



Narrowband Diversity Reception in WPAN/WLAN Environments

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Introduction

- WPAN/WLAN access points are generally equipped with space diversity antennas to improve performance in fading environments
- classical approach suggests that diversity correlation will be least (best) broadside to the antenna baseline and greatest (worst) along the antenna baseline
- however, there is little data to support the actual performance improvement obtained or how this varies with the type of environment or as a function of azimuth angle
- common assumptions regarding angle of arrival distribution and number of interfering rays may not hold in indoor environments
- urgent need to characterize the performance of space and/or polarization diversity performance in different WPAN/WLAN environments

Objectives

- evaluate the performance of space diversity as a function of different types of indoor environments and azimuth angles
 - develop a suitable measurement setup
 - collect data
 - reduce data and develop an appropriate channel model
- assess the merits of three-way space diversity as a method for mitigating reduction of diversity performance along the antenna baseline
- since diversity correlation is directly related to angle spread, use measurements of the former to estimate the latter

A First-Order Statistical Model of Narrowband Dual-Branch Diversity Channels

- **Model Description** – complete description of the channel in terms of five channel parameters
- **Estimation of Channel Parameters** – average gain, Ricean K-factor, and complex envelope coefficient
- **Measurements** – collected in suburban Illinois and New Jersey
- **Application of the Model** – software simulation, higher order diversity, hardware evaluation
- **Time Variation Model** – a supplementary model that captures the second order statistics of path gain

1. Model Description

- over bandwidths of less than 100 kHz, signal path gain is characterized by a frequency-flat but possibly time varying response

$$g(t) = V + v(t)$$

- this description applies to a particular time-frequency segment
 - 5–15 minutes in duration
 - < 100 kHz wide
- both V and the parameters of $v(t)$ may change from one time-frequency segment to another
- define $G_{\text{ave}} = \overline{|g(t)|^2} = |V|^2 + \overline{|v(t)|^2}$
- define $K = |V|^2 / \overline{|v(t)|^2}$

- we can recast our expression for $g(t)$ to yield

$$g(t) = \sqrt{\frac{G_{\text{ave}}}{K+1}} [\sqrt{K} + x(t)e^{-j\Psi}] e^{j\Psi}$$

- for diversity channels,

$$g_1(t) = \sqrt{\frac{G_{\text{ave}1}}{K_1+1}} [\sqrt{K_1} + \hat{x}_1(t)]$$

and

$$g_2(t) = \sqrt{\frac{G_{\text{ave}2}}{K_2+1}} [\sqrt{K_2} + \hat{x}_2(t)],$$

where $\hat{x}_i = x_i(t) e^{-j\Psi_i}$, $i = 1, 2$.

- define the complex envelope correlation coefficient,

$$\rho = \rho_{\text{env}} \equiv \overline{\hat{x}_1 \hat{x}_2^*} = Re^{j\theta}$$

2. Estimation of Channel Parameters

- the two-branch narrowband diversity channel is completely defined by the state vector

$$\mathbf{U} = [G_{ave1}, G_{ave2}, K_1, K_2, \rho]$$

- need to estimate these parameters from measurements of received power *vs.* time
- estimation of average path gain is simple:

$$G_{ave} = \text{Ave}_i |g_i|^2$$

- what about Ricean K-factor and complex envelope correlation coefficient?

Estimation of Ricean K-factor

- our moment-based method is simpler and more efficient than previous methods (such as goodness-of-fit and expectation-maximization)
- strategy: recast expression for $g(t)$ in terms of two moments which can be estimated from measurements of received power *vs.* time
- if $G = |g(t)|^2$, the *true* value of the first moment of G is:

$$G_a = |V|^2 + \overline{|v(t)|^2} + \overline{2\text{Re}(Vv^*(t))} = |V|^2 + \sigma^2$$

- the *true* value of the rms fluctuation of G about G_a fluctuation is

$$G_v = [\overline{(G - G_a)^2}]^{1/2}$$

$$\begin{aligned}
&= \overline{|v(t)|^4} - \sigma^4 + \overline{(2\text{Re}(Vv^*(t)))^2} \\
&= [\sigma^4 + 2|V|^2\sigma^2]^{1/2}
\end{aligned}$$

- combining the expressions for G_a and G_v and solving for $|V|^2$ and σ^2 yields

$$|V|^2 = [G_a^2 - G_v^2]^{1/2} \quad (1)$$

and

$$\sigma^2 = G_a - [G_a^2 - G_v^2]^{1/2}. \quad (2)$$

- obtain the Ricean K-factor by substituting these values into our definition
- the K-factor and average power gain, G_a , suffice to determine the Ricean envelope distribution.

