Fine Granular Scalability -

A new framework for real-time streaming of video over the Internet

Mihaela van der Schaar

Overview

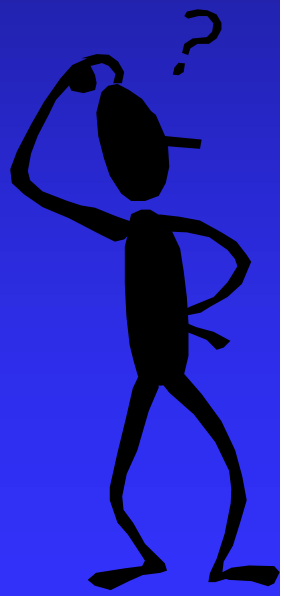
- Why a new coding paradigm for Internet Video?
- “Fine-Granular-Scalability” (FGS) framework
- FGS features
- How does FGS compare with other coding schemes?
- New extensions
- FGS applications beyond video streaming
- Conclusions

Why a new coding solution?

Internet characteristics!

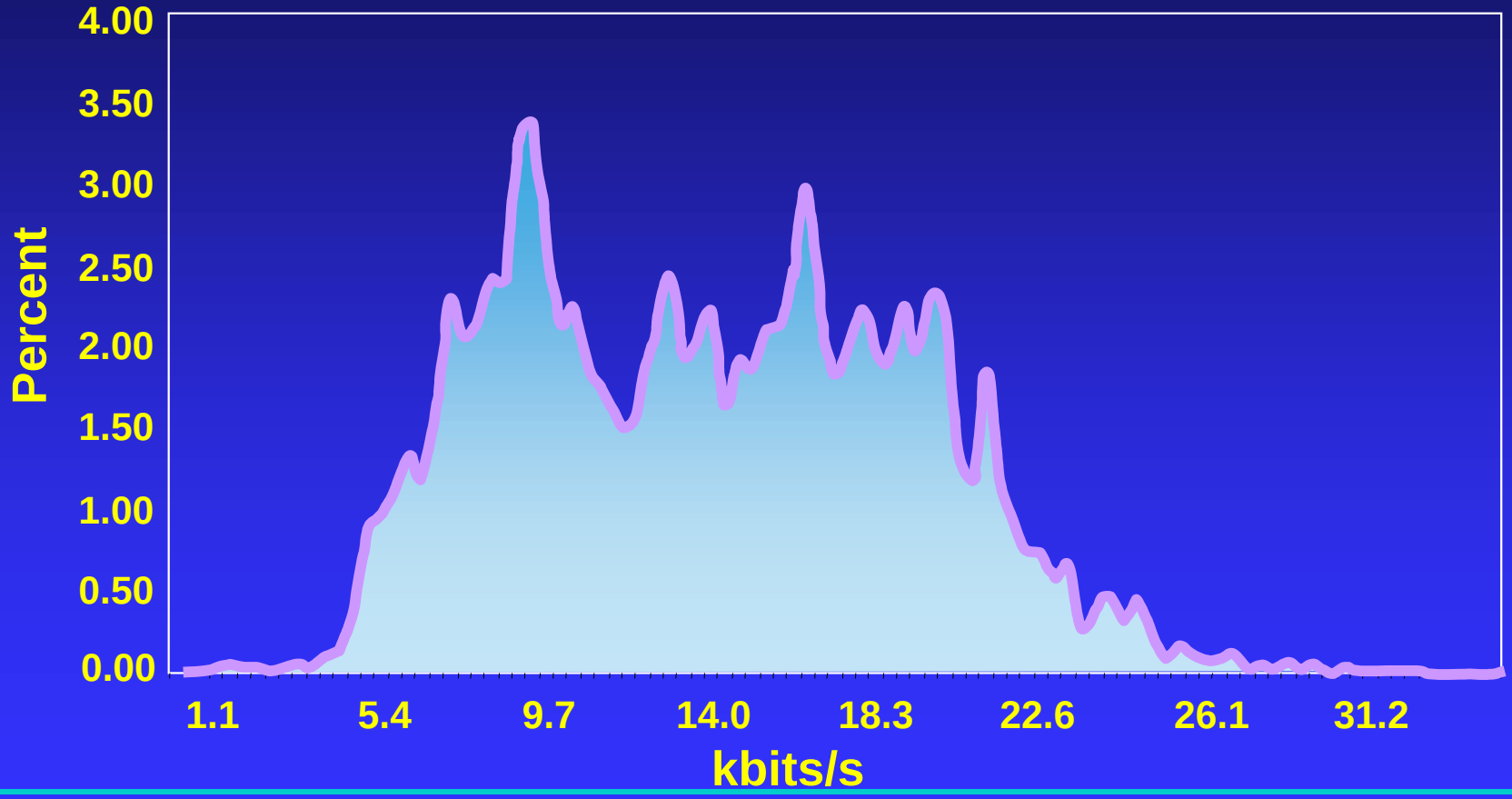
- Wide range of available bandwidths & packet-loss rates

  => No QoS guarantees

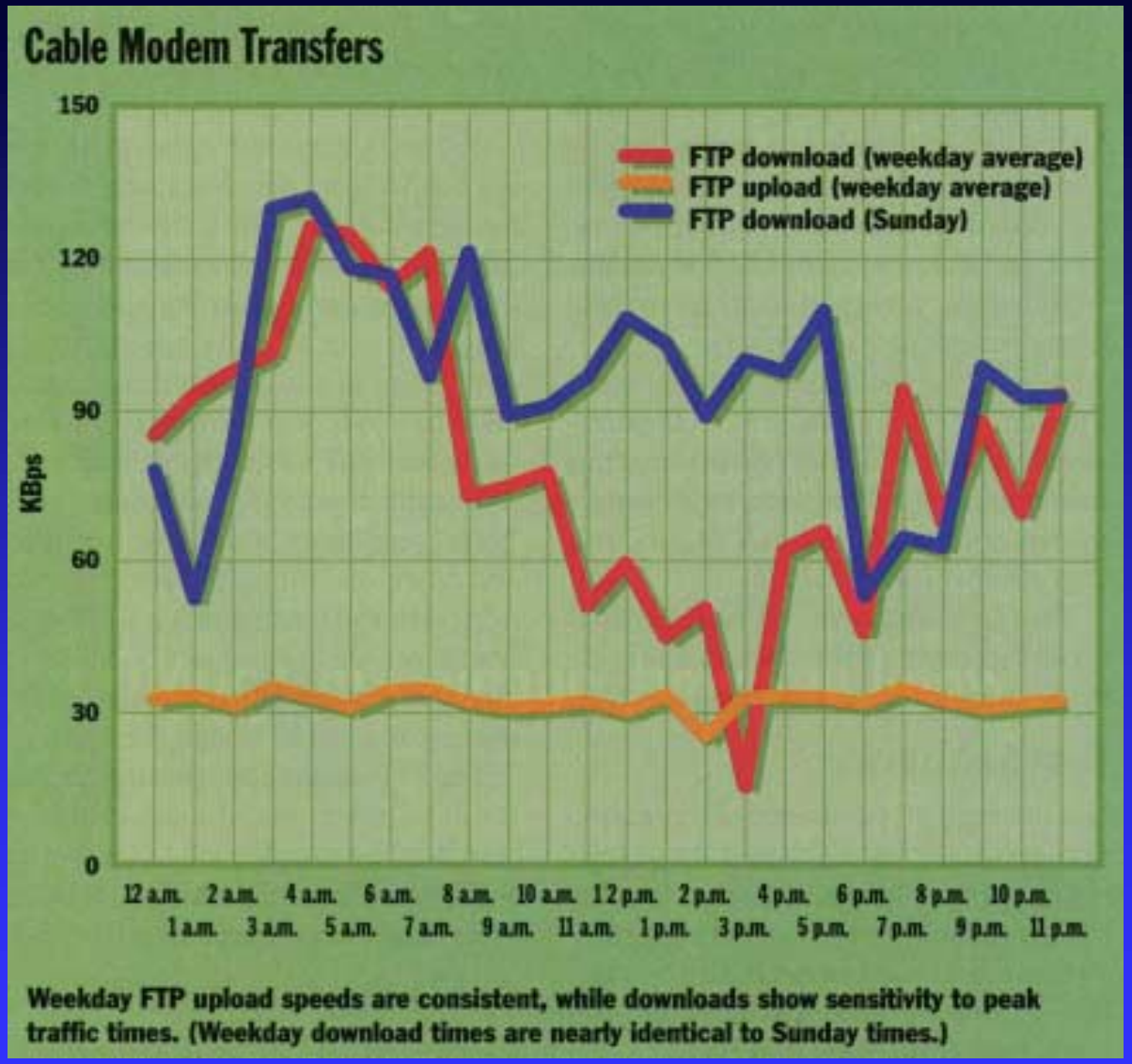


Bandwidth variations

Bandwidth probability density
New York - L.A.



Bandwidth variations

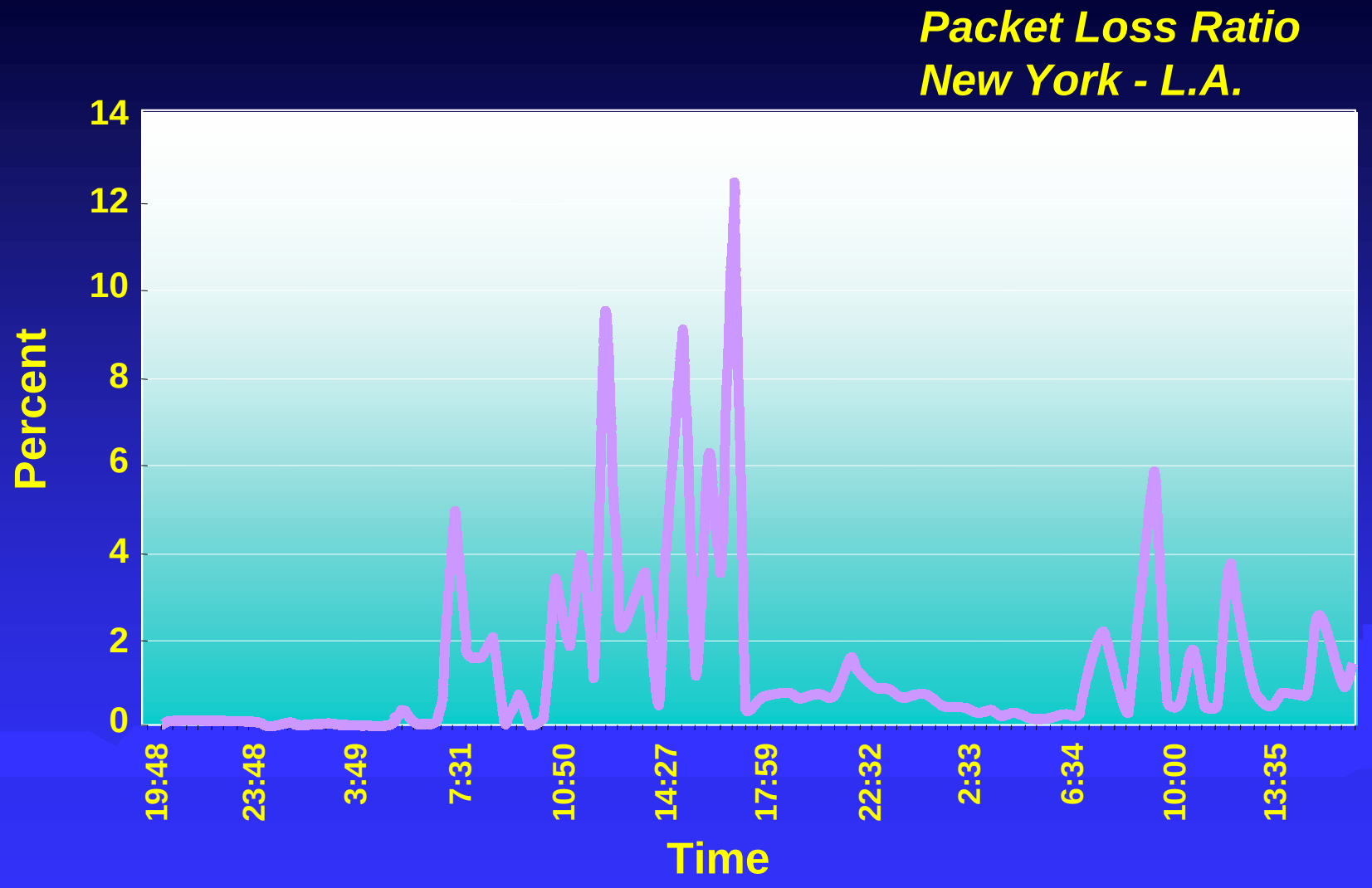


Weekday FTP upload speeds are consistent, while downloads show sensitivity to peak traffic times. (Weekday download times are nearly identical to Sunday times.)

Bandwidth variations

- “Broadband” Internet access has wider variation:
  - Cable modem: from < 100 to > 1000 Kbit/sec
  - DSL: from < 600 to > 6000 Kbit/sec

Packet-losses



Why a new coding paradigm?

Networks with time-varying bandwidth characteristics (e.g. Internet):

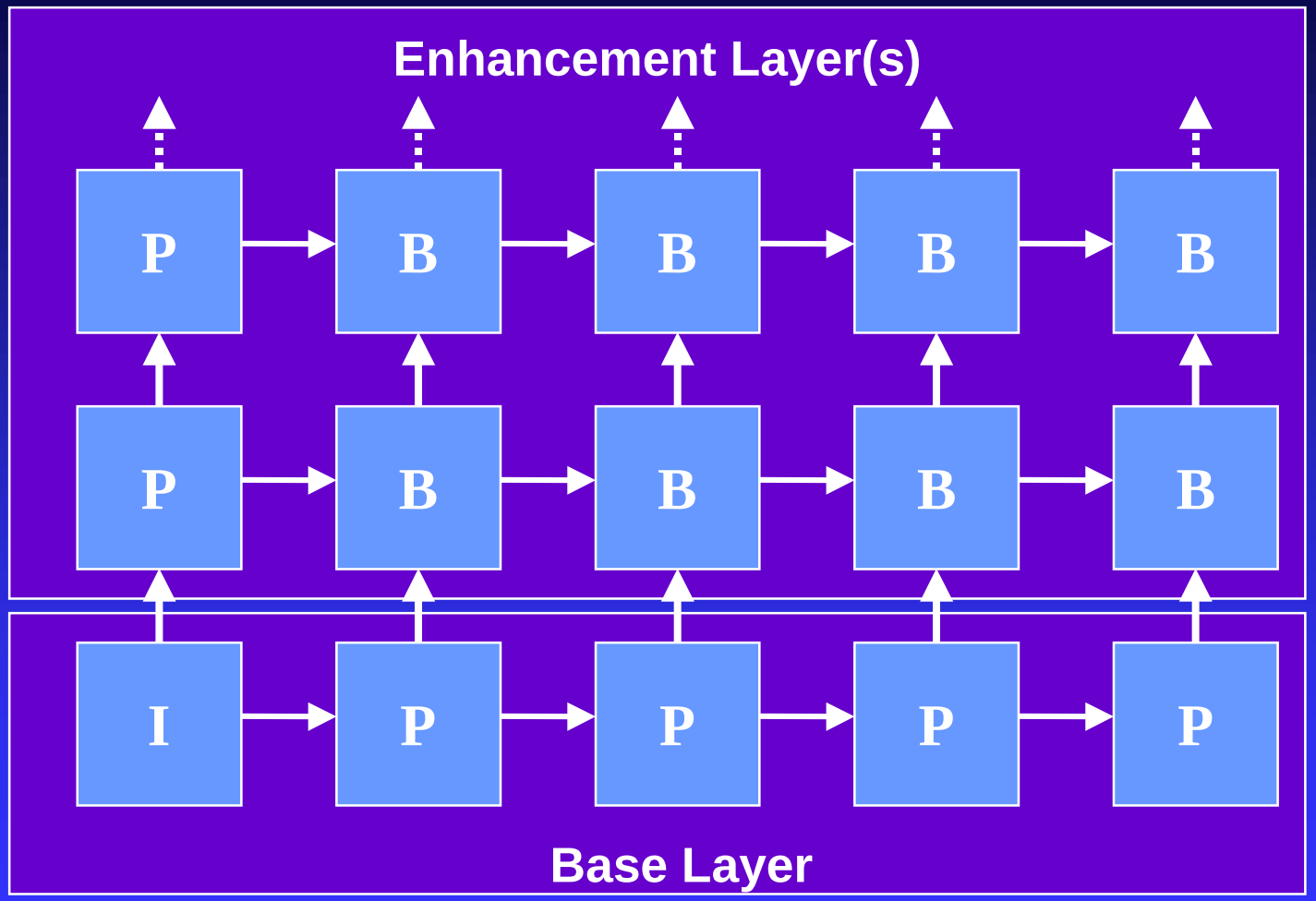
- No guarantees of QoS - wide range of available bandwidths and data loss rate

Therefore required

- Easy adaptability to changing bandwidth
- Resilience to packet-losses

Solution: scalable coding

Scalable Video in current standards



Scalable Video in current standards

- Alternative solution to simulcast

- Operate at a discrete set of bit-rates
- Supported bit-rates determined at *Encoding-Time*
- Overhead increases with the number of layers

- Not applicable for Packet Networks

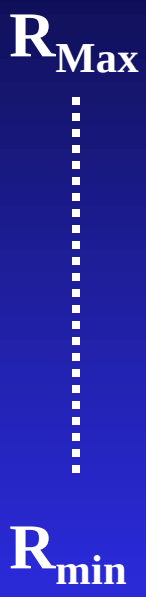
What is important for a good solution?

An adaptive solution for Internet video

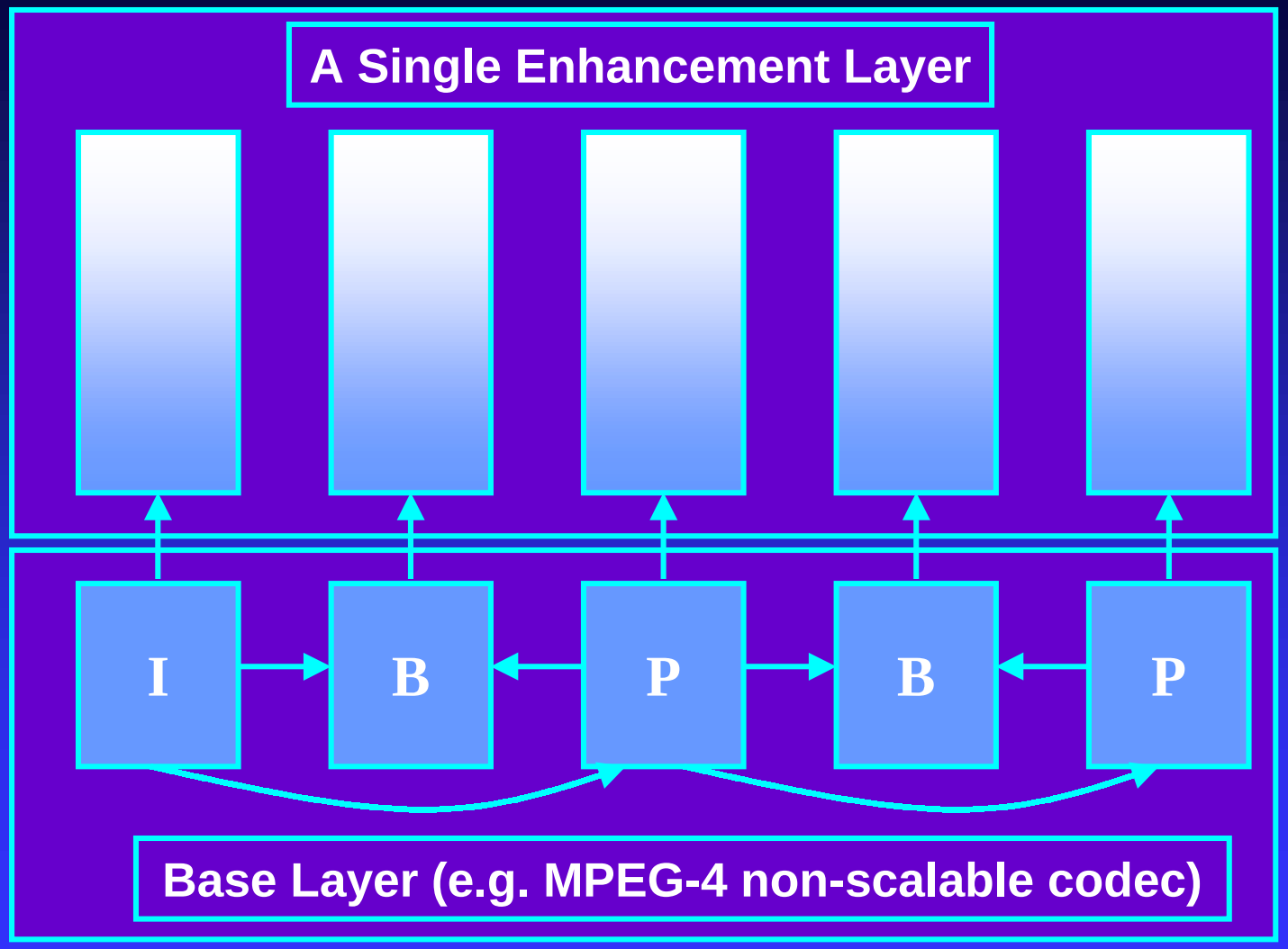
- Easy bandwidth adaptability
- Encoding & transmission processes should be separated (transmission bit-rates do not need to be specified at encoding-time)
- Resilience to packet-losses (Inter-picture predictions within EL complicates loss recovery)
- Low server complexity -> unicast
- Support both unicast & multicast
- Low/scalable decoder complexity

