بسم الله الرحمن الرحيم

Spatial Channel Model For Wireless Communication

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Introduction

This seminar presents a theoretical framework for characterizing the angle of arrival of multipath power in a way that produces simple-but-powerful insight into the nature of small-scale fading. By emphasizing the parallel mathematical analysis used for frequency selectivity and spatial selectivity

THE BASICS OF SMALL-SCALE CHANNEL MODELING

This section discusses the use of a baseband channel model to explore two types of *local area* behavior in the wireless channel:

1- frequency selectivity

2- spatial selectivity.

*A local area is a region in space over which the mean power level of the channel is undisturbed by large-scale scattering and shadowing.

RECEIVED COMPLEX VOLTAGE

As propagating waves impinge upon an antenna, they excite an oscillating voltage at the input terminals of the receiver. This voltage is a function of position, *r*, of the receiver antenna

$$\mathcal{H}(r,t) = \text{Real}\left\{\tilde{h}(r)\exp(j2\pi f_c t)\right\}$$

where f_c is the radiation carrier frequency

$\tilde{h}(r)$ complex phasor.

$\mathcal{H}(r,t)$ The received radio frequency voltage.

RECEIVED COMPLEX VOLTAGE (cont)

From complex voltage, it is possible to calculate any of the following pieces of information

$$\begin{aligned}
\text{In-Phase Received Component} &: \quad \mathrm{Real}\{\tilde{h}(r)\} \\
\text{Quadrature Received Component} &: \quad \mathrm{Im}\{\tilde{h}(r)\} \\
\text{Voltage Envelope, } R(r) &: \quad |\tilde{h}(r)| \\
\text{Power (units of } Volts^2\text{), } P(r) &: \quad |\tilde{h}(r)|^2
\end{aligned}$$

FREQUENCY SELECTIVITY

For a fixed, single-antenna receiver operating in a static channel, the principle source of channel distortion for a received signal is dispersion induced by multipath propagation delay

This time-dispersive channel is characterized by a complex, baseband *channel-impulse response*,

which measures received voltage as a function of time-delay,

FREQUENCY SELECTIVITY (cont)

A useful measure of dispersion in a wireless channel is the RMS delay spread,

$$\sigma_\tau^2 = \overline{\tau^2} - (\overline{\tau})^2, \quad \text{where } \overline{\tau^n} = \frac{\int_{-\infty}^{+\infty} \tau^n p(\tau)\, d\tau}{\int_{-\infty}^{+\infty} p(\tau)\, d\tau}$$

where σ_τ, is the RMS delay spread,

σ_τ^2 the second centered moment of the delay spectrum

SPATIAL SELECTIVITY

For a narrowband receiver operating in a static channel, the effects of *spatial selectivity* often limit the performance of a wireless link.

We characterize the received complex voltage,h(r) as a function of position, *r*. If the function h(r) is a wide-sense stationary stochastic process, then it is possible to express its mean-squared rate-of-change as

SPATIAL SELECTIVITY (cont)

$$\mathrm{E}\left\{\left|\frac{d[\tilde{h}(r)\exp(-j\bar{k}r)]}{dr}\right|^2\right\} = \sigma_k^2 \mathrm{E}\left\{|\tilde{h}(r)|^2\right\}$$

where σ_k is the *wavenumber spread* as given by

$$\sigma_k^2 = \overline{k^2} - (\bar{k})^2, \quad \text{where } \overline{k^n} = \frac{\int_{-\infty}^{+\infty} k^n S(k)dk}{\int_{-\infty}^{+\infty} S(k)dk}$$

