4. Error Resilient Coding Techniques

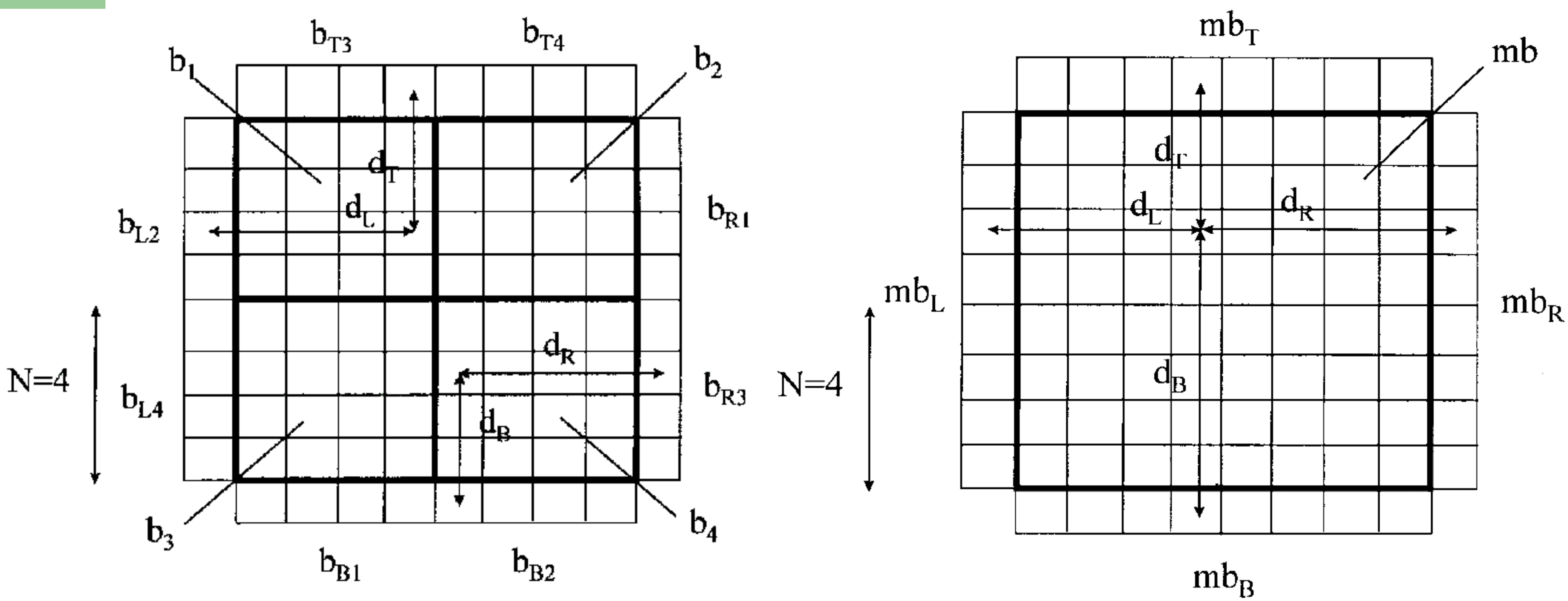
- **Error resilient coding** is applied to multimedia communications to combat **bit errors** and **packet loss**
- Can roughly be divided into two categories :
  - **Error concealment**
    - To minimize the effect of error to the bitstream
  - **Resynchronization and Data recovery**
    - To localize the error and re-establish the synchronization between the decoder and bitstream
    - To recover the lost data as much as possible

A. Error Concealment Techniques

- Error Concealment techniques are often the first attempt to deal with the errors in the bitstream
- Only the decoder is involved in the operation
- Do not prevent the errors from happening
- Only conceal the errors to let them unnoticeable
- Advantage: Very low overhead
- Effective when error is not serious
- Concealment techniques are not standardized. Up to individual implementation

Spatial Domain Interpolation

- **Error Concealment is performed by interpolating a damaged block from it's neighbor blocks**



Block based **Macroblock based**

Temporal Domain Error Concealment

Several approaches have been proposed:

- **Motion-Compensated Prediction/Interpolation**
- **Recovery of Motion Vectors and Coding Modes**
- **Using Motion Field Interpolation for Error Concealment**
- **Spatial-Temporal Smoothing**
- **Temporal Estimation of Blocks with Missing Motion Vectors**

I. Motion-Compensated Prediction/Interpolation

- **Original idea:** replacing a damaged macroblock by the spatially corresponding one in the previous frame

  ⇒ Does not work well for large motion video
- **Better idea:** replacing the damaged macroblock with the motion compensated block

What if the motion vectors are also damaged???

II. Recovery of Motion Vectors

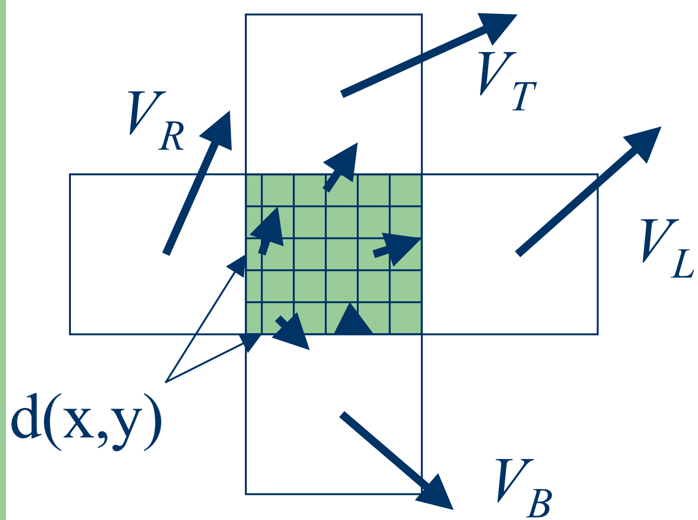
For estimating lost motion vectors, the following methods have been proposed:

- Simply setting the motion vectors to zero
- Using the motion vectors of the corresponding block in the previous frame
- Using the average of the motion vectors from spatially adjacent blocks
- Using the median of the motion vectors from spatially adjacent blocks

⇒ Have problems in case of large or non-smooth motion, e.g. objects moving in different directions

III. Using Motion Field Interpolation for Error Concealment

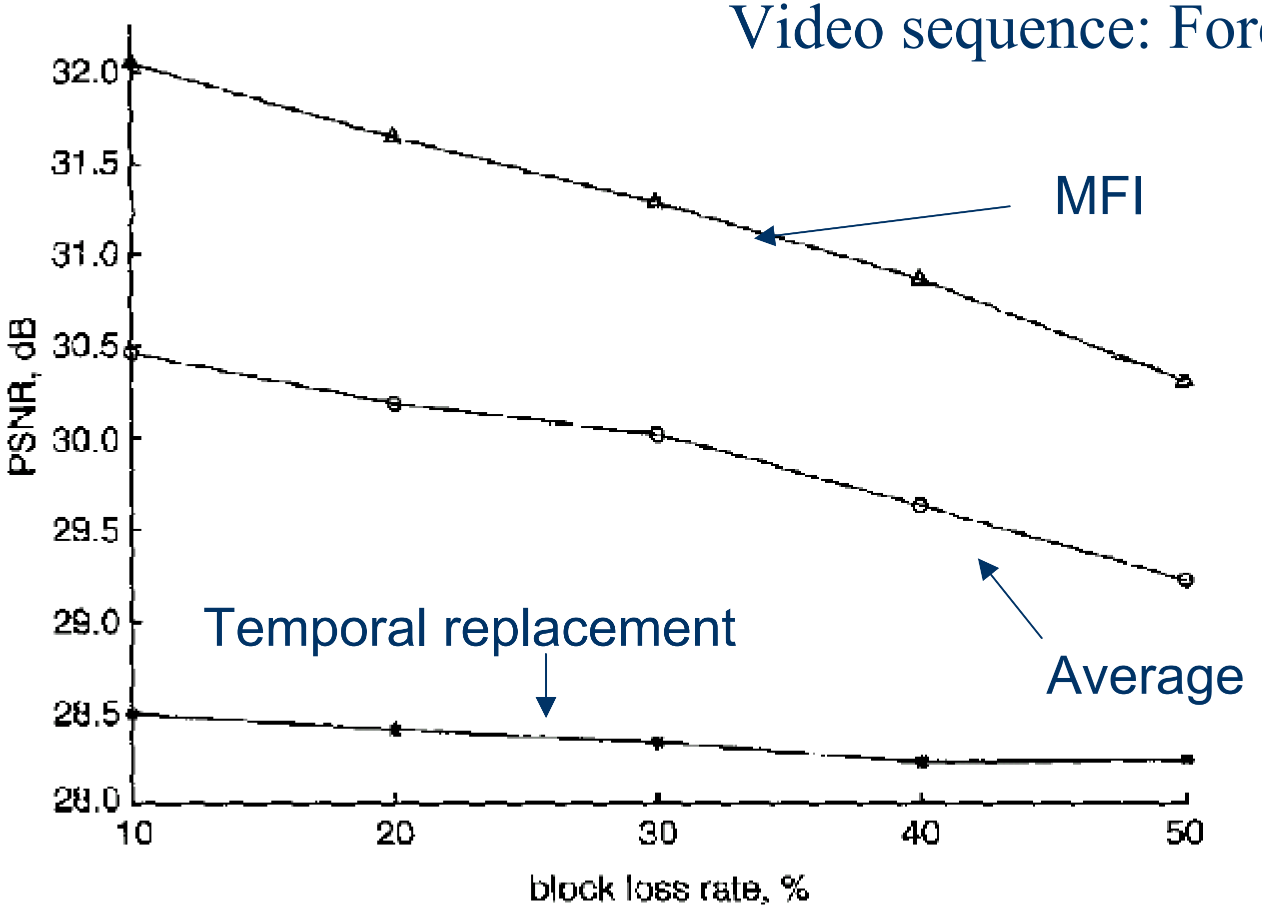
- Motion field interpolation (MFI) uses different motion vectors for each pixel
- The motion vector for each pixel is interpolated from the motion vectors at several control points



$$d(x,y) = H(v_T, v_B, v_L, v_R, x, y)$$

where H is a linear interpolator function

Video sequence: Foreman



M.E.Al-Mualla, C.N. Canagarajah and D.R. Bull, "Motion field interpolation for temporal error concealment", IEE Proc. On Vis. Image Signal Process., Vol.147, No.5, Oct 2000

B. Resynchronization and Data Recovery

- **Objectives:**
  - Localize the erroneous data
  - Restart the decoding of data from erroneous condition
  - Recover the error data as much as possible

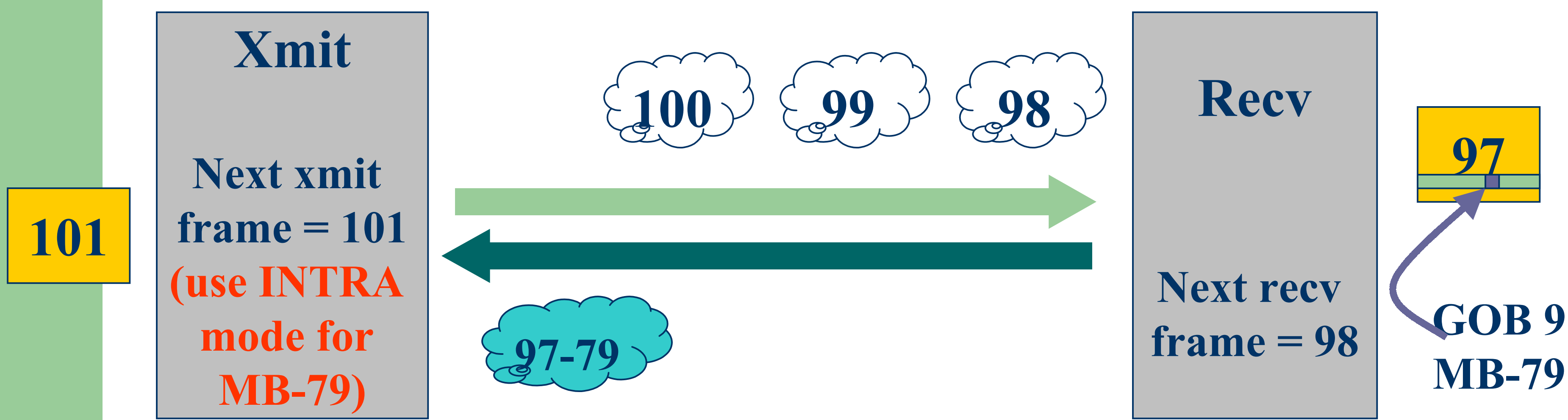
- Further divide into **feedback based** and **non-feedback based**