Solution: Fine-Granularity-Scalability

Fine-Granularity Scalability (FGS)



Fine-Granularity Scalability (FGS)



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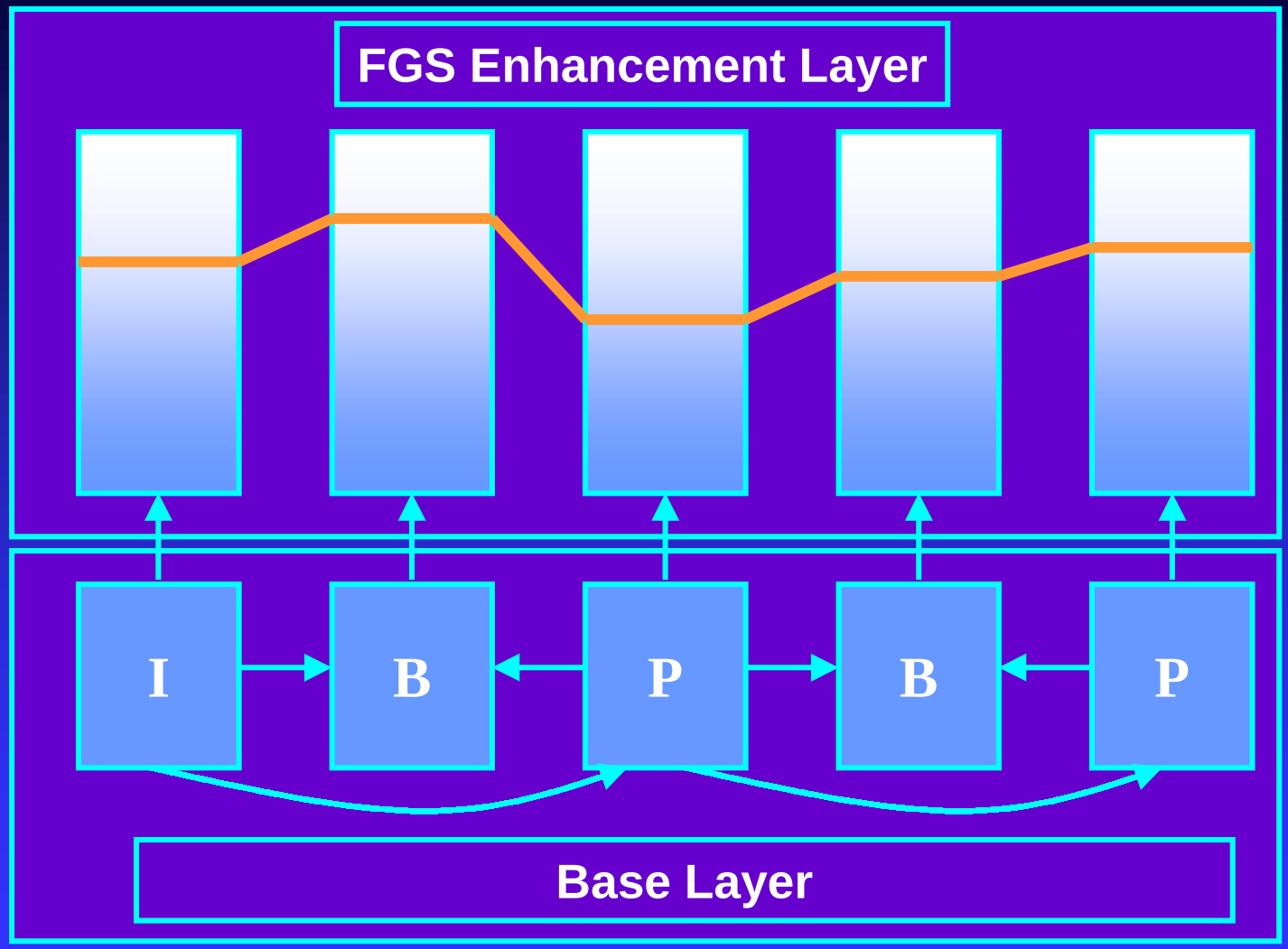
Internet Video Streaming with FGS - Server side



R(t)

FGS EL-portion transmitted in real-time

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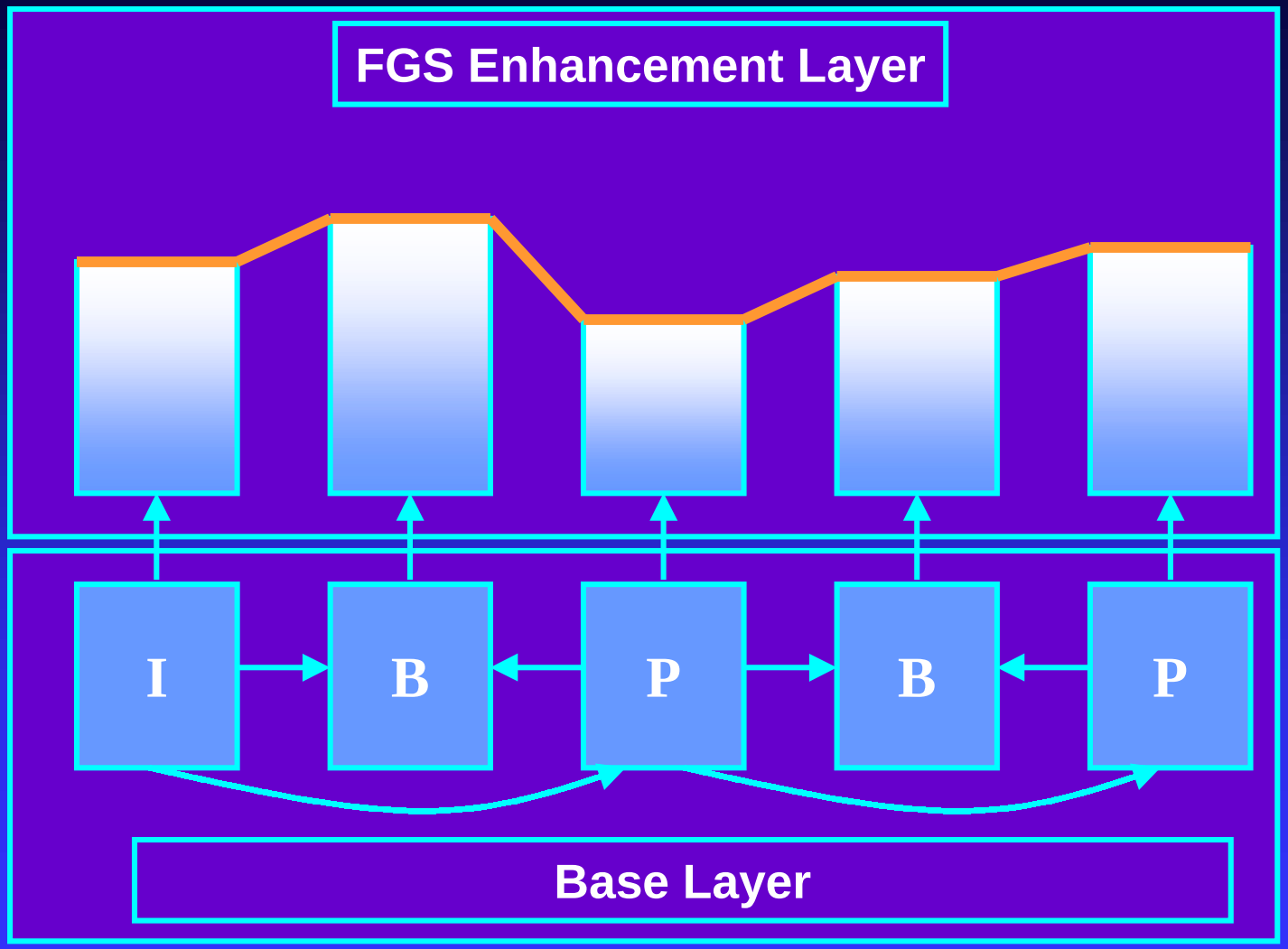
Internet Video Streaming with FGS - Decoder side



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Advantages of the FGS structure

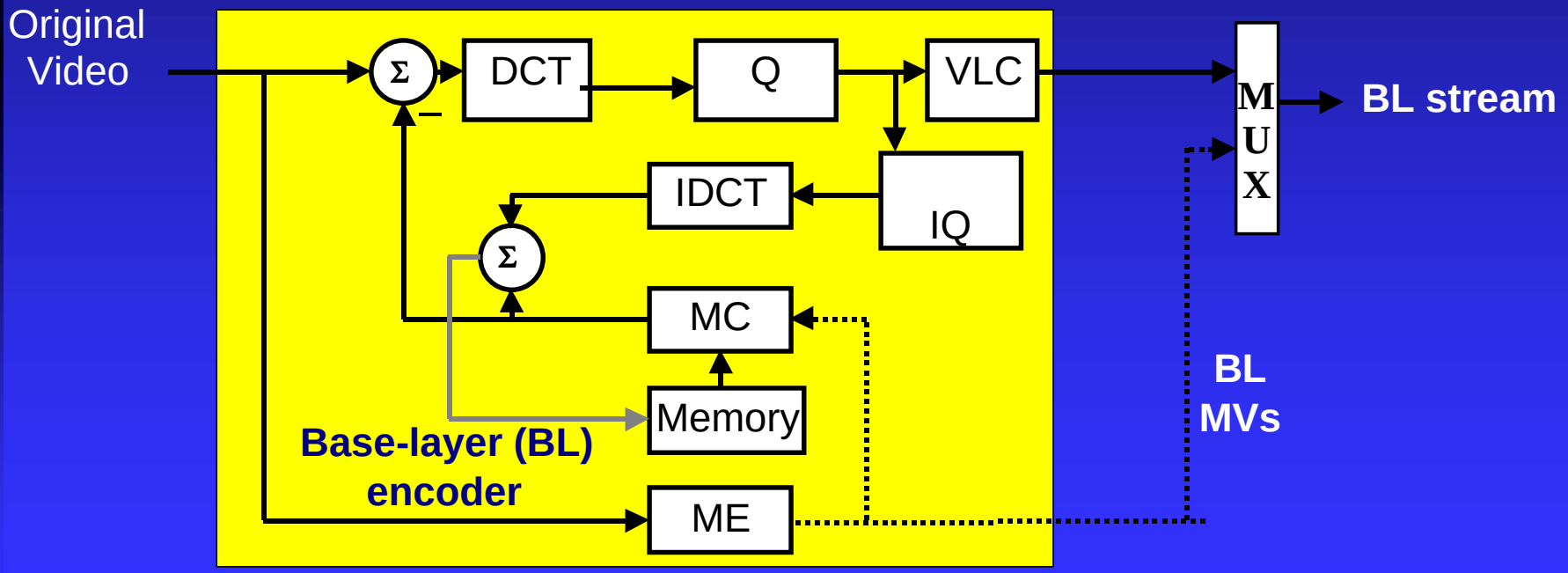
- Fine granular scalable enhancement layer
- Encoding & Transmission processes - separated
- Easy rate-control on multiple-streams for VOD
- Resilience to packet-losses

- Efficient for both unicast & multicast

FGS features

- Adaptive quantization
- Frequency weighting
- Hybrid temporal-SNR scalability
- Error-resilience markers for wireless apps

Block-diagram of FGS-scalability



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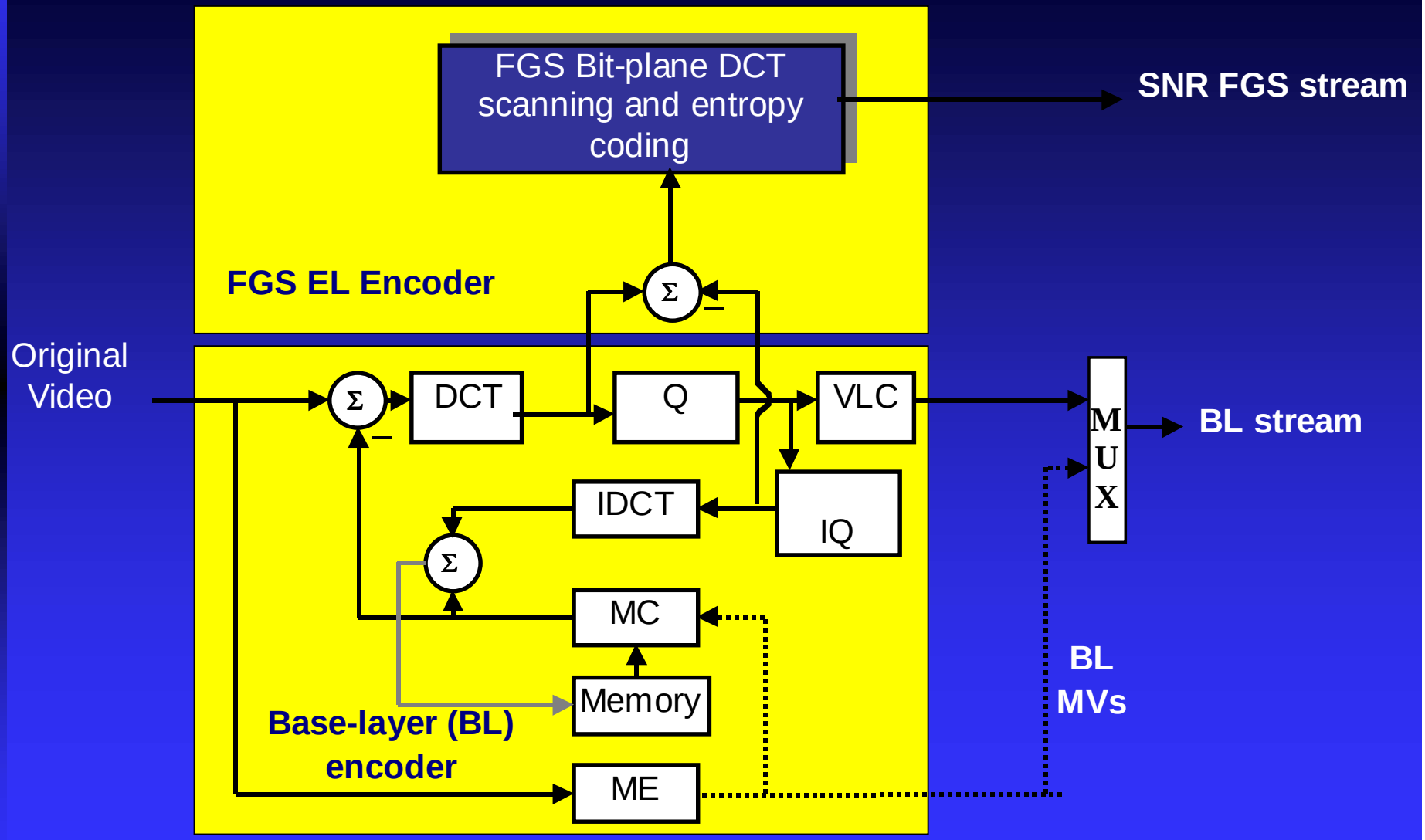
Block-diagram of FGS-scalability



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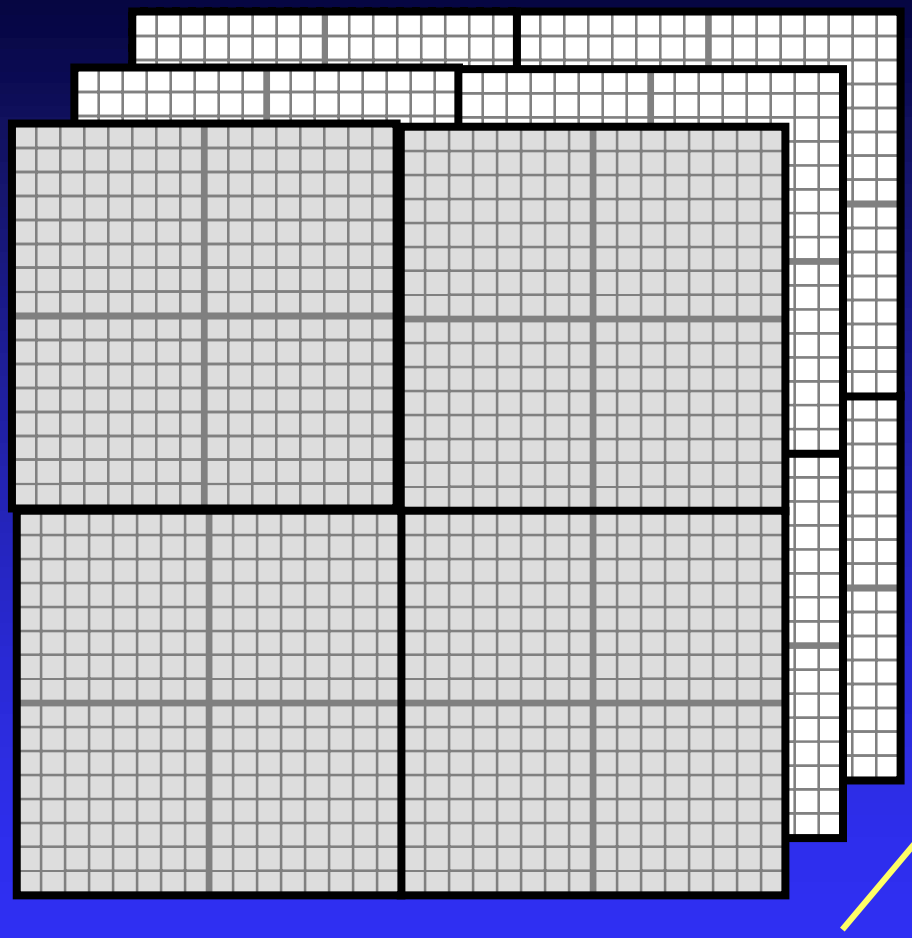
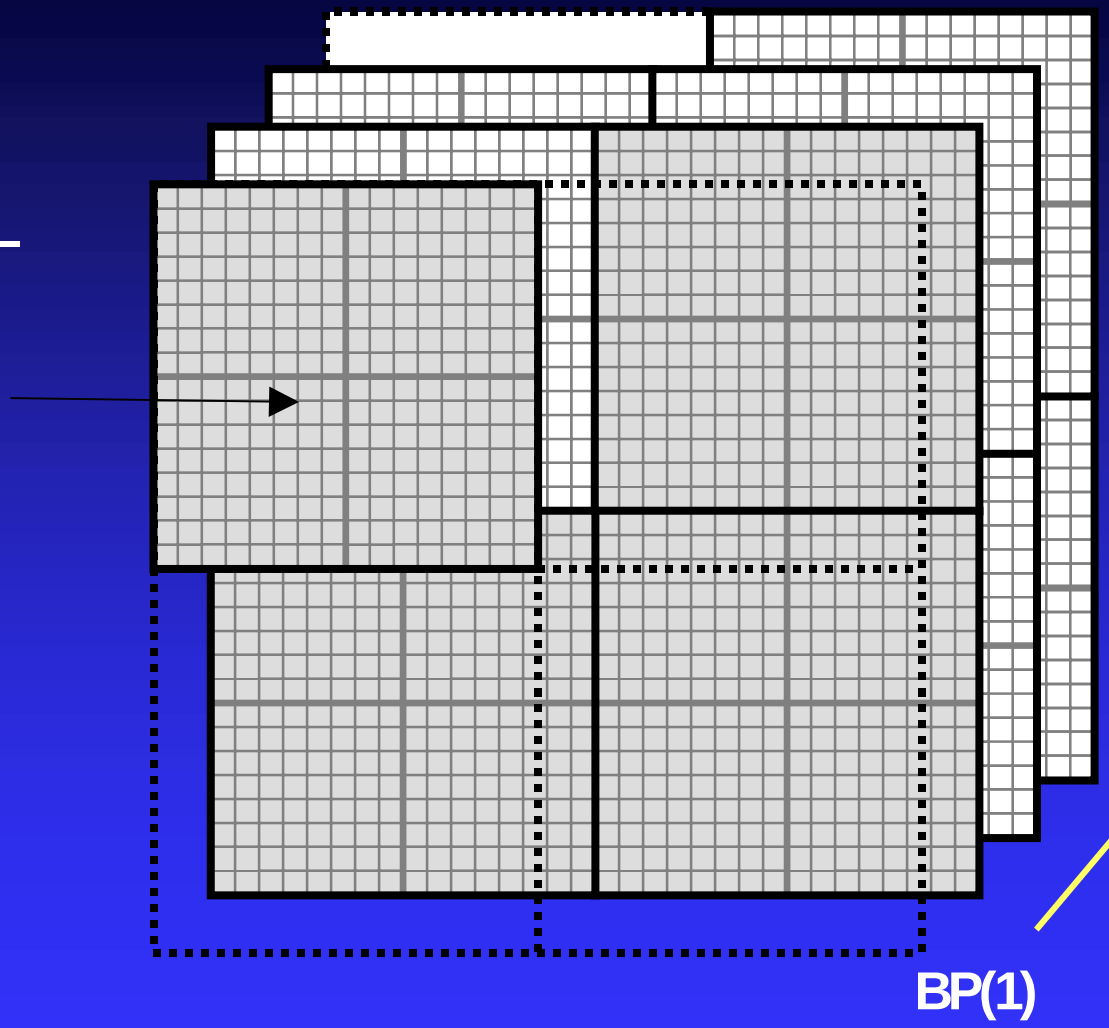
FGS bitplane coding



FGS AQ - Selective enhancement



How to select visually important regions?

