

Cooperative Source and Channel Coding for Wireless Video Transmission

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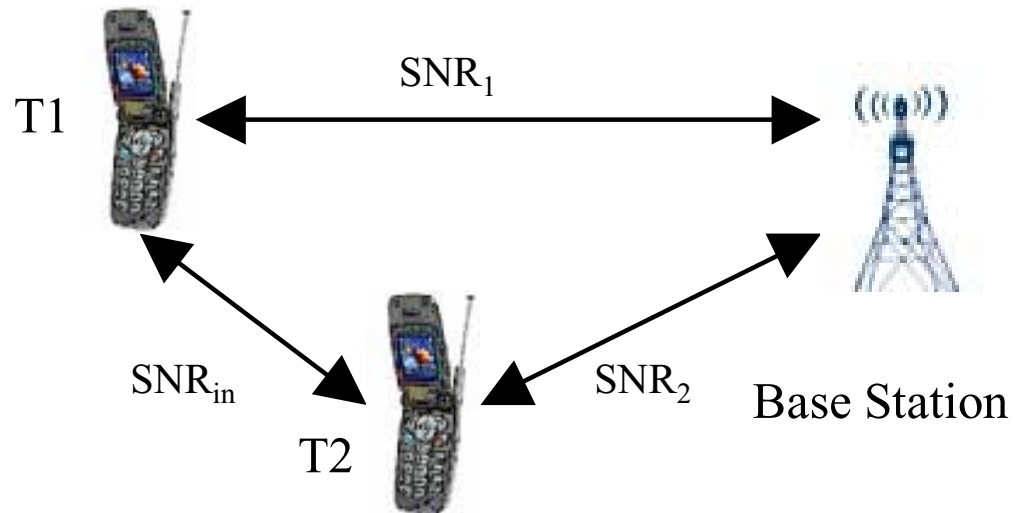
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<http://vision.poly.edu:8080/~hoiyin/project1.htm>

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What is User Cooperation?

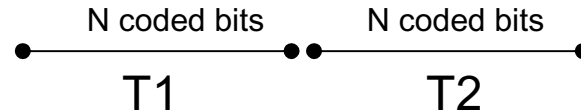
- With wireless transmission, a terminal can “overhear” the signal sent from nearby terminals to others.
- With cooperation, T1 and T2 help each other to transmit their signals to the destination.



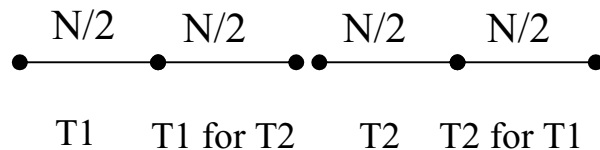
Generally, the destination could be another mobile user, and the destinations for T1 and T2 could be different.

Example: Cooperation in TDMA

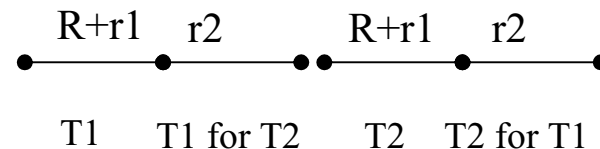
- In a TDMA system, each user sends during alternating time slots (channel frames).



- With cooperation, a user sends for the partner in part of his time slot.
 - Simple case: half for self, half for partner (repetition coding)



- More general case



How to Apply Cooperation to Multimedia Signals?

- For lossless data transmission, should maximize throughput
- For audio-visual signals, should maximize quality or minimize distortion
- Distortion caused by source compression and uncorrectable transmission errors
 - Require appropriate bit allocation between source coding, channel coding, cooperation
 - Temporal prediction used in video coding leads to transmission error propagation in decoded frames
 - Further complicates the bit allocation problem
- **Not all source bits are equal!**

Layered Cooperation

- Traditional approach: unequal error protection through layered coding and unequal FEC
 - Code the signal into base layer and enhancement layer
 - Apply more channel redundancy bits for base layer
- Proposed approach: **UEP through unequal FEC and Coop**
 - Code the signal into several layers
 - Channel bits for each layer split between the user and its partner
 - Total channel bits and the split differ among layers
 - Simple case: **Use coop only for base layer**

