A Proposal of Burst Cloning for Video Quality Improvement in Optical Burst Switching Networks

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Abstract—**This paper presents two novel cloning schemes for video delivery in Optical Burst Switching Networks. These schemes take into account the special characteristics of compressed video traffic and dramatically improve received video quality. Analytical and simulation results show up to 40% quality improvement without a substantial increase in the overall network traffic. The results show the strong dependency of these novel cloning schemes on the video traffic structure due to the coding mechanisms. Rules based on the GoP structure are presented to decide the frames to clone.**

I. Introduction

Video streaming is nowadays one of the hungriest bandwidth consuming applications. Internet video was 40% of consumer Internet traffic in 2011 and it is expected to rise to more than 60% by the end of 2015 [1]. Current and future networks need to consider the special characteristics of video traffic and treat it properly for network efficiency.

In this paper, we try to improve video quality in Optical Burst Switching (*OBS*) Networks [2]. OBS is an all-optical transport technology that could offer high switching capacities in the short to medium term while taking advantage of statistical multiplexing and joining the merits of Optical Circuit Switching and Optical Packet Switching. Therefore, OBS is suitable for core video distribution networks.

In an OBS network the ingress node aggregates packets into larger containers (a.k.a. *bursts*) that are transported by the network as a whole. These bursts use an all-optical data plane to the egress node where they are disassembled into their contained packets. When a burst is lost, all packets inside the burst are lost, resulting in bursty packet losses.

A Burst Control Packet is created and sent by the ingress node an offset time before the burst is sent. This packet is electronically switched and processed at every backbone node. It contains information that depends on the signalling solution used, e.g. the burst arrival time and the burst size [3].

The ingress node creates at least one burst formation queue (a.k.a. *burstifier*) per egress node. The most frequently used burstifier in the literature is timer-based [4]. A timer of value T_{out} is started on the arrival of an electronic packet to an empty burstifier. When the timer expires, the burst is scheduled for optical transmission on the output port of the ingress node. Optical buffering in the core network is non-existent or scarce, as it is based on Fiber Delay Lines (*FDL*). Therefore, burst losses are the result of output port contention and can be modelled [4] using a Bernoulli process [5] with parameter p, i.e. an i.i.d. burst loss probability.

Many mechanisms have been proposed to reduce the loss rate in OBS networks: retransmission, forward error correction, cloning, contention resolution (fiber delay lines, deflection routing, wavelength conversion, segmentation), contention avoidance, etc.

Contention resolution schemes appear to be the best solution to reduce the loss rate in OBS networks, but nowadays they present some serious implementation difficulties [6] [7]. FDLs are bulky and they merely offer fixed delays, so they are far from behaving like optical memories. Deflection routing has the problem of endless loops and the possibility of insufficient offset time or re-routed bursts. Finally, wavelength conversion and burst segmentation techniques are still immature and very expensive to implement.

Retransmission schemes are not useful in OBS core networks because of the high latency introduced and the requirement of larger buffers on the edge nodes. An alternative to retransmissions is data cloning at the ingress nodes, creating copies of the input traffic that improve delivering probabilities. Almost all the burst cloning proposals [8] [9] clone all the traffic and hence increase network load to at least twice the original one. None of these schemes is designed to improve video quality taking into account the particular characteristics of video. Only [10] appears to propose a cloning scheme for video, but it does not perform any analytical study of the video quality improvement or the selection of frames to clone.

In video streaming, lost frames cannot be recovered by retransmissions, because usually the retransmitted frame arrives later than the time to display the frame. Therefore, we have to avoid, or at least to minimize, the loss of frames. This paper introduces two novel schemes to improve the video delivery over OBS networks based on burst cloning and the particular characteristics of video. These schemes only clone some selected video frames. Frame selection is based on the effect that their loss would have on video quality. The paper shows, by simulation and an analytical model, that video quality can be improved, but there is a strong dependency of the improvement on the video compression structure.

II. Video quality analytical model

Video flows are compressed for efficient network transport, mainly using encoders from the MPEG family encoders [11].

Given the widespread use of these encoders throughout the industry and reaching millions of user devices, they will most likely remain in use for the foreseeable future. Three types of frames are defined in the MPEG standards. Three types of video frames are defined in the MPEG standards: intra-coded frames (a.k.a. *I-frames*), inter-coded or predicted frames (a.k.a. *P-frames*) and bidirectional coded frames (a.k.a. *B-frames*). I-frames do not depend on any frame in their coding/decoding process. P-frames depend on the previous I- or P-frame. B-frames depend on the previous I- or P-frame and the following one of either type.