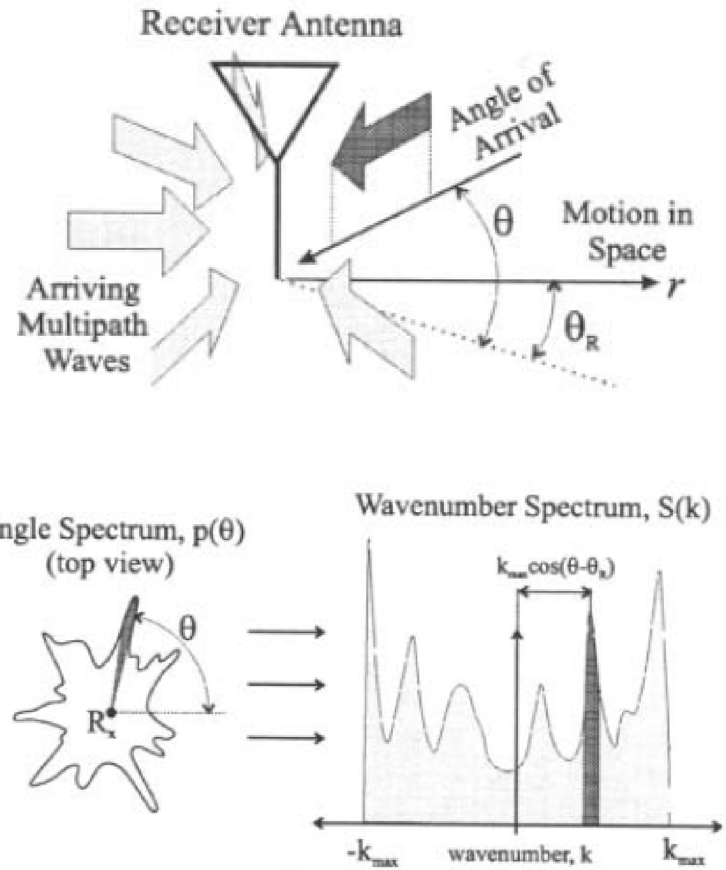
SPATIAL SELECTIVITY (cont)

Parallel mathematical relationships between spatial and frequency selectivity.

SPACE	FREQUENCY
position, r	frequency, f
wavenumber, k	delay, τ
wavenumber spread, σ_k	delay spread, σ_τ
wavenumber spectrum, $S(k)$	delay spectrum, $p(\tau)$

SPATIAL SELECTIVITY (cont)

The figure shown multipath power is mapped from the angle spectrum , to the wave number spectrum , as function of its angle of arrival



MAPPING ANGLES TO WAVENUMBERS

$$S(k) = \frac{p(\theta_R + \cos^{-1}\frac{k}{k_{max}}) + p(\theta_R - \cos^{-1}\frac{k}{k_{max}})}{\sqrt{k_{max}^2 - k^2}}, \quad |k| \le k_{max}$$

$$k = k_{max}\cos(\theta - \theta_R) \quad \text{and} \quad \frac{dk}{d\theta} = -k_{max}\sin(\theta - \theta_R)$$

MULTIPATH SHAPE FACTORS

This section introduces the concept of multipath shape factors parameters that describe multipath angle-of-arrival characteristics and also imply spatially selective behavior in a multipath channel

SHAPE FACTOR DEFINITIONS

This section presents the three multipath shape factors that characterize small-scale fading statistics in space. The shape factors are derived from the angular distribution of multipath power, which is a general representation of from-the-horizon propagation in a local area. This representation of includes antenna gains and polarization mismatch effects . Shape factors are based on the complex Fourier coefficients of $p(\theta)$:

SHAPE FACTOR DEFINITIONS (cont)

$$F_n = \int_0^{2\pi} p(\theta) \exp(jn\theta) d\theta$$

where F_n is the nth complex Fourier coefficient.

Angular Spread

The shape factor *angular spread*,(Λ) is a measure of how multipath concentrates about a single azimuthal direction. We define angular spread to be

$$\Lambda = \sqrt{1 - \frac{|F_1|^2}{F_0^2}}$$

where (Fo) and (F1) are defined by

$$F_n = \int_0^{2\pi} p(\theta) \exp(jn\theta) d\theta$$

advantages of angular spread

since angular spread is normalized

By (Fo) , it is invariant under changes in transmitted power.

is invariant under any series of rotational or reflective transformations of $p(\theta)$.

Angular Constriction

The shape factor *angular constriction* γ is a measure of how multipath concentrates about *two* azimuthal directions.

We define angular constriction to be

$$\gamma = \frac{|F_0 F_2 - F_1^2|}{F_0^2 - |F_1|^2}$$

where F_0, F_1, and F_2 are defined by

$$F_n = \int_0^{2\pi} p(\theta)\exp(jn\theta)d\theta$$

Azimuthal Direction of Maximum Fading

A third shape factor, which may be thought of as an orientation parameter, is the *azimuthal direction of maximum fading*, θ_{max}.

