University of Maryland, College Park
Institute for Systems Research
and
Department of Electrical and Computer Engineering

P. S. Krishnaprasad
Arash Komae
Kausik Chakraborty

RF and Optical Channels
Over Reliable Communication
Shadowing and propagation losses is time-variant. In environments, the degradation of the transmitted signals due to multipath.

Owing to the mobility of the transmitters and receivers, or changing physical

- Indoor network of mobile sensors and actuators.
- RF network of command posts, soldiers and equipment.
- Cellular phone network.

Examples include those arising in RF mobile wireless communication:

- Time.

Transmission channel, for instance, when the probability law changes with

without a complete knowledge of the probability law which governs the network, or the sensors and actuators in a control system, must operate.

In several situations, the transmitters and receivers in a communication

Problem Setting: Time Varying RF Channels
transmitters or receivers, leading to better communication.

Varying extents of channel state information (CSI) can often be provided to the

„conditioning“ of the channel.

terms of the evolution of an underlying channel state characterizing the

The time-varying behavior of the channel probability law is typically described in

Channel State Information
Knowledge of the state at transmitter or receivers can lead to higher throughput.

Time-varying behavior modeled by introducing a channel state $S^{t}$.

Downlink of a mobile wireless channel: time-varying fading broadcast channel.

$$Y^{t} = X^{t} + N^{t}$$
We are currently investigating the combined use of wireless RF and optical links. **Switching between RF and optical modes also offers a means of sending additional information ("sum channel").**

**With the crowding of the RF spectrum and increasing demand for bandwidth, reliable complementarity, recent proposals recommend the use of optical wireless links as a viable complement.**

**Problem Setting: Combining RF and Optical Transmissions**
Problem Setting: Optimal Fading Channel - Model, Receiver Structure
Objectives

- Optimal link fading and thermal noise.
- To design optimal receiver structures for signal detection in the presence of link-switching to achieve higher throughputs.
- To understand how RF power control can be combined with RF/optical communication over time-varying RF channels.
- To study how channel state information (CSI) can be faithfully used in designing transmitter and receiver strategies so as to enable reliable and efficient transmission.
modulation and coding.
- power control.
- broadcast.

- schemes for

Effects of varying amounts of CSI on throughputs and enhancements using

- Information-theoretic capacity regions with CSI at the transmitter or receivers.

Broadcast or "downlink" fading channel.

- Time-Varying RF Broadcast Channel
CSI as noisy versions of \( s \) can be incorporated into this model.

Generally, \( (\hat{s})^{(2)} \gamma^{(3)} \theta^{(4)} p = \gamma^{(3)} p \), \( (\hat{s})^{(2)} \theta^{(4)} = \gamma^{(3)} p \), \( (\hat{s})^{(2)} \gamma = \gamma \).

The state process evolves `autonomously` and current state \( s \) may depend on previous states but not on previous channel inputs or outputs.

**Schematic for Time-Varying RF Broadcast Channel**
References
Since no conditional Gaussianity.

- Perfect CSI at the transmitter, and (possibly) CSI at the receiver.

- Inner and outer bounds.

$\Rightarrow$ No CSI at the transmitter.

- Capacity region.

- CSI at the transmitter and receiver.

Special cases:

- Each receiver has perfect local CSI.

Transmitter or receivers.

- Various degrees of channel state information (CSI) are available to the various degrees of broadcast or downlink time-varying RF channels when

- Capacity regions of broadcast or downlink time-varying RF channels when

Some Specific Problems
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.
decodes both messages’ receiver-\( k \), decodes only its own message.

\( \gamma \sim \frac{\gamma}{\bigcup \frac{1}{1} \bigcup (\gamma)} = \frac{1}{1} \bigcup (\gamma) \)

\( \bigcup \frac{1}{1} \bigcup (\gamma) \)

inner bound for capacity region: \( \mathcal{C} \)

\( \bigcup \frac{1}{1} \bigcup (\gamma) \)

outer bound for capacity region: \( \mathcal{C} \)

satisfying

\[ \gamma \in \mathbb{R}^+ \}

\( \mathcal{P} \) \( \bigcup \frac{1}{1} \bigcup (\gamma) \)

transmitter and receivers’ in terms of power allocation policies.

Outer bound on capacity region obtained by providing CSI ordering at the

\[ \bigcup \frac{1}{1} \bigcup (\gamma) \]

Bounds on the Capacity Region
- Gap between inner and outer bounds:

\[ C_2 \subset C_1 = C_0. \]

- L.d. Rayleigh fading:

\[ f_{\bar{S}_k}(x) = \frac{x^2}{b_k^2} \exp\left(-\frac{x^2}{2b_k^2}\right), \quad x \geq 0, \quad k = 1, 2. \]

Example: Rayleigh Fading Broadcast Channel
- Partial CSI: Intermediate solutions

- No CSI: Space-time coding

- Transmit antenna and beamforming

- Adequate CSI at the transmitter and receivers: power-control across

- Downlink of mobile wireless channel

- Planned WORK
Combining RF and Optical Transmissions
Relationship to RF power control.

Information.

Sum channel with contrasts: transmission of additional

- RF/optical link-switching

Determination of capacity formula

Capacity Formula Comments
This study addresses models for optical fading and associated receiver structures.

A light beam propagating through the atmosphere suffers fading with wavelet-like effects.

Atmospheric turbulence, caused by differential thermal conditions in the troposphere, results in random variations in refractive index at optical channel
where $Y(\cdot)$ is lognormal.

Lognormal fade.

Optical channel output $y(\cdot)_{\infty}y \sim (\mathbf{1}, \cdot)_{\infty}x(\mathbf{1}, \cdot)_{\infty}y = (\mathbf{1}, \cdot)_{\infty}y = (\mathbf{1}, \cdot)_{\infty}x = x$.

Transmitted optical signal $\tilde{y}$

Optical direct-detection device

Optical direct-detection device: Model, Receiver Structure
$J \gg \text{ pulse duration}$ with $a = (\cdot)^{\delta}$

$\left(\frac{\gamma J - t}{\gamma L}\right)^{0=\eta} \bigcirc \bigcirc = (t)Z$

where

$(t)Y$ is process of Poisson pulses of rate $\gamma$.

White Gaussian noise with PSD $N_0/2 \text{ Watts/Hz}$.

Dark current rate:

$P \gamma (t) + (t)H = (t)X$
Hass, Shapiro, 03

Davis, Smolyaninov, Milner, 03

Zhau, Khan, 00, 01

Roggenmann, Welsh, Fugate, 97
Specific Problems

- Combined use of RF/optical fading links.

  - CSI at the receiver.
  - Capacity formulae.
  - Optimal signalling.
  - Performance assessment.

⇒ Computational issues.

⇒ Likelihood ratio formulae for on-off keying.