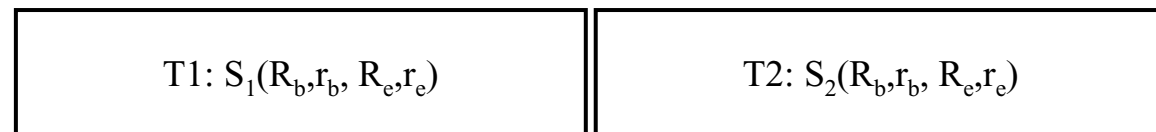
Four Modes of Communications

1 TDMA Slot = R_t bits

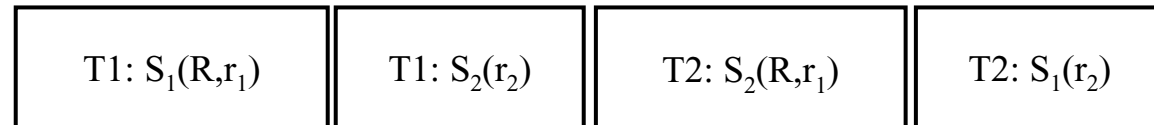
Mode 1: direct transmission



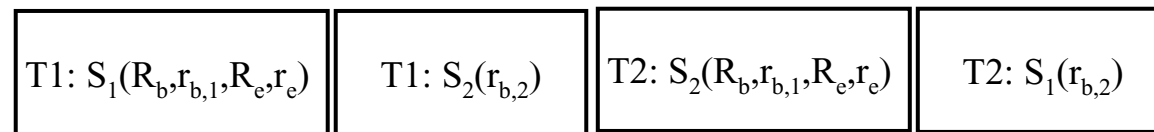
Mode 2: layered transmission



Mode 3: cooperative transmission

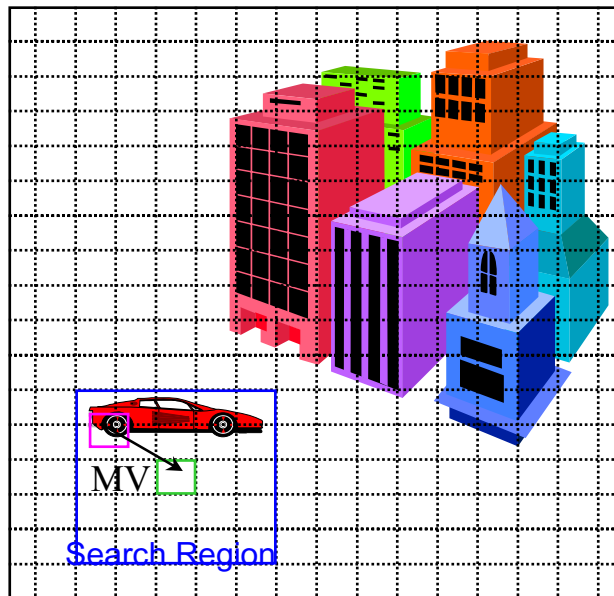


Mode 4: layered cooperation

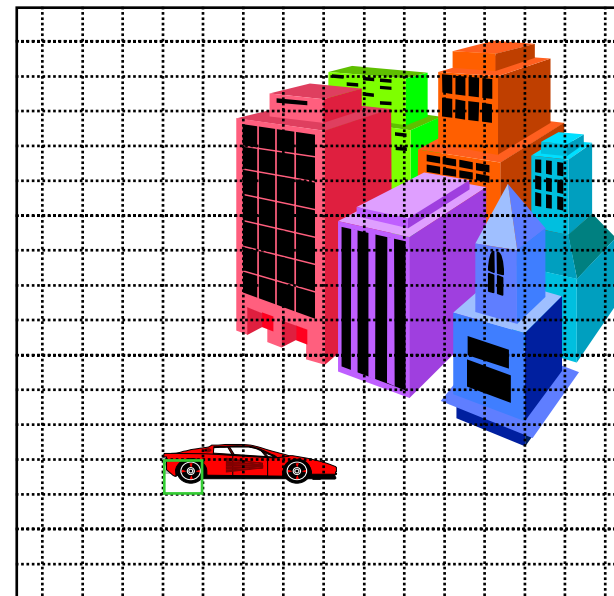


Rate constraint for Mode 4: $R_b + r_{b,1} + r_{b,2} + R_e + r_e \leq R_t$

Video Coding Using Block-based Motion Compensated Prediction



Frame $t-1$
(Reference Frame)