We define this parameter to be

$$\theta_{max} = \frac{1}{2}\arg\left\{F_0 F_2 - F_1^2\right\}$$

The physical meaning of the parameter is presented in the next section.

BASIC WAVENUMBER SPREAD RELATIONSHIP

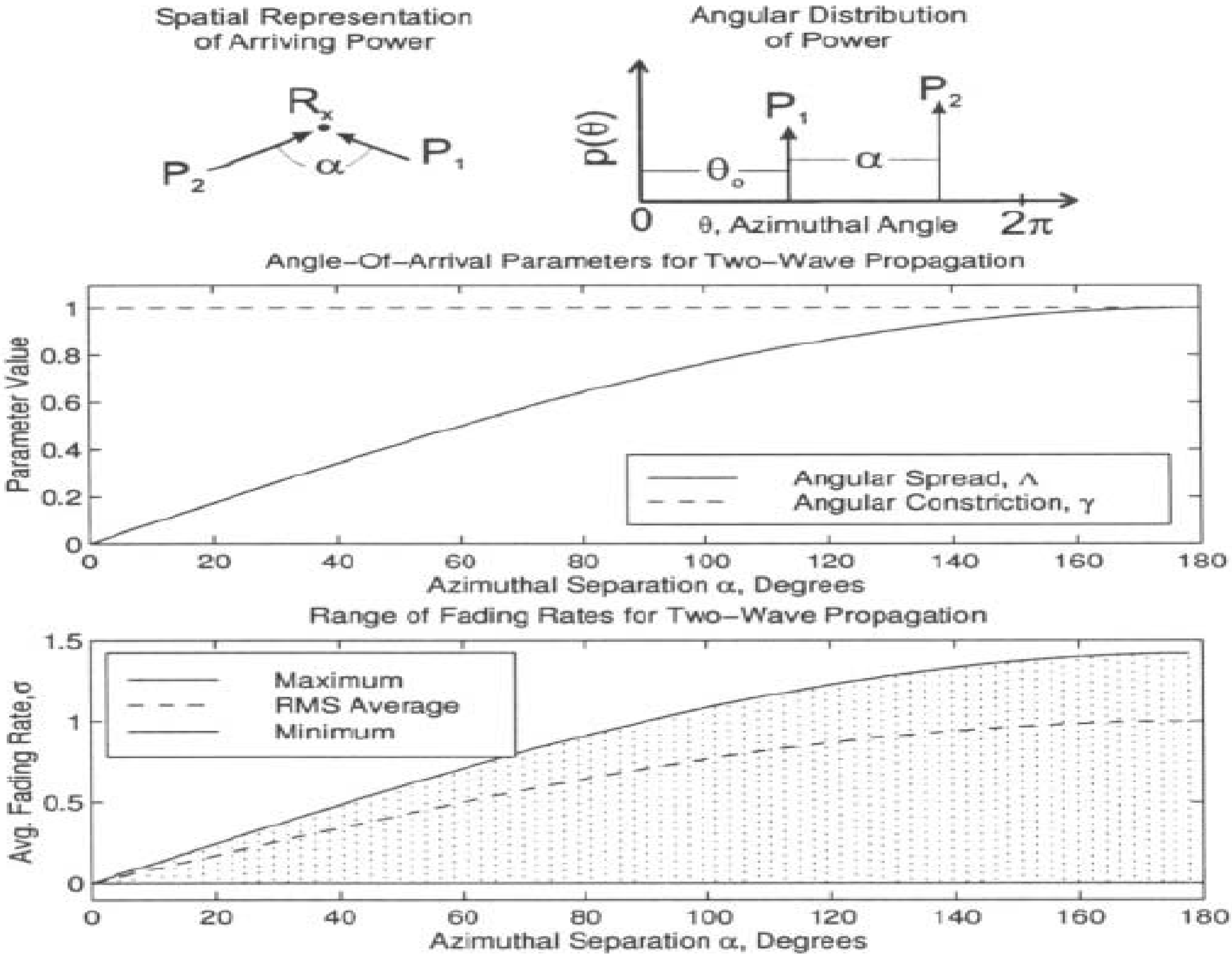
the wavenumber spread for the complex voltage of a receiver traveling along the azimuthal direction θ_R is

$$\sigma_k^2 = \frac{2\pi^2\Lambda^2}{\lambda^2}\left(1 + \gamma\cos\left[2(\theta_R - \theta_{\max})\right]\right)$$

Where λ s the wavelength of the carrier frequency

σ_k^2 describes the spatial selectivity of a channel in a local area for a receiver moving in the direction.