The set of frames between two I-frames is named Group of Pictures (*GoP*). A typical nomenclature for a regular GoP structure is *GxBy*, where x is the total number of frames and y is the number of consecutive B-frames. $G_{\{I,P,B\}}$ is the number of frames from each frame type in a GoP and it can be obtained by (1).

$$G_I = 1 \qquad G_P = \left\lfloor \frac{x-1}{y+1} \right\rfloor \tag{1}$$
$$G_B = x - 1 - G_P = x - 1 - \left\lfloor \frac{x-1}{y+1} \right\rfloor$$

A typical GoP structure is, e.g., *G12B2* or *IBBPBBPBBPBB*. It is an open GoP, because the last two B-frames depend on the I-frame from the next GoP. Therefore, in an open GoP $G_B = y \cdot (G_P + 1)$. In a closed GoP there is no dependence on frames out of the GoP, like, e.g., in *G10B2* or *IBBPBBPBBP*. Therefore, in an closed GoP $G_B = y \cdot G_P$. We can define the variable z (2), where $z = 1$ for an open GoP and $z = 0$ for a closed GoP.

$$z = \left\lceil \frac{G_B}{y \cdot G_P} \right\rceil - 1 = \left\lceil \frac{x - 1 - G_P}{y \cdot G_P} \right\rceil - 1 \tag{2}$$

This hierarchical structure of MPEG encoding implies a possible error propagation through its frames, adding an extra handicap to the transport of MPEG video flows over lossy networks [12]. Frames that arrive at the destination could be useless if the other frames that they depend on have been dropped by the network. Therefore, small frame loss rates may cause high frame error rates, degrading the video quality perceived by the user.

A video provider needs to quantify the video quality problems, optimally before the user perceives them. The concept of *Quality of Experience (QoE)* emerged from this identified need. ITU-T defines QoE [13] as “The overall acceptability of an application or service, as perceived subjectively by the end-user”.

The user perceives the time periods when video is not correctly decoded. These time periods can be measured as the number of seconds over one hour that could not be displayed (VT_{nd}). The proportion of frames that could be decoded and displayed is named the *Decodable Frame Rate (Q)*. Therefore, $VT_{nd} = (1 - Q) * 3600$. A value of $Q = 0.99$ indicates that, on average, 36 seconds of video will not be correctly decoded for each hour.

An analytical model for Q in scenarios where frame losses can be considered mutually independent was presented on [14]. The model from [14] is only valid for open GoPs, but it can be easily extended to closed GoPs. The analytical model for open and closed GoPs is (3), where $P_{\{I,P,B\}}$ is the probability to lose a {I, P, B}-frame. The term multiplied by z (2) is the difference between open and closed GoPs.

$$Q = \frac{(1-P_I) + (1-P_I)\left[1 + y(1-P_B)\right] \sum_{i=1}^{G_P} (1-P_P)^i}{x} + \\ + z\, \frac{y(1-P_I)^2(1-P_B)(1-P_P)^{G_P}}{x} \tag{3}$$

OBS burst losses can be considered mutually independent due to the bufferless nature of the optical switches [4]. Video streaming servers usually send all packets from a frame back-to-back. These packets arrive at the burstifier at approximately the same time. In an OBS network with timer-based burstifiers, if a packet from a frame gets into a burst, we assume that the rest of the packets from the frame do so as well. If the timer T_{out} is smaller than the inter-frame time T_{if} (typical value of 40 ms), bursts contain only one whole frame. As burst losses can be considered mutually independent, then the frame losses can be considered mutually independent too and (3) can be applied.

III. Proposed Cloning Schemes

In the Burst Cloning Scheme proposal [8], one or more cloned bursts can be created from each original burst and scheduled for transmission at the output port of the ingress node. If at least one of these bursts arrives at the destination, the original burst is considered to be successful. If more copies are made for a particular burst, then it is more likely to become successful. In [10], the authors propose a cloning scheme for video over OBS, but they do not perform any analytical study on the video quality improvement or the selection of frames to clone.