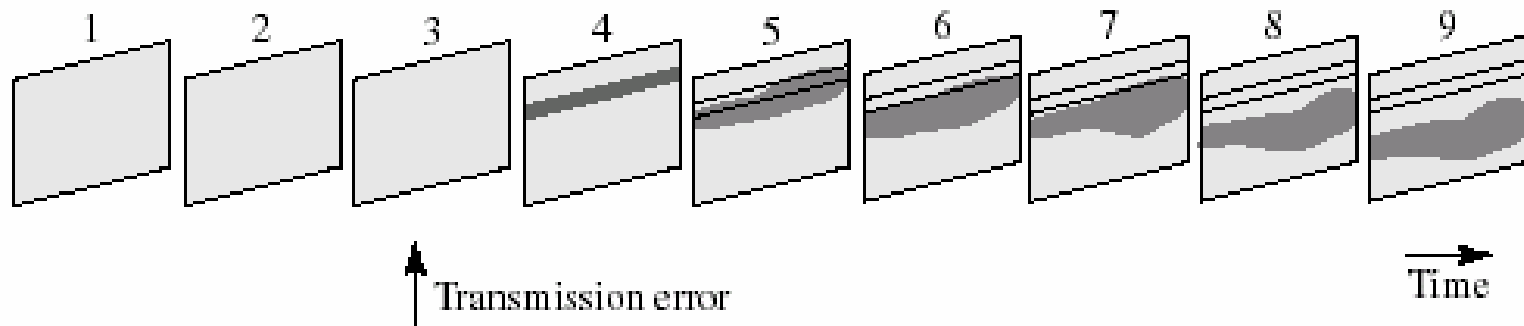


Frame t
(Predicted frame)

- MCP can effectively exploit the correlation among adjacent video frames and hence improve the coding efficiency

What if some source bits are lost?

- Lost bits make a group of video blocks (GoB) containing these bits undecodable
- Decoder recovers these blocks using a chosen error concealment method
 - E.g. Copy from corresponding region in the previous frame
- The prediction loop causes error propagation in decoded video



How to limit Error Propagation?

- INTRA Coding:
 - Code a block directly (using DCT) w/o prediction from previous frame
 - Stops error propagation, at the expense of coding efficiency
- Periodic INTRA Frame:
 - Cause bit rate spikes, not suitable for real-time applications or constant rate channels
- Periodic INTRA Blocks:
 - A fraction (β) of blocks in any frame are coded in INTRA
 - Different sets of blocks are chosen in different frames
 - Over a time interval ($T=1/\beta$ frames) all blocks are refreshed

Optimization Problem

- For each mode, and given channel conditions ($\text{SNR}_1, \text{SNR}_2, \text{SNR}_{\text{in}}$)
- Determine the bit allocation ($R_b, R_e, r_{b1}, r_{b2}, r_e$) and intra rate (β) that maximizes the decoded video quality under the total rate constraint ($R_b + R_e + r_{b1} + r_{b2} + r_e = R_t$)
 - Redundancy allocation among source coding, channel coding, and cooperation
- Use average PSNR over all decoded frames as the quality measure
 - PSNR for one frame = $10 \cdot \log(255^2 / \text{MSE})$
- Closed form expression for PSNR or MSE are difficult to obtain
 - MSE for one frame depends on MSE for previous frame due to error propagation!
- Use simulations with different parameter settings to determine the optimal configuration

