Shannon Limits for Optical Communication

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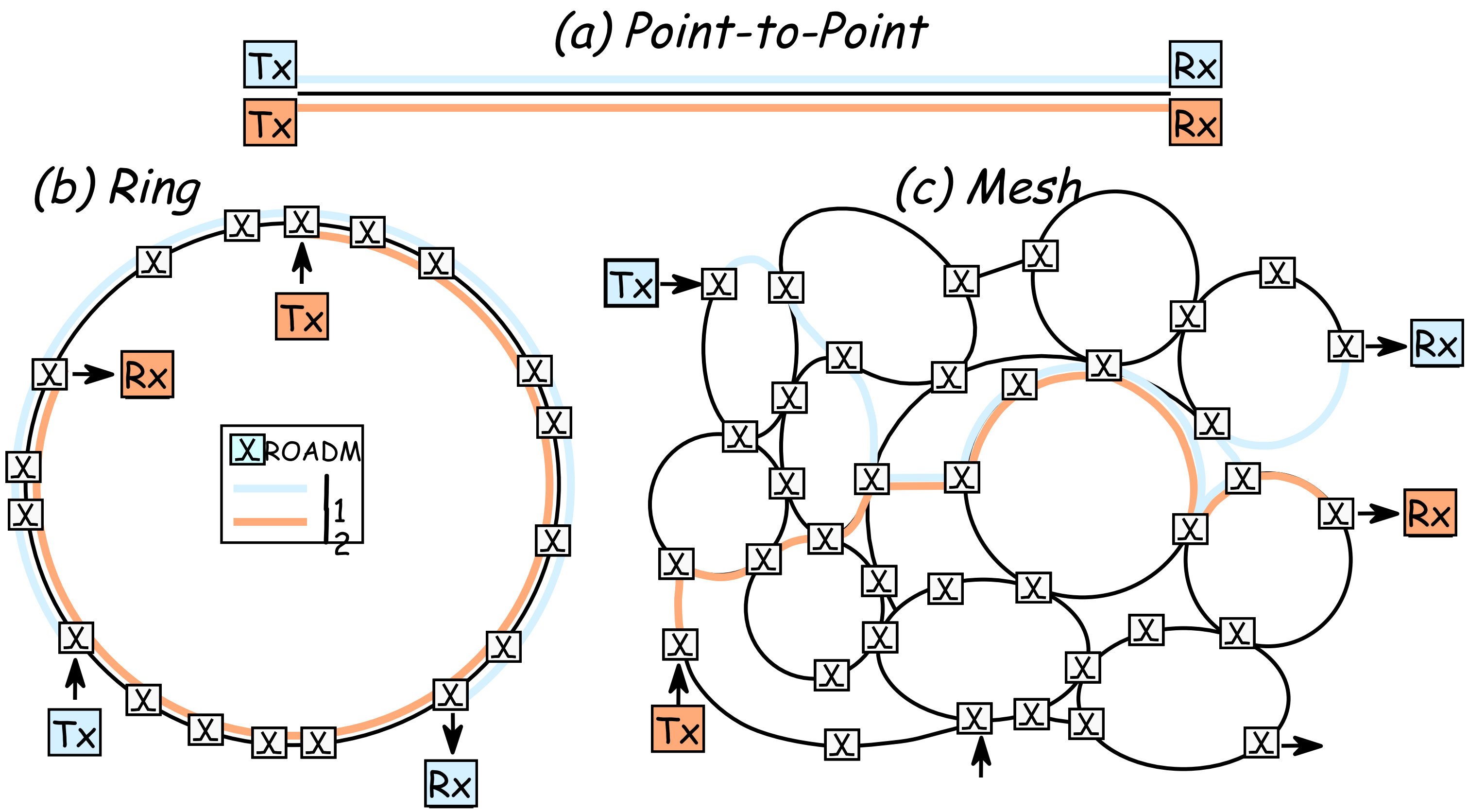
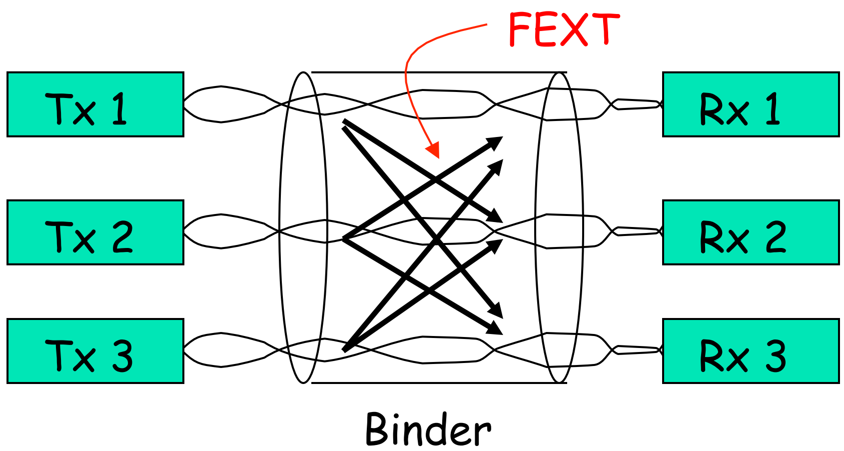
Optically-Routed Networks