I. Feedback Based Approaches

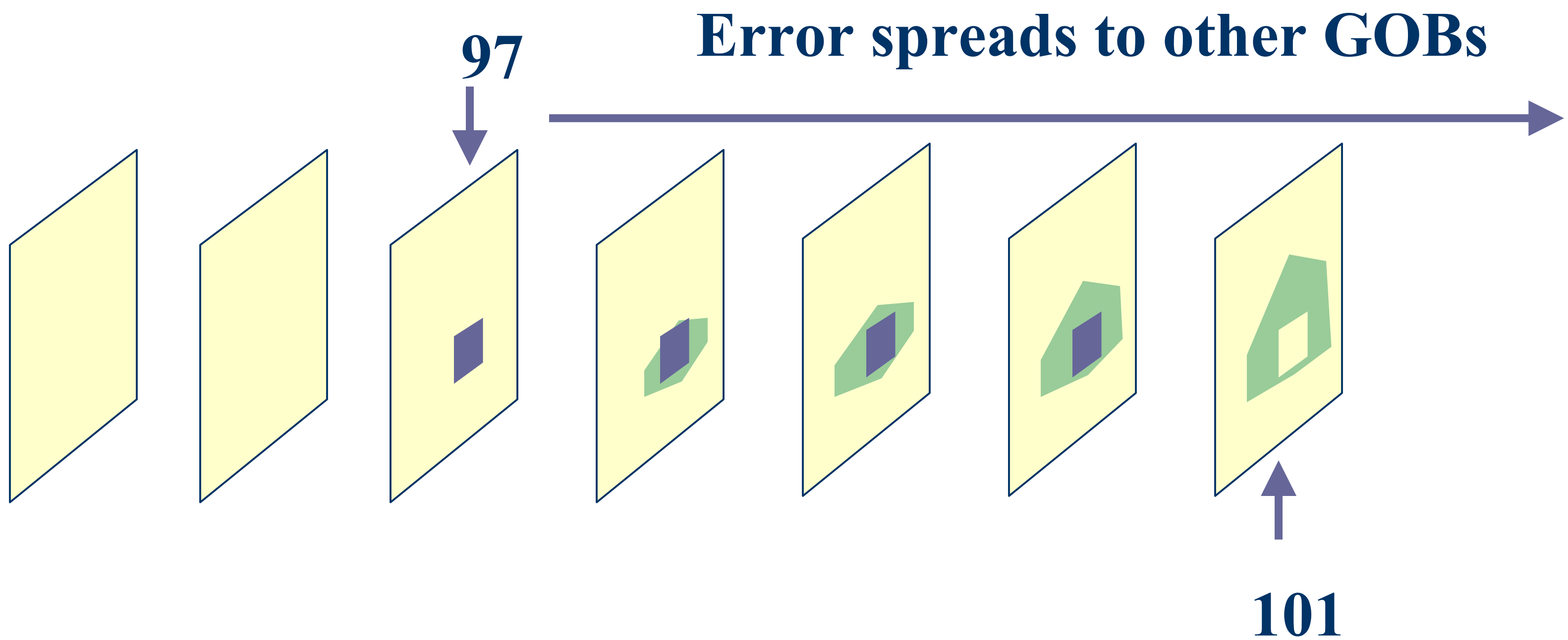
a. Error Tracking (Appendix I of H.263+)

- Utilize the INTRA mode to stop temporal error propagation
- A feedback channel is required to send negative acknowledgements (NACKs) back to the encoder

First idea



- **This simple idea does not work very well since the error will spread to other MBs or even other GOBs in the later frames**
- **It is due to motion compensation**



- The idea of "Error Tracking" is that the encoder should keep track of which GOBs in the later frames will be affected by the error GOB

	59	60	61	62	63
	68	69	70	71	72
	77	78	79	80	81
	86	87	88	89	90

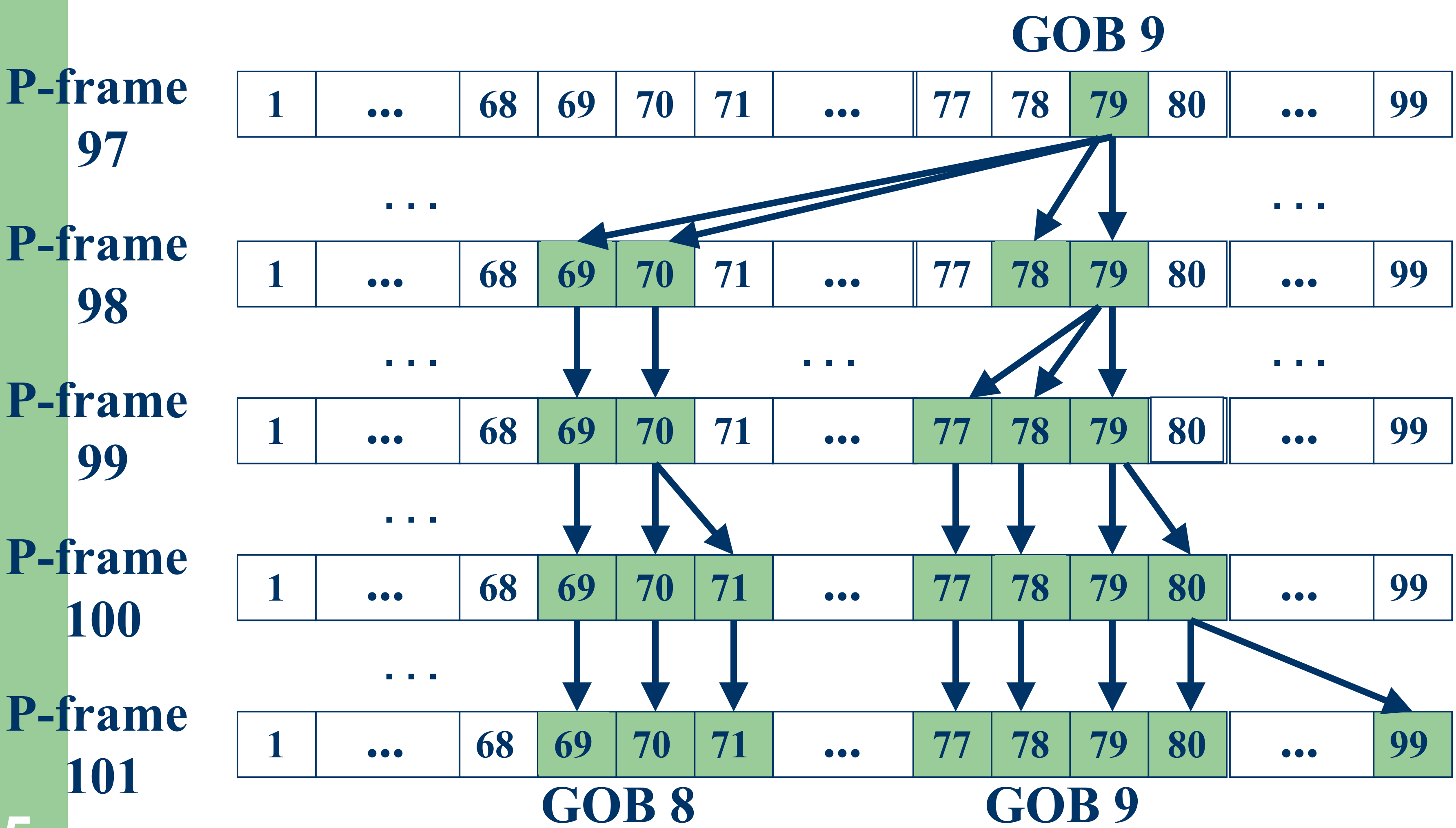
P-frame 97

GOB
7
8
9
10

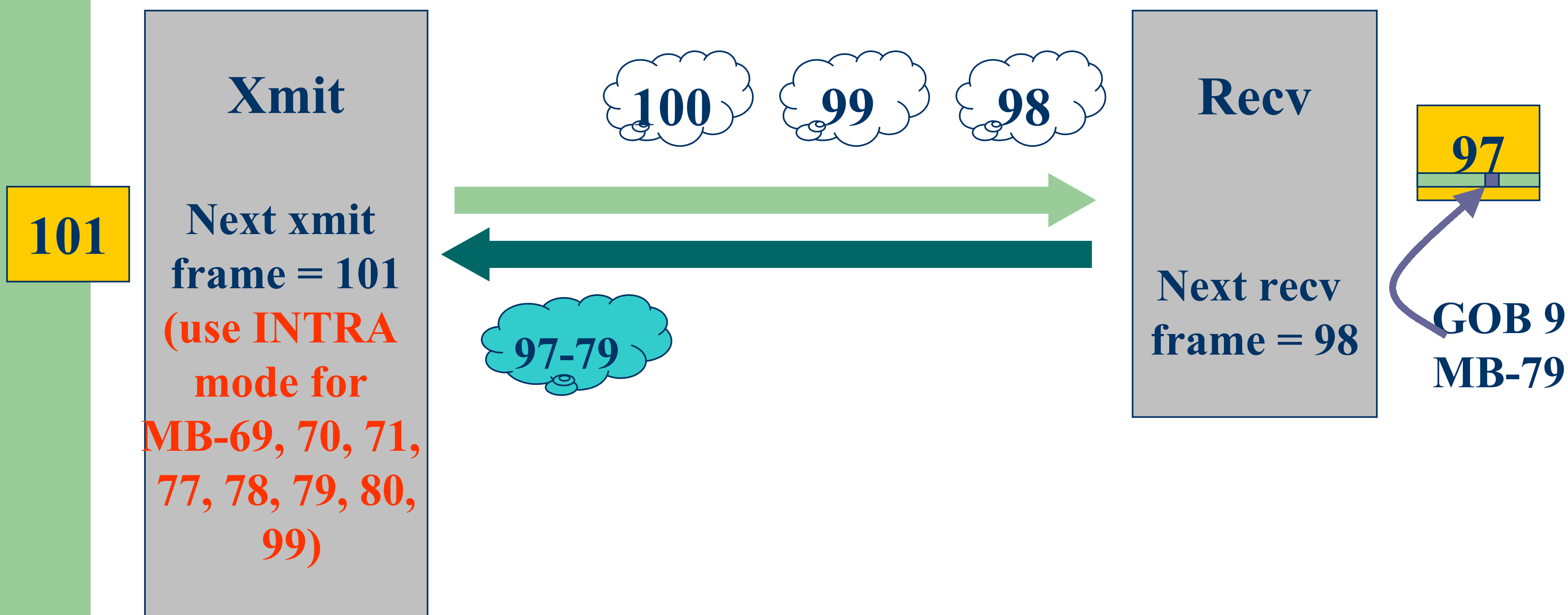
	59	60	61	62	63
	68			71	72
	77			80	81
	86	87	88	89	90