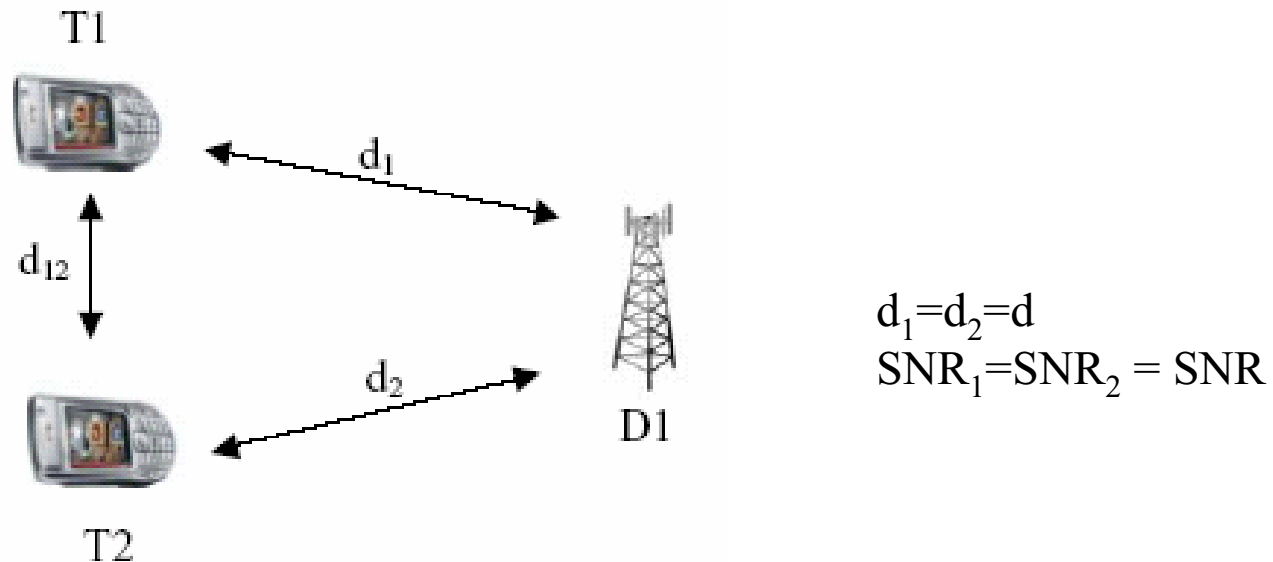
Simulation Setup

- H.263+ video codec with SNR scalability
- Test sequences:
 - *Mother-Daughter* (low-motion), *Foreman* (medium motion), *Football* (fast motion), QCIF (176x144), coded at 10 fps
- Channel simulation:
 - TDMA frame=10 ms, 1728 bits per frame (172.8 kbps total)
 - Quasi-static fading, fading level changes every 100 ms = 1 video frame (slowly moving users)
 - Source bit rate range: 43 ~ 172 kbps
- Video decoder:
 - Uncorrectable frame error -> loss of all source bits in a channel frame -> loss of several video blocks
 - Recover using corresponding blocks in the previous frame

FEC Simulation

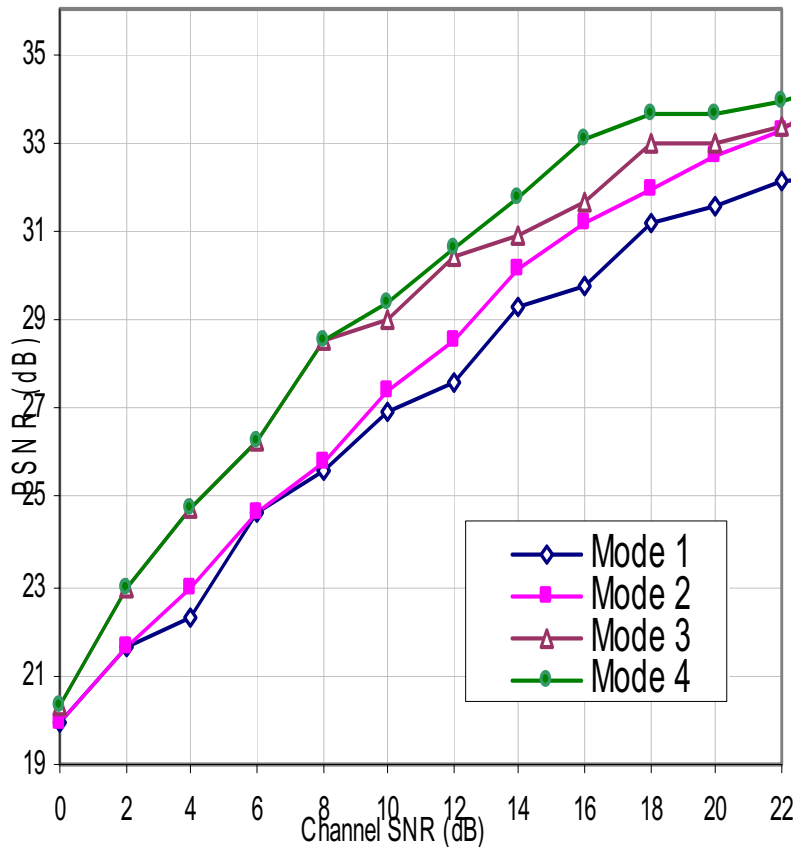
- Use the RCPC rate $\frac{1}{4}$ mother code
- Truncate to 1, $\frac{2}{3}$, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$ to realize different bit allocation
- Destination combines bits received from both channels to decode
- Assume the decoder can accurately measure the instantaneous fading level in each channel
- Maximum likelihood decoding (Viterbi) based on the measured fading level