COMPARISON TO OMNIDIRECTIONAL PROPAGATION



EXAMPLES

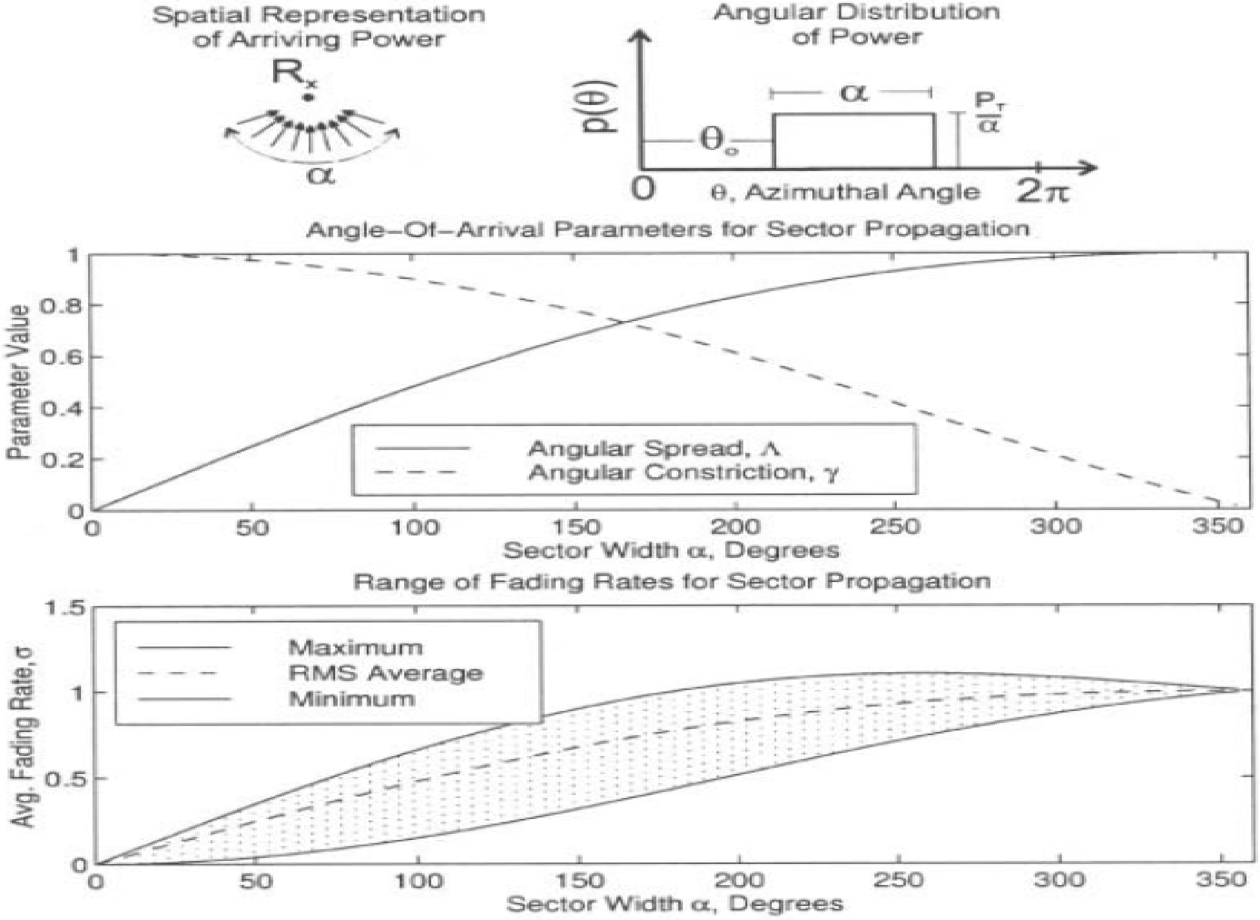
This section presents three different analytical examples of directional propagation channels that provide insight into the shape factor definitions and how they describe fading rates. Each example is accompanied by a graph of the angular spread and angular constriction and a graph showing the average and limiting cases of fading rate variance with respect to omnidirectional propagation.