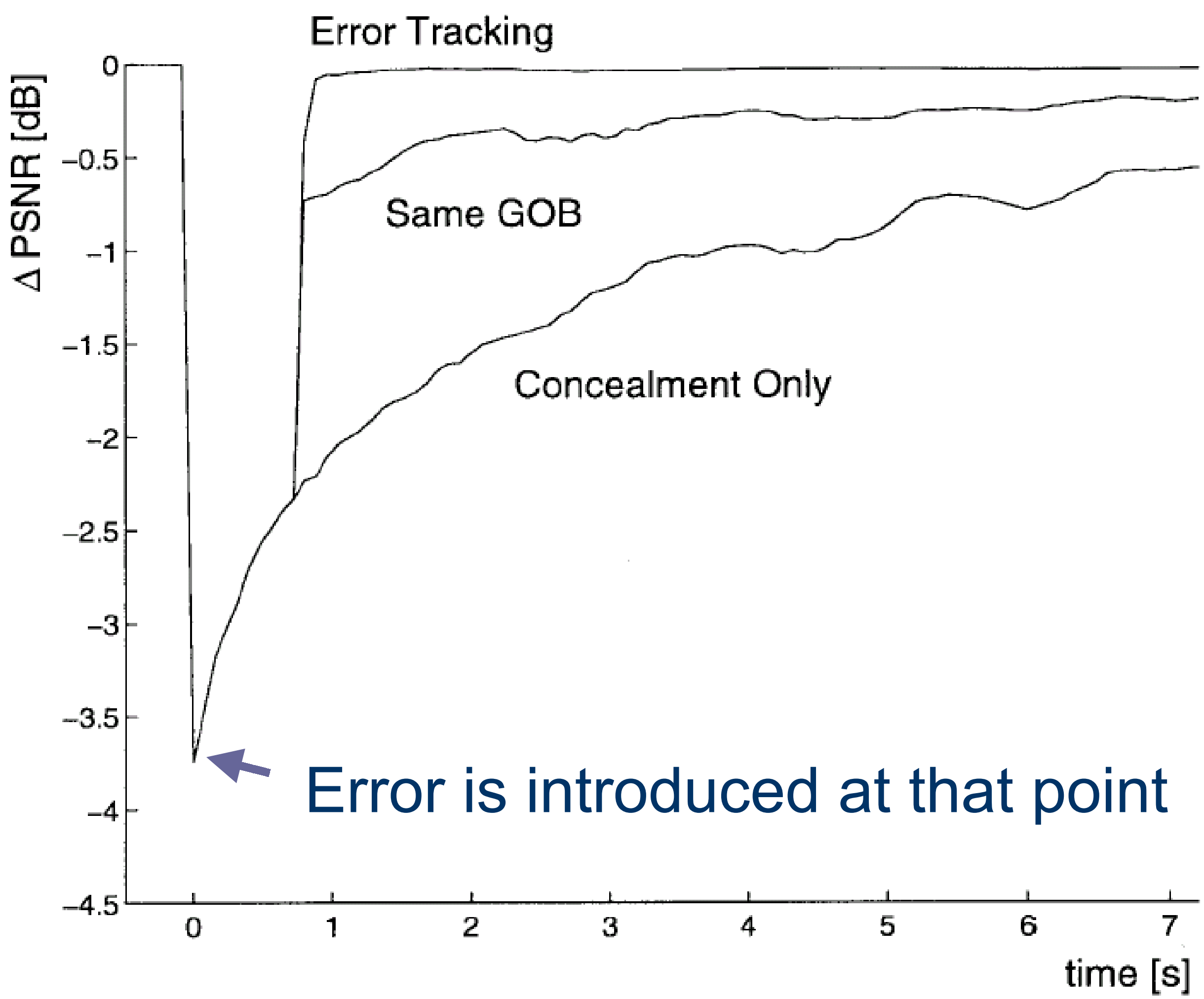
P-frame 98

- MB 79 in frame 97 affects MBs 69, 70, 78, 79 in frame 98


GOB 9
P-frame 97
1 … 68 69 70 71 … 77 78 79 80 … 99
P-frame 98
1 … 68 69 70 71 … 77 78 79 80 … 99
P-frame 99
1 … 68 69 70 71 … 77 78 79 80 … 99
P-frame 100
1 … 68 69 70 71 … 77 78 79 80 … 99
P-frame 101
1 … 68 69 70 71 … 77 78 79 80 … 99
GOB 8
GOB 9

With Error Tracking

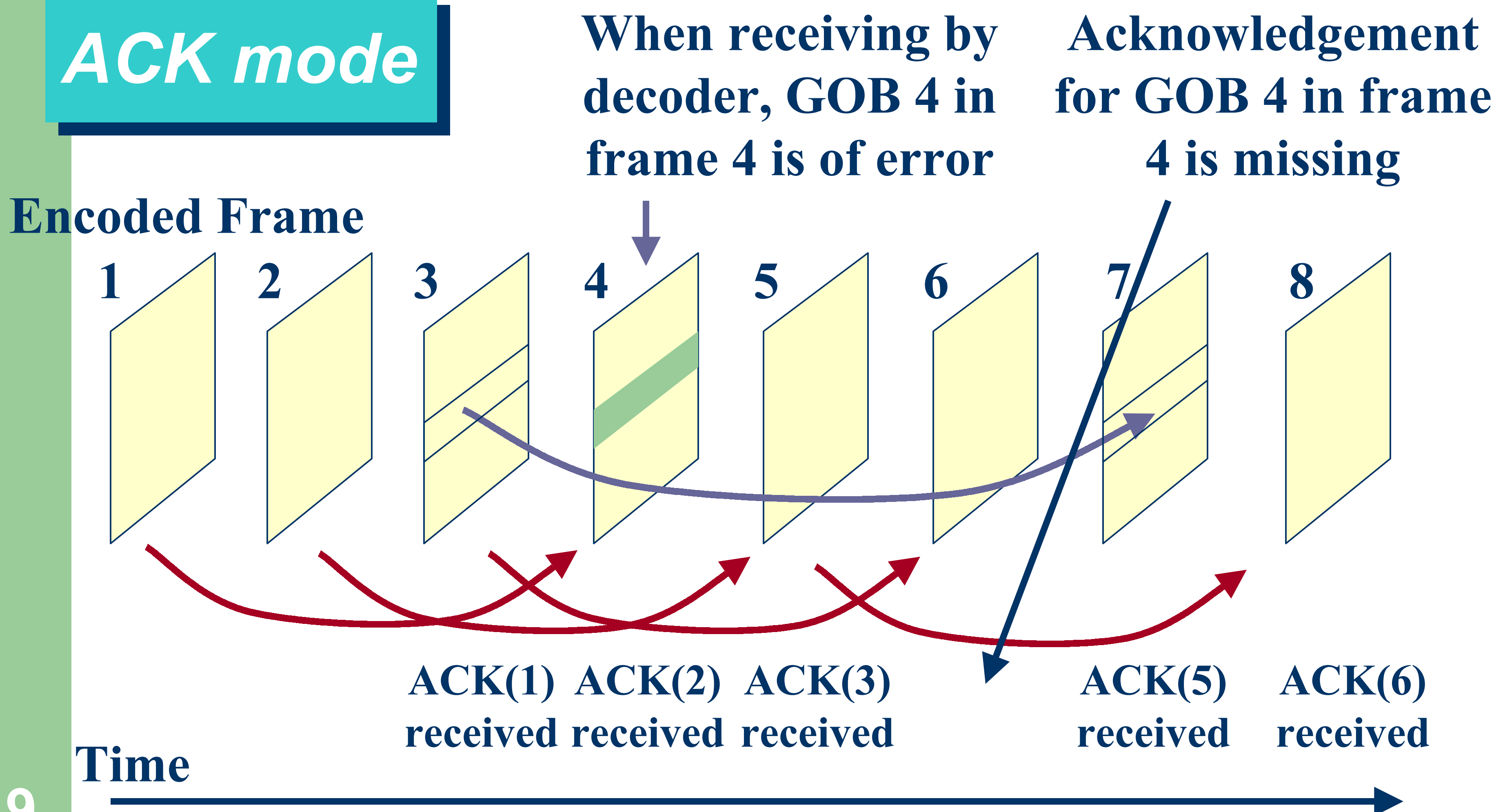



Error Tracking
Same GOB
Concealment Only
Δ PSNR [dB]
0
–0.5
–1
–1.5
–2
–2.5
–3
–3.5
–4
–4.5
0
1
2
3
4
5
6
7
time [s]
Error is introduced at that point

b. Reference Picture Selection (Annex N of H.263+)

- Although Error Tracking can solve the problem of temporal error propagation, the use of INTRA mode coding can significantly increase the data rate
- Reference Picture Selection (RPS) allows the encoder to select one of the several previously decoded frames as a reference for prediction
- The reference picture is selected on a GOB basis
  $\Rightarrow$ for all MBs within one GOB, the same reference picture is used

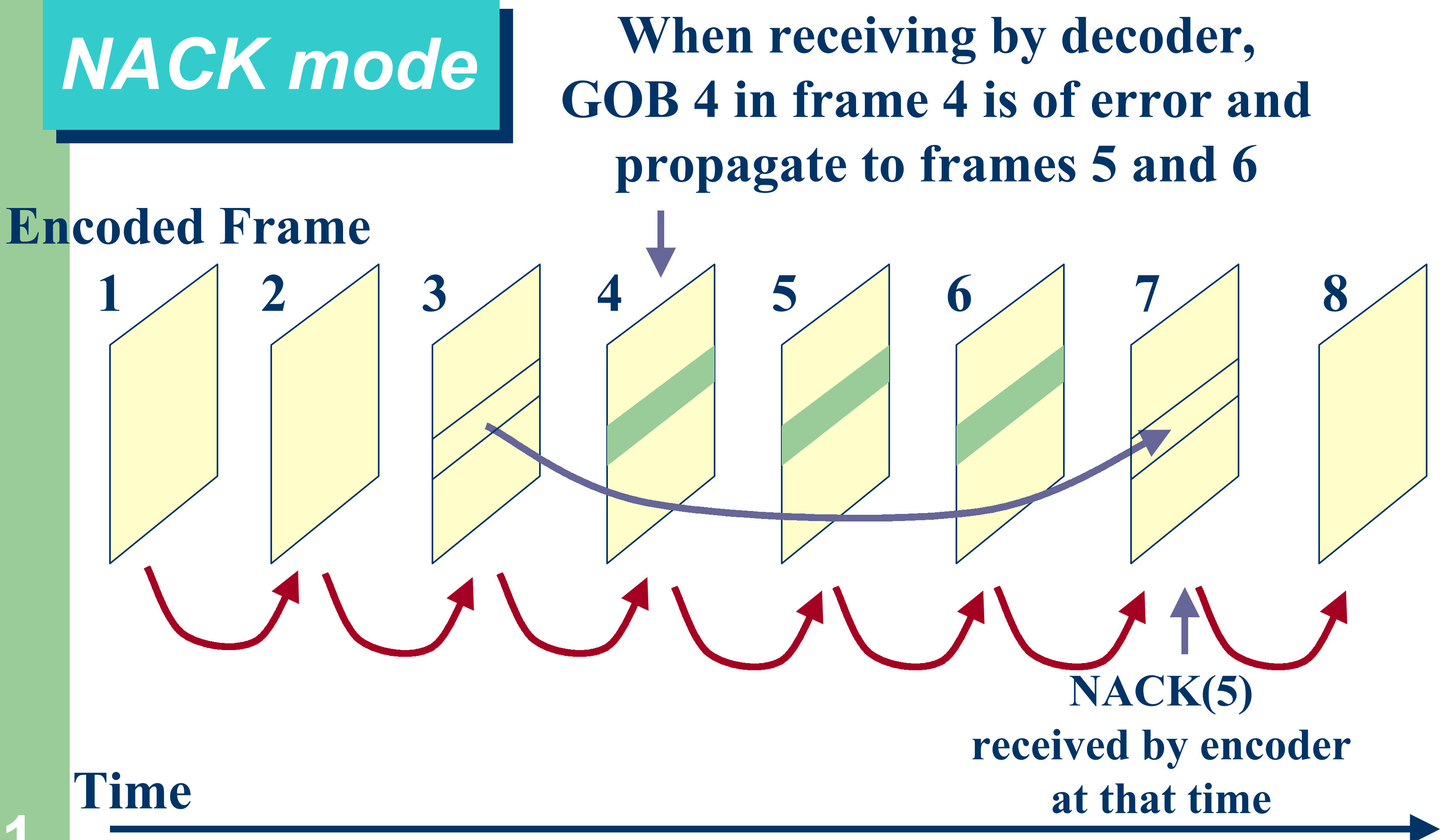
ACK mode


When receiving by decoder, GOB 4 in frame 4 is of error
Acknowledgement for GOB 4 in frame 4 is missing
Encoded Frame
1
2
3
4
5
6
7
8
ACK(1) received
ACK(2) received
ACK(3) received
ACK(5) received
ACK(6) received
Time

- In **ACK mode**, the receiver acknowledges all correctly decoded GOBs thru. the feedback channel
- Error GOB is predicted from the same GOBs of a previous frame known to be correctly decoded
- Due to channel delay, ack. of a frame is received a few frames after it is transmitted
- Hence frame from far apart may be used for prediction that leads to **lower prediction quality**
- However, it **creates less error frame**
- **Overhead is large** in sending acknowledgement.