Symmetric Cooperation



- For selected d_{12} (SNR_{in}), varying d (SNR) over a large range

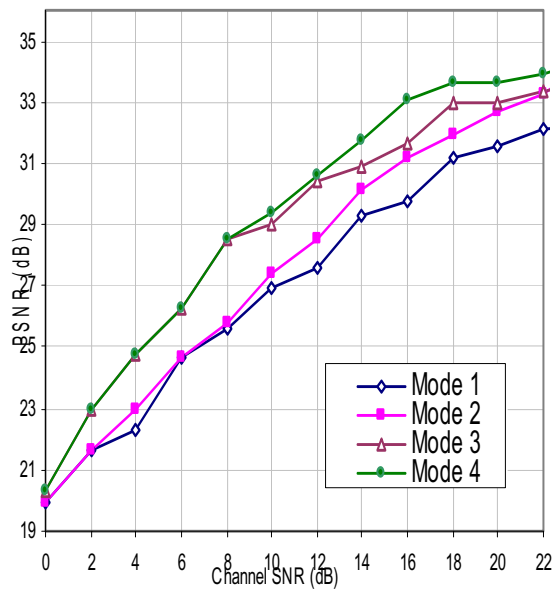
Results for *Foreman* (Assuming Perfect Inter-Partner Channel)



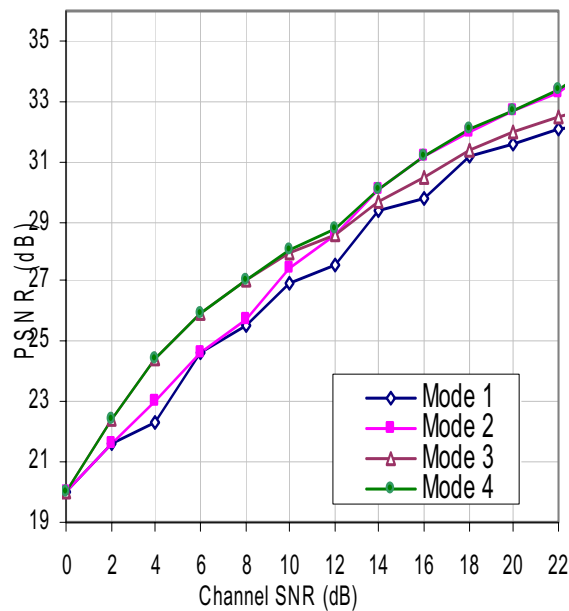
Perfect Inter-partner channel

- At Low to medium channel SNR, cooperation (mode3, mode4) significantly improves over no-cooperation (mode1, mode2)
- Layered transmission (mode2) becomes better than mode3 at higher channel SNR
- Layered cooperation (mode4) is best over the entire range

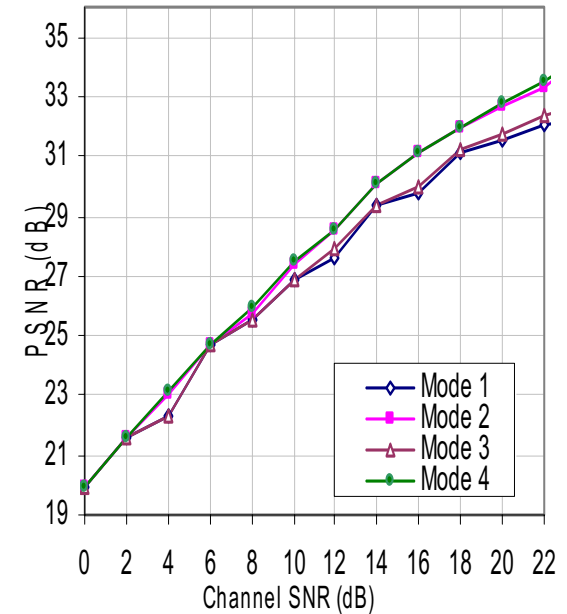
What if the inter-partner channel is not perfect?