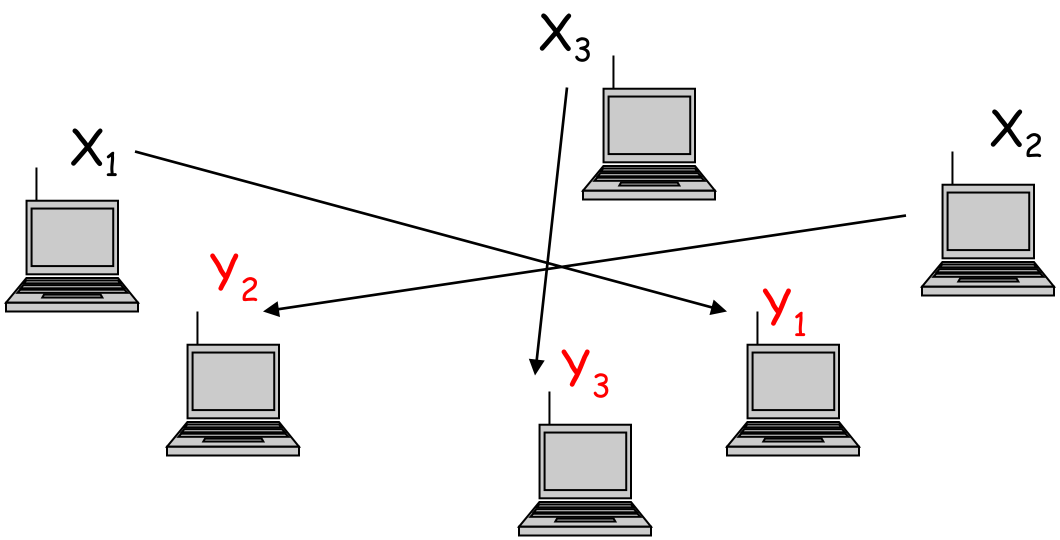
- Neighboring WDM signals interfere due to fiber nonlinearities.
- Above: 2 Tx-Rx Pairs. The K-pair problem is called a K-user interference network (IN) by information theorists.

