Fine Grain Adaptive FEC (FGA-FEC) over Wireless Networks

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Problem statement and challenges

- Problem:
  - Simultaneously streaming video to diverse users, such as powerful PCs, laptops and handset devices, over heterogeneous networks.

- Challenges:
  - Different users may have different video frame-rate /resolution /quality preferences.
  - Users may be in different networks, such as high-speed wired network, multi-hop ad hoc wireless network, or cellular network.
  - Neither the network nor the video application can provide quality assurances working independently of each other.

Problem statement and challenges

In addition to congestion related packet losses, in wireless case we must deal with:

- ☐ channel bit errors due to channel fading and noise,
- ☐ large bandwidth fluctuations, and
- ☐ intermediate node computational capability constraint,
- ☐ limited maximum transmission unit (MTU) size.

FGA-FEC (fine grain adaptive - FEC)

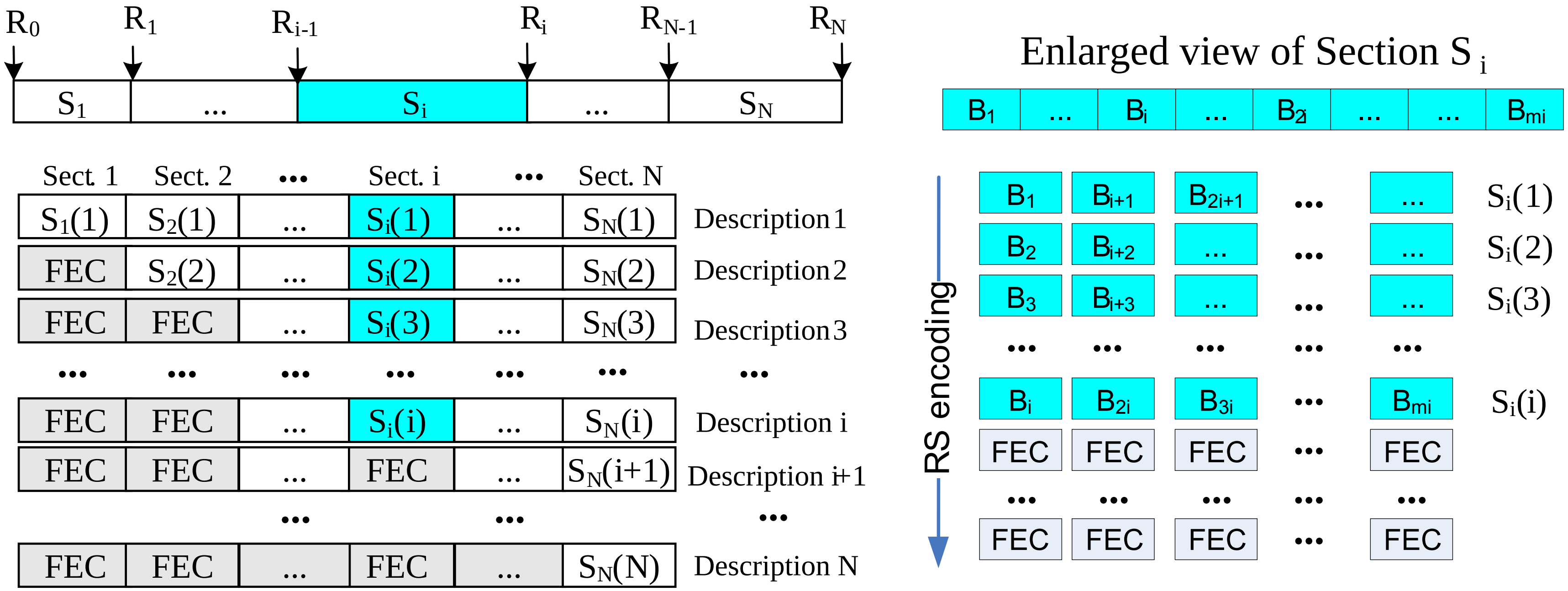
Goal:

- **To encode a video to facilitate efficient and precise adaptation of the encoded bitstream at intermediate overlay nodes for diverse users.**

Main idea:

Extend existing approaches (PET, MD-FEC) to scalable video with simultaneous in-network adaptation of bitrate, frame-rate, and spatial resolution.