Suitable for error prone channel

NACK mode


When receiving by decoder,
GOB 4 in frame 4 is of error and
propagate to frames 5 and 6
Encoded Frame
1
2
3
4
5
6
7
8
NACK(5)
received by encoder
at that time
Time

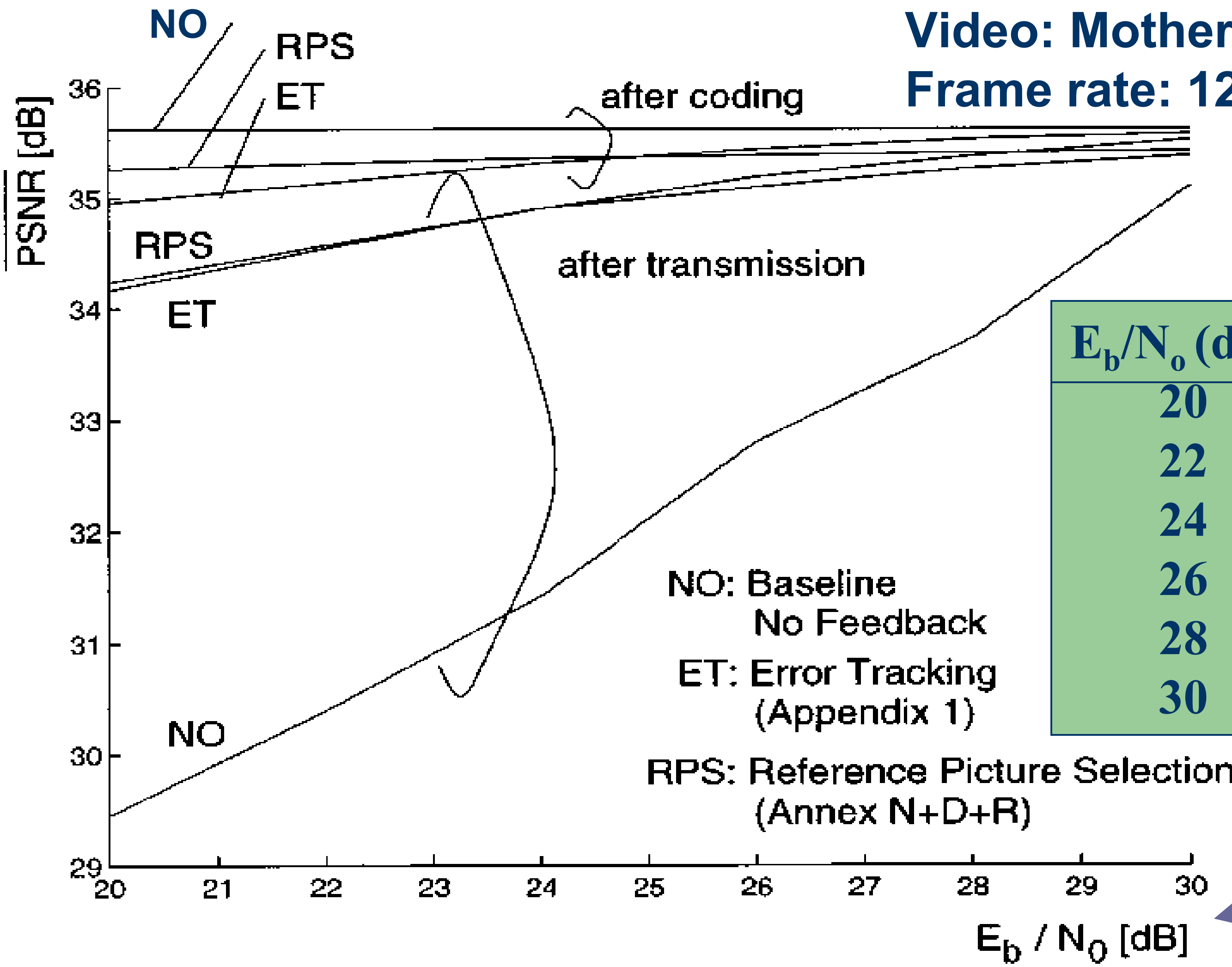
- Receiver acknowledges only error GOBs
- Error GOB is predicted from the same GOBs from a previous frame known to be correctly decoded
- NACK modes creates more error frames
- Quality of the decoded picture is better, since predict from a nearby frame
- Overhead is small in sending acknowledgement for error-free channel
- Both the ACK mode and NACK mode requires additional storage of a few frames

- A hybrid approach
  - From ACK to NACK

    $\Rightarrow$ If consecutive M ACKs are received
  - From NACK to ACK

    $\Rightarrow$ If consecutive N ACKs are received
- (N,M) forms a parameter set for the codec to switch from one mode to another
- Become the Annex N of the H.263+

Video: Mother and Daughter
Frame rate: 12.5fps



E_b/N_o (dB)	BER
20	0.002578
22	0.001646
24	0.001025
26	0.000644
28	0.000390
30	0.000234

Carrier-to-noise ratio

B. Girod and N. Farber, "Feedback-based Error Control for Mobile Video Transmission", Proceedings of the IEEE, Vol.87, No.10, Oct 1999, pp.1707-1723.

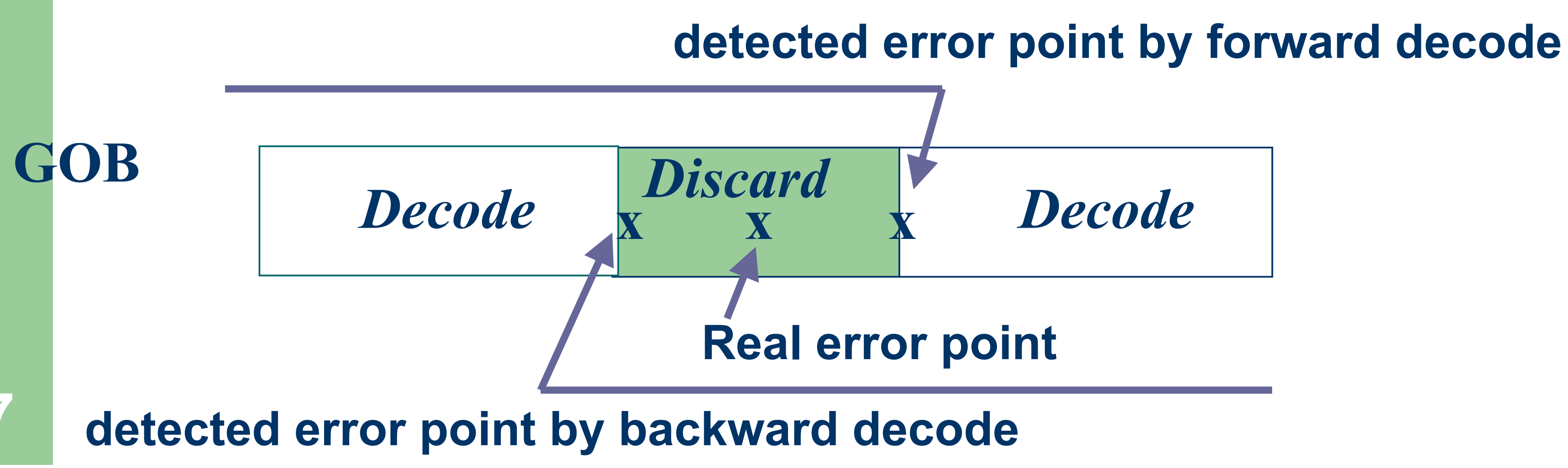
II. Non-Feedback Based Approaches

a. Introduction

- For most mobile systems, transport level feedback channel can be expensive
- Without feedback, error resilience is achieved relying on:
  - The extra information given by the encoder
  - The capability of the decoder to detect and recover from the error
- Performance is often worse than the feedback based approach

b. Reversible VLC (Part of Annex V of H.263+)

- **RVLC is the VLC that can be decoded both in the forward and backward directions**
- **Once an error is detected in forward decode, switch to the next sync point and decode backward**
- **Greatly reduce the discarded data**



A Simple Example of Reversible VLC

- The simplest method to construct the RVLCs is to take a constant Hamming weight code and add a fixed-length prefix and suffix
- Can be decoded by counting the no. of '1's
- 3 '1's for each code word
- More complex RVLC can be constructed by lengthening the prefix and suffix

VLC code with Hamming weight of 1	RVLC
	0
1	111
01	1011
001	10011
0001	100011

Reversible VLC in H.263+ and MPEG-4

- The RVLC has been adopted in MPEG-4 and H.263+ standard
- MPEG-4 adopted the proposal from Toshiba
- H.263+ adopted the proposal from UCLA and Ericsson for the coding of headers and motion information
- Modify from the Golomb-Rice (GR) codes and exp-Golomb (EG) codes
- Known to be the near optimal codes for coding of exponentially distributed non-negative integers
- Experimental results show that the use of RVLC in H.263+ introduces only an average of 1.3% increase in the size of bitstream comparing with using VLC

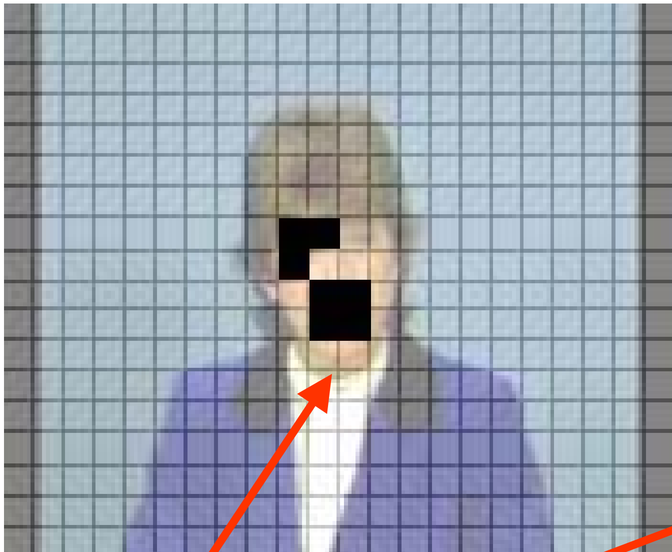
c. Other Standardized Error Resilient Tools

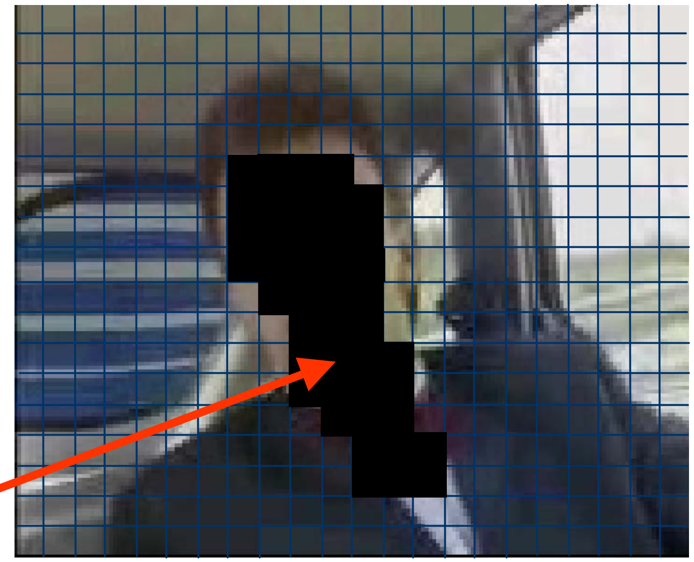
- Slice structured mode (Annex K of H.263+)
  - Sync markers are inserted into the bitstream regularly in terms of data size
- Independent segment decoding (ISD-Annex R of H.263++)
  - Restrict the propagation of error within one slice
- Data partitioning (Part of Annex N of H.263+)
  - Group MB header, MV and DCT information into different partitions and protect them separately according to their importance
- Header repetition (Annex W of H.263++)
  - Redundant information of headers

d. Conditional Replenishment

- Temporal error propagation is due to the use of prediction coding
- A simple way to solve the problem is to give up prediction coding

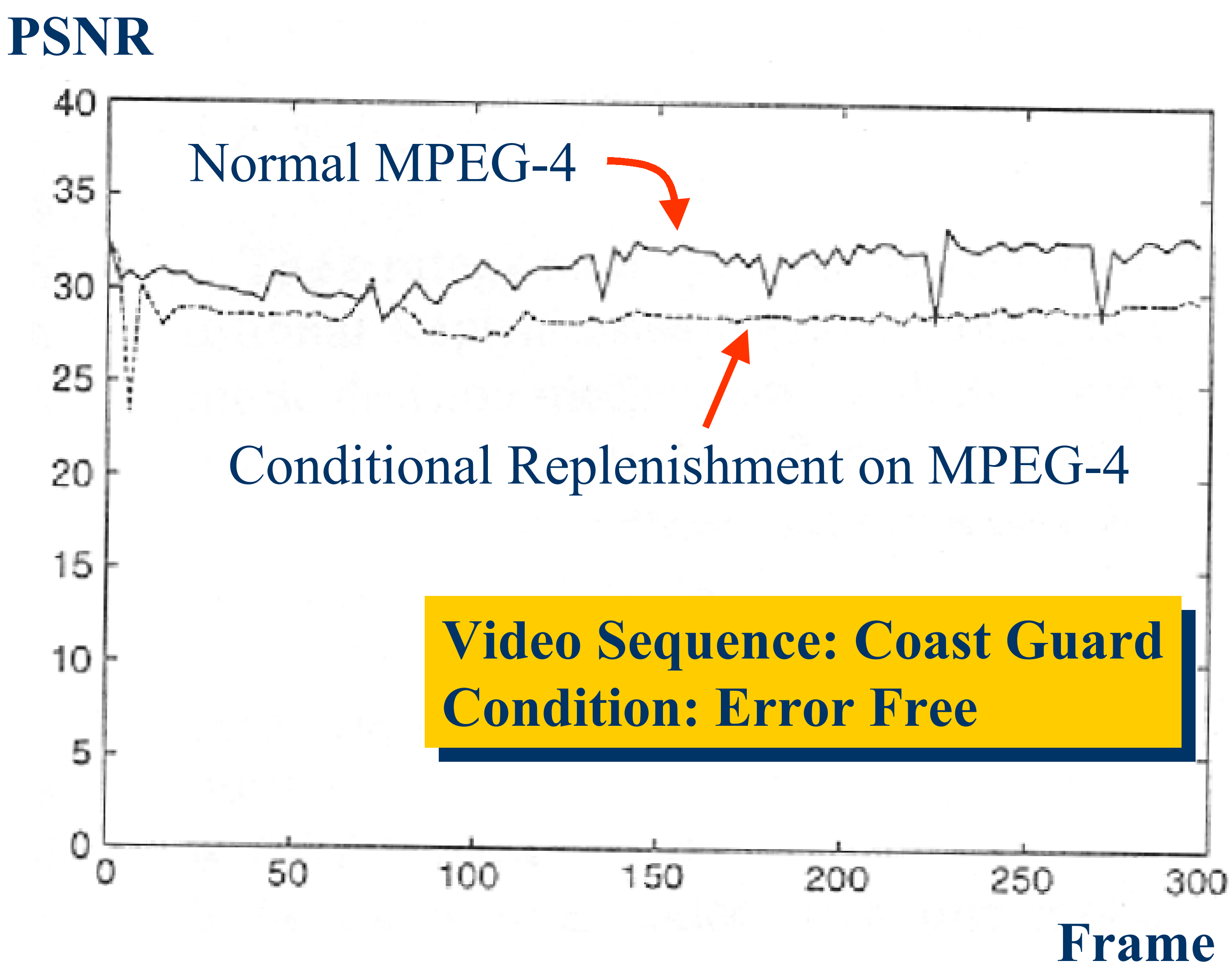
  ⇒ All I-frame coding
- Seem to incur significant growth in bit rate
- For some applications, only a minor portion of MBs is moving
- Unmoved MBs need not be coded