Possible solution:

use real-time face-detection/tracking algorithms

FGS - Selective enhancement result

Hybrid FGS temporal-SNR scalability - *Motivation*

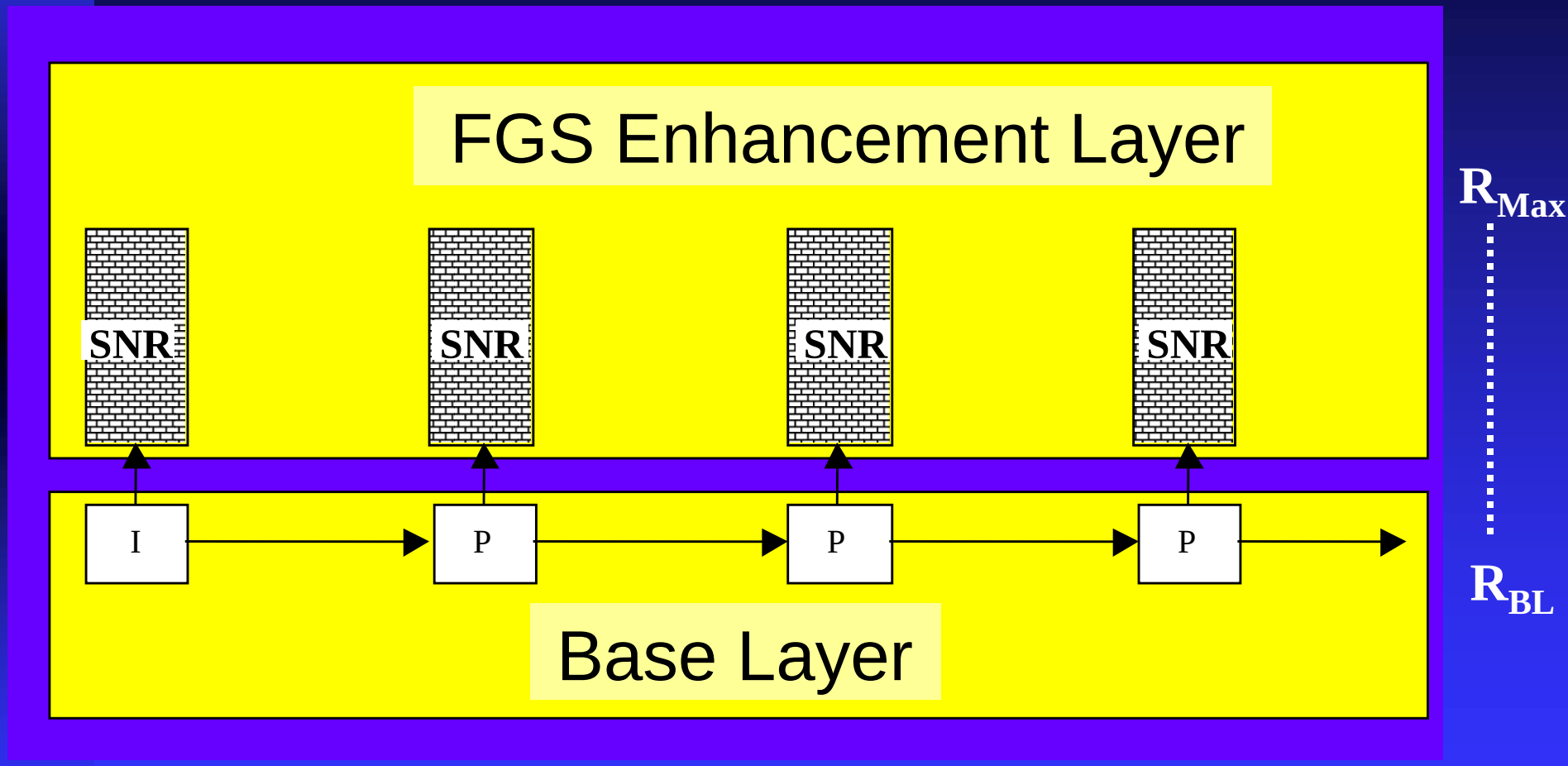
- For optimal quality: trade-offs between individual image quality (SNR) and temporal resolution (higher frame-rates)
- Transmission frame-rate ~ transmission bit-rate

=> Hybrid SNR-temporal FGS scalability

Improved scalability

- A single FGS enhancement-layer
- Total flexibility in supporting
  - SNR scalability with same frame-rate
  - temporal scalability by increasing ONLY the frame-rate
  - both FGS & temporal scalability
- Low added complexity

An all FGS temporal-SNR scalability



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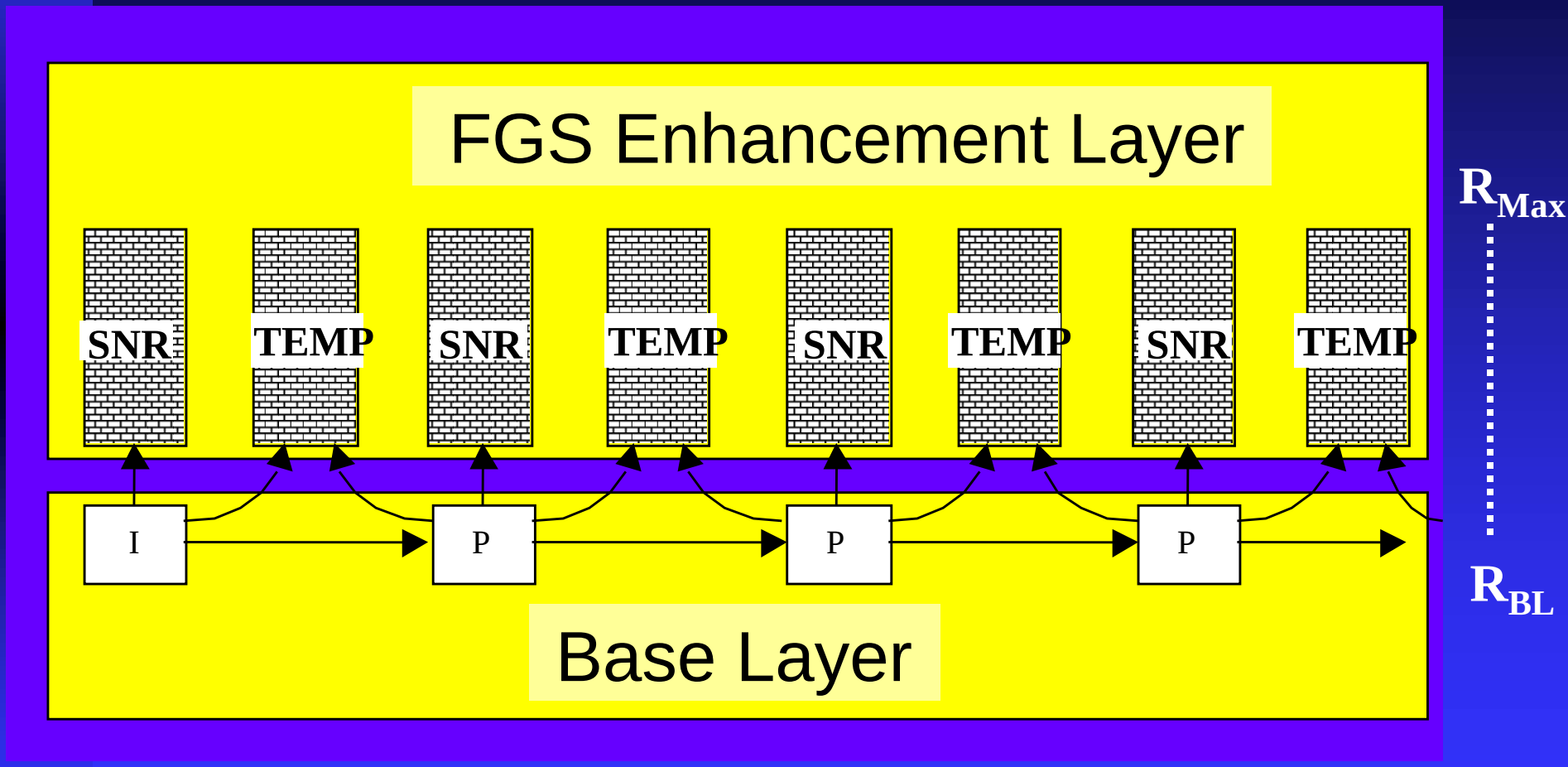
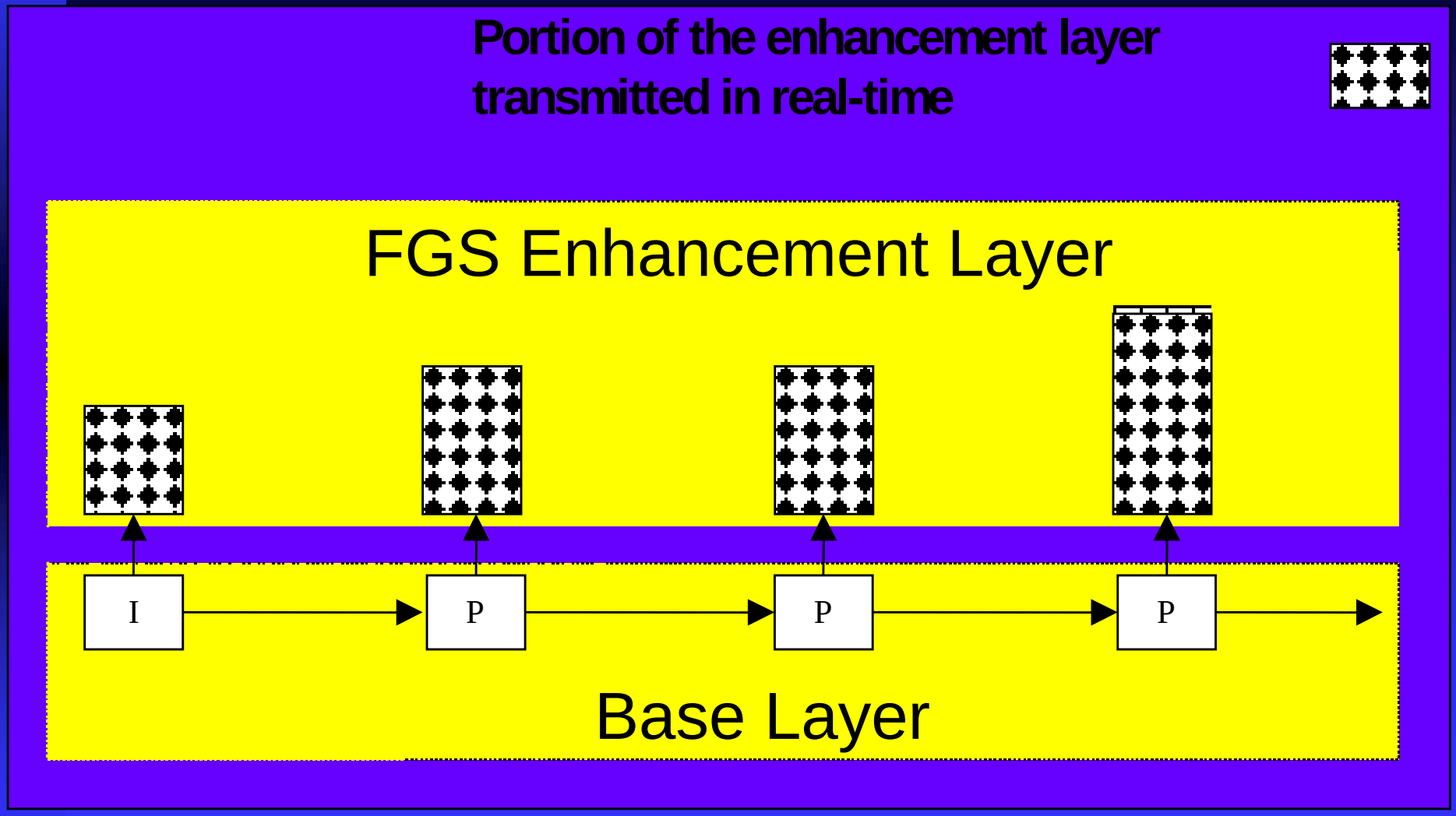
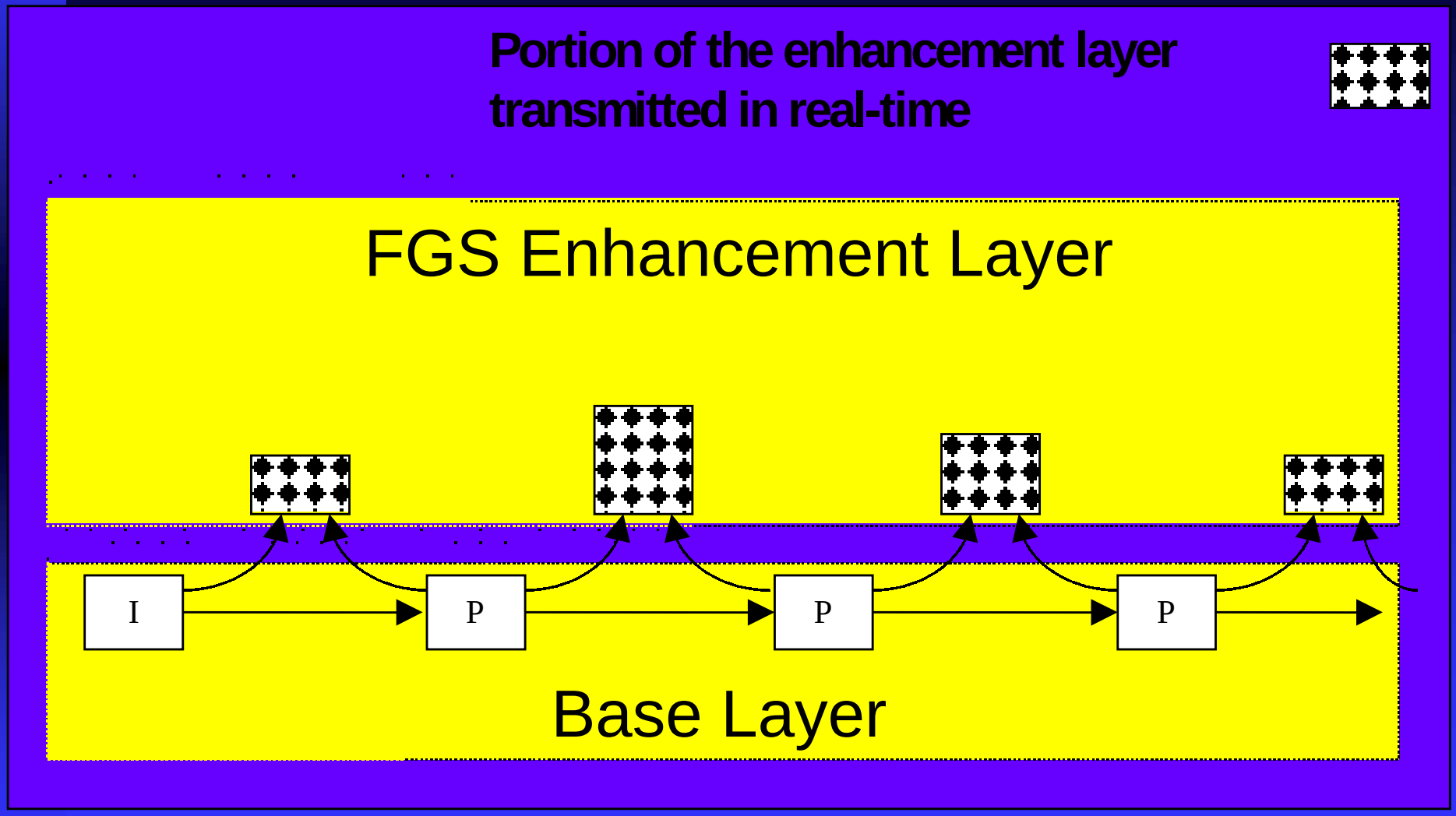
An all FGS temporal-SNR scalability



