Computer Simulation of Multiple Transmitter, Multiple Receiver Wireless Channels

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I. Introduction

New multiple-transmitter, multiple-receiver (MTMR) systems promise huge gains in data capacity that cannot be ignored by a wireless industry that desires to increase the data capacity for subscribers in an increasingly congested frequency spectrum. Design of such systems, however, will require an entirely new approach to channel modeling, since traditional techniques have dealt with single antenna links [1]. This paper presents a new technique for computer simulation of the MTMR wireless channel. The method is based on the first-principle physics of radio wave propagation. Our technique is capable of modeling the correct channel correlation behavior between multiple transmitter and receiver antenna elements. A key outcome of this research is to design MTMR channel modeling software as a resource for industry engineers.

II. The MTMR Channel

Regardless of the spatial processing algorithm used, the wireless link must obey the mathematical Shannon limit of channel capacity. For a narrowband system, link capacity is expressed as a function of the complex, baseband-equivalent channel matrix, $\hat{H}$. This is an $M$-by-$N$ matrix that maps the strength of signals sent through $M$ transmitter antennas and received at $N$ receiver antennas. The effects of the channel on $M$ transmit antenna signals to $N$ receiver antenna elements is represented mathematically by the following sets of equations:

$$\begin{align*}
\tilde{y}(t) &= 
\begin{bmatrix}
\tilde{y}_1(t) \\
\tilde{y}_2(t) \\
\vdots \\
\tilde{y}_N(t)
\end{bmatrix}, \\
\tilde{x}(t) &= 
\begin{bmatrix}
\tilde{x}_1(t) \\
\tilde{x}_2(t) \\
\vdots \\
\tilde{x}_M(t)
\end{bmatrix}
\end{align*}$$

$$\hat{H} = 
\begin{bmatrix}
\hat{h}_{11} & \hat{h}_{12} & \cdots & \hat{h}_{1M} \\
\hat{h}_{21} & \hat{h}_{22} & \cdots & \hat{h}_{2M} \\
\vdots & \vdots & \ddots & \vdots \\
\hat{h}_{1N} & \hat{h}_{2N} & \cdots & \hat{h}_{MN}
\end{bmatrix} \tag{1}
$$

In this representation, the channel matrix element $\hat{h}_{ij}$ represents the signal strength excitation of the $i$th transmitter element onto the $j$th receiver element. The vectors $\tilde{x}$ and $\tilde{y}$ are the sets of transmitted and received signals, respectively. In this way, we can represent the effects of the narrowband MTMR channel as the simple matrix product: $\tilde{y}(t) = \hat{H}\tilde{x}(t)$.

In the presence of unit-variance additive white Gaussian noise, the channel capacity, $C$, for an MTMR system with bandwidth $B$ was derived by Foschini in [2]:

$$C = B \log_2 \left( \det \left( \mathbf{I} + \hat{H}\hat{H}^\dagger \right) \right) \tag{2}$$

which has units of bits-per-second. The capacity of Eqn (2) can be quite large compared to a single transmitter, single receiver antenna link, but is heavily dependent on the radio propagation characteristics. It is particularly critical to capture the correct correlation behavior of the various elements in $\hat{H}$ [3].

III. Modeling Technique

Model development of the baseband channel matrix $\hat{H}$ is challenging because the individual elements must obey the laws of free space propagation. The technique introduced in this paper applies the local area assumption to create a realistic MTMR channel model. The approach is to represent the channel matrix as the sum of $L$ individual channel matrices, $\hat{H}_l$, which are due to single multipath waves in the environment:

$$\hat{H} = \sum_{l=1}^{L} \hat{H}_l \tag{3}$$

The divide-and-conquer method of Eqn (3) is capable of producing Rayleigh, Nakagami-Rice, and many other types of wireless channels [4].

![Transmitter-to-Receiver Wave Propagation](image)

Fig. 1. The physics of local area propagation for transmitter and receiver antennas.

Once we apply Eqn (3), we can construct the individual elements of $\hat{H}_l$ based on wave propagation in Figure 1. The channel between the $i$th transmitter element
of the channel simulation. Using this systematic approach, a complete MTMR channel matrix may be simulated that contains the correct correlation behavior for the various configuration of antenna elements.

IV. EXAMPLE

We present an intuitive example of synthesizing the MTMR channel for the linear arrangement of transmitter and receiver antennas in Figure 2. In this scenario, multipath angles-of-departure are spread evenly over a 20° sector pointing transverse to the line of transmitter antennas; multipath angles-of-arrival are spread evenly over the entire azimuth. For our simulation, we choose 256 multipath components – $L$ in Eqn (3) – with equal amplitudes and random angles of arrival/departure according to the distributions in Figure 2. There are 128 transmitter antennas $M$ and 128 receiver antennas $N$, both sets uniformly spaced with 0.05λ between each element. Although the separation distance is small and the quantity of elements is large compared to a useful system, this configuration easily illustrates the validity of the channel simulation.

Figure 3 shows the unit autocovariance of the channel matrix envelope, $|\tilde{H}|$, for one realization of the propagation in Figure 2. The top graph of Figure 3 demonstrates how the envelope of individual channels, $|\tilde{h}_{ij}|$, are correlated to one another. The bottom graph of Figure 3 shows two correlation graphs – one comparing transmit envelopes $|\tilde{h}_{xj}|$ with the same $j$ and the other comparing receive antenna envelopes $|\tilde{h}_{ix}|$ with the same $i$. The omnidirectional multipath causes the receiver envelopes to decorrelate rapidly (about 0.2λ) while the sector multipath causes the transmitter envelopes to decorrelate much more slowly – just like the conventional behavior predicted for single-excitation spatial channels [4].

V. SUMMARY

The technique for simulating the MTMR channel given in this paper produces results that are useful for simulating transmitter and receiver systems operating with multiple co-polar antenna elements. Future work will extend the modeling software to non-co-polar elements and frequency-selective channels.

REFERENCES