Slide material from OFC Tutorial | March 2009

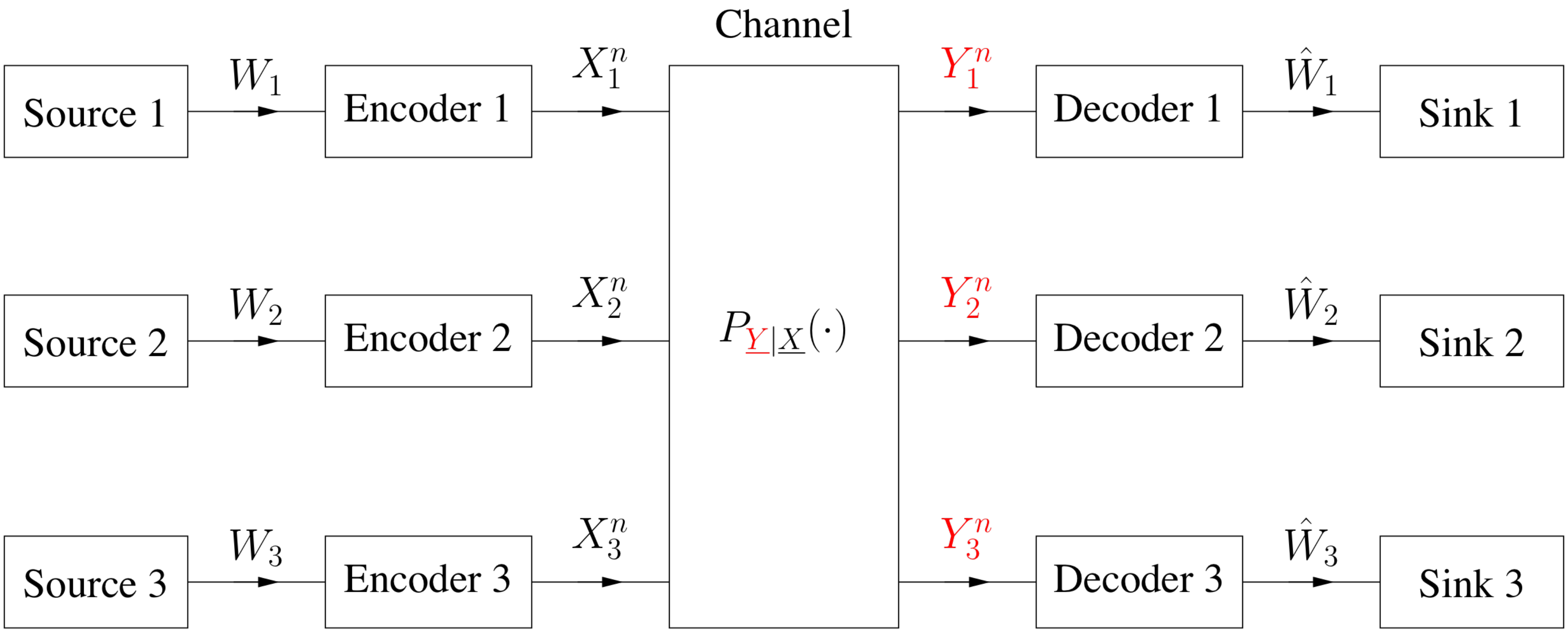
- Other interference networks (INs):
  - Copper DSL loops



  - Wireless



- General model for K=3:



- Linear channel: $\underline{Y}_i = H \underline{X}_i + \underline{Z}_i$, $i=1,2,\ldots,n$
- Problem: find the $(R_1,R_2,\ldots,R_K)$ at which one can reliably communicate. Difficult even for K=2 and linear channels.