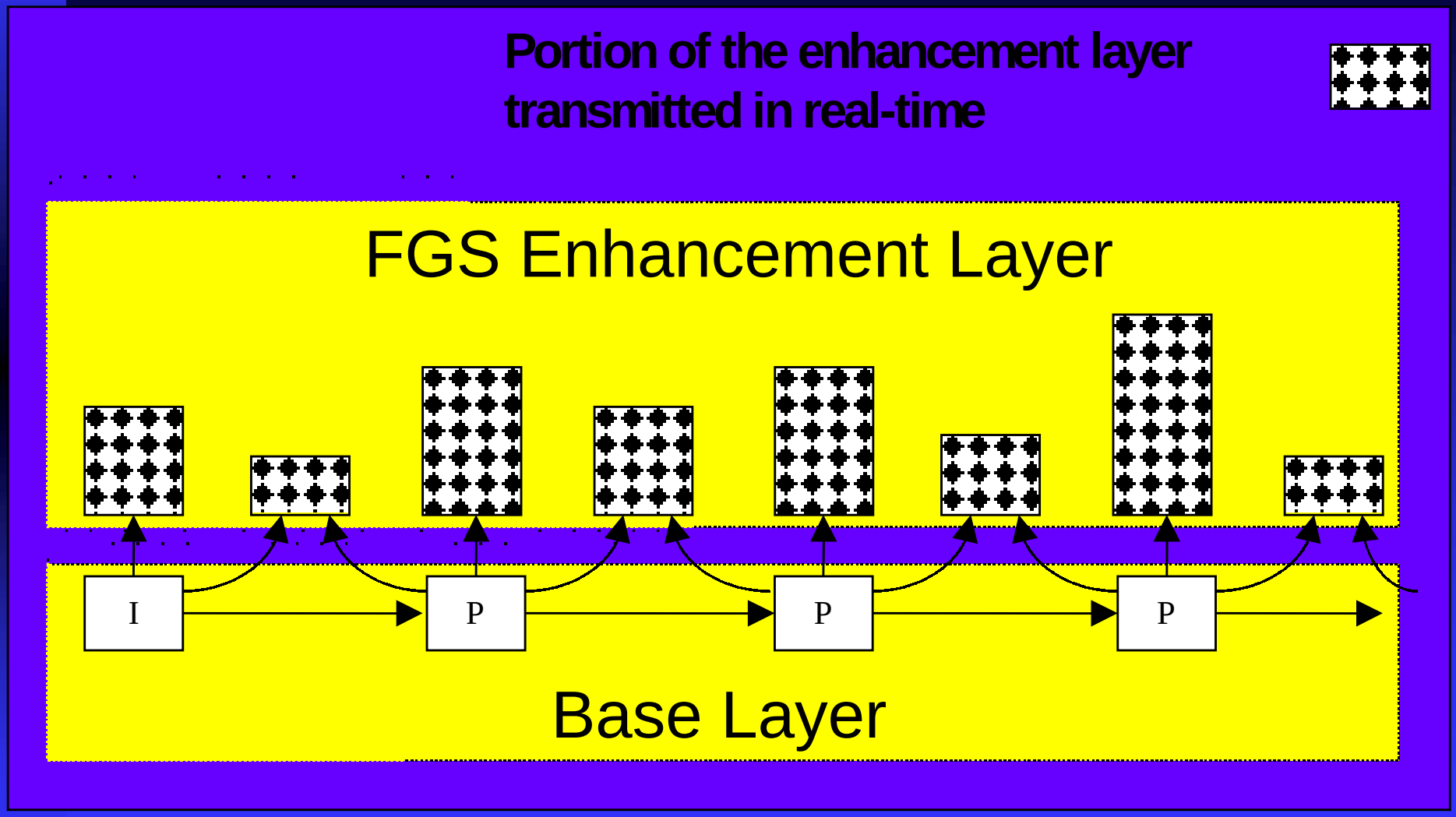
Real-time trade-off SNR-temporal



Real-time trade-off SNR-temporal



Real-time trade-off SNR-temporal



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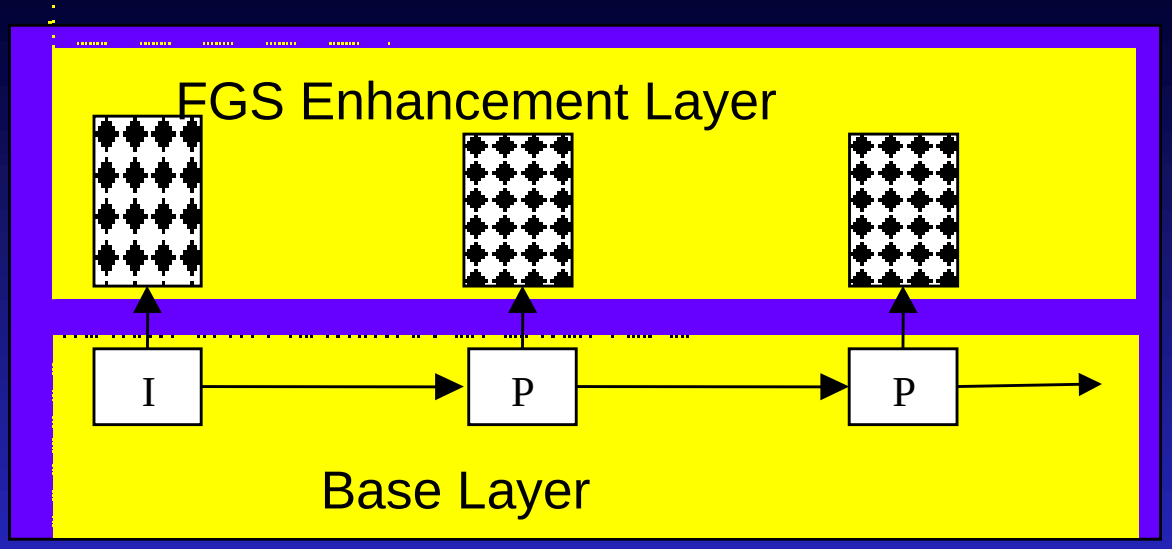
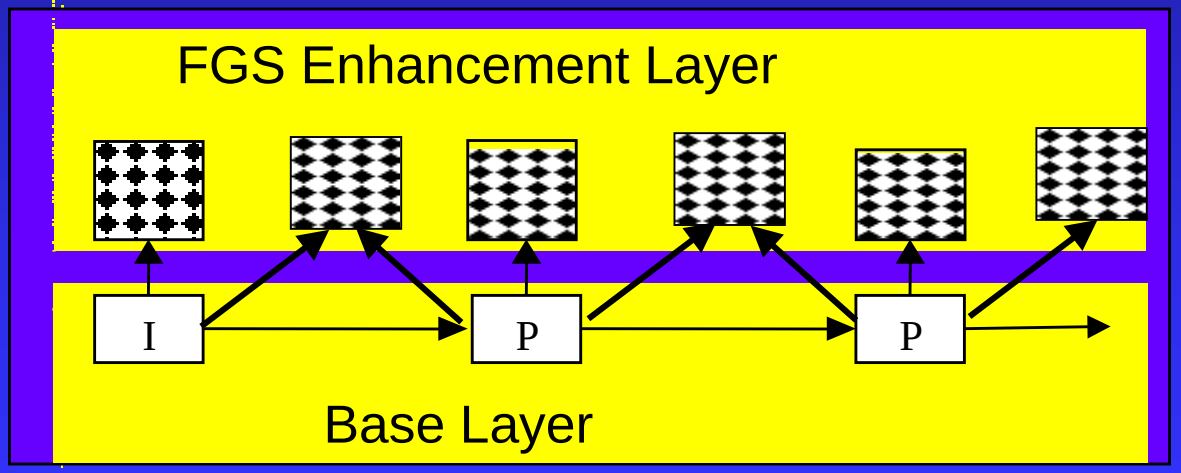
Rate-control SNR/Temporal



Scenario A



Scenario B

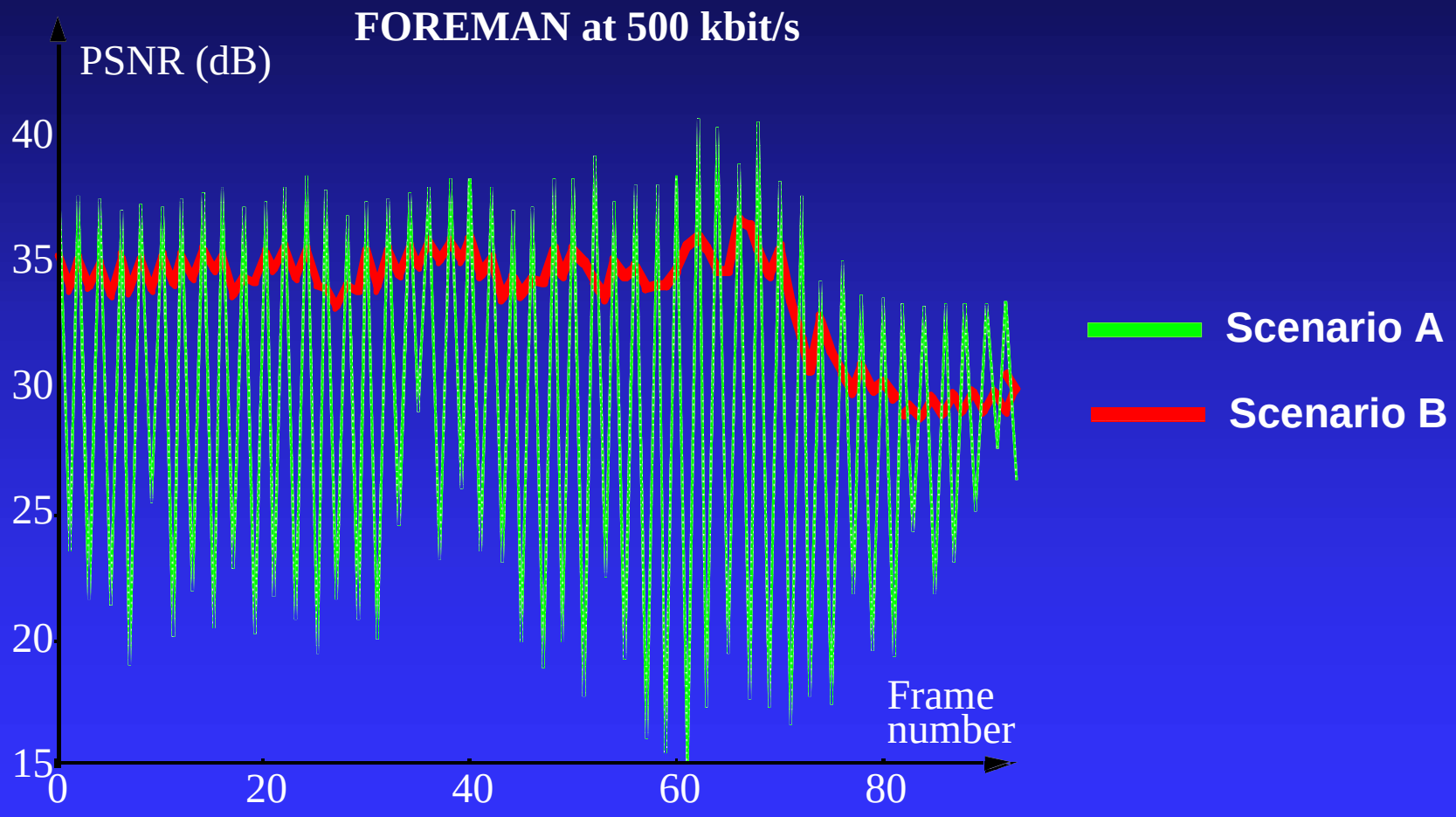
Rate-control SNR/Temporal

SNR versus temporal trade-off based on sequence characteristics (*static*):

- motion-info (e.g. MVs size)
- texture characteristics (e.g. Xi computed by base-layer RC)

However, also dependent on Rt

Performance of FGS and FGS+FGST at same bit-rate



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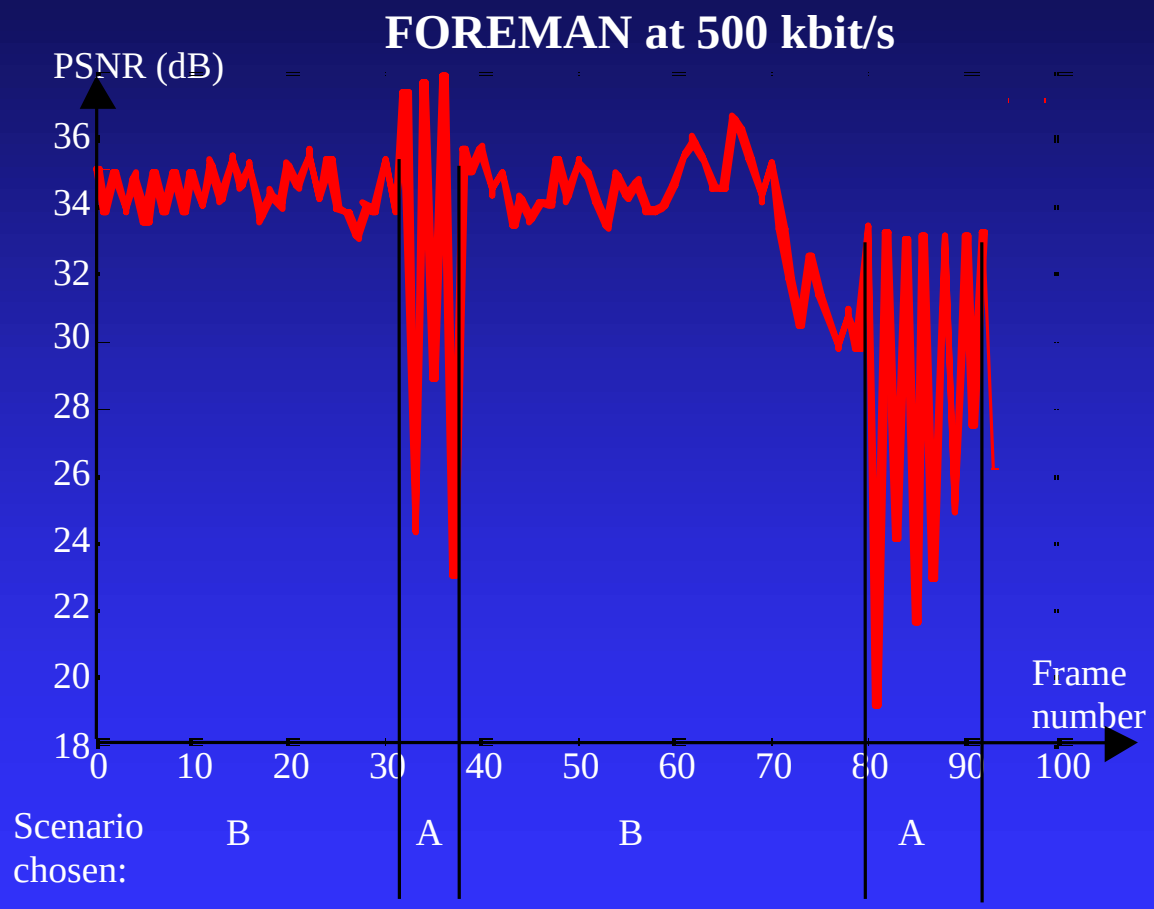
SNR versus motion-smoothness



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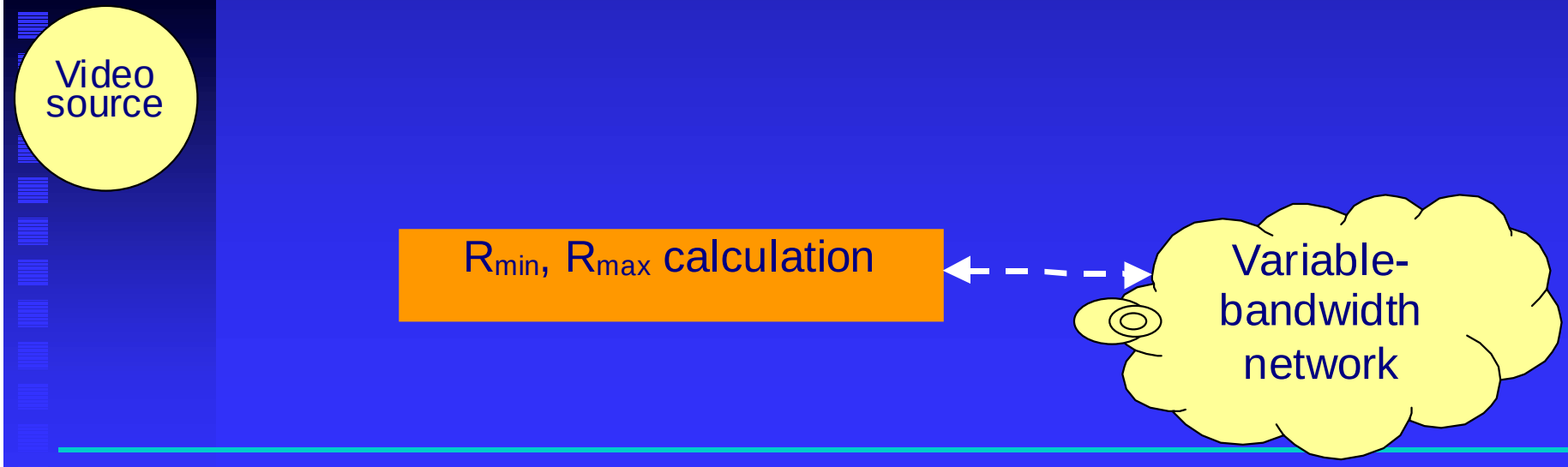
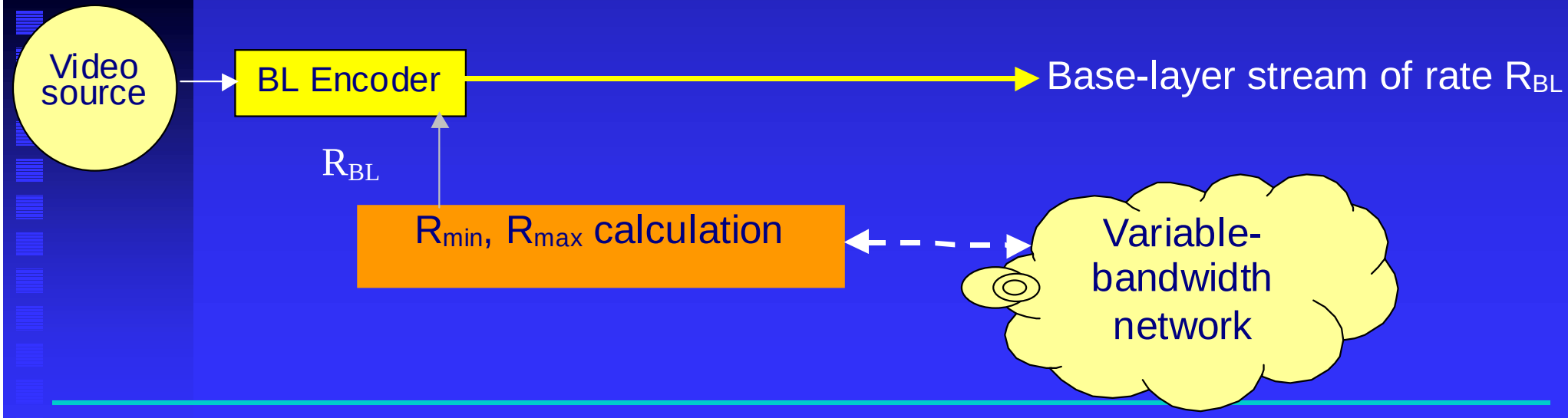
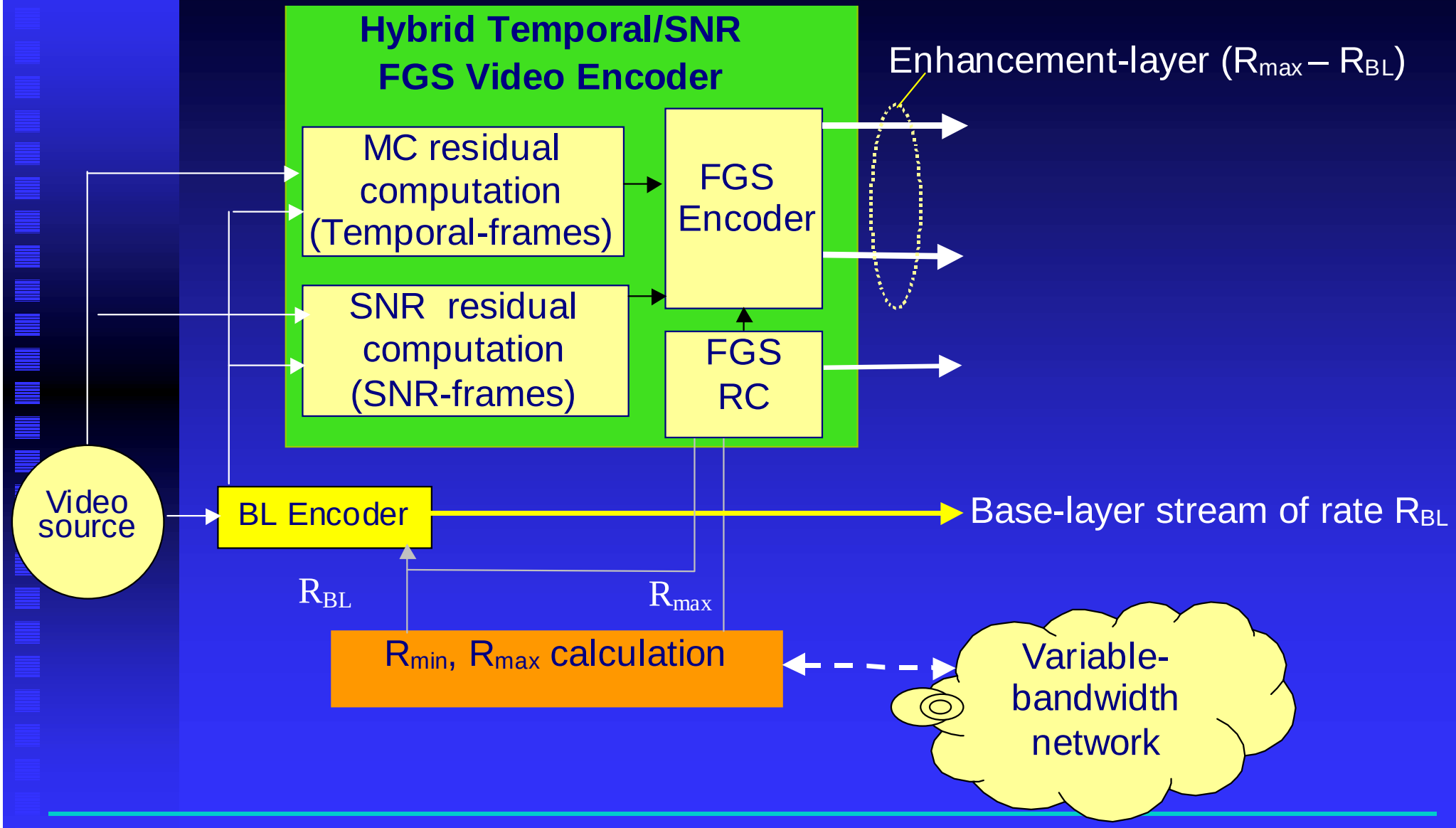
Internet video streaming - Encoding



