **K** results inappropriate. Thus a connection outage occurs because the total recovery time after the second channel outage event, that is $\tau_{1,2} + \tau_2$ is too long. The outage margin after tunnel #2 was long enough to recover the window #2 in $\tau_2$ seconds, but the presence of an additional window to recover in $\tau_{1,2}$ brings the system to failure. In practice, when **K>1**, connection outages can occur only when the train is in a tunnel. But **K>1** means that more than 50% of total bandwidth is allotted to recovery operations; this is a poor efficiency in link utilization. When **K<1**, the time needed to recover a flow interval is longer than the interval itself; this means that an "unreceived window" cannot be recovered while delivering it. The estimation of this time is not a simple work, because it depends on the total number of real time streams, the bitrate of each one, which of them are involved in the "channel outage", and the interaction of the recovery procedure with VoD services (sharing the same bandwidth). A view of a possible outage margin dynamic is shown in figure 8, where M is the play-out adopted, intervals indicated with D are outages, and with $\tau$ recovery periods are denoted.

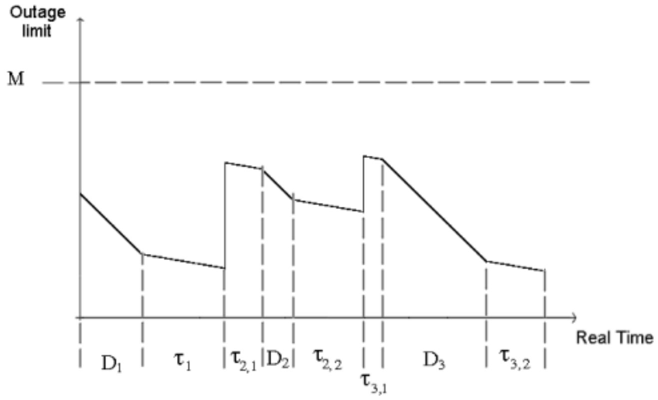


**Figure 7 Behavior of outage margin**

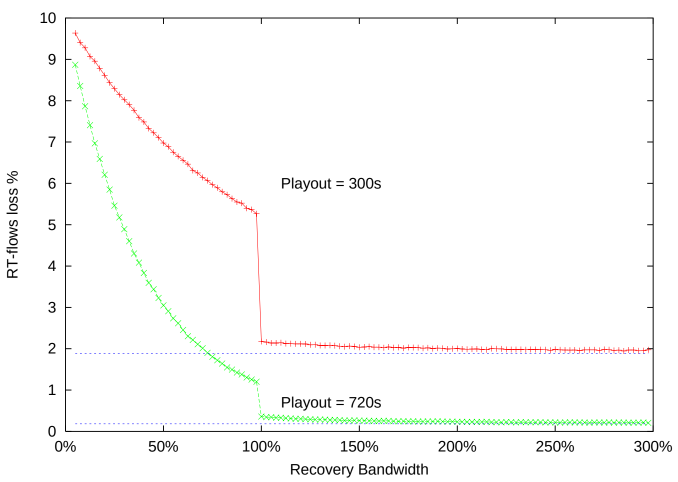


**Figure 8 Unrecovered broadcast data**

# 6 DS performance evaluation over A2M

Some simulation results are reported here as to concern to the DS evaluation using the A2M mechanism. Results were obtained by means of the same C++ simulation cited in section 4.1, using DS streams instead of VoDs, and the system was stressed by adopting a single never-lasting broadcast transmission instead of a continuous load. Moreover, a supplementary parameter to be considered in such simulations is the play-out delay to be adopted before serving a stream to the end user, while a certain amount of bandwidth resource has to be reserved to recovery procedures, i.e. a recovery channel has to be set (parameter **K** as in section 5). Figure 8 represents the percentage of DS-flows lost as a consequence of connection outages (unrecovered data) vs. Recovery Bandwidth (presented in terms of percent extra-bandwidth with respect to the natural DS broadcast bandwidth). A dependence on the recovery bandwidth is given: when it grows, DS-flows losses decrease. It shows an asymptote that depends of the play-out time, that is the connection outage probability computed under the assumption that recovery bandwidth is unlimited, and in turns this is the probability of a channel outage be longer than the play-out time. It is possible to see that very good performance can be experienced with a reduced recovery bandwidth amount; moreover it is not useful to increase the recovery bandwidth far above the natural flow stream, i.e. the "broadcast" data rate.

Another important detail is the discontinuity shown in correspondence to a recovery bandwidth of 100%. This band is equal to the total flow bandwidth, so it corresponds to **K=1**. The meaning of the discontinuity is: when **K>=1** and a connection outage occurs inside a tunnel, the content-time lost is equal to the remaining fraction of the tunnel; connection outage cannot occur outside a tunnel. When **K<1** and a connection outage occurs inside a tunnel, the loss is equal to the remaining fraction of unreceived window that has not been recovered; moreover, and mostly important, connection outages can occur outside a tunnel (see also figure 6).

Finally we propose a significant performance figure obtained by simulating DS services over an high speed train while running on its real path from Rome to Florence[6].

Figure 9 depicts a "zero-loss curve", i.e. a set of couples (play-out, bandwidth) which represents minimal requirements to obtain a correct reception at client-side, using a real-time never-lasting stream. Due to the presence of tunnels, a minimum play-out is given (look at the asymptotic value shown in the picture, corresponding to the longer tunnel to be crossed); actually we can use a finite bandwidth, and in order to obtain appreciable performance, we have to reserve at least as much bandwidth as for the broadcast channel (recovery bandwidth=100% in the picture, i.e **K=1**). Those results are strongly dependent on selected path, but

[6] Simulation were performed taking into account Trenitalia S.p.A. Time-table and path data about real tunnels distribution

they can be useful adopted in order to well-design each single train-system by previously loading path data.

## 7 Conclusion

In a VAN framework, users attempt to download multimedia contents from the network. We shown that a value-added approach is built on the use of a dedicated mobile proxy. This allows the network to split data flows into two parts: a secure and reliable proxy-client connection, and a time-variant server-proxy connection. VoD and DS services have been taken into account, and a suitable bandwidth sharing algorithm, A2M, has been proposed to confer reliability to both kinds of service. Simulation results show the validity of A2M, minimising the probability that a client's download is stopped due to proxy buffer emptying, when satellite server is out-of-sight. The proposed approach is not strictly related to the use of a satellite, but also radio technologies like UMTS or, in a few months, IEEE 802.20, could be appropriate in order to cover vehicular users networks.

Anyway, A2M can be considered a well suited bandwidth sharing algorithm, able to improve the robustness of the proxy system; it is also a scalable mechanism, especially in the case of VoD services, where no complex state information has to be managed, but the number of downloads. Next steps in research mainly relate to the download transport protocol influence, and the implementation of an advanced admission control scheme, taking advantage from the amount of pre-fetched data in the local proxy server. Moreover, the formalization of analytic expressions useful to foresee the outage margin evolution and the study the influence of architectural freedom degrees (as the number of channels or the total bandwidth) will be addressed in a short time.

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