The major side effect of burst cloning is an increase of the network load. Each network link carries on average twice the original load or more, as some studies suggest making more than one copy for the original burst [15]. This network load increase can cause the opposite effect, a higher contention probability resulting in higher loss rates.

Two different cloning schemes are proposed in this paper: *Frame Duplication at Next Burst (FDNB)* and *Frame Duplication at Exclusive Burst (FDEB)*. Both schemes avoid cloning all incoming traffic. FDNB duplicates into the next burst only selected types of video frames (*priority frames*). FDEB duplicates the priority frames creating an independent burst. The priority frames are selected such that the video quality improvement is maximized, i.e., such that they minimize the VT_{nd}. To the best of the authors' knowledge, the improvement on video quality using cloning has not yet been analytically studied.

The cloning of frames is done in the burstification process of the Ingress node, therefore it is done in the electronic domain. OBS Core nodes do not need to differentiate between burst with cloned and without cloned frames, therefore any OBS backbone can use the cloning schemes presented in this paper.

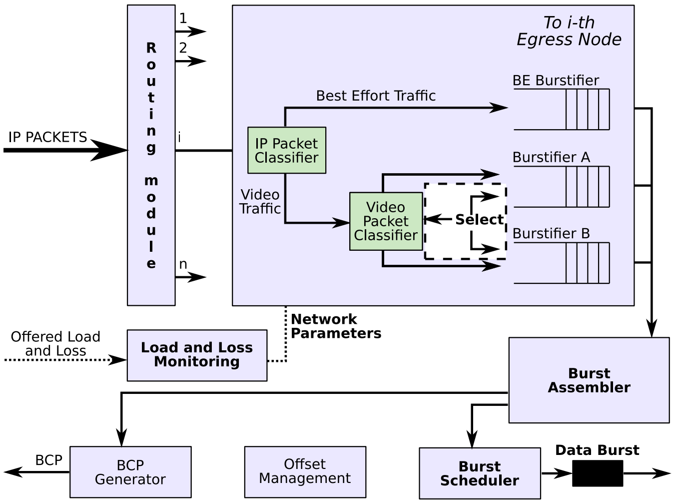


Fig. 1. Diagram of Ingress node (dotted section is only for FDNB)

The FDEB Ingress node in Fig. 1 consists on three burstifiers per egress node. One burstifier is used for best effort traffic. The other two burstifiers are used simultaneously and with a common timer for video traffic. In OBS, the video traffic can be several videos to the same optical egress node. *Burstifier A* aggregates all the incoming video traffic and *Burstifier B* only aggregates a copy of selected frames from each video. When the common timer expires, the bursts from both burstifiers are scheduled for transmission at the output port. If *Burstifier B* is empty, then only the burst from *Burstifier A* is scheduled. Using this procedure, the FDEB duplicates the priority frames from each video using extra bursts.

The FDNB Ingress node adds the "select" signal to the FDEB Ingress node (dotted section in Fig. 1). Every time a burst is generated, the value of the "select" signal is toggled. If the signal is "0", then *Burstifier A* aggregates all the incoming video traffic while *Burstifier B* aggregates only a copy of the priority frames for each video. Thus priority video frames get duplicated in *Burstifier B*. The burstifier that aggregates the total video traffic is the only one with an active formation timer. In this case, with signal value "0", it is *Burstifier A* the one with an active timer. When the timer expires, the burst from *Burstifier A* is scheduled for transmission at the output port and the "select" signal flips to "1". Now, all the incoming video traffic will go to *Burstifier B*, that stored duplicate priority frames from the previous burst. Meanwhile, the arriving priority frames get duplicated into *Burstifier A*. Using this procedure, the FDNB duplicates the priority frames from each video at the next burst.

Both FDEB and FDNB increase in the same proportion the network load, because both duplicate the same priority frames but using different methods. FDEB creates extra bursts to duplicate the priority frames, while FDNB does not. On OBS, the optical switching limits impose a minimum burst size. As the extra bursts could be aggregating low amounts of traffic, burst sizes could result below this minimum. Therefore, padding could be required for the extra bursts, increasing even more the network load. FDNB does not created extra bursts, but it does increase the burst sizes.

On both schemes, the selected priority frames could be different for each video, although they use the same video burstifiers. This is accomplished by the *Video Packet Classifier* sub-module at the ingress node. The selection will depend on the network loss rate and the GoP structure of the video.

