Enabling Technologies for Ubiquitous Personal Area Networks

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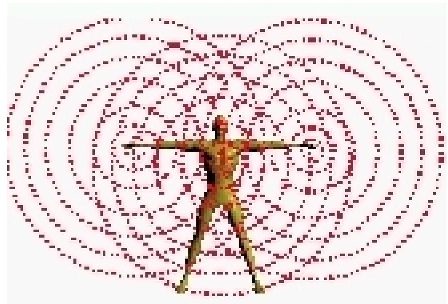

Narrowband Diversity Reception in WPAN/WLAN Environments

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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 $G_{\rm ave} = \overline{|g(t)|^2} = |V|^2 + \overline{|v(t)|^2}$
- 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 $\hat{x}_i = x_i(t)\, e^{-j\Psi_i}, \quad i = 1, 2.$

- 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

$$\mathbf{U} = [G_{ave\,1}, G_{ave\,2}, K_1, K_2, \rho]$$

- need to estimate these parameters from measurements of received power $vs.$ time

- estimation of average path gain is simple:

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

- 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:

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

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

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

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

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

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

and

$$\sigma^2 = G_a - [G_a^2 - G_v^2]^{1/2} \,. \tag{2}$$

- 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

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

- recast as

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

- can show that

$$\rho_{\mathrm{env}} = Re^{j\theta} = -\sqrt{K_1 K_2} + \sqrt{K_1 K_2 + D}$$

where

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

3. Applications

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

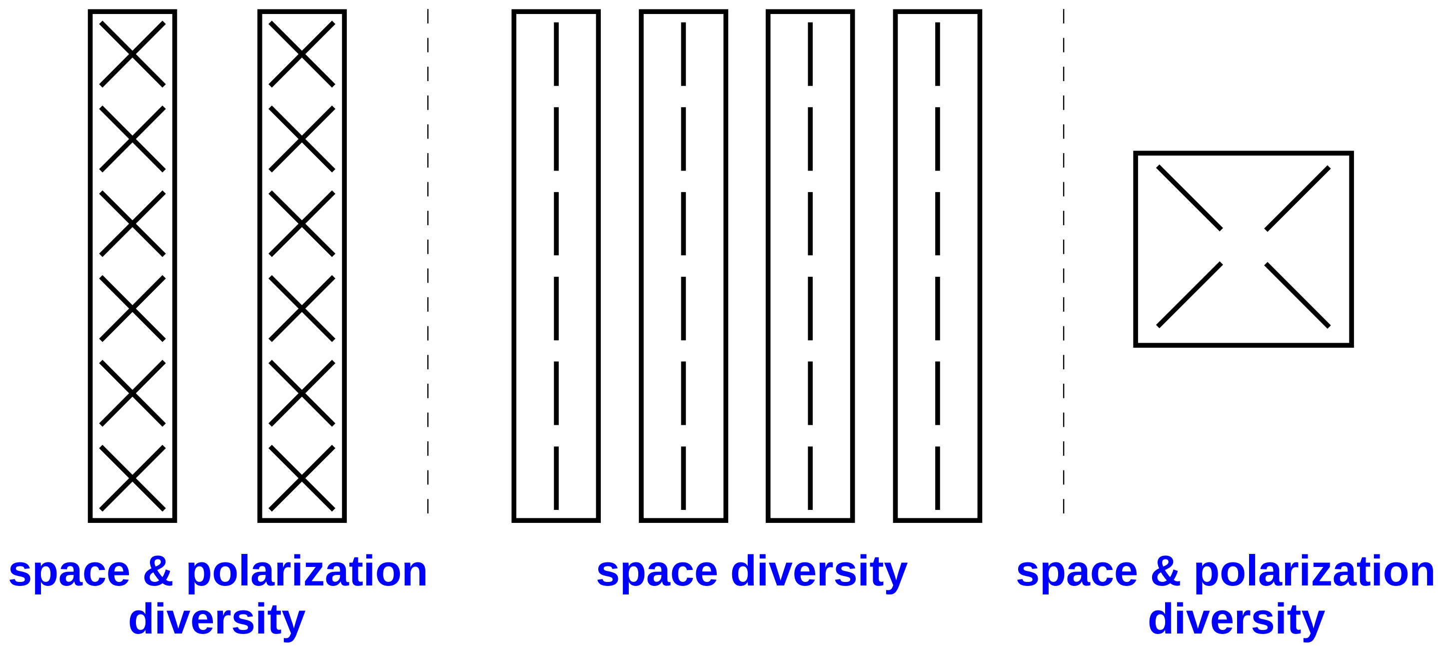
$$\mathbf{D}' = [C]^{1/2}\mathbf{U} + \mu$$

- 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:

$$\mathbf{D} = [\mathbf{G_{ave}} \mid \mathbf{K} \mid \rho]$$

where

$$\begin{aligned} \mathbf{G_{ave}} &= [G_{ave\,1}, G_{ave\,2}, \ldots, G_{ave\,n}] \\ \mathbf{K} &= [K_1, K_2, \ldots, K_n] \end{aligned}$$

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:

$$\begin{aligned}
x([n+1]T) &= A(T)\,x(nT) + \sqrt{1-A^2(T)}\,\epsilon_n \\
x_1(nT) &= \sqrt{\frac{1+\rho}{2}}\,x_a(nT) + \sqrt{\frac{1-\rho}{2}}\,x_b(nT) \\
x_2(nT) &= \sqrt{\frac{1+\rho}{2}}\,x_a(nT) - \sqrt{\frac{1-\rho}{2}}\,x_b(nT)
\end{aligned}$$

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 poiints
- assessment of the potential improvement that could be obtained by implementing three-way space diversity reception on WPAN or WLAN access poiints