FGA-FEC Encoding

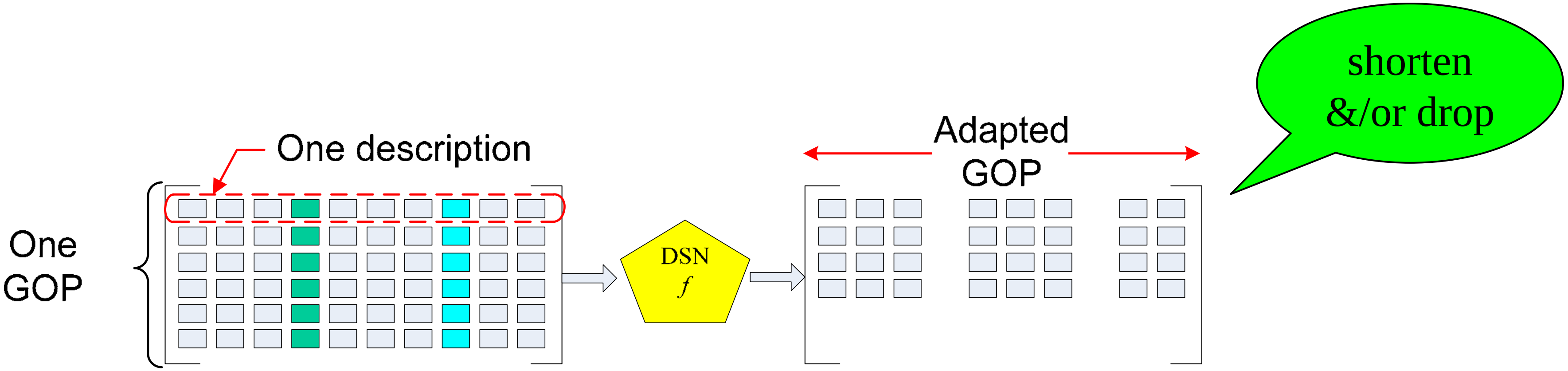


Sect. 1	Sect. 2	•••	Sect. i	•••	Sect. N	
$S_1(1)$	$S_2(1)$	...	$S_i(1)$	...	$S_N(1)$	Description 1
FEC	$S_2(2)$	...	$S_i(2)$	...	$S_N(2)$	Description 2
FEC	FEC	...	$S_i(3)$	...	$S_N(3)$	Description 3
•••	•••	•••	•••	•••	•••	•••
FEC	FEC	...	$S_i(i)$	...	$S_N(i)$	Description i
FEC	FEC	...	FEC	...	$S_N(i+1)$	Description i+1
		•••		•••		•••
FEC	FEC	...	FEC	...	$S_N(N)$	Description N

B_1	B_{i+1}	B_{2i+1}	•••	...	$S_i(1)$
B_2	B_{i+2}	...	•••	...	$S_i(2)$
B_3	B_{i+3}	...	•••	...	$S_i(3)$
•••	•••	•••	•••	•••	
B_i	B_{2i}	B_{3i}	•••	B_{mi}	$S_i(i)$
FEC	FEC	FEC	•••	FEC	
•••	•••	•••	•••	•••	
FEC	FEC	FEC	•••	FEC	

- Bitstream is divided into *N* sections from MSB down to LSB
- Each section is further split into small blocks
- RS(N,i) codes are applied at block level to section S_i, vertically
- Each block column is independently accessible
- one description = one network packet