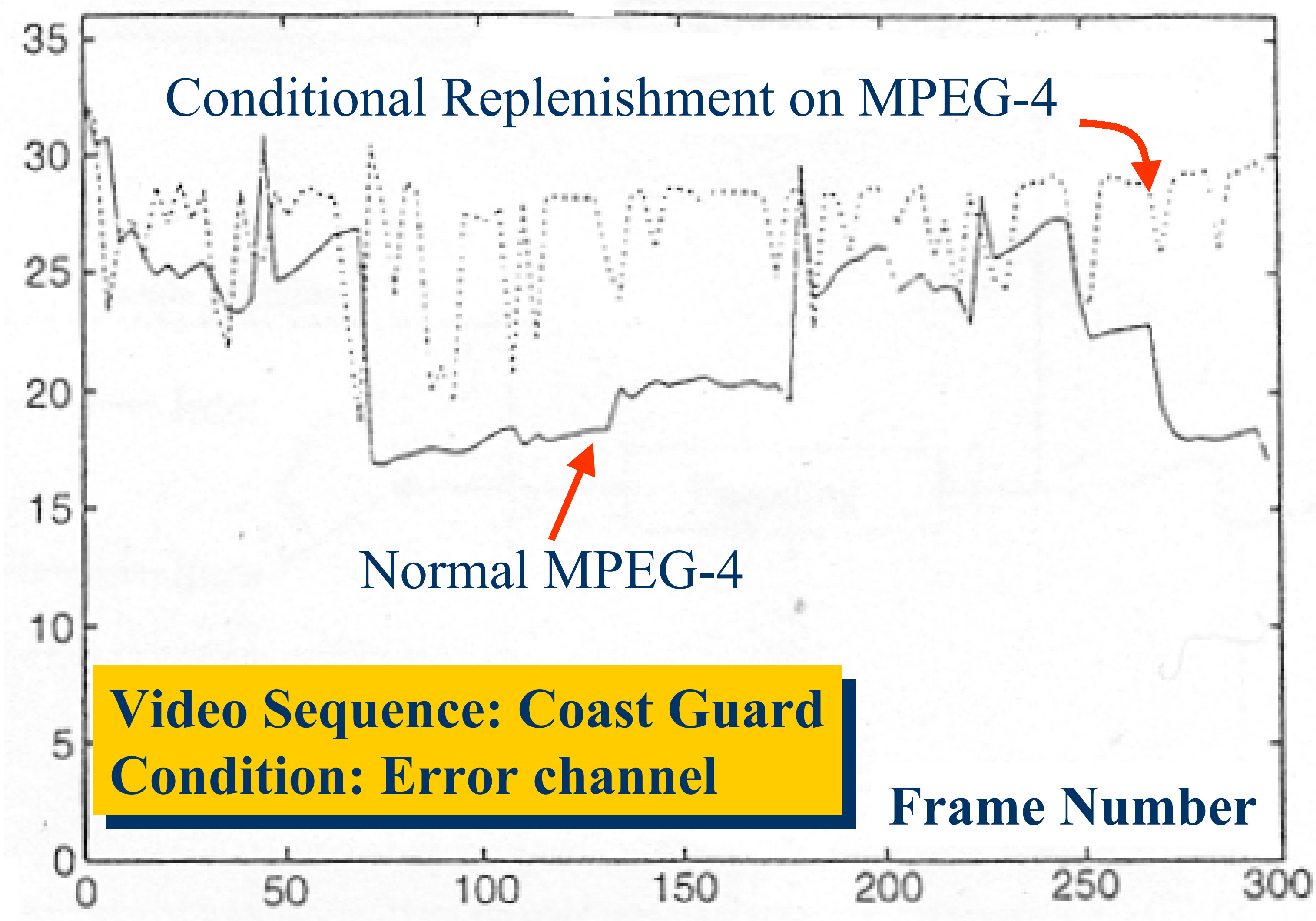


Motion MBs

Only moving MBs are coded in INTRA mode, the others simply untouch


PSNR
40
35
30
25
20
15
10
5
0
Normal MPEG-4
Conditional Replenishment on MPEG-4
Video Sequence: Coast Guard
Condition: Error Free
0
50
100
150
200
250
300
Frame

PSNR


35
30
25
20
15
10
5
0
Conditional Replenishment on MPEG-4
Normal MPEG-4
Video Sequence: Coast Guard
Condition: Error channel
Frame Number
0
50
100
150
200
250
300

e. INTER/INTRA Mode Switching

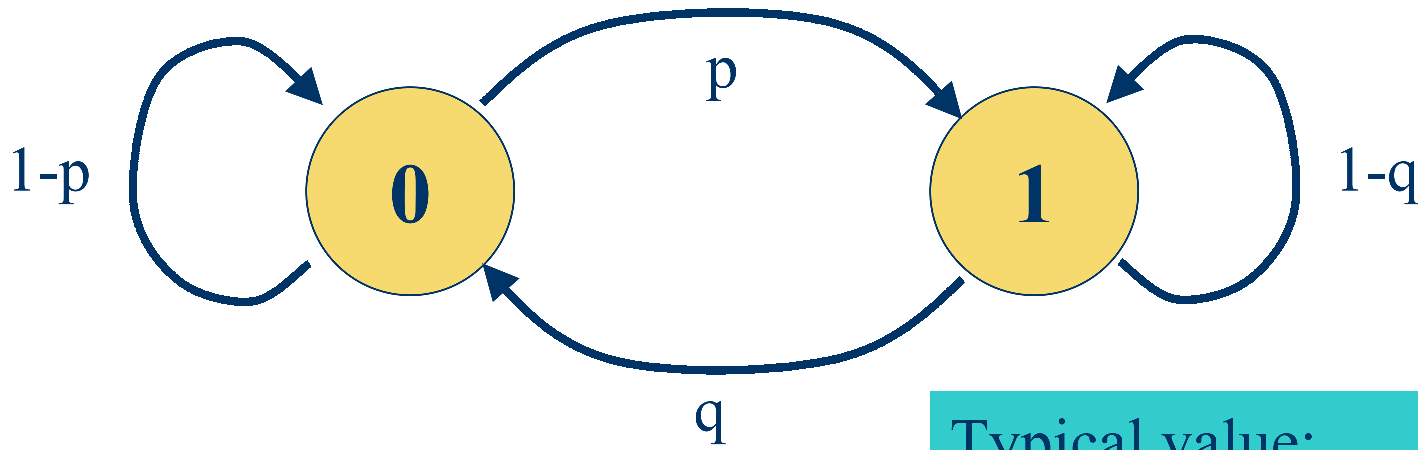
- The choice of using INTRA or INTER mode is determined by the level of channel error

  Error $\Uparrow$ $\Rightarrow$ INTRA

  Error $\Downarrow$ $\Rightarrow$ INTER

- If the statistic of channel error is known, an adaptive scheme can be derived

- **Let's consider the packet loss probability of Internet**



0: Receive   1: Lost

Typical value:
$p = 0.08; q = 0.60$

Average error rate: $\bar{P}_e = \dfrac{p}{p+q}$

Problem

If the channel packet loss probability is known, for a particular MB, when should we use INTRA mode and when should we use INTER mode?

Assumptions

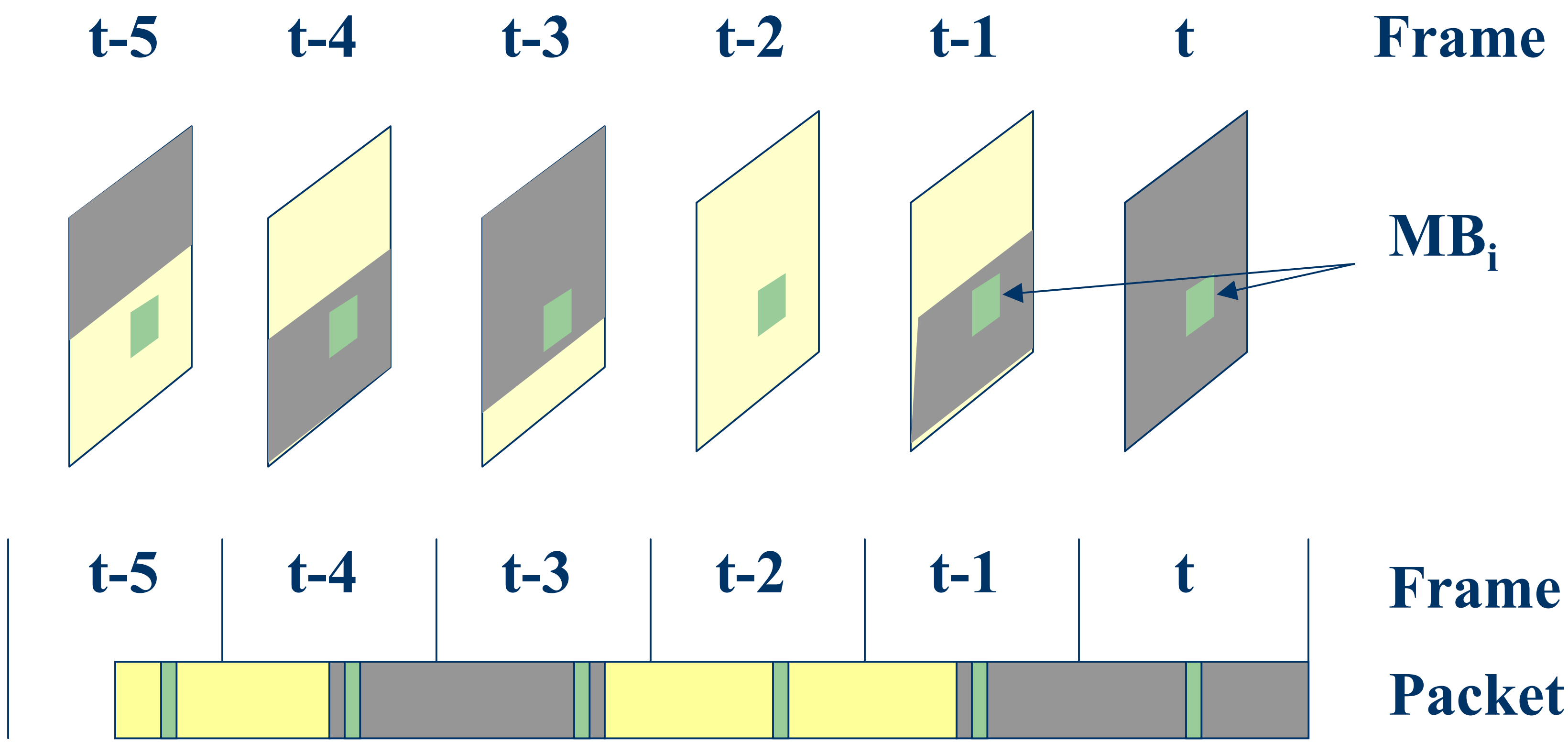
- **Each MB can be coded as INTRA or INTER**
- **If a MB is missing, it will be concealed by using the same MB in the previous frame**