SECTOR CHANNEL MODEL

$$p(\theta) = \begin{cases} \frac{P_T}{\alpha} & : \quad \theta_o \le \theta \le \theta_o + \alpha \\ 0 & : \quad \text{elsewhere} \end{cases}$$

$$\Lambda = \sqrt{1 - \frac{4\sin^2\frac{\alpha}{2}}{\alpha^2}}, \qquad \gamma = \frac{4\sin^2\frac{\alpha}{2} - \alpha\sin\alpha}{\alpha^2 - 4\sin^2\frac{\alpha}{2}}, \qquad \theta_{max} = \theta_0 + \frac{\alpha + \pi}{2}$$

SECTOR CHANNEL MODEL (cont))



Multipath sector propagation model.

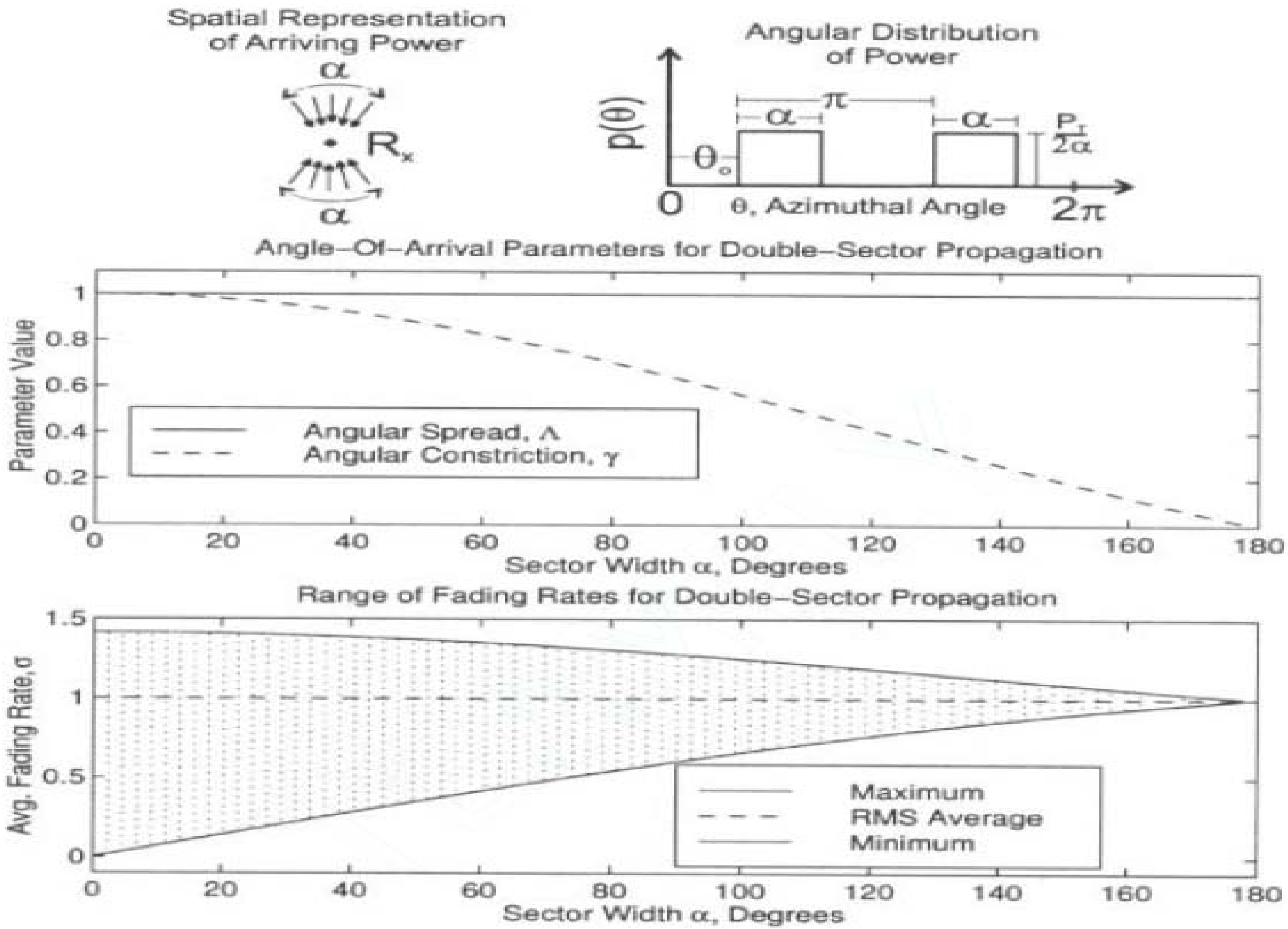
DOUBLE SECTOR CHANNEL MODEL

$$p(\theta) = \begin{cases} \frac{P_T}{2\alpha} & : \quad \theta_o \leq \theta \leq \theta_o + \alpha, \quad \theta_o + \pi \leq \theta \leq \theta_o + \alpha + \pi \\ 0 & : \quad \text{elsewhere} \end{cases}$$

The angle α is the sector width and the angle θ_o is an arbitrary offset angle. the expressions for A , γ, and θ_{max} for this distribution are

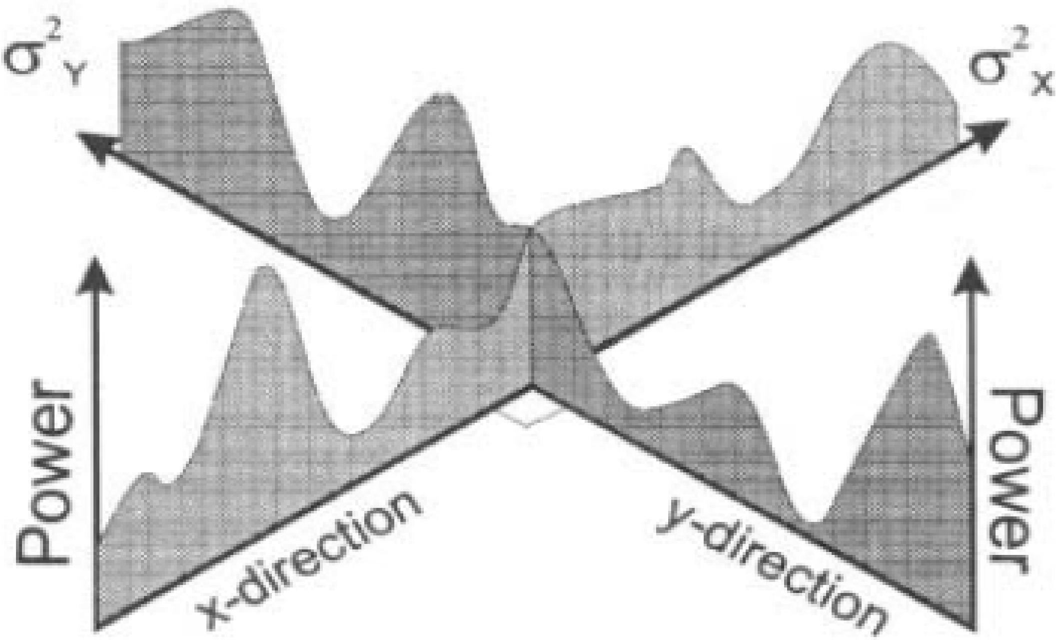
$$\Lambda = 1, \qquad \gamma = \frac{\sin \alpha}{\alpha}, \qquad \theta_{max} = \theta_0 + \frac{\alpha}{2}$$

DOUBLE SECTOR CHANNEL MODEL (cont)



Multipath double sector propagation model.

The limiting case of $\alpha = 180^\circ$ (omnidirectional propagation) results in a angular constriction of $\gamma = 0$. As decreases, the angular distribution of power becomes more and more constricted. In the limit of $\alpha = 0$, the value of angular constriction reaches its maximum, $\gamma = 1$.



Power measured along two perpendicular linear tracks in space within a local area.

Conclusion

This seminar has presented a theoretical framework for relating multipath angle-of-arrival characteristics to the spatially - selective behavior of small-scale fading. The framework characterizes the multipath angle-of-arrival using geometrical shape factors.

References

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Any question

Thank you