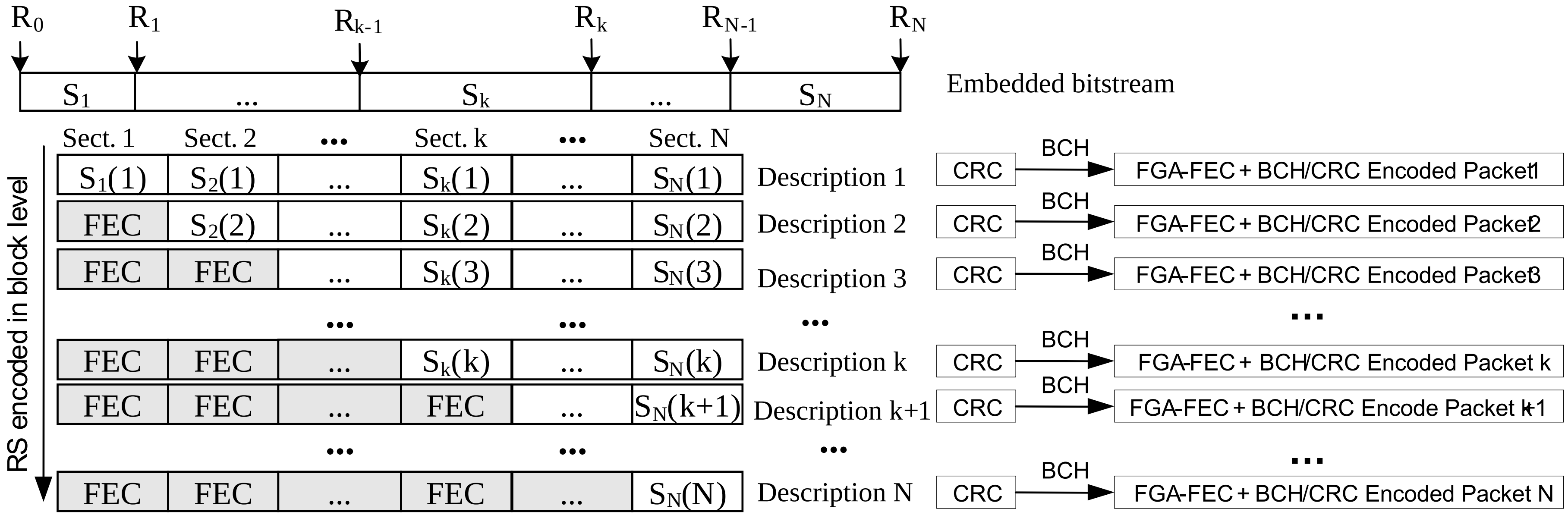
FGA-FEC adaptation at intermediate nodes



Two adaptation methods are used in FGA-FEC :

- ***Direct truncation*: only shorten each packet in a GOP by removing unwanted blocks.**
- ***FGA-FEC adaptation*: adapt the encoded GOP by a combined shortening and/or dropping packets.**
- **An algorithm is proposed to near optimally adapt the encoded GOP for available bandwidth and user preference**
- **No video or FEC transcoding, only a packet shortening and/or dropping**

Generalized FGA-FEC for wireless



Generalized FGA-FEC = FGA-FEC + Bit level protection

a type of product code (extend Sherwood and Zeger's code)**:**

- ❑ column codes: Reed-Solomon for packet loss
- ❑ row codes: CRC + BCH for bit errors

A BCH code is represented as: BCH(n,k,t): $n = 2^m$-1, n-k <= mt

Optimal product code assignment

Find a concatenated column RS code assignment c_c and row BCH code assignment c_r from a set of RS codes C_{RS} and BCH codes C_{BCH} BCH(n,k,t), such that the end-to-end video distortion over a lossy channel is minimized.

$$c_c, c_r = \arg\min_{c_c \in C_{RS}, c_r \in C_{BCH}} E[D \mid C_{RS}, C_{BCH}, C_{CRC}]$$

Subject to channel rate constraint:

$$R_S + R_{RS} + R_{CRC} + R_{BCH} \leq B$$

where R_s , R_{RS} , R_{CRC} and R_{BCH} are rates allocated to the video source, RS parity bits, CRC and BCH check bits, respectively. Here B denotes the maximum available channel bandwidth

The optimization algorithm

Problem:

Minimize the e2e distortion for each user:

$$E[D(R_i)] = \sum_{i=0}^{N} q_i D(R_i)$$

Subject to:

$$\begin{cases} 0 \le R_1 \le R_2 \le \cdots \le R_N \\ R_{total} \le B \\ R_i - R_{i-1} = r_i \times i \quad r_i \ge 0,\ \forall\, i \in [1, N] \end{cases}$$

where

$$q_i = \binom{N}{i}(1-p)^i p^{N-i}$$

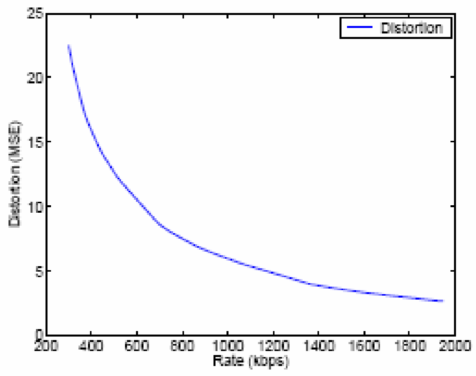
$$R_{total} = \sum_{i=1}^{N} \frac{N}{i(i+1)} R_i = \sum_{i=1}^{N} \alpha_i R_i$$