Trade-off

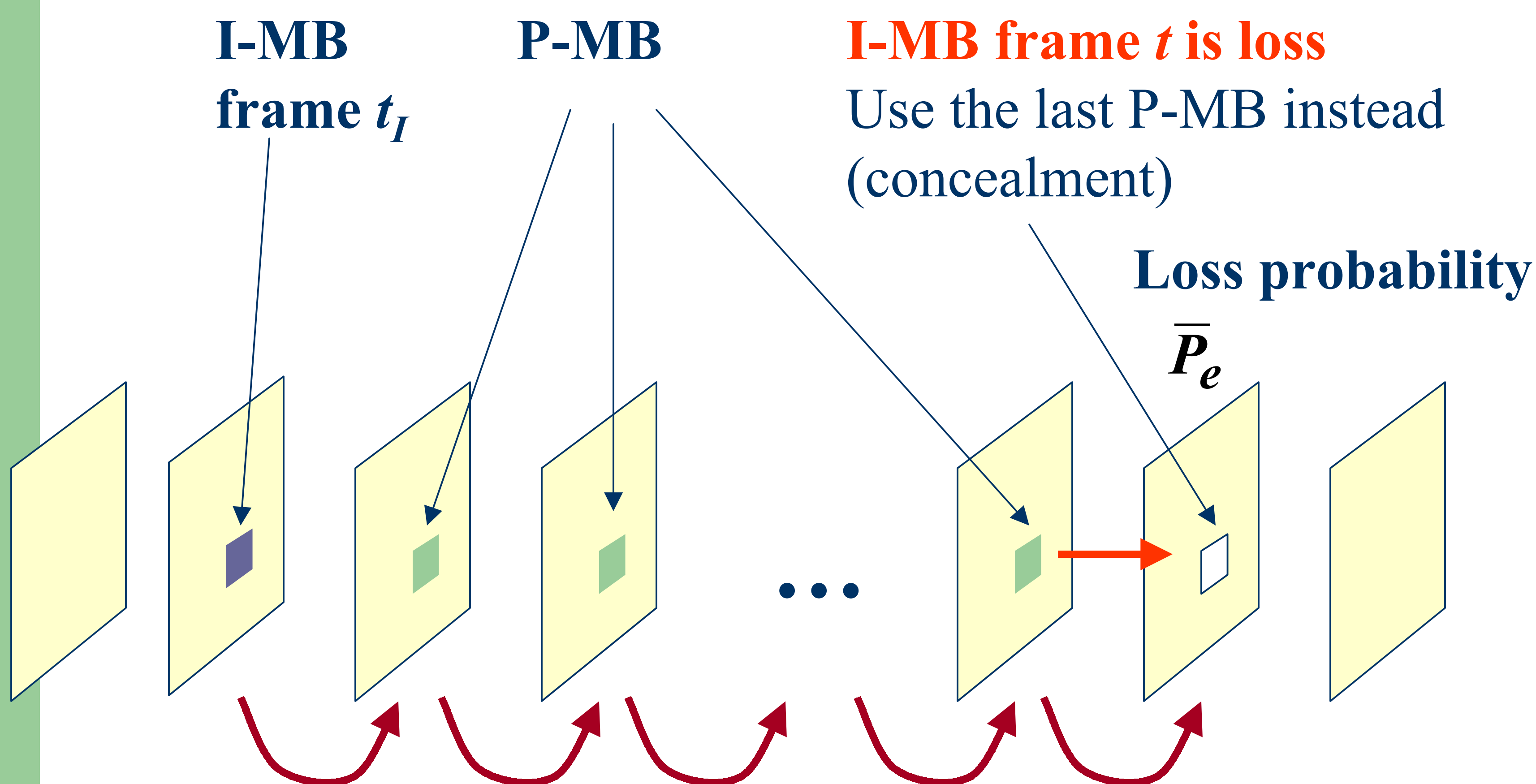
$$\text{Error} \Uparrow \;\Rightarrow \text{INTRA} \Rightarrow \;\text{Distortion} \Downarrow \text{Rate} \Uparrow$$
$$\text{Error} \Downarrow \;\Rightarrow \text{INTER} \Rightarrow \;\text{Distortion} \Uparrow \text{Rate} \Downarrow$$

- The first problem we need to tackle is, for an erroneous channel with known packet loss probability, how much distortion is introduced when using the INTRA or INTER mode?

Relationship between frame and packet



Each packet may contain one or more MBs at location *i*.
Losing one packet may lose one or more MBs at location *i*



The occurrence of I-MB is rare

Can use the average loss probability, i.e. $\overline{P}_e$

- **For an INTRA coded MB, the possible distortion introduced due to an erroneous channel can be**

MB *i*, Frame *t*

MB *i*, Frame *t* after quantization

MB *i*, Frame *t-1* after quantization

$$D(X_i^t, INTRA) = (1 - \overline{P}_e)\underbrace{\left| X_i^t - \hat{X}_i^t \right|}_{\text{Distortion due to quantization (normal)}} + \overline{P}_e \underbrace{\left| X_i^t - \hat{X}_i^{t-1} \right|}_{\text{Distortion due to loss packet (concealment applied)}}$$

Distortion due to quantization (normal)

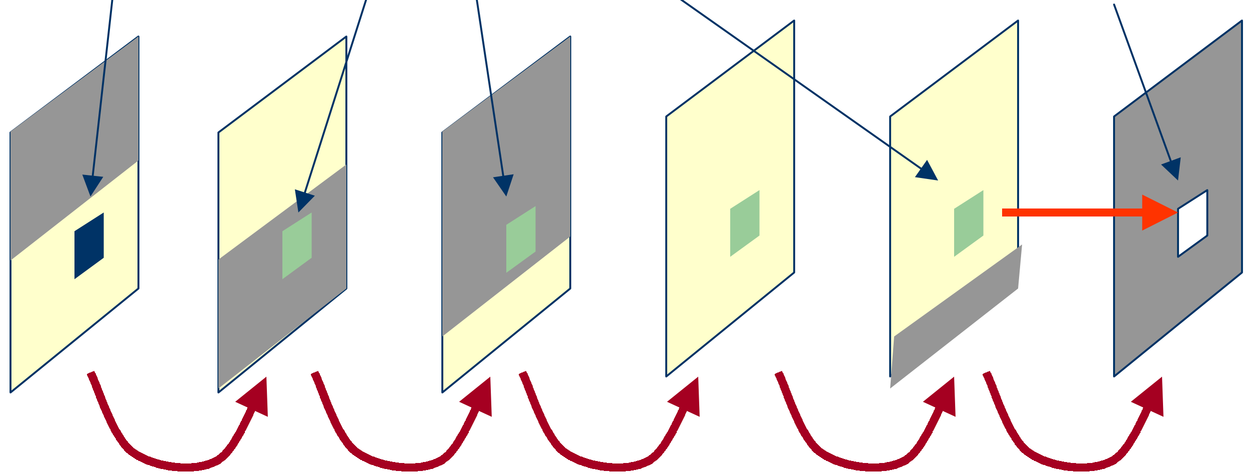
Distortion due to loss packet (concealment applied)

I-MB frame t_I

P-MB

P-MB frame *t* is loss

Use the last received P-MB instead (concealment)



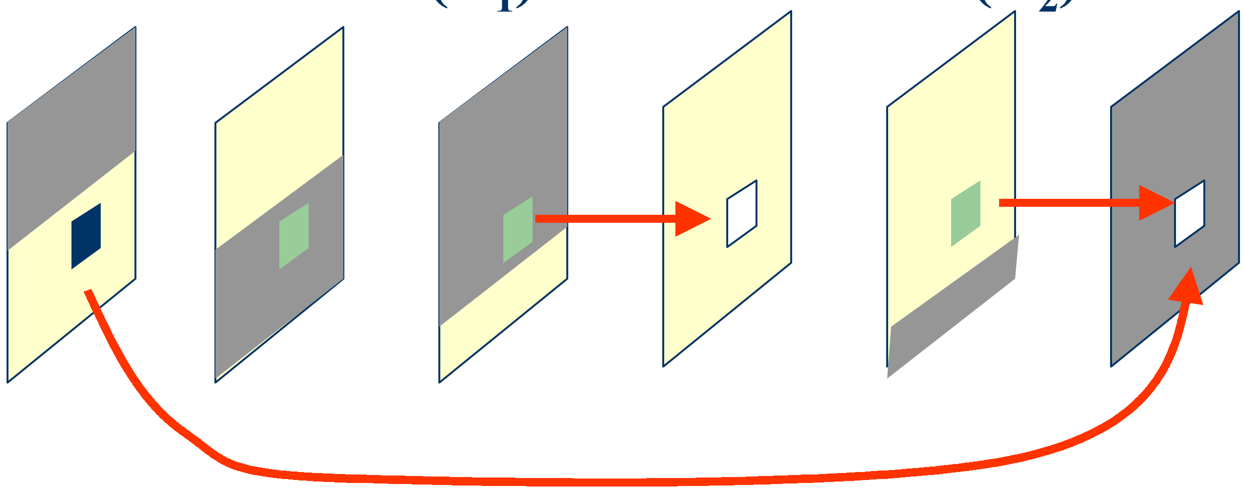
Probability of correctly receiving a packet = *1-p*

Probability of missing this P-MB
⇒ Depending on the history

- To give an accurate account of the loss probability of a P-MB, need the history of the previous P-MB
- To do so, need to keep the history of every MB in a frame
- To simplify, consider only the worst case
- Consider if the loss P-MB is concealed with the nearest I-MB, the distortion introduced is the highest no matter if the previous P-MBs are loss or not

Distortion due to this concealment (D_1)

Distortion due to this concealment (D_2)



Distortion if conceal in this way (D_3)

Assumption: $D_3 \geq D_1 + D_2$

- **For an INTER coded MB, the maximum distortion with an erroneous channel can be**

Total number of packets sent since last I-MB at location i

$$D(X_i^t, INTER) \leq (1-p)^{k_i} \left| X_i^t - \hat{X}_i^t \right| + (1-(1-p)^{k_i}) \underbrace{\left| X_i^t - \hat{X}_i^{t_I} \right|}$$

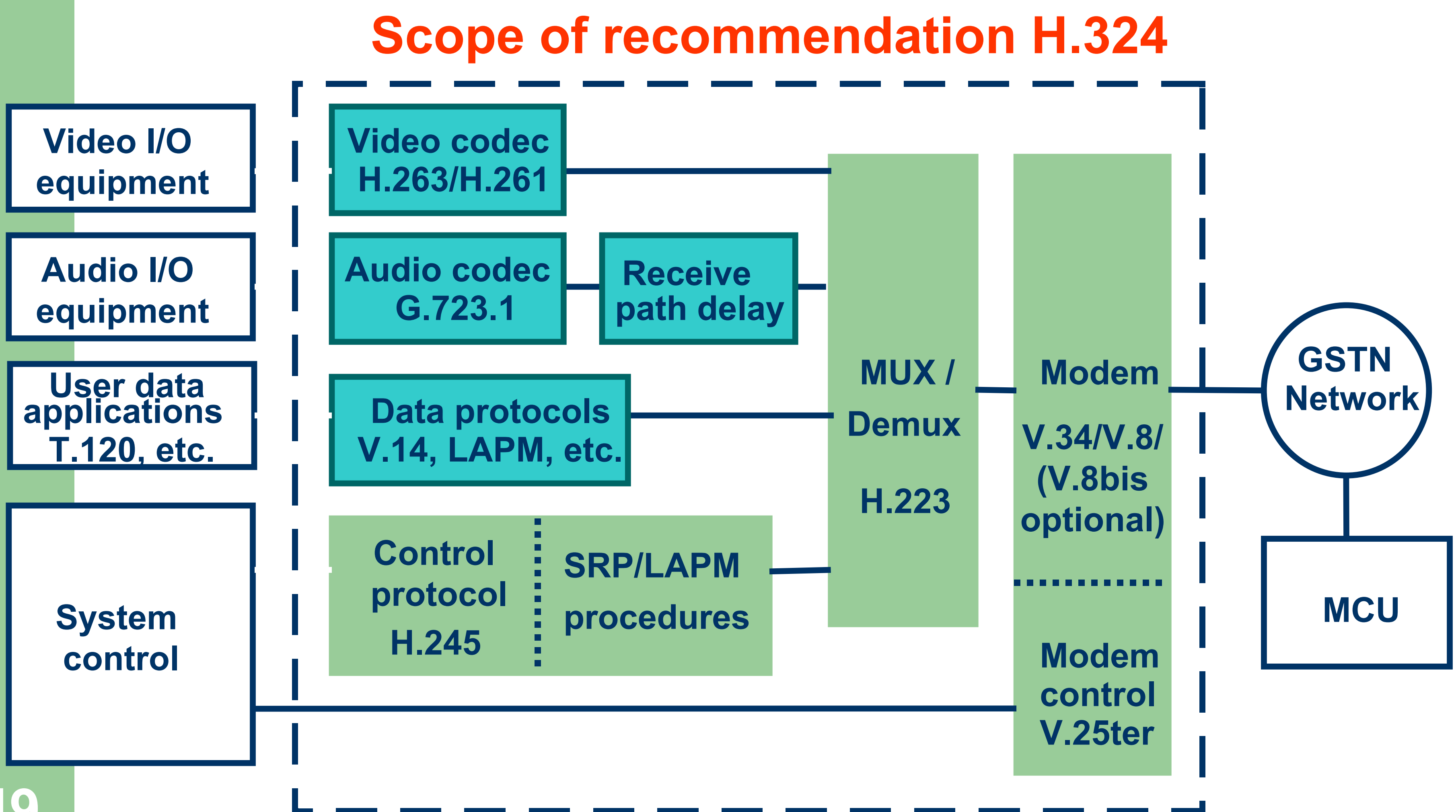
No matter how many packets are loss, maximum distortion will be introduced if we use the last I-MB at location *i* for concealment of the current block.

