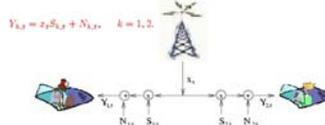


Problem Setting: Time Varying RF Channels

- In several situations, the transmitters and receivers in a communication network, or the sensors and actuators in a control system, must operate without a complete knowledge of the probability law which governs the transmission channel, for instance, when the probability law changes with time.
- Examples include those arising in RF mobile wireless communication:
 - cellular phone network;
 - indoor network of mobile sensors and actuators.
- Owing to the mobility of the transmitters and receivers, or changing physical environments, the degradation of the transmitted signals due to multipath, shadowing and propagation losses, is time-varying.
- The time-varying behavior of the channel probability law is typically described in terms of the evolution of an underlying channel state characterizing the "condition" of the channel.
- Characterizing extents of channel state information (CSI) can often be provided to the transmitters or receivers, leading to better communication.

Time-Varying RF Broadcast Channel



- Downlink of a mobile wireless channel: *time-varying fading broadcast channel*.
- Time-varying behavior modeled by introducing a channel state $S_t = (S_{1,t}, S_{2,t})$.
- Knowledge of the state at transmitter or receivers can lead to higher "throughput."
- Key Objective:** To study how CSI can be gainfully used in devising transmitter and receiver strategies so as to enable reliable and efficient communication over time-varying RF channels.

Problem Setting: Combining RF and Optical Transmissions

- With the crowding of the RF spectrum and increasing demand for bandwidth availability, recent proposals recommend the use of *optical wireless links* as a viable complement.
- Switching between RF and optical modes also affords a means of sending additional information ("sum channel").
- We are currently investigating the *combined* use of wireless RF and optical links.
- Key Objective:** To understand how RF power control can be combined with RF/optical link-switching to achieve higher throughputs.

Some Specific Problems

- Capacity regions of broadcast or downlink time-varying RF channels when various degrees of channel state information (CSI) are available to the transmitter or receivers.
 - For all problems, we assume that each receiver has perfect local CSI.
- Special cases:
 - CSI ordering at the transmitter and receivers.
 - Capacity region.
 - No CSI at the transmitter.
 - Inner and outer bounds.
 - Perfect CSI at the transmitter, and (possibly) CSI ordering at the receivers.
 - Conditional Gaussianity is lost.

Fading Broadcast Channel without Transmitter CSI

Two-receiver fading broadcast channel (slow, flat fading channel): At receiver- k , $k = 1, 2$:

$$Y_{k,t} = x_t S_{k,t} + N_{k,t}, \quad t \geq 1,$$

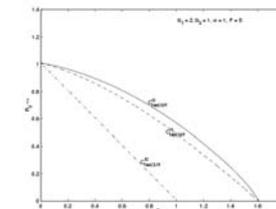
where

- $\{x_t\}$ is the \mathbb{R} -valued transmitted signal with average power P ;
- $\{S_{k,t}\}$ is the \mathbb{R}^+ -valued fade suffered by the transmission to receiver- k ;
- $\{N_{k,t}\}$ is i.i.d. Gaussian noise $\sim \mathcal{N}(0, \sigma^2)$ at receiver k .
- Transmitter has no CSI while each receiver- k has perfect local CSI.

We have derived the following inner and outer bounds on the capacity region.

- Outer bound C^O is obtained by providing CSI ordering at the transmitter and receivers.
- Inner bound $C^I = \text{co}(C_1^I \cup C_2^I)$, where C_k^I ~ receiver- k decodes both messages, receiver- k' decodes only its own message.

Example: Rayleigh Fading Broadcast Channel

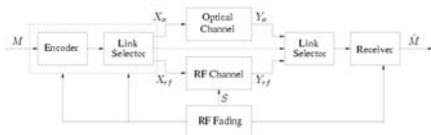


- i.i.d. Rayleigh fading:

$$f_{S_k}(x) = \frac{x}{2\sigma^2} \exp\left(-\frac{x^2}{2\sigma^2}\right), \quad x \geq 0, \quad k = 1, 2.$$
- Gap between inner and outer bounds:

$$C_2^I \subset C_1^I = C^I \subset C^O.$$

Combining RF and Optical Transmissions



- RF fading link: $F_{V,r} | X_r, S \sim \text{Gaussian}(s x_r, \sigma_r^2)$.
- Optical link: $F_{V,o} | X_o \sim \text{Poisson}(x_o + \lambda_o)$.
- Input constraints:
 - Average power constraint for the RF link.
 - Average and peak power constraints for the optical link.
 - Constraint to limit use of optical link.

Combined RF/Optical Channel Model

- Discrete time model for the switching channel.
 - At each time, the channel selector selects one of the two available channels.
 - The decision V depends on RF channel fade information S .
 - Randomness in switching decision contributes to additional information.
- Combined channel transfer function:

$$W^n(y^n | x^n, s^n, v^n) = \prod_{t=1}^n W_{r,t}(y_t | x_t, s_t) * \prod_{t=1}^n W_o(y_t | x_t).$$

- Input constraints:
 - Peak power constraint for optical channel:

$$0 \leq x_t \leq A \quad \forall t: v_t = 0.$$
 - Average power constraint for the combined channel:

$$\frac{1}{n} \sum_{t=1}^n E[X_t^2 1(V_t) + X_t 1(\bar{V}_t)] \leq P.$$
 - Constraint on overuse of optical channel.

Planned Work

- Downlink of mobile wireless channel
 - Adequate CSI at the transmitter and receivers: power-control across transmit antennae and beamforming?
 - No CSI: Space-time coding?
 - Partial CSI: Intermediate solutions?
- Determination of capacity formula for the combined RF/optical channel
 - RF/optical "link-switching"
 - "Sum channel" with constraints: transmission of additional information.
 - Relationship to RF power control.
 - Combined use of RF/optical fading links.