As expected, and as the simulation results will show, for both schemes the best improvement is obtained by cloning all the frames. However, in some situations this will dramatically boost the network load and loss rate, seriously affecting the best effort traffic. In these cases, only some frames should be cloned, and surprisingly, the I-frames are not always the selected ones as the choice depends on the GoP structure of the video.

IV. Results

Simulations were made to measure the video quality improvement achieved by the proposed FDEB and FDNB cloning schemes for different priority frames selection policies. As a first approach, the OBS core network is modelled as a black box with a burst loss probability p not affected by the load increase from cloning. This assumption is valid for a scenario where the video traffic load is small compared to the best effort traffic on the OBS core network, so the cloning is not noticeable.

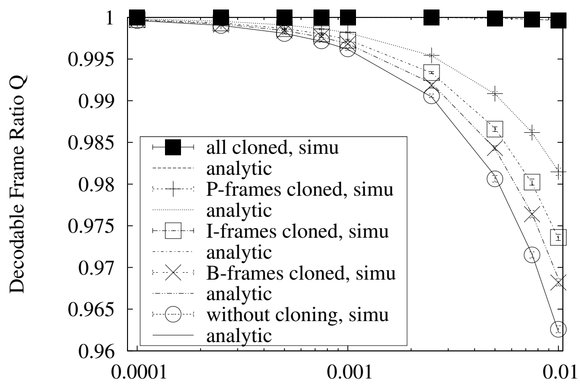
A specific simulator for this simplified network model was developed. Different network scenarios were evaluated using $p = [10^{-4}, 10^{-2}]$. Previous papers have studied the effect of this range of loss ratios in TCP traffic [16]. The video source uses a video trace describing the size and time for each frame. Different video traces from [17] were used as video flows (TABLE I).

TABLE I
Summary of traces used in the simulations

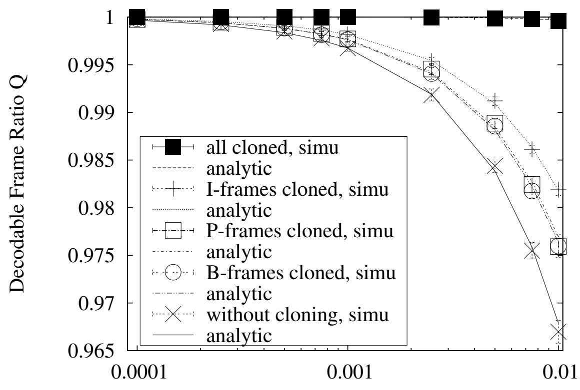
Trace	GoP	Bit rate (Mbps)	I-frames bit rate (%)	P-frames bit rate (%)	B-frames bit rate (%)
The Matrix	*G12B2*	0.403	24.245	29.464	46.291
Tokyo	*G16B1*	0.699	16.906	54.621	28.472
The Silence Of The Lambs	*G16B3*	0.385	21.850	24.729	53.421
Star Wars IV	*G16B7*	3.143	9.537	8.314	82.149

Five configurations where evaluated: without cloning; all frames are cloned; only I-frames are cloned; only P-frames are cloned; and only B-frames are cloned. The burstifier timer T_{out} is limited to a value smaller than the inter-frame time T_{if}, so the frame losses can be considered mutually independent. The frame loss probability for the priority frames is the probability of losing both the burst with the original frame and the burst with the cloned one, i.e., p^2. The frame loss probability for all other frames is equal to the burst loss probability p.

Fig. 2 shows the simulation and analytical results for Q. Results are obtained at 95% confidence level, but most confidence intervals are too small to be noticed in the figure. For space constraints, only results from *The Matrix* and *Star Wars IV* traces are plotted. Both use different GoP structures and bit rates, but the analytical results match the simulations well for both traces. Obviously, cloning all the frames offers the best results, but at the highest cost in network traffic increase. The second best choice is obtained by I-frames cloning for *Star Wars IV* trace, but by P-frames cloning for *The Matrix* trace. Therefore, the Decodable Frame Rate reduction depends on characteristics from the videos.