- The above two equations give the distortion measures when using INTRA or INTER mode for a macro-block transmitted thru an erroneous channel
- Consider also the rate incurred when using the two modes, an appropriate operating mode and point can be selected

5. Error Resilience in Communication Systems – Case study: H.324M

- **H.324 is an ITU standard for real-time multimedia communication on low-bit-rate circuit-switched network**
  - **Ordinary analog telephone networks**
  - **Mobile Radio telephone network**
- **H.324 targets at multimedia transmission at data rate 28.8/33.6 kbps with the V.34 data modem**
- **Also support very low-bit-rate (as low as 9.6kbps) multimedia data transmission for mobile radio applications**

A. Protocol Stack

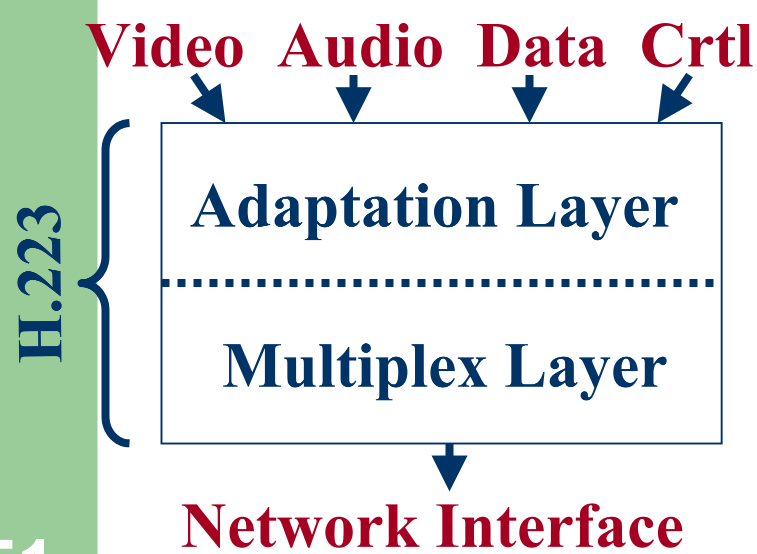


Work toward the H.324M Recommendation

- ITU-T started a new Ad Hoc Group (AHG) in 1994 to investigate the use of H.324 in mobile communication
- Has been divided into four areas:
  - Speech error protection
  - Video error protection
    - mobile extension to H.263 ⇒ H.263+
  - Communications control - adjustments to H.245
  - Error control of the multiplexed signal
    - extension to H.223
  - System

B. Multiplexer - H.223

- H.324 uses a special multiplexer standard - H.223
- H.223 mixes the various streams of video, audio, data, and the control into a single bitstream

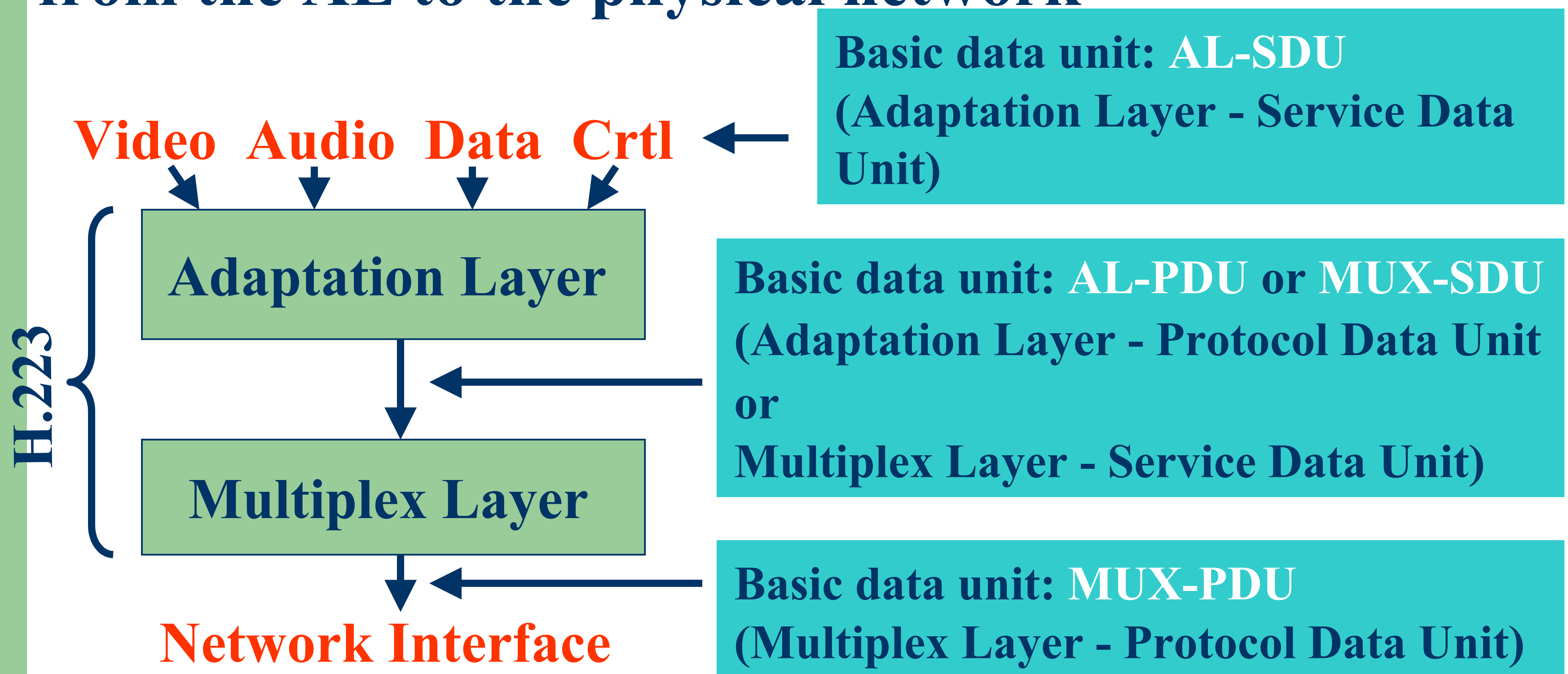


<u>Adaptation Layer</u>
- 4 layers for different media types
- Perform logical framing
- Sequence numbering
- Error detection and correction by retransmission

<u>Multiplex Layer</u>
- Perform actual multiplexing

I. Multiplex Layer

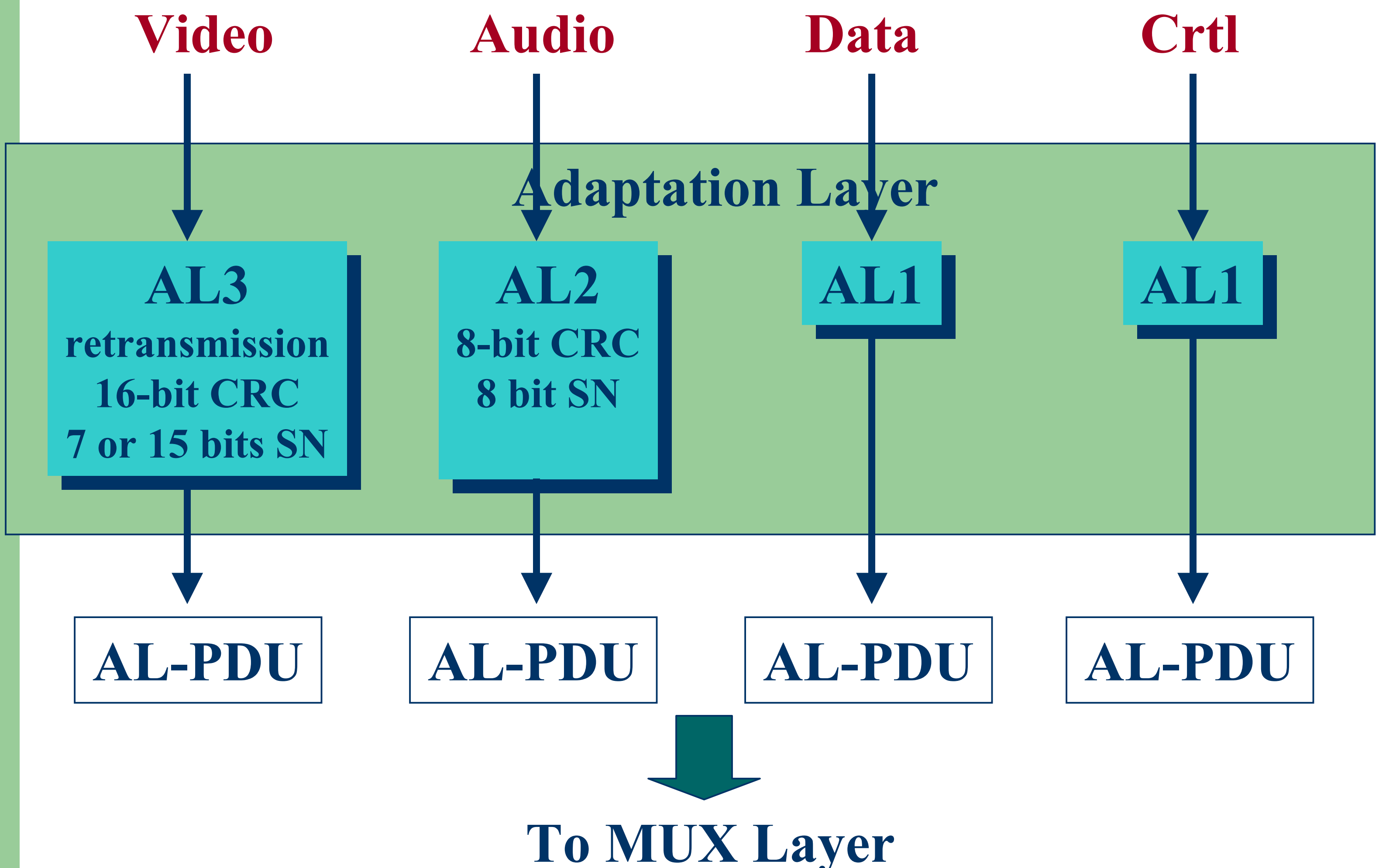
- **Responsible for transferring information received from the AL to the physical network**



II. Adaptation Layer

- Different media types (audio, video, data, control) require different levels of error protection
- Data & Control - relatively delay-insentive, but extremely error-sensitive
  - Require sophisticate error detection and protection
  - But allow lengthy process
- Audio - extremely delay sensitive, accept occasional error
  - Require some error protection
  - But need to be fast
- Video - moderate error and delay sensitive
  - Require better error protection than audio
  - It can tolerate to use more time for error protection