Solution:

Use Lagrange multiplier method:

$$F(R_1, R_2, \ldots, R_N, \lambda) = \sum_{i=1}^{N} q_i D(R_i) - \lambda\left(\sum_{i=1}^{N} \alpha_i R_i - B\right)$$

$$\begin{cases} \dfrac{\partial D(R_1)}{\partial R_1} = -\dfrac{\alpha_1}{q_1}\lambda \\ \quad\cdots \\ \dfrac{\partial D(R_i)}{\partial R_i} = -\dfrac{\alpha_i}{q_i}\lambda \\ \quad\cdots \\ \dfrac{\partial D(R_N)}{\partial R_N} = -\dfrac{\alpha_N}{q_N}\lambda \\ \displaystyle\sum_{i=0}^{N} \alpha_i R_i = B \end{cases}$$



Given one value of λ, $\dfrac{\partial D(R_i)}{\partial R_i} = -\dfrac{\alpha_i}{q_i}\lambda$ corresponds to the point on the *D*(*R*) curve with slope equal to $-\dfrac{\alpha_i}{q_i}\lambda$

Solution can be found by searching over λ

Fast optimization method

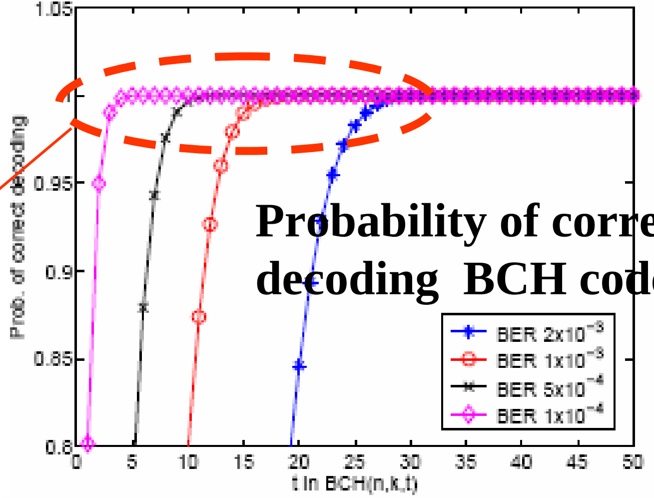
Given a BCH code BCH(n,k,t)

$$P_{BCH}(C) = \sum_{j=0}^{t} \binom{n}{j} p_b{}^{j} (1 - p_b)^{n-j}$$

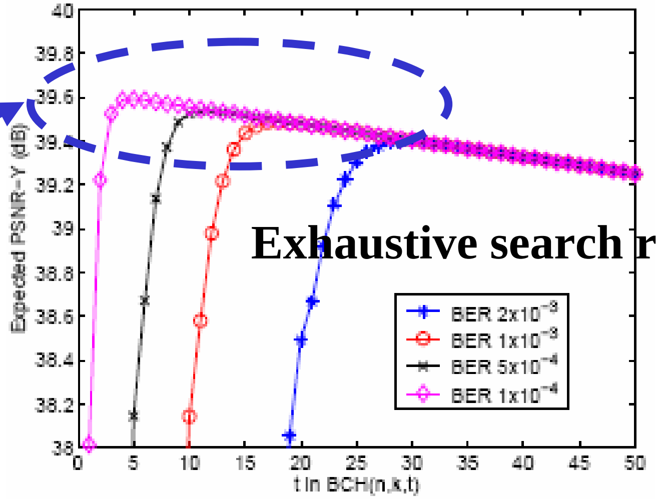
Near optimal points, search starts here,