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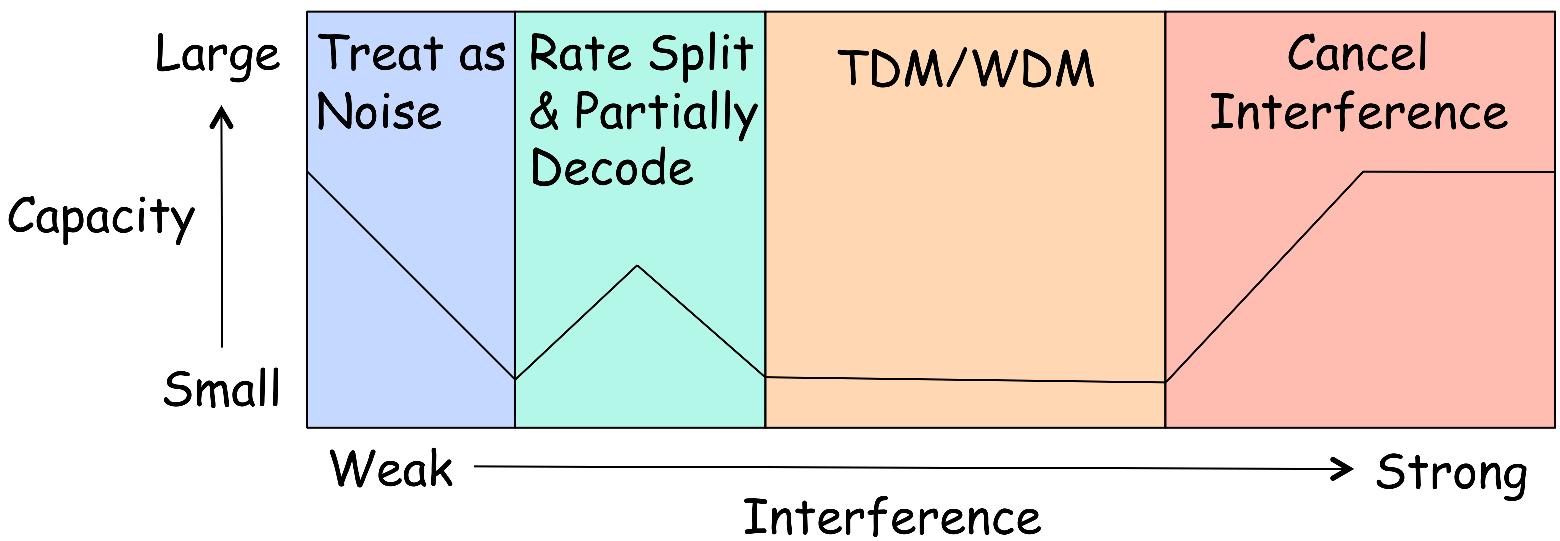
K=2 and Linear Channel

- K=2 additive Gaussian noise model: 1

$$\begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} Z_1 \\ Z_2 \end{bmatrix}$$

- Best strategies for K=2:



K=3 and Linear Channel

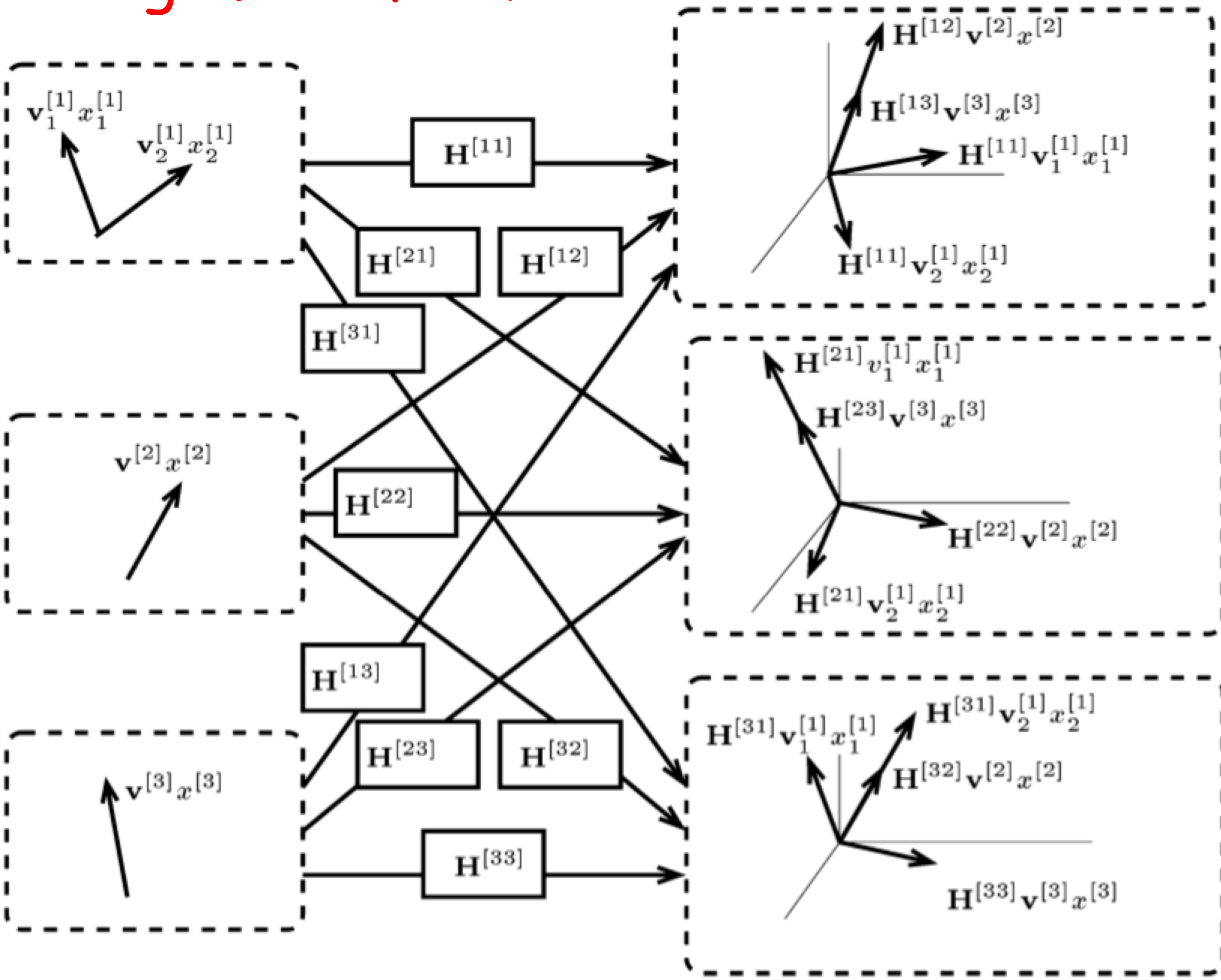
- K=3 additive Gaussian noise model:

$$\begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \end{bmatrix} = \begin{bmatrix} H_{11} & H_{12} & H_{13} \\ H_{21} & H_{22} & H_{23} \\ H_{31} & H_{32} & H_{33} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ X_3 \end{bmatrix} + \begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \end{bmatrix}$$

- Similar regimes exist as for K=2 but there is …
- New phenomena: for time or frequency-varying linear channels, can use "beamforming" sequences that align interference in a common "direction" at every receiver.
- Method invented by Maddah-Ali, Motahari, Khandani (2006/8)
- Improved and applied to INs by Cadambe/Jafar (2007/8) (2009 IEEE Information Theory Society Paper Award)

Interference Alignment for K=3

- Example from Cadambe & Jafar (2008)
- Huge capacity gains (vs. TDM/WDM) for linear channels under rather idealistic assumptions



Questions & Directions

- What methods can be used for non-linear optical channels?
  - Treating intereference as noise ✔
  - Partial decoding ??
  - TDM/WDM ✔
  - Interference cancelation ? (Permit strong interference?)
  - Interference alignment ???
    (Challenges: need "rich" channel, universal channel knowledge)
- Interference networks assume limited node cooperation.
  Can smart relaying and cooperative communication methods help, e.g, intermediate decoding, multi-path routing, etc.
  (Wireless researchers are seriously studying such approaches)
- Information theory serves as a guide