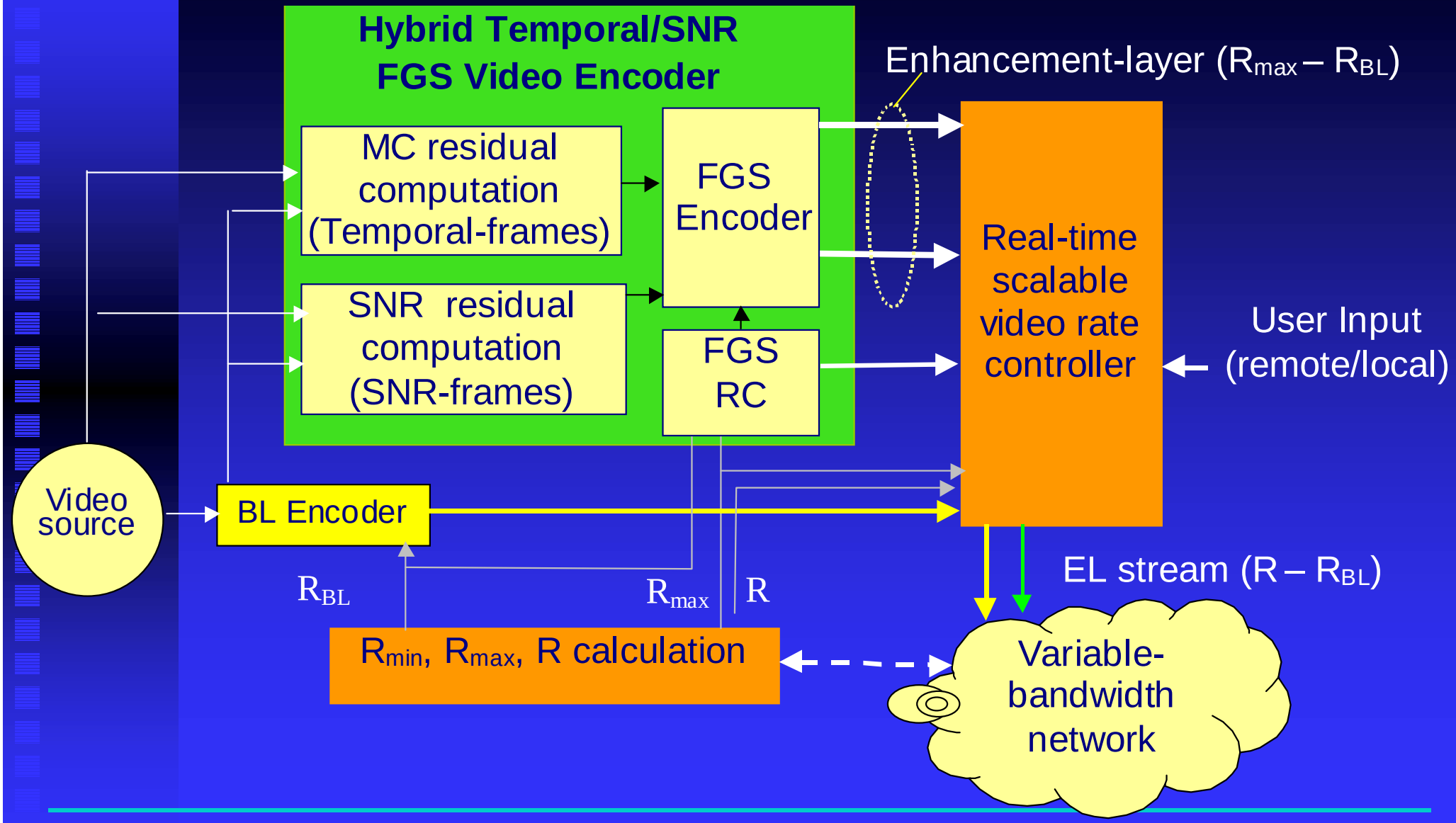
Internet video streaming - Encoding



Internet video streaming - Encoding



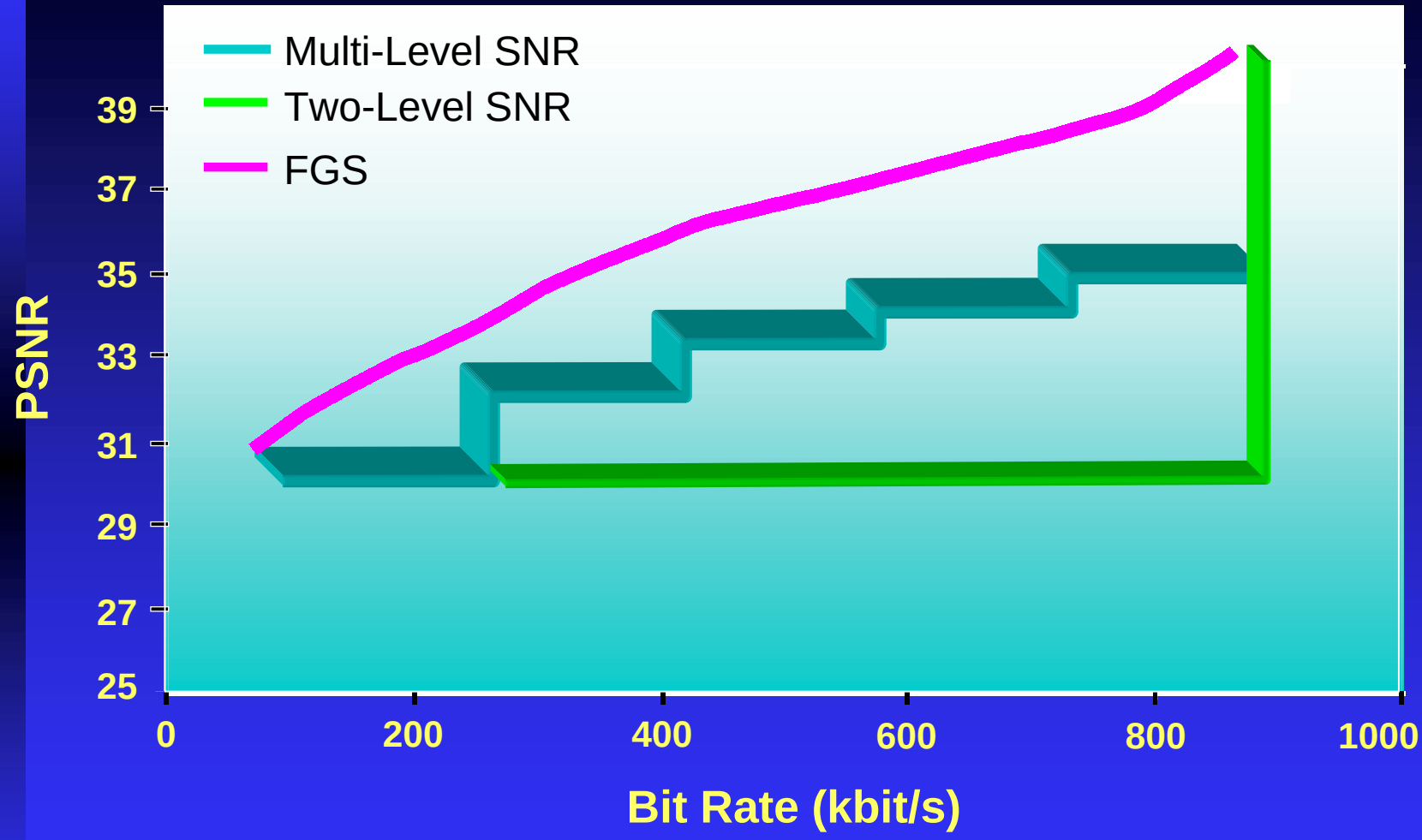
Internet video streaming - Transmission



How does FGS compare with other streaming solutions?

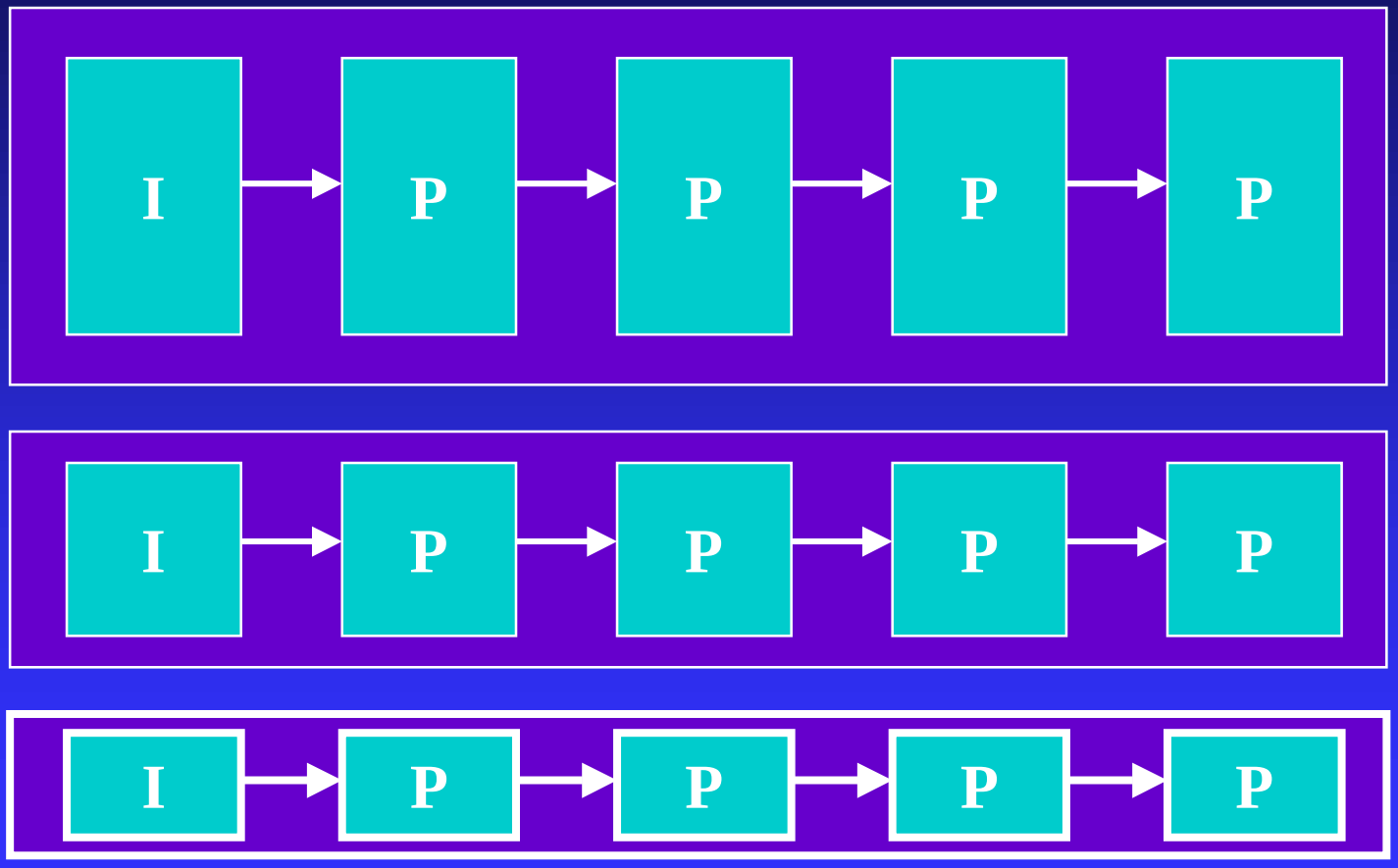
- Quality in absence of packet-losses
- Quality in presence of packet-losses

Performance of FGS vs. SNR-scalability



No coding penalty due to the fine-granularity!

Single-layer switching (SLS)



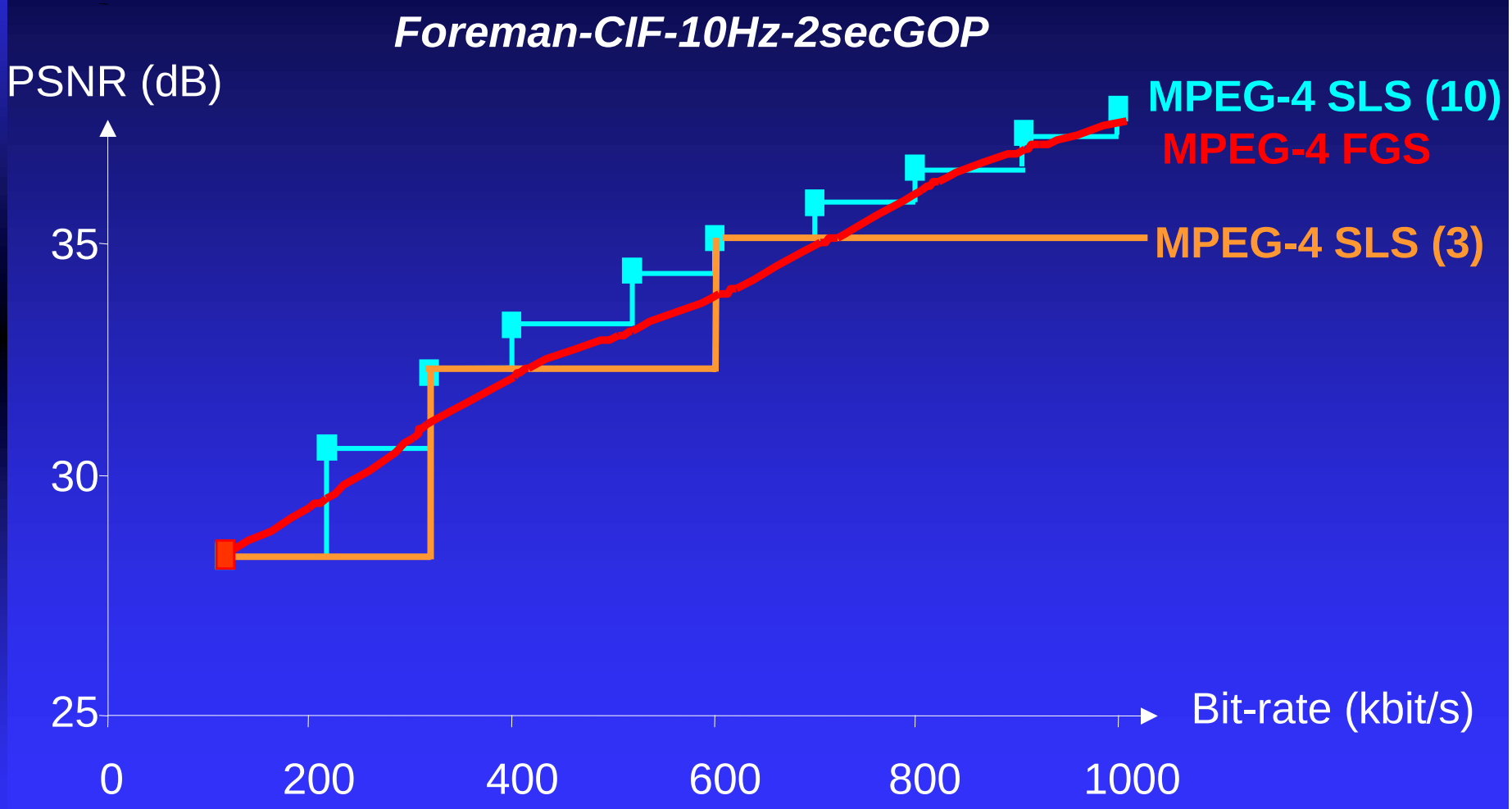
R_{max}

$R_{min} + R_2$

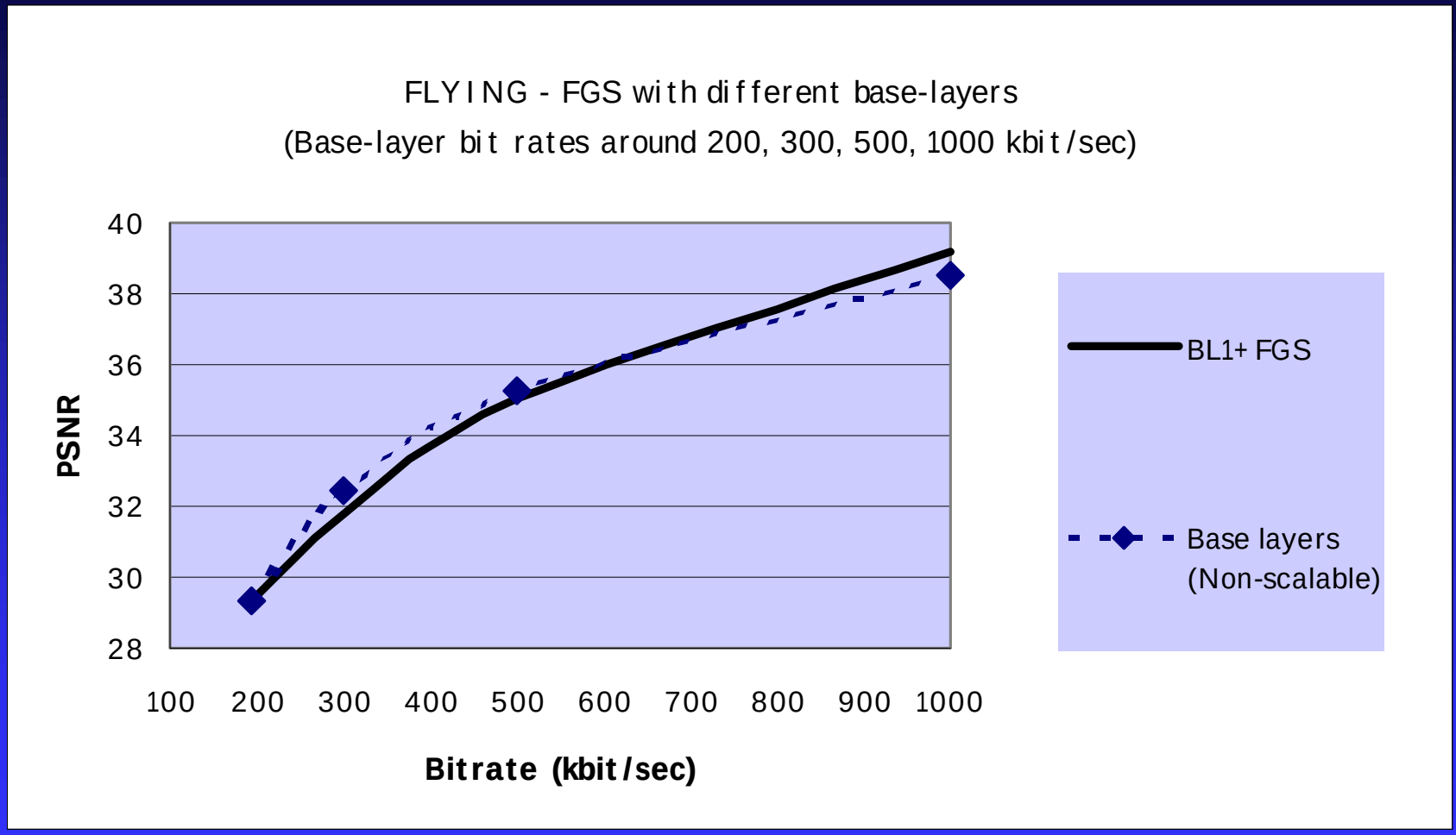
$R_{min} + R_1$

R_{min}

Performance of MPEG-4 FGS vs.SLS under lossless conditions



FGS vs. SL


FLYING - FGS with different base-layers
(Base-layer bit rates around 200, 300, 500, 1000 kbit/sec)
PSNR
40
38
36
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100
200
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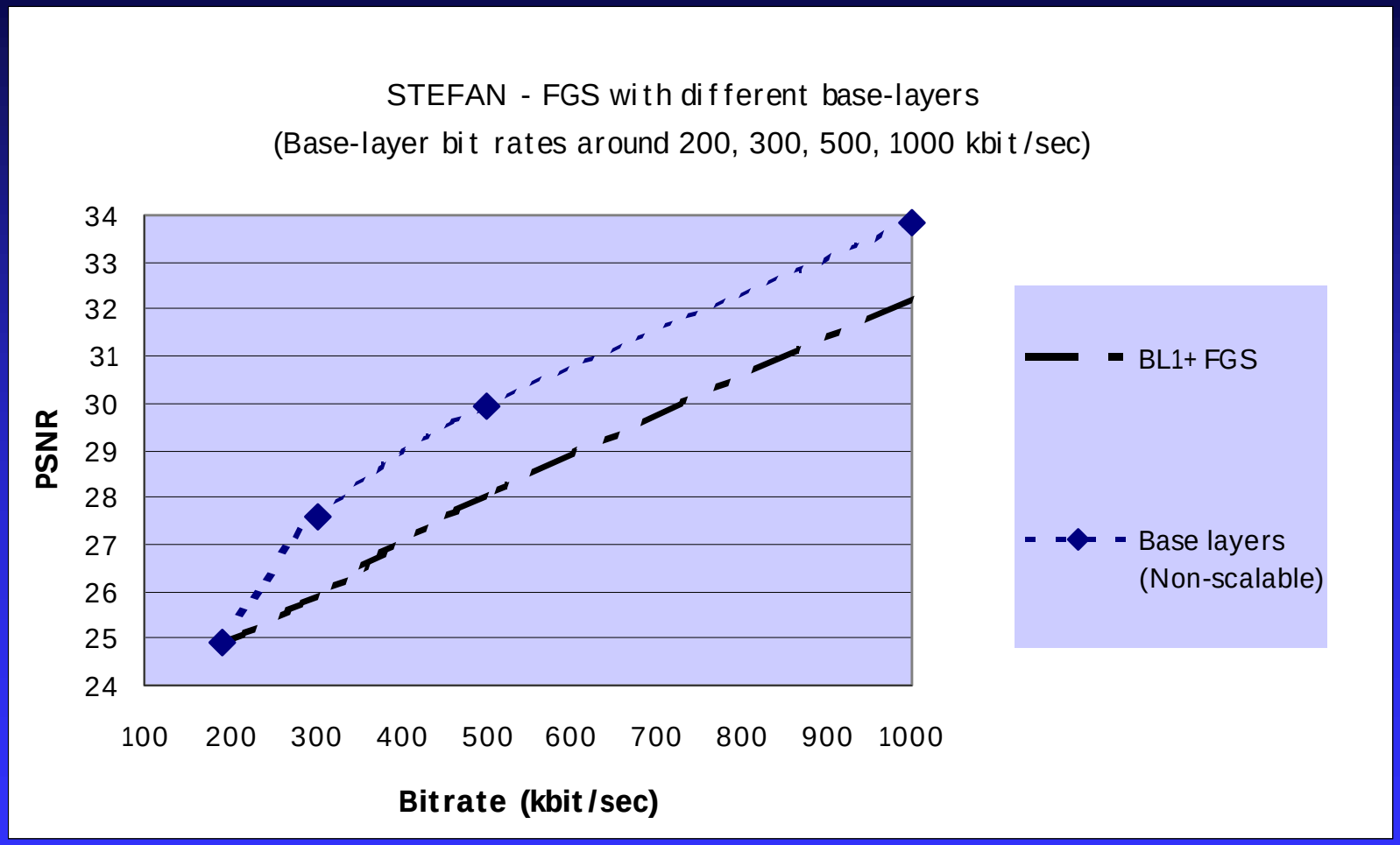
Bitrate (kbit/sec)
BL1+ FGS
Base layers
(Non-scalable)