it can find the optimal solution within a few iterations

n=8191, m=13



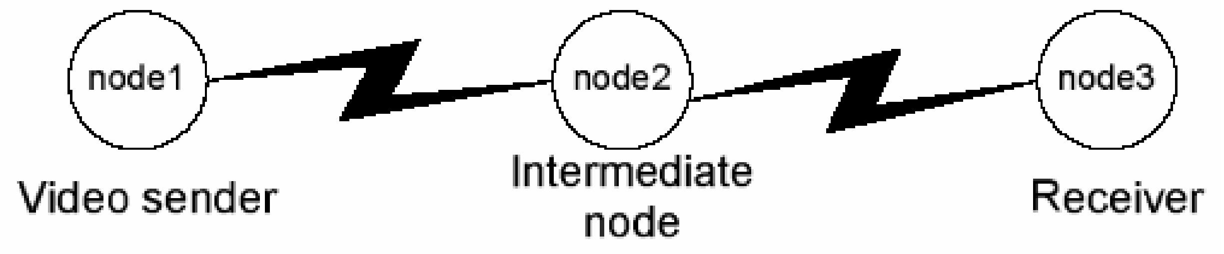
Probability of correctly decoding BCH code



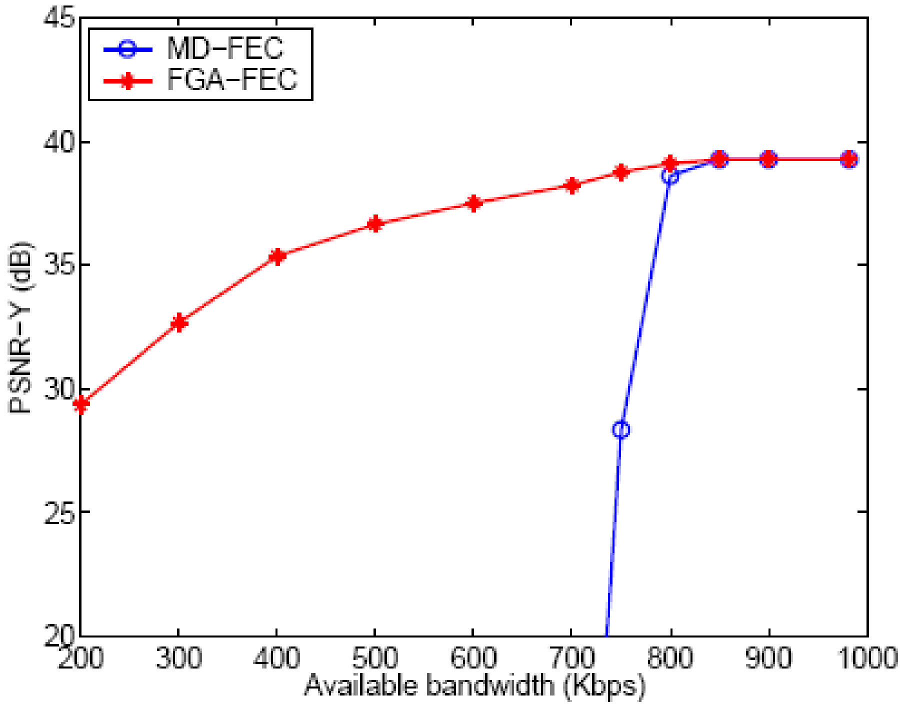
Exhaustive search results

GOP #7 of *Foreman*, CIF, N= 64, p_{drop}=0.05, BER pb varies

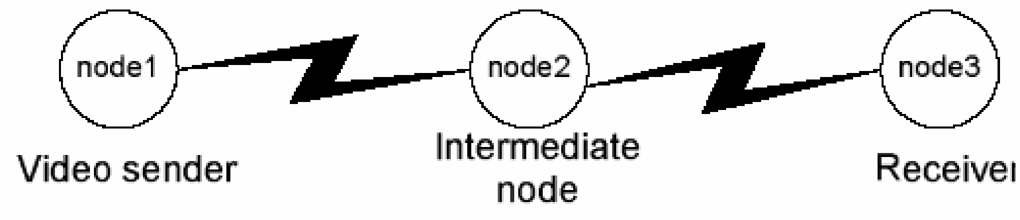
Simulation – FGA-FEC vs. MD-FEC in wireless