Perfect Inter-partner channel



14 dB Inter-partner channel



0 dB Inter-partner channel

- Cooperation is less effective
- Cross-point between mode2 and mode3 moves towards lower channel SNR
- Layered cooperation still outperforms other modes over the entire range

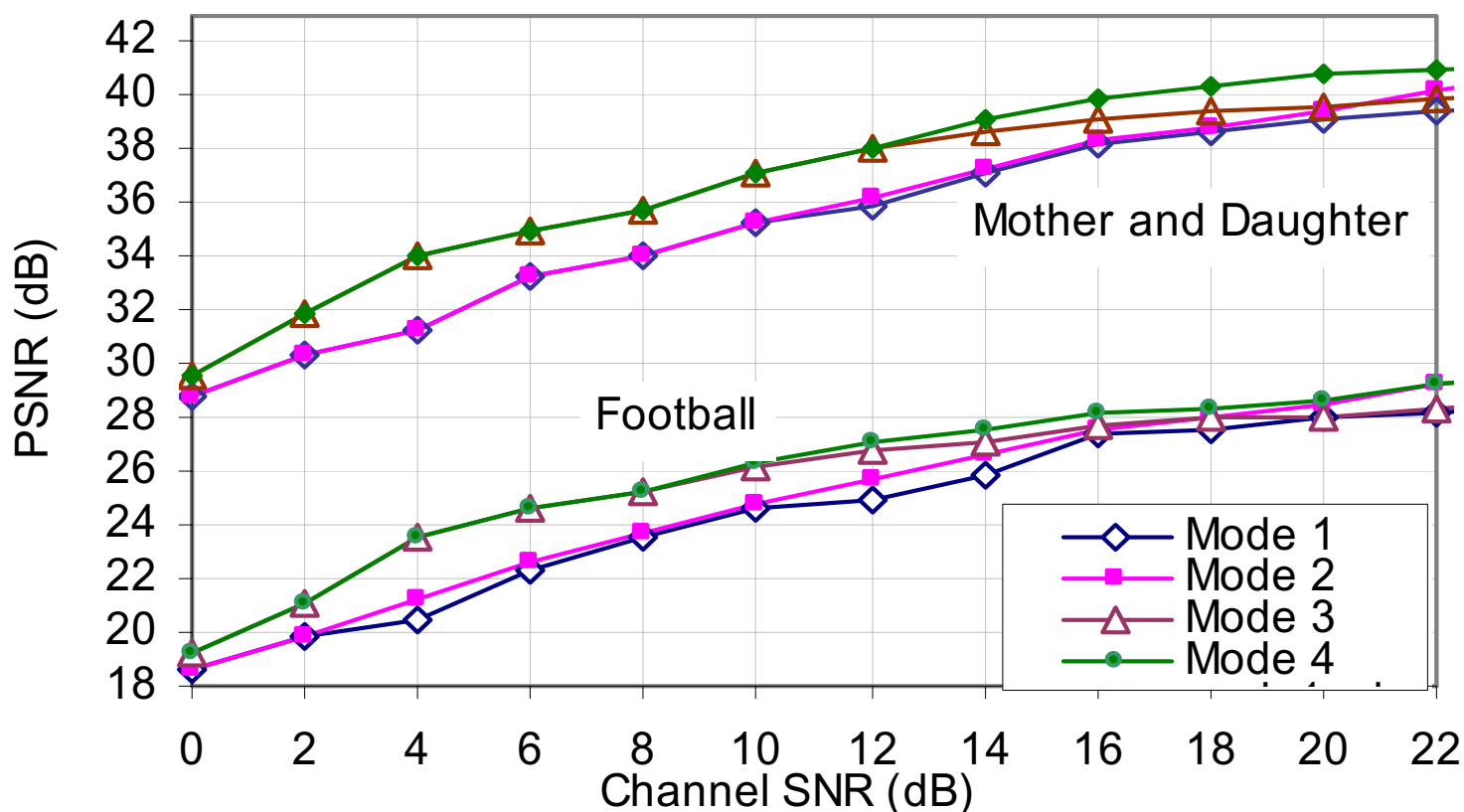
Visual Comparison: Mode1 vs. Mode3 (w/o vs. w/ coop, non-layered)

- Compare video sequences obtained with mode1 and mode3 at low channel SNR (8dB), assuming perfect inter-partner channel
 - Optimal bit allocation per channel frame
 - Mode1: $R=432, r_1=1296, r_2=0, \beta=20\%$
 - Mode3: $R=432, r_1=432, r_2=864, \beta=4\%$
 - With mode1, channel coding cannot correct many frame errors, hence more error propagation
 - With mode3, channel coding plus cooperation can correct most frame errors, hence limited error propagation
 - Same total source rate, but mode1 uses a higher INTRA rate, hence higher compression distortion

Visual Comparison: Mode3 vs. Mode4 (w/ coop: non-layered vs. layered)