FGS vs. SL


STEFAN - FGS with different base-layers
(Base-layer bit rates around 200, 300, 500, 1000 kbit/sec)
PSNR
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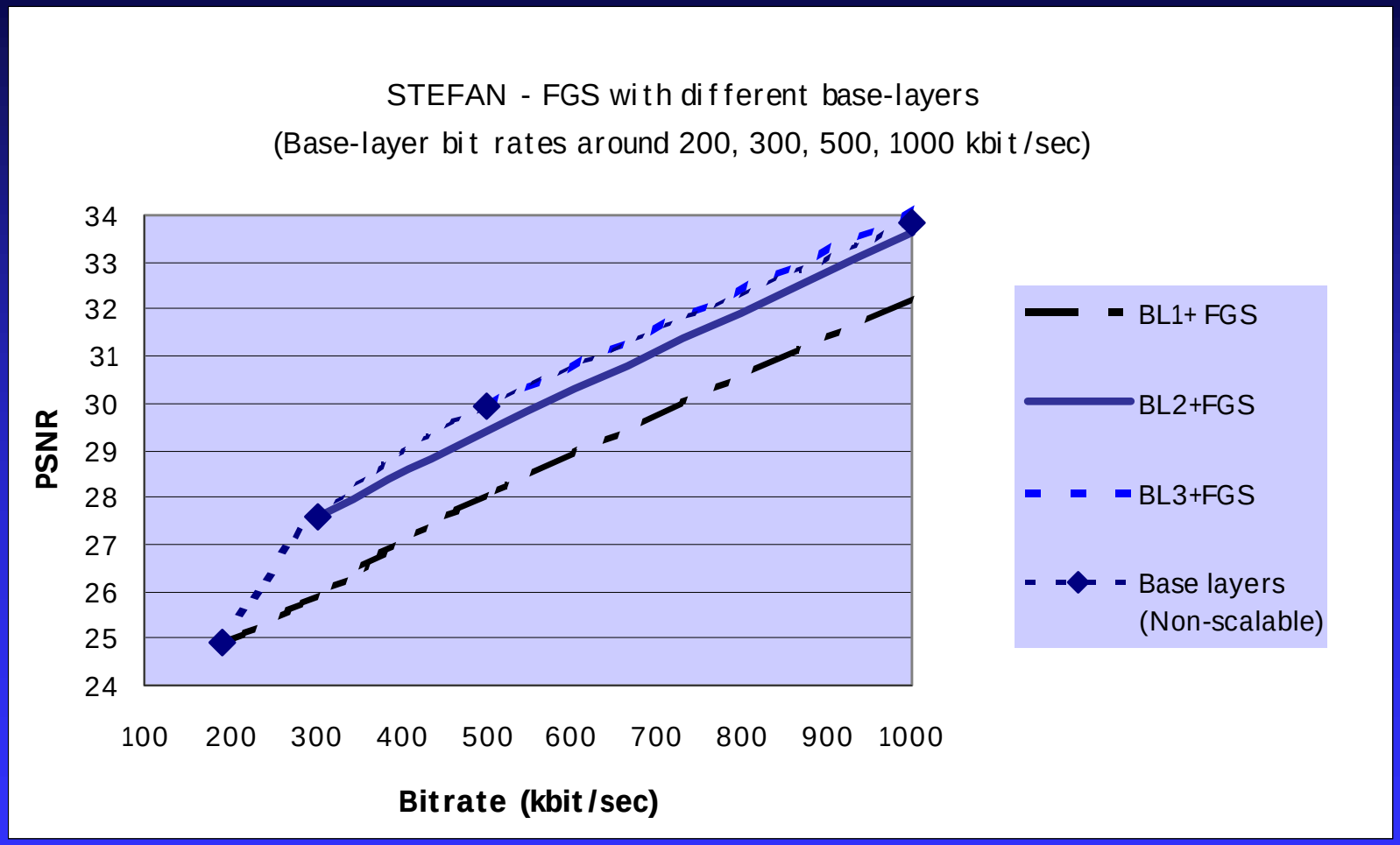
Bitrate (kbit/sec)
BL1+ FGS
Base layers
(Non-scalable)

FGS vs. SL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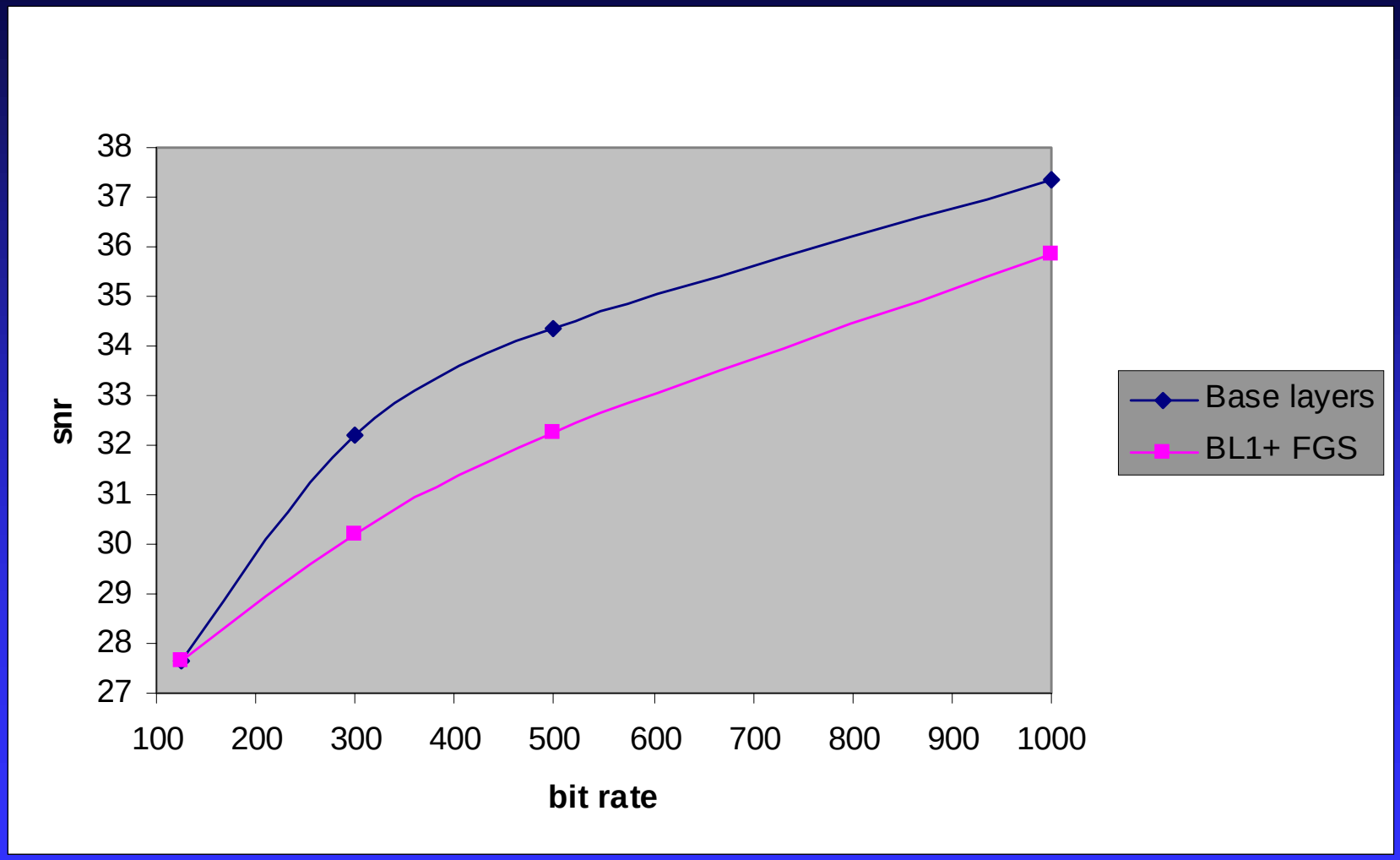
Bitrate (kbit/sec)
BL1+ FGS
BL2+FGS
BL3+FGS
Base layers
(Non-scalable)

How to eliminate FGS coding penalty?

SL vs. FGS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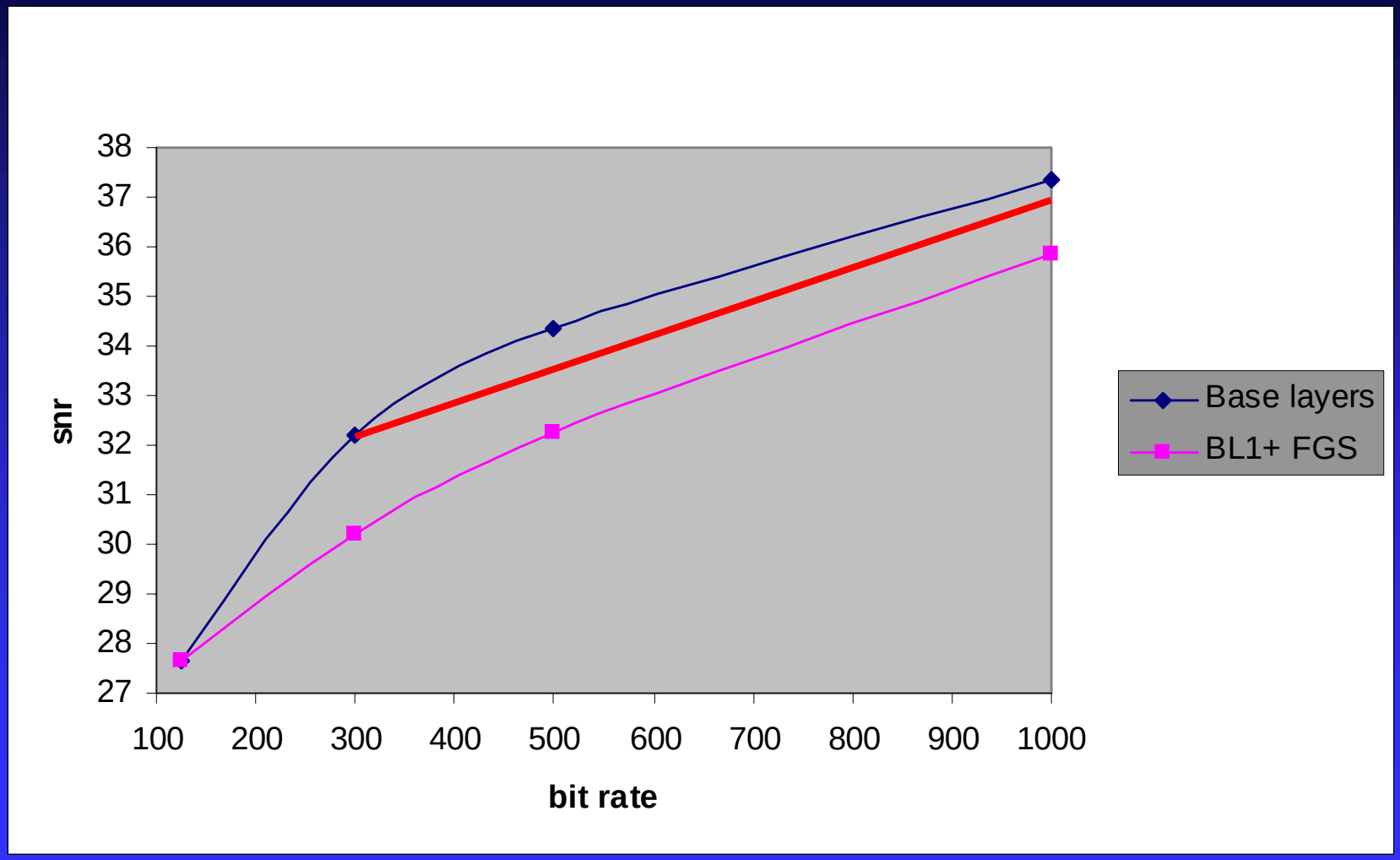
bit rate
Base layers
BL1+ FGS

SL vs. FGS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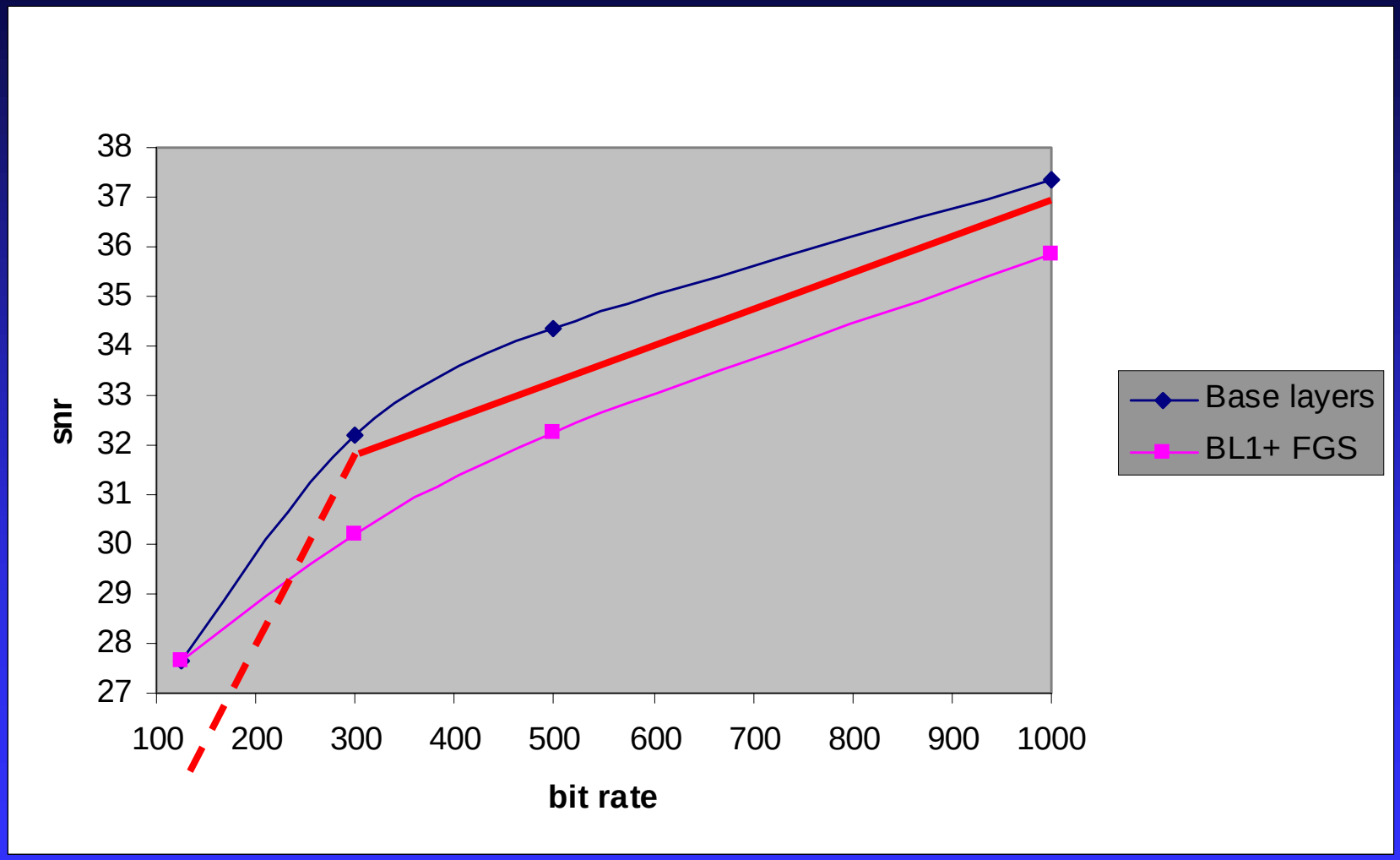
BL1+ FGS

SL vs. FGS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bit rate
Base layers
BL1+ FGS

MC-FGS structures

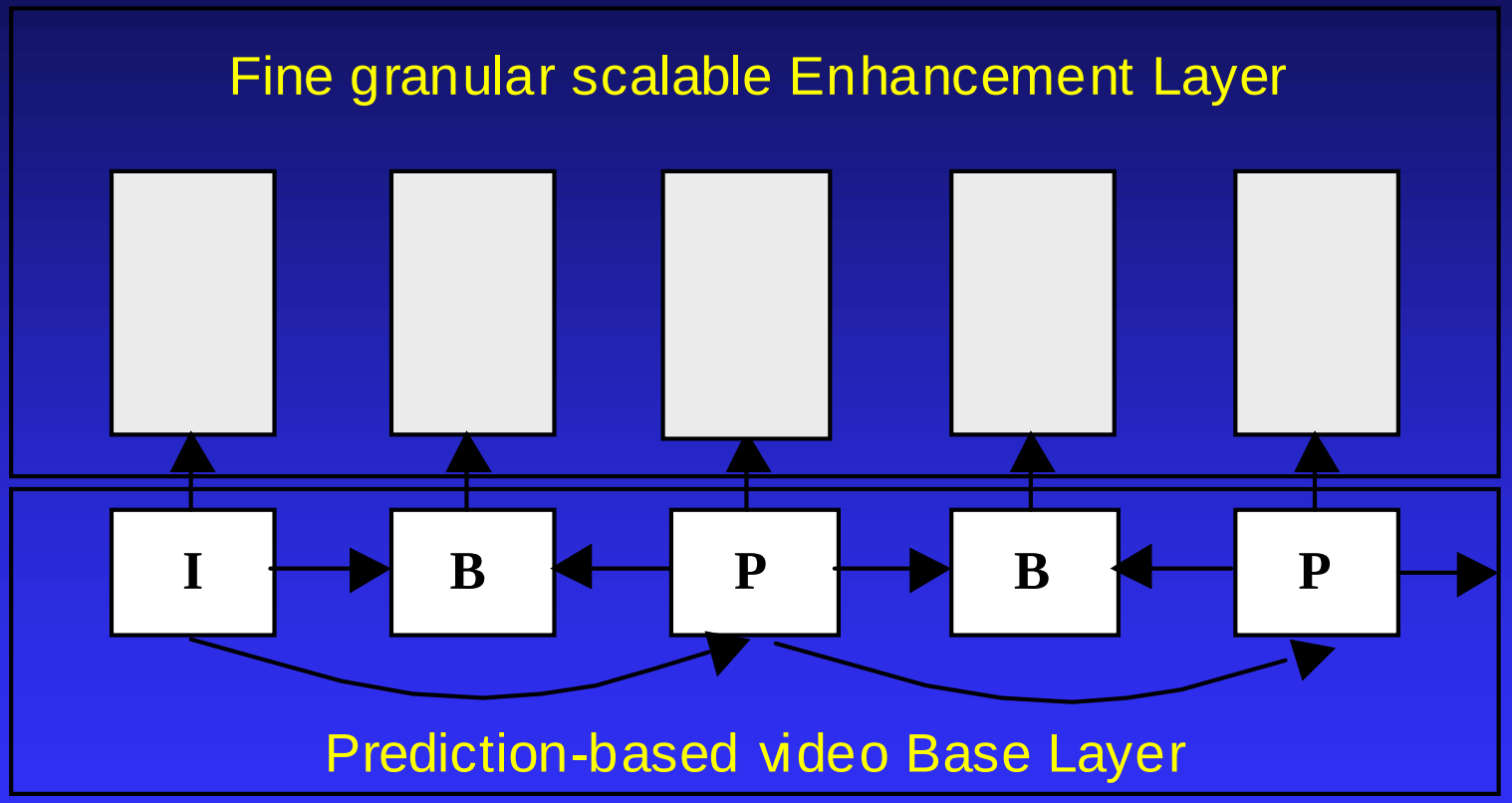
Proposed in MPEG-4:

- One/Two-loop MC-FGS structures

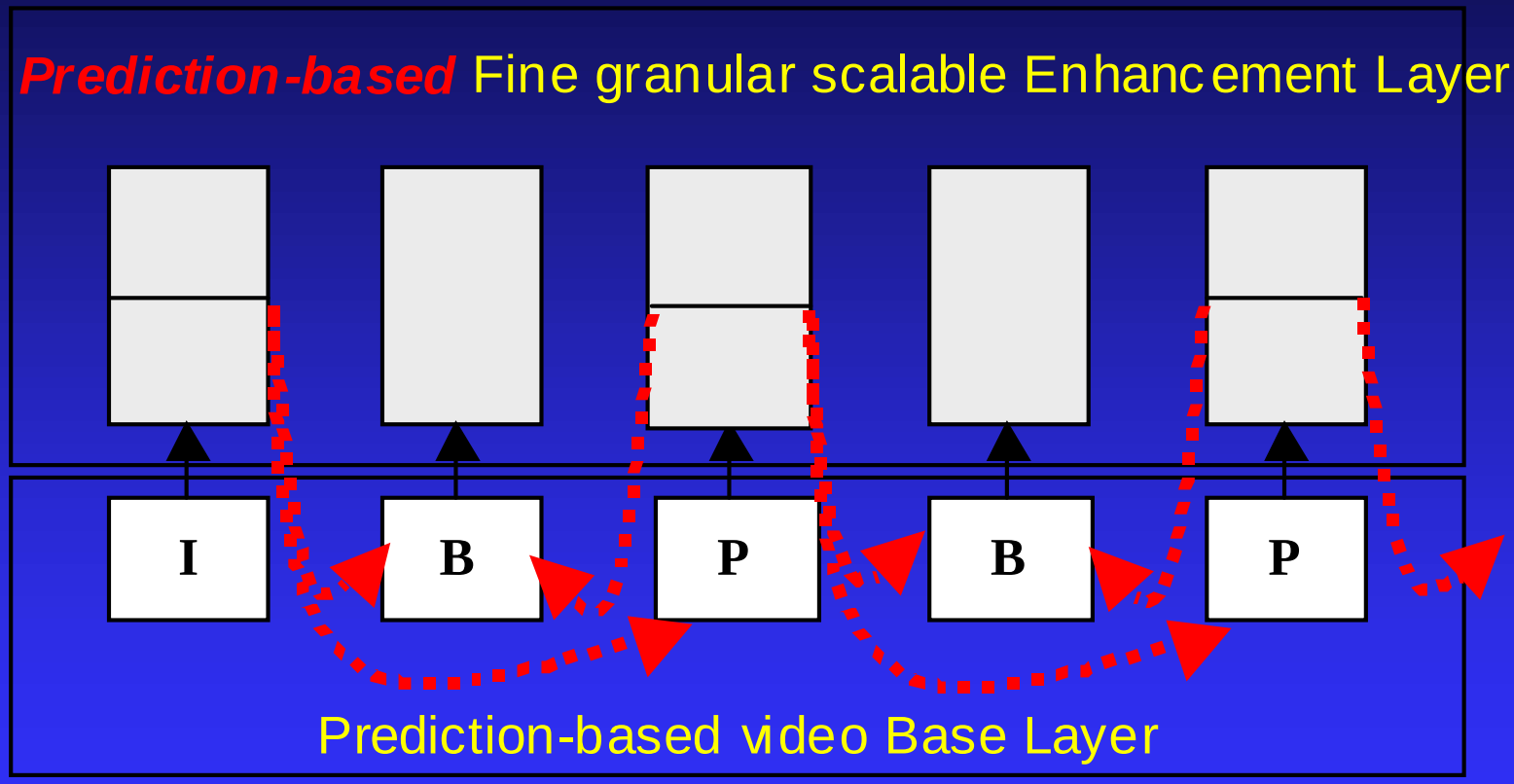
Largest gain can be obtained by 1-loop MC:

- Quality improvement (sequence dependent) - 2dB!!

Original FGS scheme



Single-loop MC-FGS for all frames



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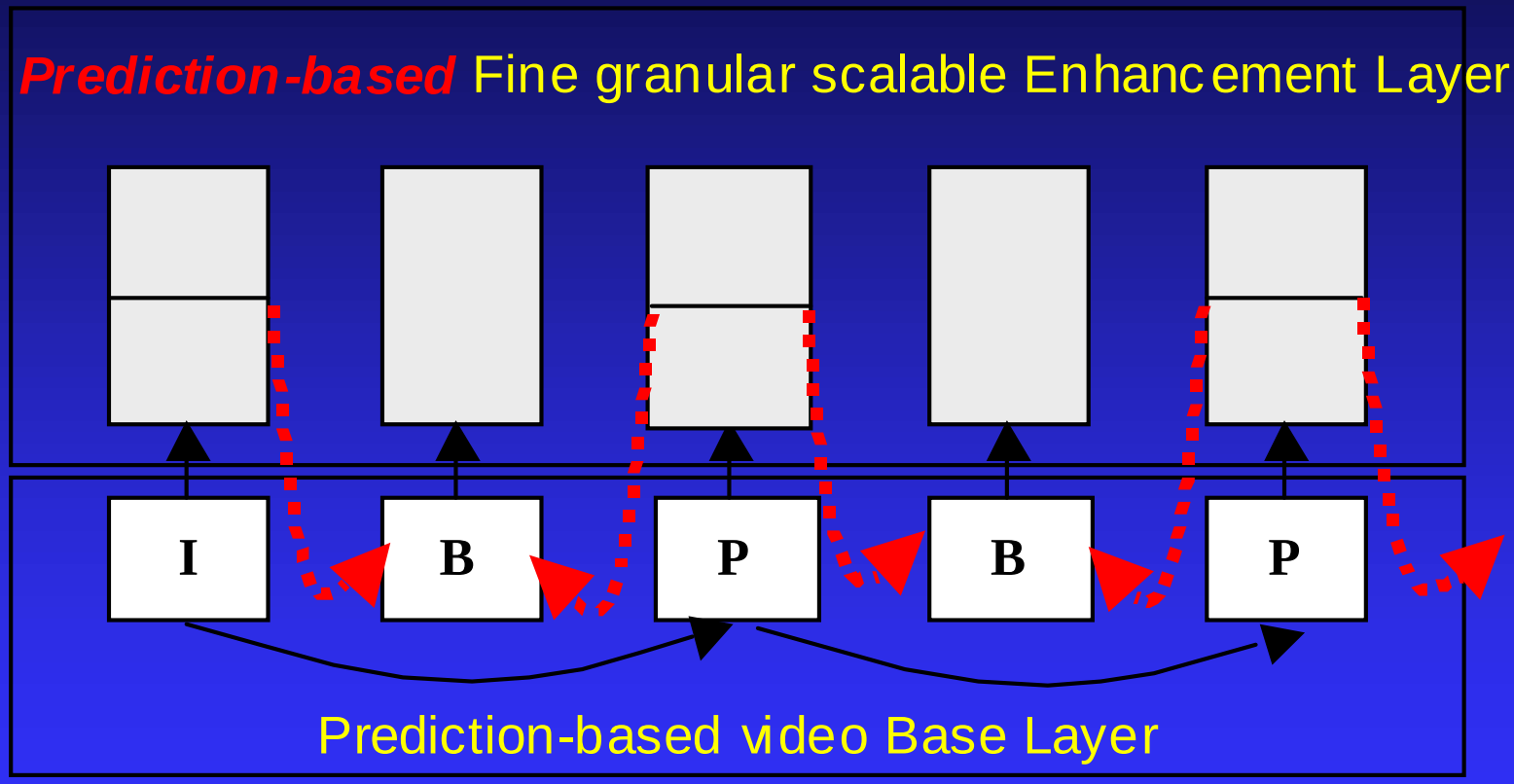
Single-loop MC-FGS for B-frames



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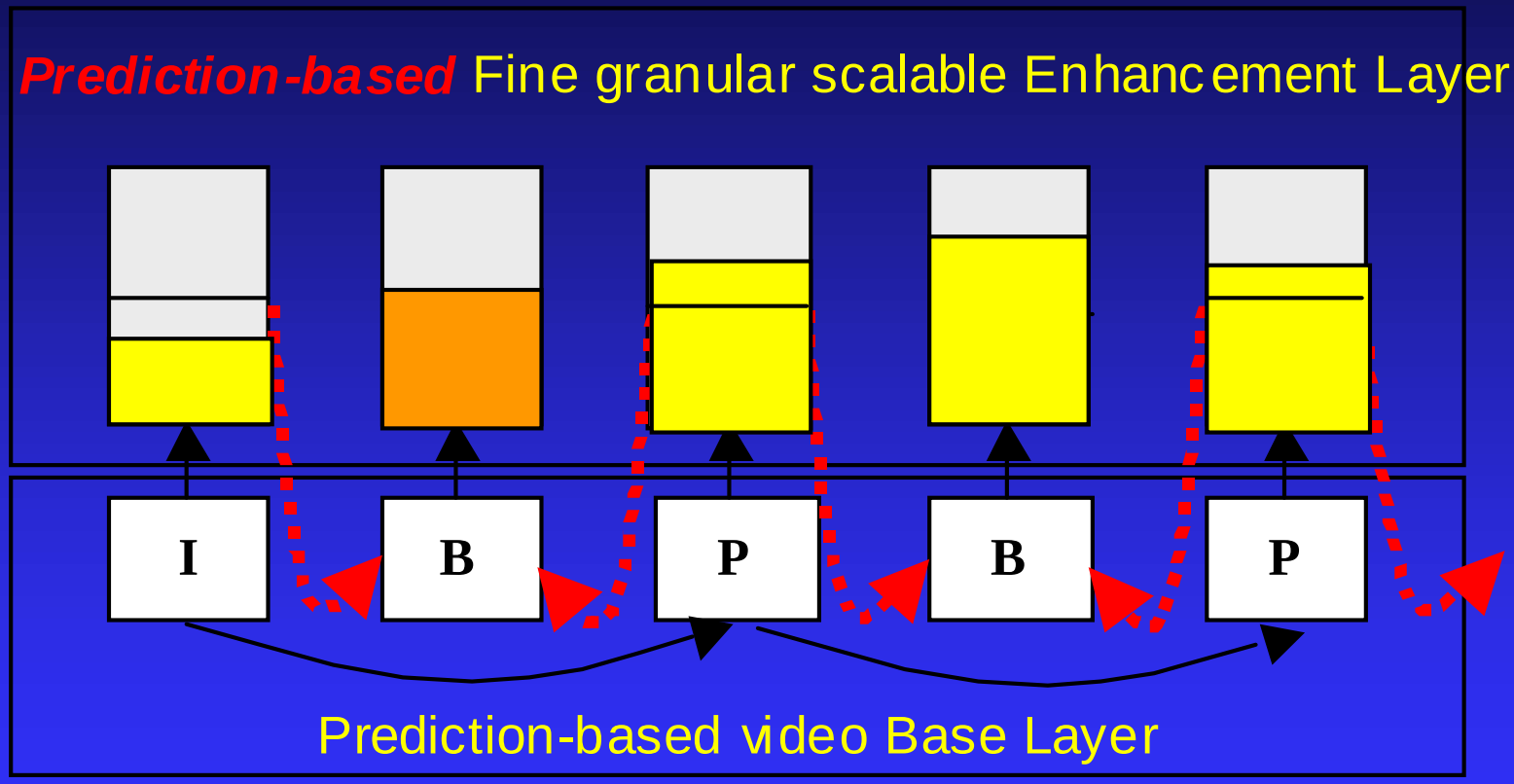
Why MC *only* for B-frames?

- B-frames represent 66% of FGS-stream in IBBP-GOPs
- B-frames have more accurate prediction
- No drift
- No propagation of losses

Single-loop MC-FGS for B-frames:
NO DRIFT & NO Error Propagation



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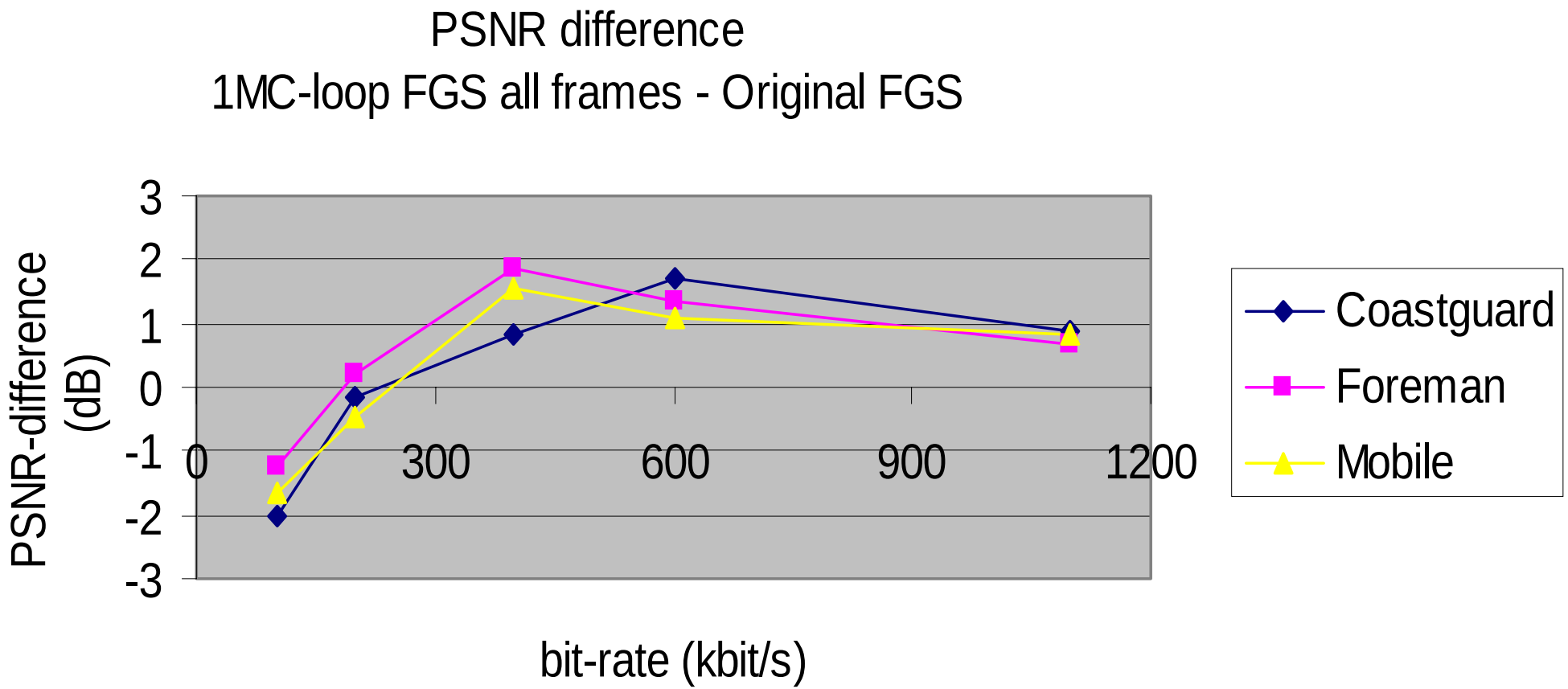
Results - 1 MC-FGS loop - A



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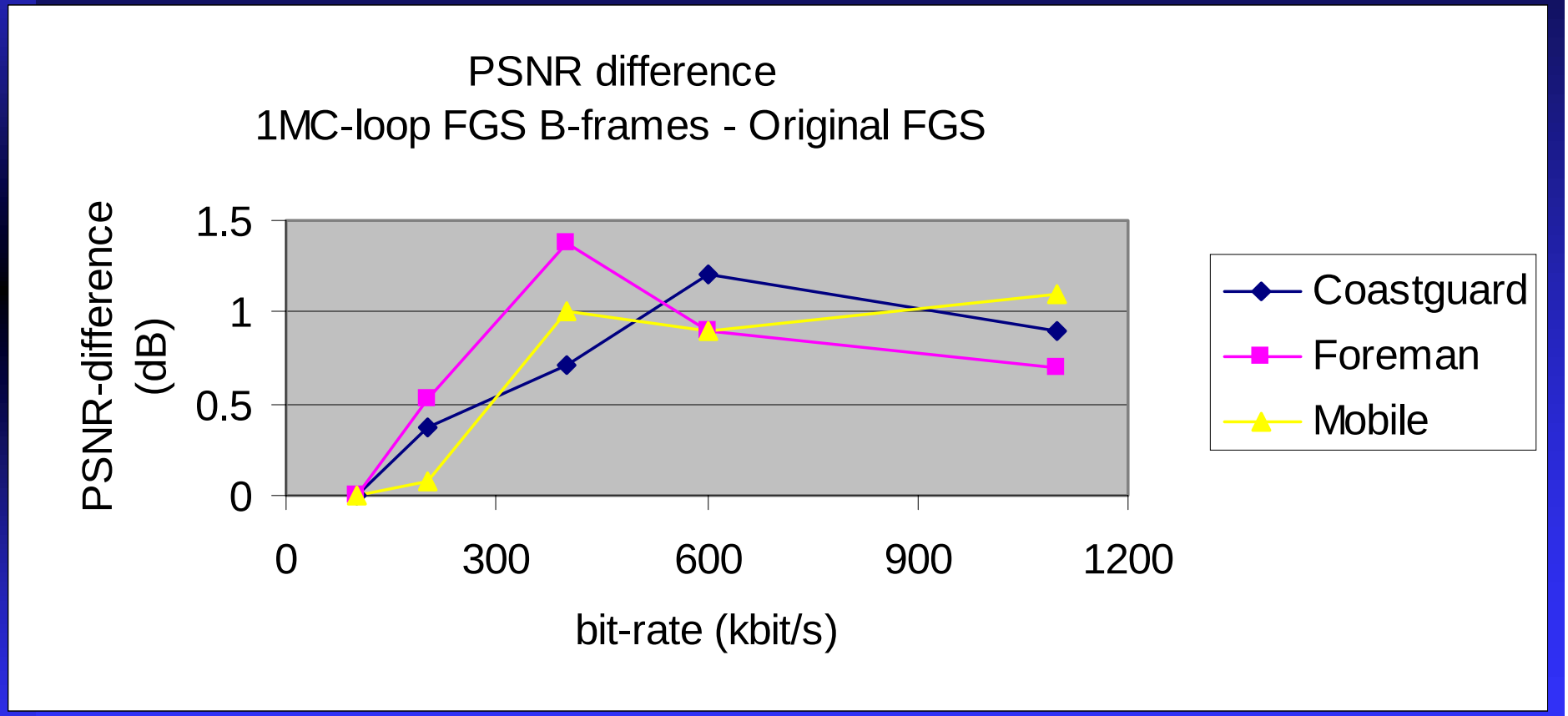
Results - 1 MC-FGS loop - B