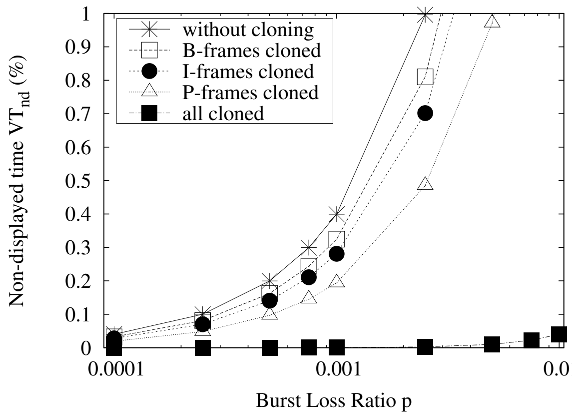
(a) *The Matrix*



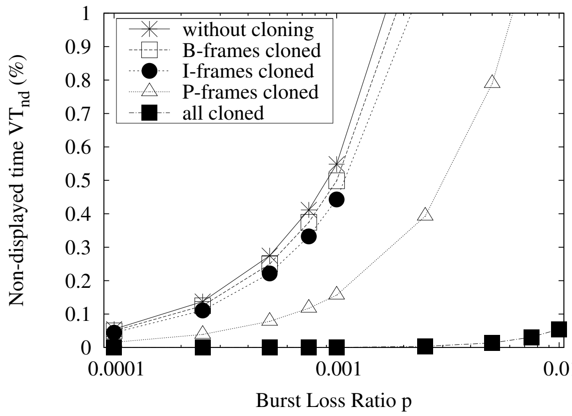
(b) *Star Wars IV*

Fig. 2. Decodable Frame Rate for traces with different GoP structures and bit rates

As the simulation and analytical results match so well, due to space constraints, only analytical results will be presented from now on. Fig. 4 and 3 show, as expected, that all cloning configurations improve the video quality. Excluding the case of cloning all the frames, the configuration that obtains the best results varies from one trace to another. For *Star Wars IV* trace, the best choice is I-frames cloning. However, for the other traces (*The Silence Of The Lambs*, *Tokyo* and *The Matrix*), the best choice is P-frames cloning. The analytical model (3) only requires knowing the GoP structure of the video. Therefore, for the same p, the GoP structure is the determinant factor for



(a) *The Silence Of The Lambs*



(b) *Tokyo*

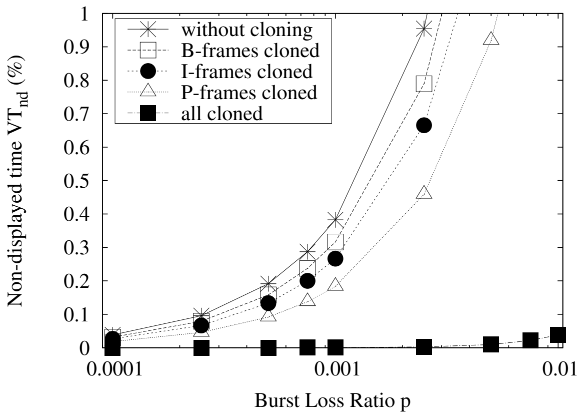
Fig. 3. Video quality measured as video time that could not be displayed (VT_{nd}) for different scheme configurations and traces

the selection of the priority frames.

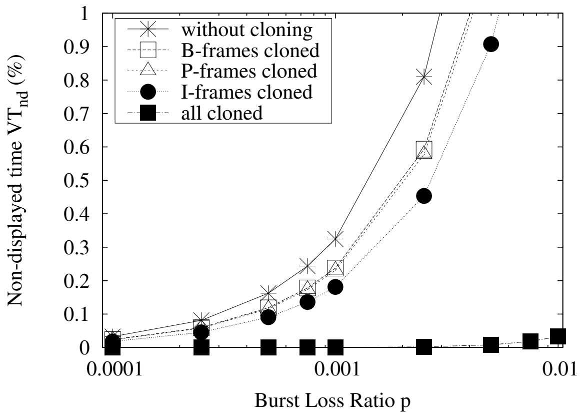
The results so far did not take into account that cloning increases the network load, and therefore the output port contention and the network burst loss probability. This higher loss probability has a negative effect on video quality and it could reduce the gain obtained by cloning. It could also have a high impact on the best effort traffic.

The OBS core network path can be modelled using M consecutive and independent bufferless servers. Assuming that the traffic to each OBS switch output port in the path arrives from many independent sources, the aggregate traffic to the output port can be considered a Poisson process. Therefore, the burst loss probability on each server (p_0) can be computed using the Erlang-B formula [18]. If the traffic to each switch comes from independent sources, then the network burst loss probability is just $p = 1 - (1 - p_0)^M$.