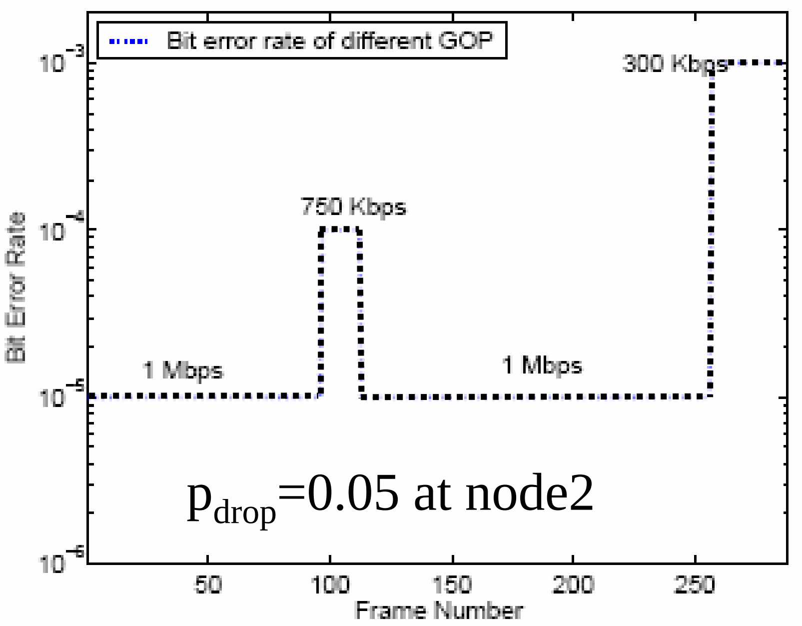
- ❑ Foreman CIF sequence
- ❑ Channel changes over time between node 2 and 3, from 200 Kbps to 100 Kbps, BER = 1x10-4, packet drop probability at node2 is 0.05.
- ❑ Only SNR scalability



Simulation – FGA-FEC vs. MD-FEC in wireless



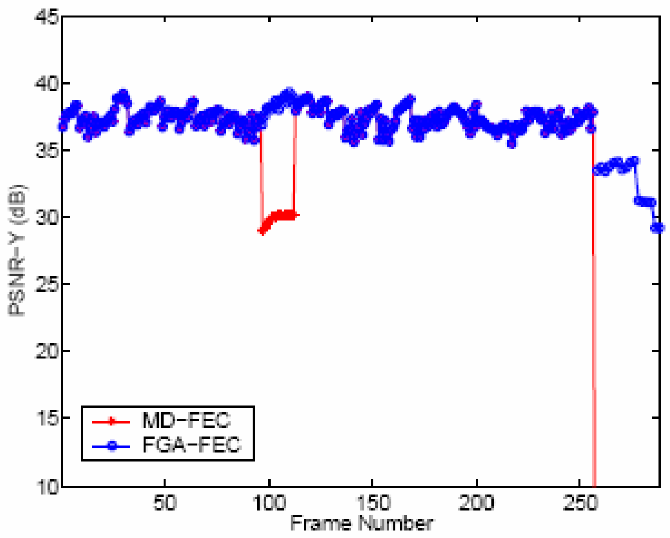
Channel changes over time between node 2 and 3



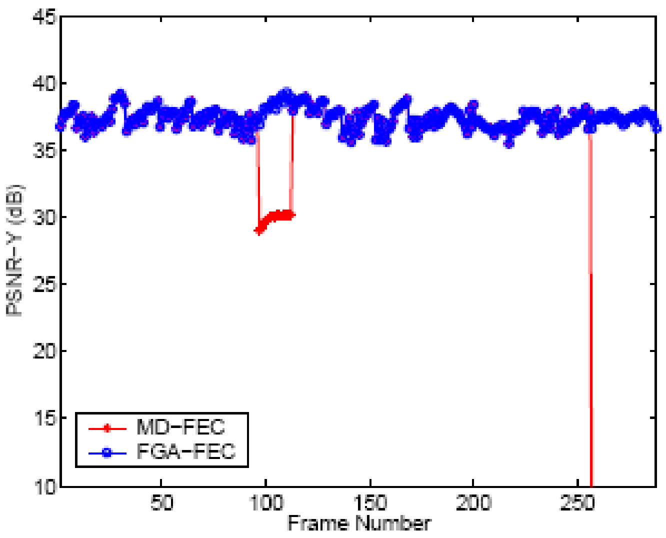
p_{drop}=0.05 at node2

Consider two adaptation orders:

SNR -> Temporal, SNR -> Spatial



Frame rate scaling



Resolution scaling

Conclusions

In this paper, we generalize FGA-FEC (ICIP ’05) for embedded video bitstream protection and content adaptation over *wireless* channels. We propose a fast search algorithm to assign the optimal product codes. Simulations indicate efficiency for simultaneous content protection and adaptation.