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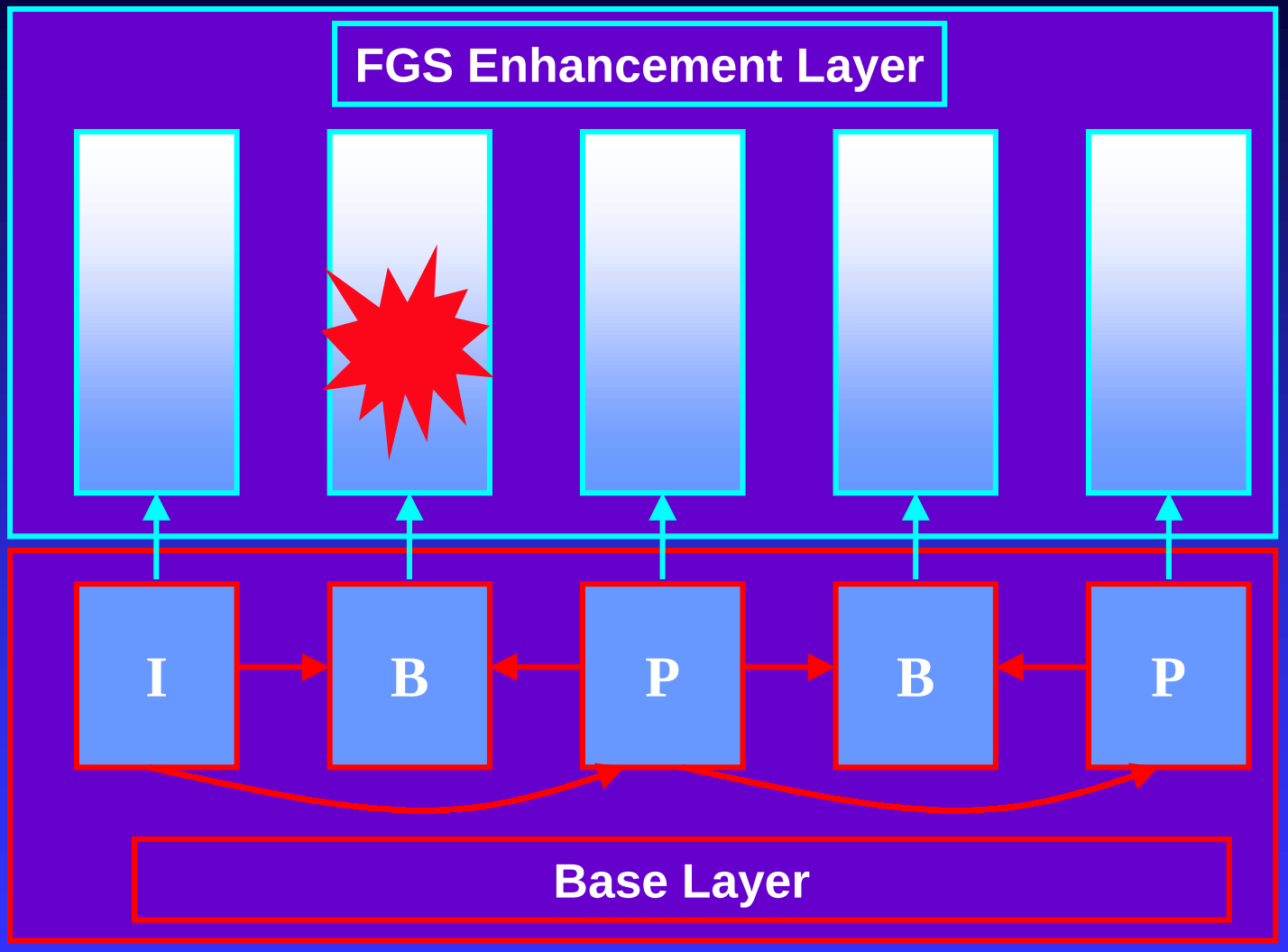
FGS resilience to packet-losses

Packet-loss in FGS



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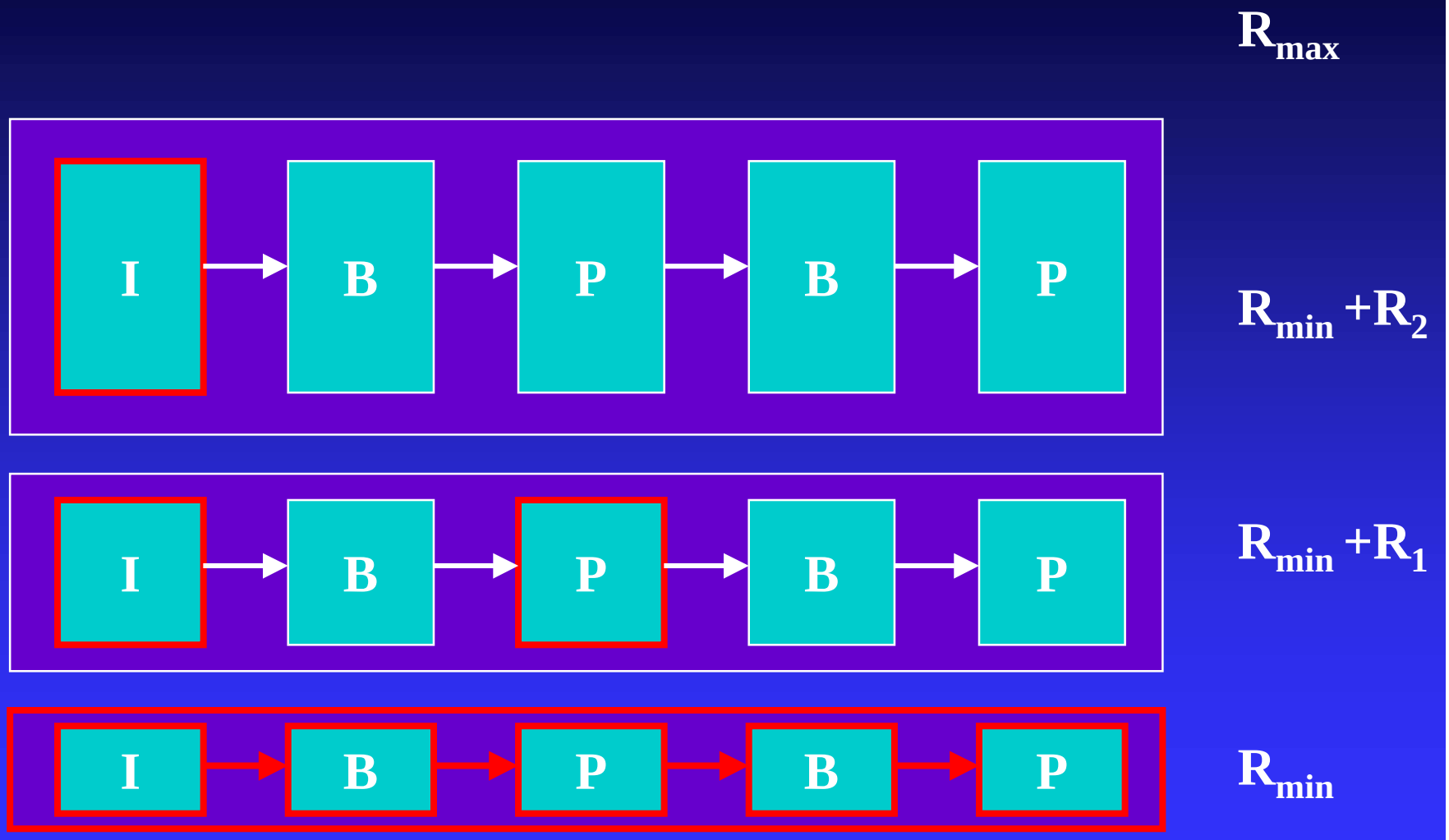
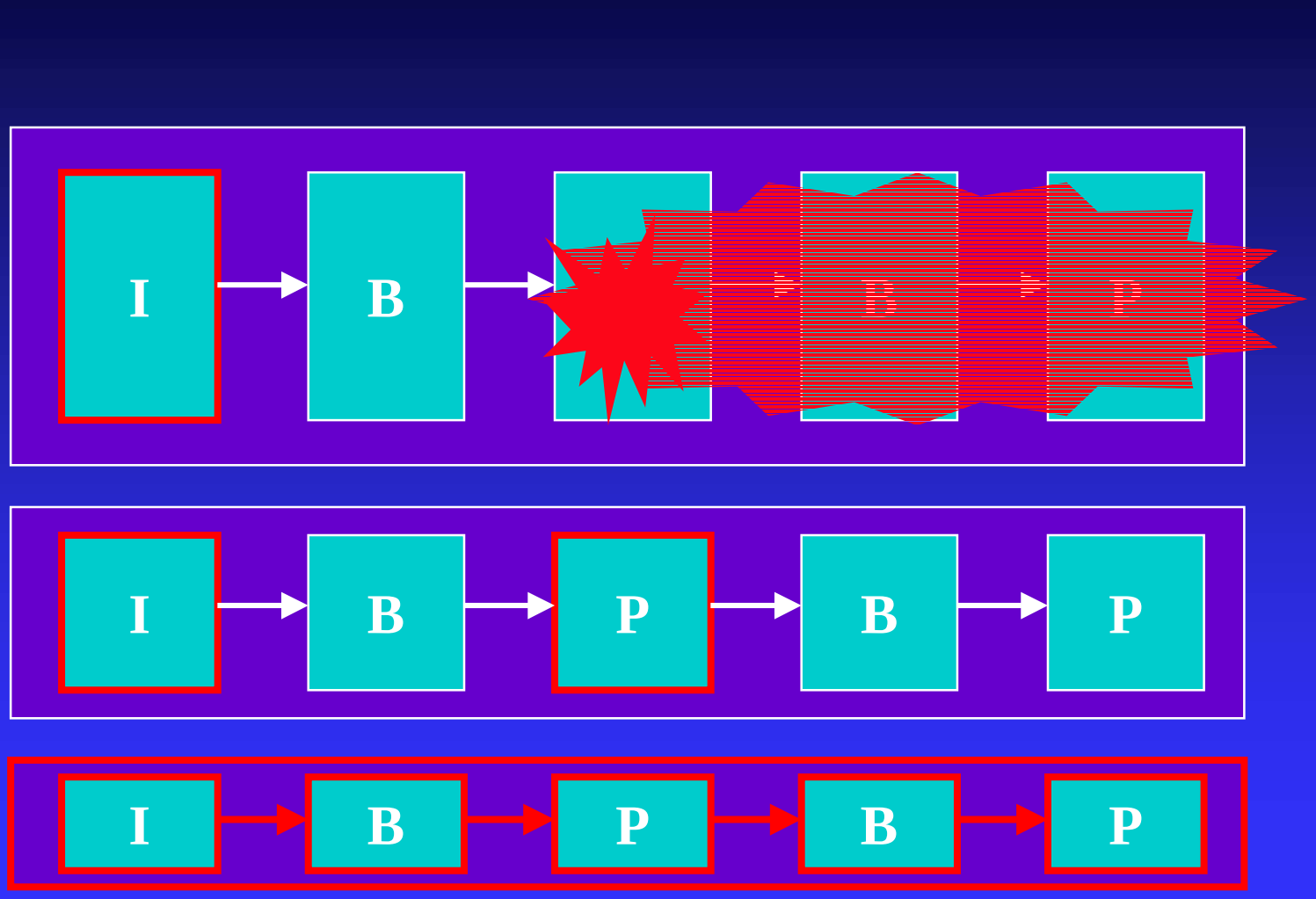
FGS - packet-loss resilience properties

- Loss within an EL picture does not propagate
- Uneven packet-loss protection
- Lower packet-loss probability for FGS base-layer than for single-layer codec at same bit-rate
- Better FGS performance compared to conventional SNR scalability
- Error resilience over a wide range of bit-rates and packet-loss rates

Packet-loss in SLS



Packet-loss in SLS



R_{max}

$R_{min} + R_2$

$R_{min} + R_1$

R_{min}

Effective Packet-loss ratio (EP)

Packet-Loss Ratio (PLR)
1% - 20 %

Effective Packet-loss ratio

EP=PLR.(1-RR)

Recovery Ratio (RR)
0% - 100%

EP ~ amount of unrecoverable packets

Example: PLR=10%, RR=90% -> EP=1%

Packet-loss protection and concealment

SLS

- Strategy A: loss detected => frame freeze
- Strategy B: employ MPEG-4 error resilience tools

  Protection levels: *GOP / VOP/ Video-packets*

- Concealment: copy data from previous frame

Packet-loss protection and concealment

FGS:

- FGS base-layer: same as for SLS
- Packet-loss in EL => discard remaining (less significant) bit-planes
- No error concealment in FGS enhancement-layer

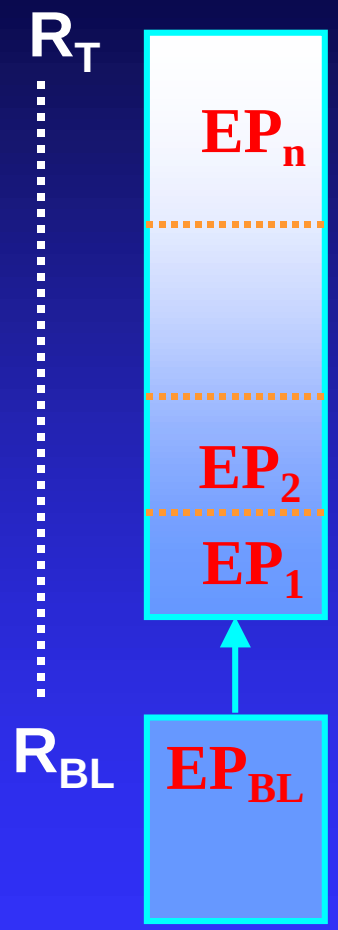
Packet-loss resilience (Rt=500kbit/s, EP=5%)

SLS

FGS

Packet-loss protection strategies for FGS

- Within the enhancement-layer:
  Fine Grained Loss Protection
  (UPP within enhancement-layer)



FGS packet-loss robustness

- **Packet-loss robustness over various bit-rates and EP**
- **EPP: FGS outperforms SLS at moderate-high EP (5-10%)**
- **UPP between base/enhancement-layers and FGLP within enhancement-layer can provide significant resilience compared with SLS**

Fine-Granular-Scalability (FGS) in MPEG-4

- July ‘98 **Activity initiated by Philips Research**
  MPEG-4 approved an FGS core-experiment
- Dec ‘98 **FGS Requirements formally established**

… .

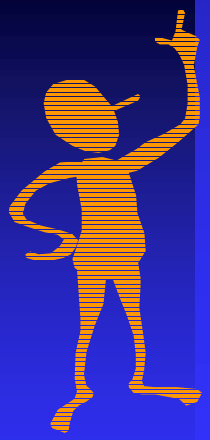
- July ‘00 **FGS reaches FPDAM-status**

… .

- March ‘01 **FGS will become an IS** (MPEG-4 v4)

Preliminary conclusions

- MPEG-4 FGS solves the bandwidth-variation problem over the Internet
  - A single enhancement-layer stream
- Totally flexible, efficient, and simple solution
  - For both unicast and multicast
- Packet loss resilient
- Open standard



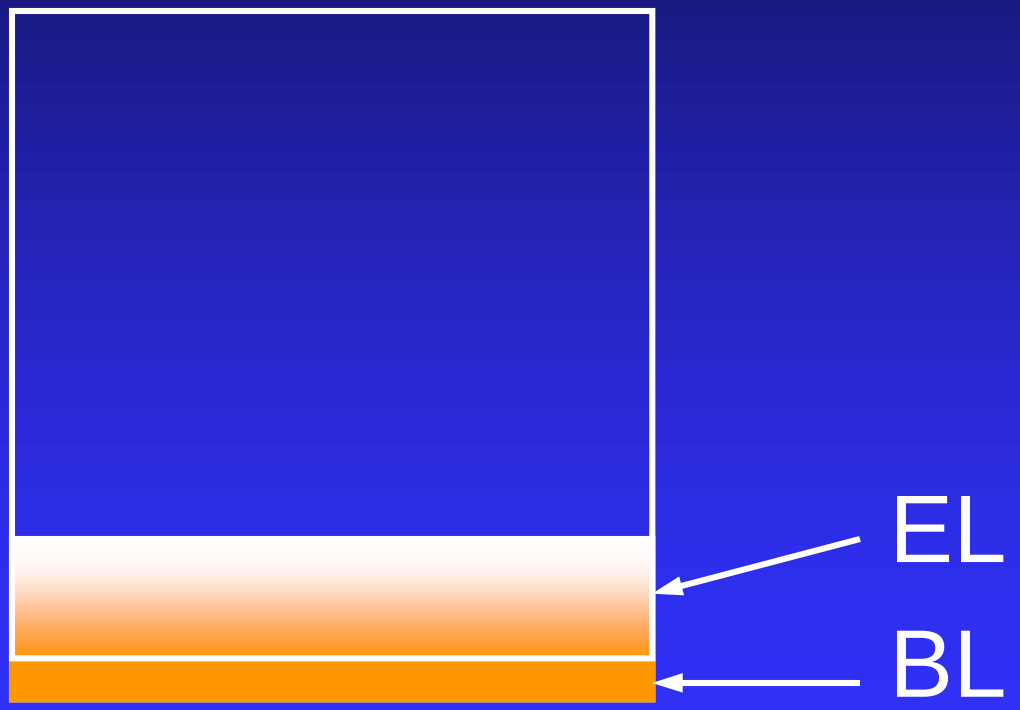
Hybrid FGS temporal-SNR scalability - important MPEG-4 tool for Internet Video

FGS - beyond video streaming

- Storage applications

FGS - beyond video streaming

- Storage applications



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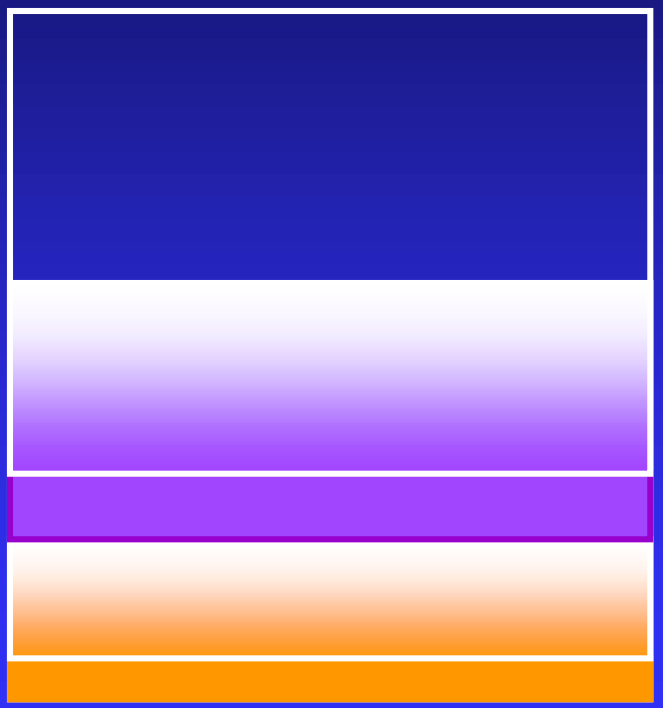
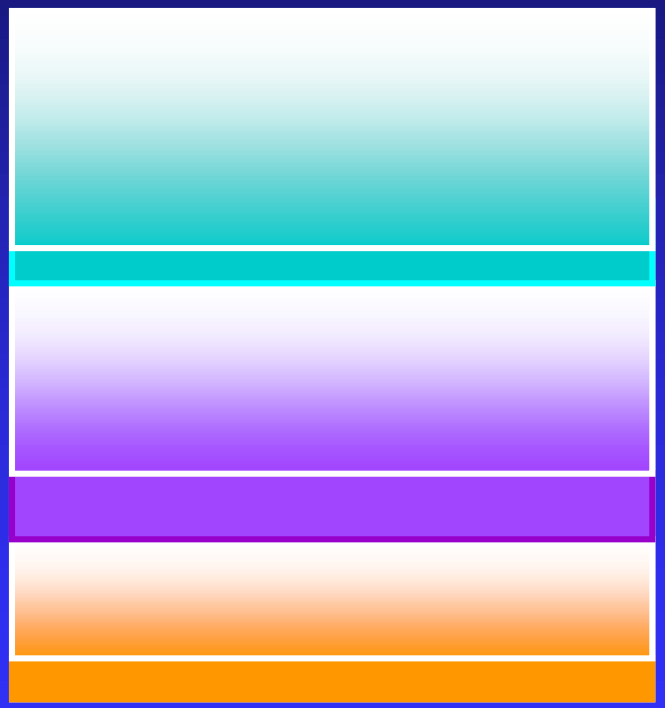
FGS - beyond video streaming

- Storage applications



FGS - beyond video streaming

- Storage applications

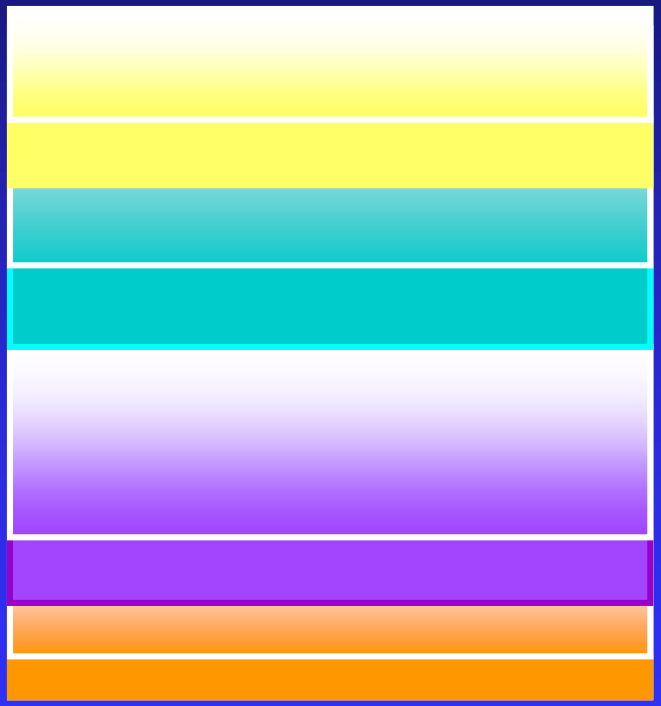


Disk full-

What now?

FGS - beyond video streaming

- Storage applications



FGS - beyond video streaming

- Storage applications
- Progressive transmission of video data (caching)
- Joint bit-rate control for transmission

etc. etc.

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Mihaela.vanderschaar@philips.com