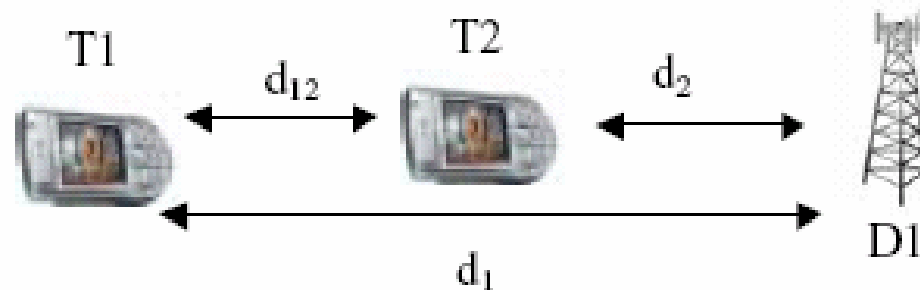
- Compare video sequences obtained with mode3 and mode4 at an intermediate channel SNR (14dB), assuming perfect inter-partner channel
 - With optimal bit allocation, same total source rate, but mode4 splits it among base and enhancement layer.
 - With mode3, uncorrectable frames lead to loss of all source bits, leading to noticeable artifacts
 - With mode4, base-layer bits are more likely received, less noticeable artifacts

Impact of Video Content (Assuming Perfect Inter-Partner Channel)



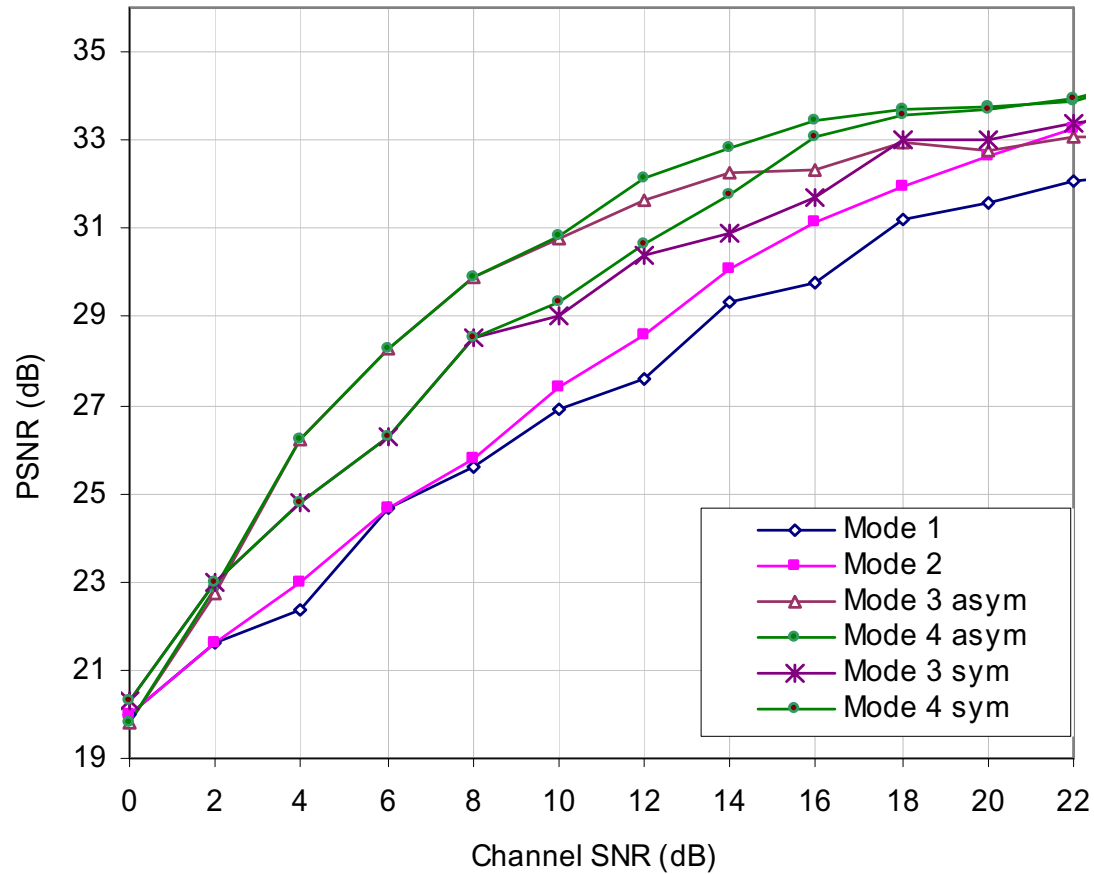
- Cooperation has similar gains to sequences with different characteristics at low to intermediate channel SNR
- Layering is more important for high motion sequences

Asymmetric Cooperation



- T2 is mid-way between T1 and D1
 - $d_2 = d_{12} = d_1/2$
 - $\text{SNR}_2 = \text{SNR}_{\text{in}} = 2^\alpha \text{SNR}_1$ ($\alpha=2$ for free space)
- Varying SNR_1 over a large range

Results for *Foreman*



Choosing a partner with a better channel brings more cooperation gain!