Fig. 5 and 6 for the the video quality and the network burst loss probability for the five cloning configurations taking into account the network load increase due to cloning. For space constraints, only results from *Star Wars IV* trace are presented. The network has four core nodes ($M = 4$) from the ingress node to the egress node and each optical link has 16 wavelengths at 1 Gbps. The network carries N video flows from the ingress node to the egress node and a background



(a) *The Matrix*



(b) *Star Wars IV*

Fig. 4. Video quality measured as video time that could not be displayed (VT_{nd}) for different scheme configurations and traces

traffic of low ($\rho_b = 0.25$) or medium ($\rho_b = 0.5$) utilization.

Cloning all the frames outperforms the rest of the alternatives, even though it highly increases the network burst loss probability. For the video traffic, the higher loss probability is compensated by the loss recovery obtained by cloning all the frames. However, for the rest of the traffic (background traffic) the increase represents unacceptable high loss rates, even at low utilization. For example, at $\rho_b = 0.25$ the loss probability increases from $8.28 \cdot 10^{-5}$ to $3.39 \cdot 10^{-4}$ when there are 200 videos being completely cloned, and it raises from $6.26 \cdot 10^{-4}$ to $6.93 \cdot 10^{-3}$ when there are 500 videos. Therefore, cloning all the frames is not a good strategy, unless it does not matter to severely penalize the non-video traffic.

In contrast, the duplication of I- or P-frames improves the video quality without significantly increasing the network burst loss probability. For example, at $\rho_b = 0.5$ and adding 100 videos, I-frames cloning improves the video quality up to 40%, from $VT_{nd} = 276.25\ s$ to $164.30\ s$, and P-frames cloning improves the video quality up to 25% ($VT_{nd} = 205.55\ s$). I-frames cloning or P-frames cloning are the best strategies.

V. Priority frames selection based on GoP

As shown in section IV, the GoP structure is of great importance for priority frames selection. The ingress node cannot change the GoP structure of the video, but it can

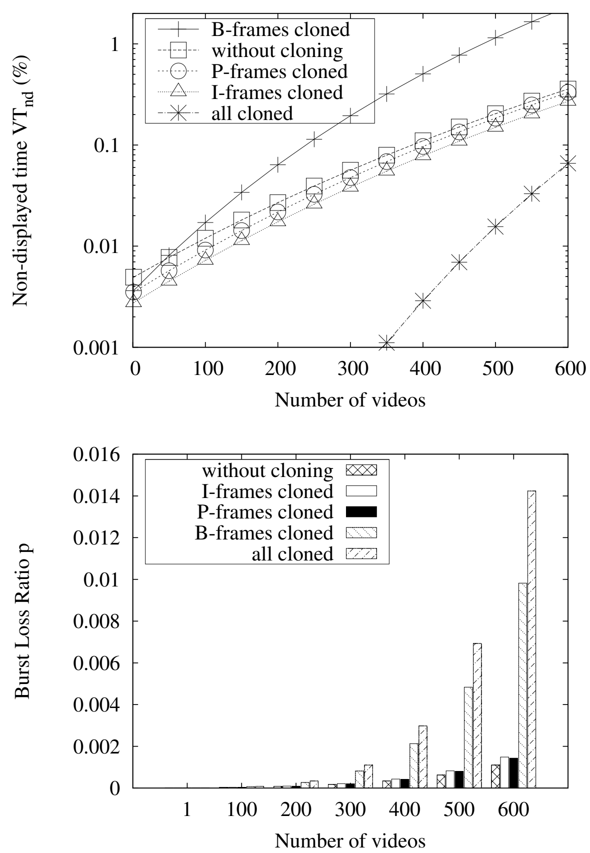


Fig. 5. Video quality and network burst loss ratio for *Star Wars IV* trace and $\rho_b = 0.25$ taking into account the network load increase due to cloning

choose depending on the GoP structure the types of frames to duplicate such that the video quality is maximized. Cloning B-frames does not significantly improve the video quality and cloning all frames is too costly.