Three Adaptation Layers

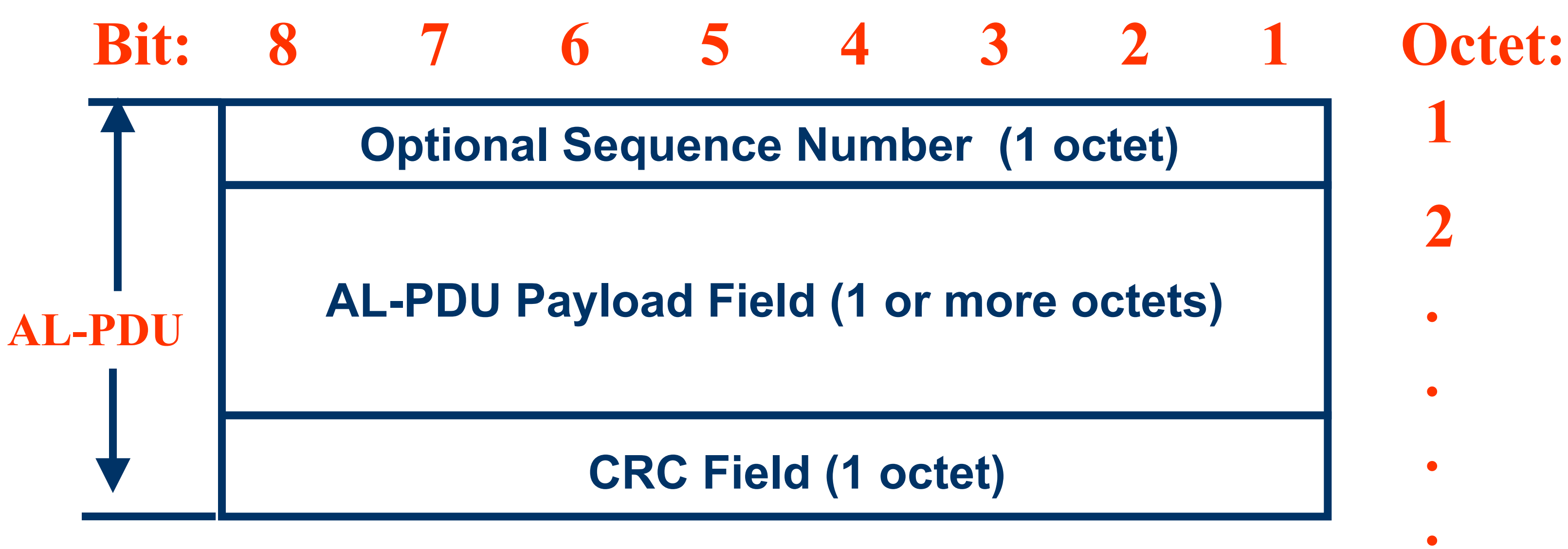


a. Adaptation Layer Type 1 (AL1)

- Design primarily for the transfer of data or control information
- Does not provide any error detection or correction capability
- Need higher layer to provide error detection and correction
- Provide two transfer modes:
  - Framed transfer mode
    Transfer data frames generated by higher-layer protocol
    e.g. LAPM/V.42, LAPF/Q.922
  - Unframed transfer mode
    Transfer unframed octet sequence
    Any framing information is not visible to AL1

b. Adaptation Layer Type 2 (AL2)

- Design primarily for the transfer of digital audio
- Provide an 8-bit CRC for error-detection
- Support optional sequence numbering which may be used to detect missing and misdelivered AL-PDUs



c. Adaptation Layer Type 3 (AL3)

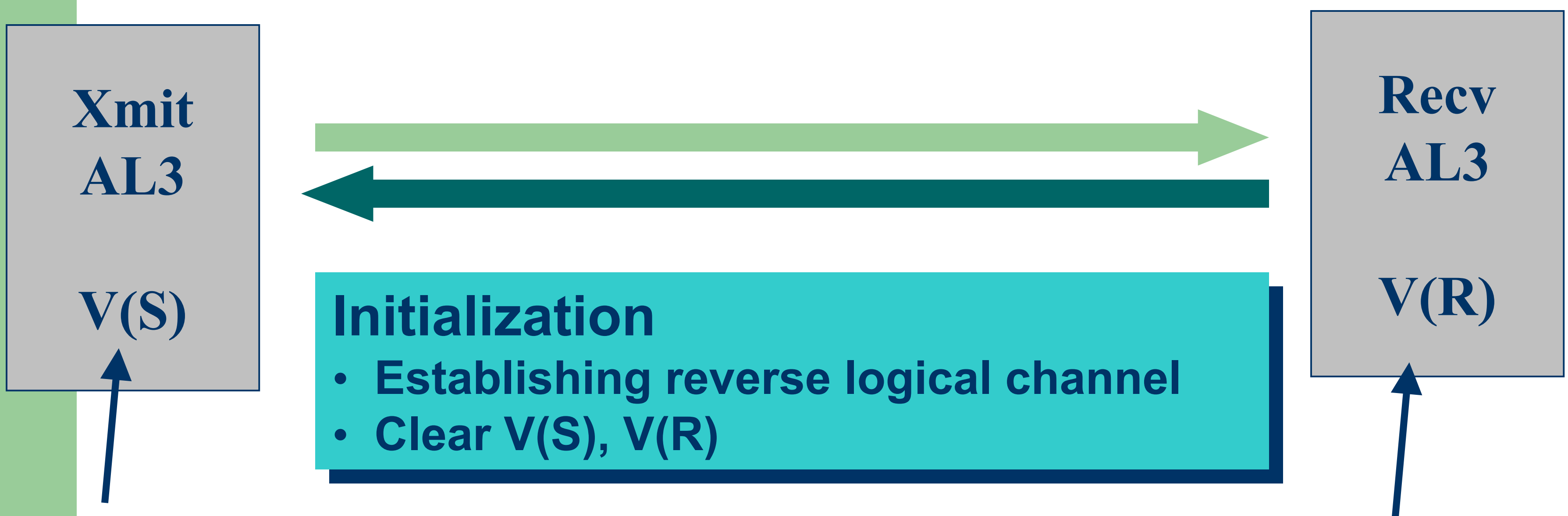
- Design primarily for the transfer of digital video
- Include a 16-bit CRC for error-detection
- Also support optional 7 or15 bits sequence numbering which may be used to detect missing and misdelivered AL-PDUs
- Provide an optional retransmission procedure for video

	Bit: 8 7 6 5 4 3 2 1	Octet:
AL-PDU	Control Field (0, 1, or 2 octets)	1
	AL-PDU Payload (1 or more octets)	. . .
	CRC Field (2 octets)	. .

d. AL3 Error Control - Invalid AL-PDUs

- An invalid AL-PDU is one which:
  - has fewer than the minimum number of octets; or
  - does not contain an integral number of octets; or
  - is longer than the maximum AL-PDU size; or
  - contains a CRC error
- When control field is present, the AL3 receiver has the option of invoking the retransmission procedure in case of receiving invalid AL-PDU

e. AL3 Error Control - Retransmission



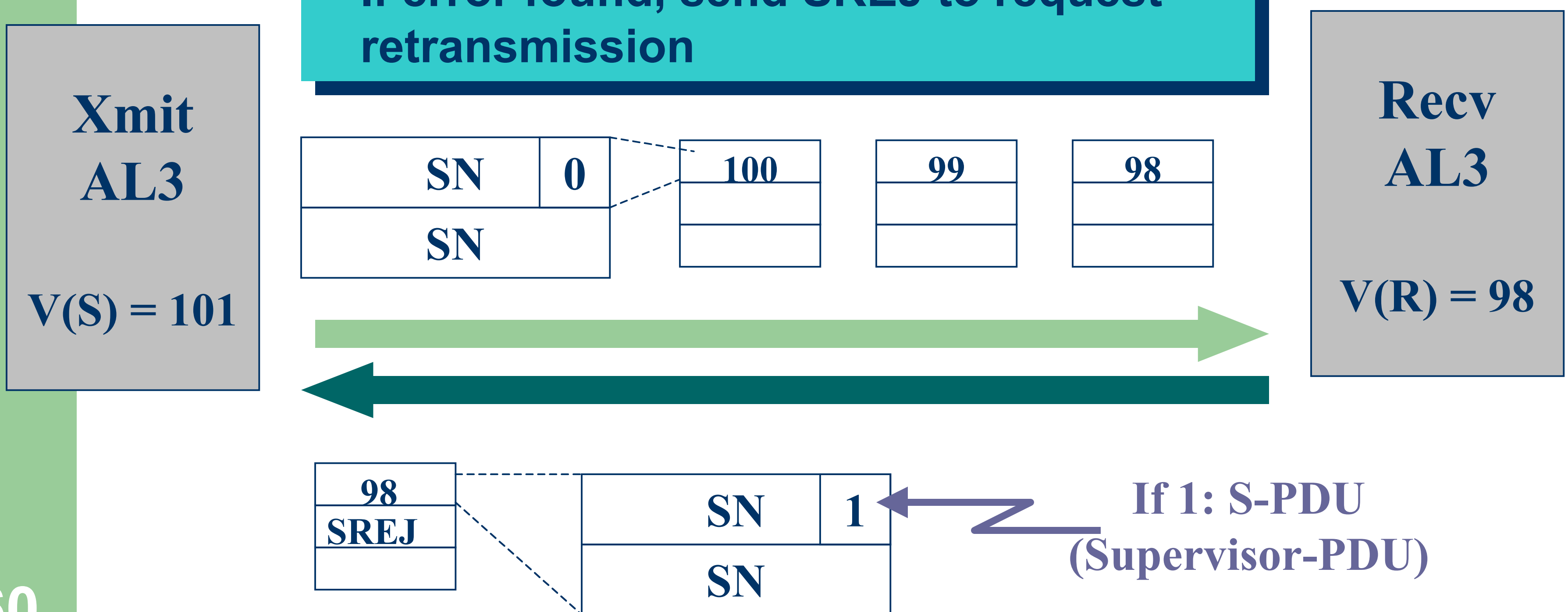
SN of next Xmit I-PDU
I-PDU: Normal PDU

SN of next expected recv I-PDU
I-PDU: Normal PDU

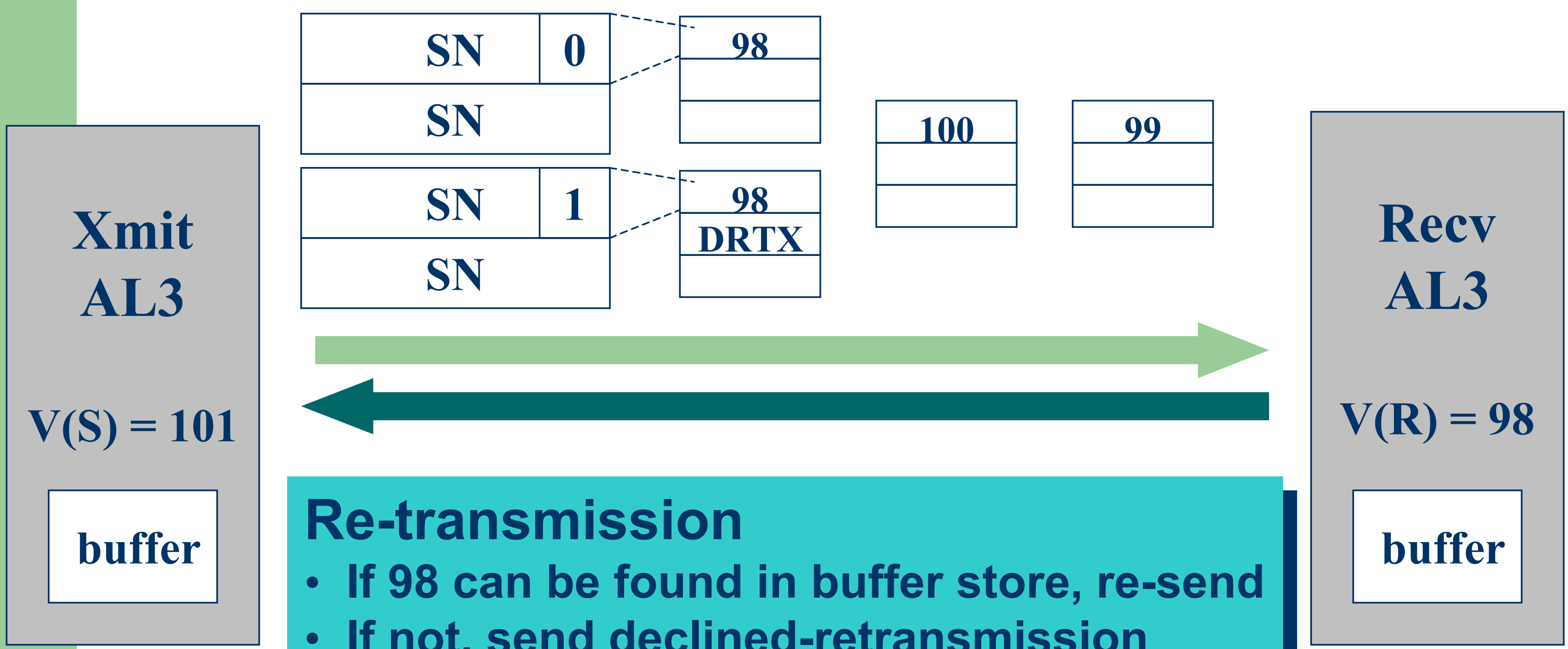
e. AL3 Error Control - Retransmission (Con't)

In-sequence communication

- SN of I-PDU = V(S)
- V(R) = SN of I-PDU
- If error found, send SREJ to request retransmission



e. AL3 Error Control - Retransmission (Con't)



Re-transmission

- If 98 can be found in buffer store, re-send
- If not, send declined-retransmission (DRTX)