Conclusions

- For multimedia transport, should jointly design source coding, channel coding and cooperation to minimize source distortion
- Cooperation can significantly improve the system performance when the user-to-destination channel is poor
- Applying cooperation equally among all bits is not as good as layered transmission w/o cooperation when the channel is good
- Layered cooperation extends the benefit of cooperation to the entire range of channel conditions
- Partner selection is also important
- For video, optimal bit allocation (among source, channel, coop) is challenging because of transmission error propagation, needs to be jointly considered with encoder error resilience parameters (e.g. INTRA rate)

Backup Slides

Channel Model

- Flat, quasi-static Rayleigh fading in each channel
 - Fading level is constant over a short period (coherence time) and changes randomly from one period to the next following the Rayleigh distribution
- Independent fading among different channels
 - Accurate for small scale fading (no common obstacle or bad weather)
- Symmetric case:
 - T1-BS and T2-BS channels have the same average received SNR: $SNR_1 = SNR_2 = SNR$
 - Model a scenario in which T1 and T2 have the same fixed transmit power and are equidistant from the base station.
 - Varying SNR (distance to BS) and SNR_{in} (partner distance)
- Asymmetric case
 - T2 is mid-way between T1 and BS, $SNR_2 = SNR_{in} = ? SNR_1$
 - Varying SNR (distance to BS)

Why cooperate?

- Wireless link unreliable with time varying fading and multi-path effect
- When the T1-BS channel is bad, the T2-BS channel may be good, even though the average quality of the two channels are similar or one is worse than the other on average
- User cooperation is a form of spatial diversity
 - Similar to MIMO, but use partner's antenna
 - Non-perfect inter-user channel
- Benefits:
 - Higher reliability, higher data rates, increased battery life, extended coverage

Optimal Bit Allocation Problem

- For each mode, and for given channel condition (SNR_1 , SNR_2 , SNR_{in}), find the bit allocation that minimizes the expected distortion (ED), subject to the total rate constraint.
- Assuming the source is i.i.d, ED can be expressed as

$$\begin{aligned} ED &= D_s(R_b + R_e)P_b(R_b, r_{b,1}, r_{b,2})P_e(R_e, r_e) \\ &\quad + D_s(R_b)P_b(R_b, r_{b,1}, r_{b,2})(1 - P_e(R_e, r_e)) \\ &\quad + D_s(0)(1 - P_b(R_b, r_{b,1}, r_{b,2})) \end{aligned}$$

$$\begin{aligned} P_b(R_b, r_{b,1}, r_{b,2}) &= \Pr. \{ \text{Receiver successfully decodes } R_b \} \\ &= P_{b|\text{in}}(R_b, r_{b,1}; \text{SNR}_{\text{in}})P_{b|c1,c2}(R_b, r_{b,1}, r_{b,2}; \text{SNR}_1, \text{SNR}_2) \\ &\quad + (1 - P_{b|\text{in}}(R_b, r_{b,1}; \text{SNR}_{\text{in}}))P_{b|c1}(R_b, r_{b,1}, r_{b,2}; \text{SNR}_1) \end{aligned}$$

$$\begin{aligned} P_e(R_e, r_e, \text{SNR}_1) &= \Pr. \{ \text{Receiver successfully decodes } R_e \} \\ &= P_{b|c1}(R_e, r_e; \text{SNR}_1) \end{aligned}$$

Past Work:

Coop for Data Transmission

- For fixed bit allocation (given R, r_1, r_2), design channel codes to minimize residual frame error rate (FER)
 - A. Stefanov and E. Erkip. Cooperative coding for wireless networks. *IEEE Transactions on Communications*, vol. 52, no. 9, pp. 1470-1476, September 2004.
- For fixed bit allocation (given R, r_1, r_2), analyze and determine bound on the residual frame error rate
 - T.E. Hunter and A. Nosratinia, "Performance analysis of coded cooperation diversity," International Conference on Communications, pp. 2688-2692, Anchorage, Alaska, 2003.