We define variable δ as the difference between the video quality for I-frames cloning and for P-frames cloning. If δ is negative, the best choice is I-frames cloning. If δ is positive, the best choice is P-frames cloning. For the scenario studied in this paper, δ can be computed by (4).

$$\begin{aligned}
\delta &= x\frac{VT_{nd,I} - VT_{nd,P}}{3600} = x(Q_P - Q_I) = \qquad (4)\\
&= (1-p) + [(1-p) + y(1-p)(1-p)]\sum_{i=1}^{G_P}(1-p^2)^i + \\
&+ zy(1-p)^2(1-p)(1-p^2)^{G_P} + \\
&- (1-p^2) - \left[(1-p^2) + y(1-p)(1-p^2)\right]\sum_{i=1}^{G_P}(1-p)^i + \\
&- zy(1-p^2)^2(1-p)(1-p)^{G_P} = \\
&= -p(1-p) + zy(1-p)^{G_P+3}\left[(1+p)^{G_P} - (1+p)^2\right] + \\
&+ \left[(1-p) + y(1-p)^2\right]\sum_{i=1}^{G_P}(1-p)^i\left[(1+p)^i - (1+p)\right]
\end{aligned}$$

The first term in (4) is always negative and it does not depend on the GoP structure. The last term is always equal or

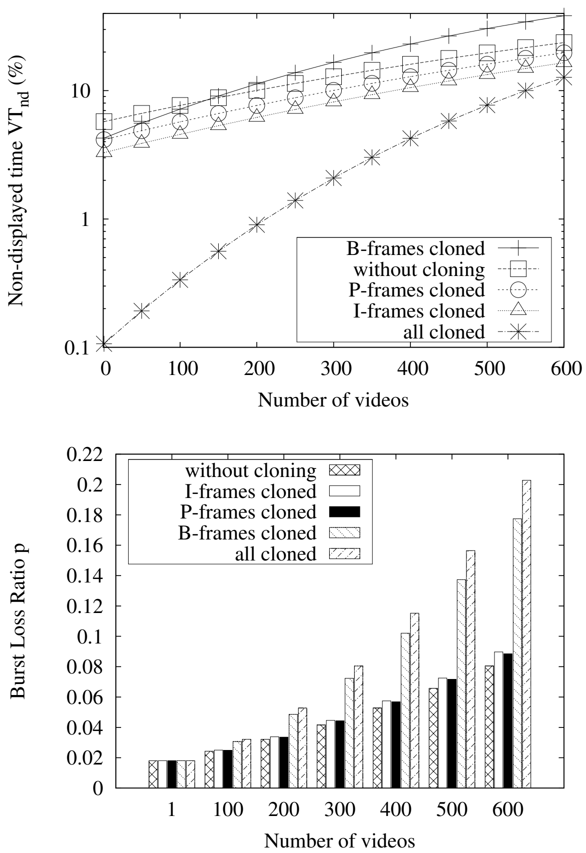


Fig. 6. Video quality and network burst loss ratio for *Star Wars IV* trace and $\rho_b = 0.5$ taking into account the network load increase due to cloning

greater than zero, but its value depends on the GoP structure and it decides the priority frames for closed GoPs. The second term is only for open GoPs and depending on the GoP structure it is equal, greater or lower than zero.

Using δ, some conclusions can be extracted. If the GoP has only one P-frame, then $\delta = -p(1-p) - zyp(1-p)^4(1+p)$ is always negative regardless of x and y. Therefore, the best priority frames for GoPs with only one P-frame are always I-frames. This conclusion explains the results obtained from *Star Wars IV* trace with the *G16B7* GoP structure that has only one P-frame.

If the GoP has exactly two P-frames, then $\delta = -p(1-p)[1-(1+p)[(1-p)^2 - y(1-p)^3]]$ for open or closed GoPs. If $p < 0.329$, for any $y > 0$ the best priority frames should be P-frames ($\delta > 0$) regardless of being an open or closed GoP.

VI. Conclusions

This paper presents two novel video quality improvement cloning schemes for OBS networks: Frame Duplication at Exclusive Burst cloning scheme and Frame Duplication at Next Burst cloning scheme. The most important frames for video quality are cloned into an extra burst or into the next burst, respectively. The simulations and the analytical model show a significant improvement of quality, up to 40%, in some cases with virtually no trade offs. The selection of frames to clone has strong dependence on the GoP structure. A selection method and some selection examples were presented.

Acknowledgements

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