Complex Envelope Correlation Coefficient

- consider

$$\rho_{\text{pwr}} = \frac{\overline{|g_1|^2 |g_2|^2} - \overline{|g_1|^2} \overline{|g_2|^2}}{\text{var}(|g_1|^2) \text{var}(|g_2|^2)}$$

- recast as

$$\rho_{\text{pwr}} = \frac{R^2 + 2\sqrt{K_1 K_2} R \cos \theta}{\sqrt{(2K_1 + 1)(2K_2 + 1)}}$$

- can show that

$$\rho_{\text{env}} = R e^{j\theta} = -\sqrt{K_1 K_2} + \sqrt{K_1 K_2 + D}$$

where

$$D = \rho_{\text{pwr}} \sqrt{(2K_1 + 1)(2K_2 + 1)}$$

3. Applications

- simulation studies require a statistically equivalent random series of channel state vectors \mathbf{D}'
- generate a vector \mathbf{U} that contains five iid sequences of Gaussian random numbers with zero-mean and unit variance
- apply the transformation

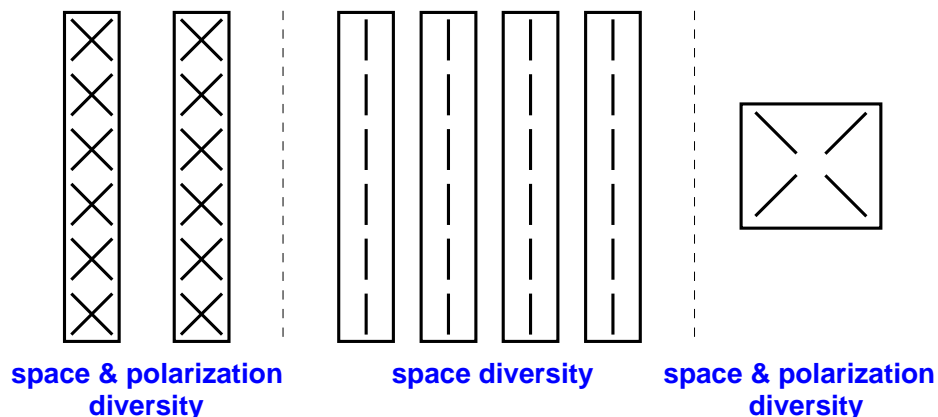
$$\mathbf{D}' = [\mathbf{C}]^{1/2}\mathbf{U} + \mu$$

- an implementation of the model in MATLAB

```
function D = propmodel (C, m)
D = C^(0.5) * randn(size(m)) + m
```

Generalization to n -branch Diversity

- how to model the first order statistics of n -branch diversity reception involving spatial, polarization, angular, or frequency diversity or combinations thereof?



- the channel state vector for n -branch diversity:

$$\mathbf{D} = [\mathbf{G}_{\text{ave}} \mid \mathbf{K} \mid \rho]$$

where

$$\mathbf{G}_{\text{ave}} = [G_{\text{ave}1}, G_{\text{ave}2}, \dots, G_{\text{ave}n}]$$

$$\mathbf{K} = [K_1, K_2, \dots, K_n]$$

and ρ are the upper or lower off-diagonal elements of

$$[\rho] = \begin{bmatrix} \rho_{11} & \rho_{12} & \cdots & \rho_{1n} \\ \rho_{21} & \rho_{22} & \cdots & \rho_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{n1} & \rho_{n2} & \cdots & \rho_{nn} \end{bmatrix}$$

- in the general case, the state vector is defined by $n(n+3)/2$ parameters

Time Variation Model

- Doppler spectrum captures the second order statistics of the signal
- most variation in fixed wireless environment appears to be due to wind-induced movement of foliage
- analysis of measured data shows that

$$S_d(j\omega) = \frac{1}{1 + (\omega/\omega_c)^2}$$

where $f_c = \omega_c/2\pi$ ranges between 1 and 10 Hz.

- this single-pole model for fixed channels is much simpler than Clarke's model for mobility channels

Simulation Using the Time Variation Model

- the corresponding autocorrelation function for each $x(t)$:

$$A(\tau) = \frac{1}{2} \exp(-2\pi f_c |\tau|)$$

- generation of discrete samples with this ACF:

$$x([n + 1]T) = A(T) x(nT) + \sqrt{1 - A^2(T)} \epsilon_n$$

$$x_1(nT) = \sqrt{\frac{1 + \rho}{2}} x_a(nT) + \sqrt{\frac{1 - \rho}{2}} x_b(nT)$$

$$x_2(nT) = \sqrt{\frac{1 + \rho}{2}} x_a(nT) - \sqrt{\frac{1 - \rho}{2}} x_b(nT)$$

Summary – Narrowband Diversity Model

- first-order statistics of two-branch diversity reception can be completely characterized in terms of just five channel parameters
- our model is applicable to any case where fading is Ricean distributed and can be easily generalized to n diversity branches
- in suburban macrocell environments, the set may be cast as a five-element vector of jointly random Gaussian processes that are completely specified by a mean vector and a covariance matrix
- remarkable consistency in the model parameters from different suburban sites suggest they are broadly applicable
- easy to generate a random sequence of channel state vectors with the same first-order statistics as the measured data

Anticipated Results

- a complete first-order statistical model of diversity reception in a variety of indoor environments
- assessment of the effectiveness of two-way space diversity for use in WPAN or WLAN access points
- assessment of the potential improvement that could be obtained by implementing three-way space diversity reception on WPAN or WLAN access points